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GeoTrails: New Visions from the Escarpment

Critical Minerals: Dissecting Divergent Perceptions

Discovering Ancient and Modern Earth —
Découvrir la Terre Ancienne à Moderne:
Abstracts from the Sudbury 2023 GAC–MAC–SGA Conference

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Alexander Murray Bld., Rm ER4063
Memorial University of Newfoundland
St. John's, NL, Canada, A1B 3X5
Tel: (709) 864-7660
Fax: (709) 864-2532
gac@mun.ca
www.gac.ca

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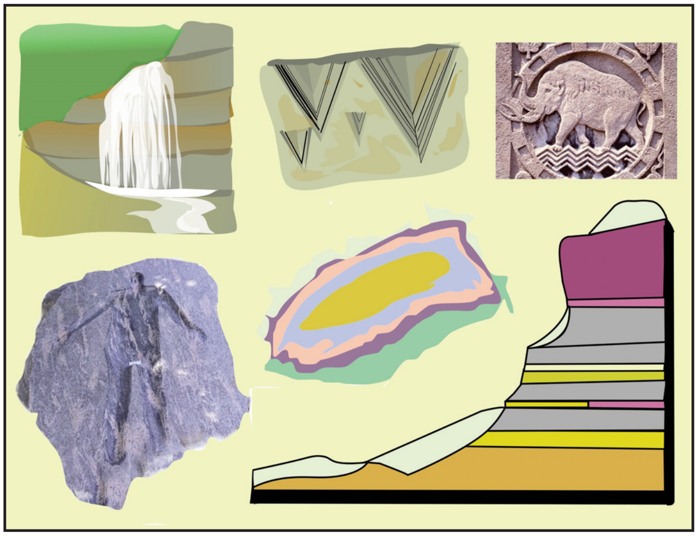
Cover Image: The Ball's Fall GeoTrail starts with the cap dolostone rock layers of the Niagara Escarpment exposed at the Upper Falls and ends with the spectacular stratigraphy exposed at the Lower Falls seen here (https://geoscienceinfo.com/geotrails/). Photo Credit: K.M. Maloney.

SERIES



Earth Science Education 7. GeoTrails: Accessible Online Tools for Outreach and Education

Katie M. Maloney[1,2], Alexander L. Peace[1], Joe Hansen[1], Keira L. Hum[1], Julia P. Nielsen[1], Kate F. Pearson[1], Shania Ramharrack-Maharaj[1], Deana M. Schwarz[3], Elli Papangelakis[1], and Carolyn H. Eyles[1]

[1]*School of Earth, Environment and Society, McMaster University 1280 Main Street West, Hamilton, Ontario, L8S 4L8, Canada E-mail: katie.maloney@mail.mcgill.ca*

[2]*Department of Earth and Planetary Sciences, McGill University 3450 University Street, Montreal, Quebec, H3A 0E8, Canada*

[3]*APGO Education Foundation, Suite 704, One Yonge Street, Toronto, Ontario, M5E 1E5, Canada*

SUMMARY
As geoscientists, we must prioritize improving our ability to communicate science to the public. Effective geoscience communication enables communities to understand how geological processes have shaped our planet and make informed decisions about Earth's future. However, geoscience research outputs have traditionally been published in peer-reviewed journals and presented at academic conferences. Consequently, essential information about local geology is rarely available in accessible, open access, and engaging formats. Here, we propose virtual field trips, or 'GeoTrails', as a possible solution to address the disconnect between geoscience research and public knowledge by improving our communication to the public. This initiative is largely driven by undergraduate students, who identify points of geological interest along selected hiking trails, write concise descriptions derived from scientific sources (e.g. longer peer-reviewed articles and government reports), and collect field data (e.g. 3-D LiDAR models, drone photography) to illustrate the characteristics of these geological features. The goal of the project is to communicate the importance of local geology on our environment and to raise awareness of how changing climates could affect us in the future; this information can empower communities to make better, more informed planning decisions. The creation of GeoTrails along the Niagara Escarpment offers a promising strategy to highlight the role of geoscientists and to engage the public in ongoing research that aims to showcase Canada's geoheritage.

RÉSUMÉ
En tant que géoscientifiques, nous devons donner la priorité à l'amélioration de notre capacité à communiquer la science au public. Une communication efficace des géosciences permet aux communautés de comprendre comment les processus géologiques ont façonné notre planète et de prendre des décisions éclairées sur l'avenir de la Terre. Cependant, les résultats de la recherche en géosciences ont traditionnellement été publiés dans des revues à comité de lecture et présentés lors de conférences académiques. Par conséquent, les informations essentielles sur la géologie locale sont rarement disponibles sous des formats accessibles, en libre accès et attrayants. Dans cette optique, nous proposons des excursions virtuelles, ou « GeoTrails », comme solution possible pour combler le fossé entre la recherche en géosciences et la connaissance du public en améliorant notre communication avec celui-ci. Cette initiative est en grande partie menée par des étudiants de premier cycle, qui identifient des points d'intérêt géologiques le long de sentiers de randonnée sélectionnés, rédigent des descriptions concises basées sur des sources scientifiques (par exemple, des articles à comité de lecture plus longs et des rapports gouvernementaux) et collectent des données sur le terrain (par exemple, des modèles LiDAR 3-D, des photographies par drone) pour illustrer les caractéristiques de ces caractéristiques géologiques. L'objectif du projet est de communiquer l'impor-

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tance de la géologie locale sur notre environnement et de sensibiliser aux façons dont les changements climatiques pourraient nous affecter à l'avenir; cette information peut permettre aux communautés de prendre des décisions de planification meilleures et plus éclairées. La création de GeoTrails le long de l'escarpement du Niagara offre une stratégie prometteuse pour mettre en valeur le rôle des géoscientifiques et pour engager le public dans notre recherche en cours qui vise à présenter le patrimoine géologique du Canada.

Traduit par la Traductrice

INTRODUCTION

The role of scientists has traditionally been to advance the state of knowledge by asking questions, seeking answers and publishing findings in peer-reviewed journals (Baron 2010; Stewart and Nield 2013). Geoscience societies, associations and surveys have created useful outreach materials (e.g. Geoscapes posters, *Four Billion Years and Counting* book) and workshops for teachers (e.g. National EdGEO Program) to promote accurate geoscience information to the public. However, press releases, news articles and online blogs are often the most publicly accessible sources of information to communicate research findings relevant to local communities (Bond and Paterson 2005; Colson 2011), and these may be sensationalized, politicized, or influenced by search engine algorithms (Brossard and Scheufele 2013). Over the last decade, undergraduate educators have started to emphasize the importance of teaching scientific communication to a variety of audiences (Brownell et al. 2013; Symons et al. 2017). At the same time, there has been an increased interest in outdoor activities during and after the COVID-19 pandemic. For example, Morse et al. (2020) studied the responses of over 3000 adults and found that participation in hiking, watching wildlife, and other outdoor hobbies in Vermont increased during the pandemic. This increased interest in outdoor activities presents a timely opportunity for new outdoor education initiatives.

Given the backdrop of intersecting global crises, many of which involve geoscientific issues (e.g. climate change, resource exploitation), geoscientists need to realize the benefit of effectively communicating scientific findings with the public to provide an opportunity for the sharing and exchange of knowledge (Stewart and Lewis 2017; Illingworth et al. 2018). By empowering our communities with geoscientific knowledge, we can also raise awareness about local environmental issues and the influence of changing climates on urban infrastructure and sustainability. Here, we seek to aid in addressing the disconnect between geoscientists and the public by introducing a new platform for geoscience communication. We outline the creation of a set of accessible and educational virtual trails called 'GeoTrails', which are integrated with digital field tools (3-D models, 360° images, drone imagery) to provide an immersive and informative virtual field experience. GeoTrails are constructed in collaboration with the APGO Education Foundation using ArcGIS™ StoryMaps™ by Environmental Systems Research Institute Incorporated (ESRI). This platform can be accessed through a variety of devices (e.g. cell phones, tablets and laptops) when walking the trail, or explored virtually from anywhere in the world, and has great potential to be used as an educational tool in the classroom.

Geoscientists will play an important role in building a sustainable future for Canada; however, decreasing enrollment trends demonstrate a lack of interest by students to pursue geoscience careers (Center for Geoscience and Society 2018; Mosher and Keane 2021). Today, many students are driven by altruism (Carter et al. 2021) and want to learn how to address problems in the real world (Disbrow-Monz et al. 2023). GeoTrails could provide a recruitment strategy by highlighting geoscience research and its importance in the community. Hence, to enhance the communication of important geoscientific information to members of the diverse, predominantly urban communities in southern Ontario, we targeted sites along the Bruce Trail and Niagara Escarpment to create informative GeoTrails on an openly accessible, user-friendly platform.

The Niagara Escarpment is a steep cliff, stretching from southern Ontario to northern Michigan, that formed primarily by differential erosion processes during the late Cenozoic and now exposes a variety of Paleozoic sedimentary rocks (Fig. 1, Brunton 2009; Brett et al. 2018; Brunton and Brintnell 2020). The escarpment geology influences multiple aspects of the local environment including soil quality (Kingston and Presant 1989; Haynes 2000) and the movement of groundwater and contaminants (Brunton and Brintnell 2020). Much of the Niagara Escarpment is located in southern Ontario, which has a population of over 7.5 million (Statistics Canada 2023) and is frequently visited by international tourists who come to see famous sites along the escarpment such as the Niagara Falls. Most public hiking trails that follow the Niagara Escarpment in southern Ontario are part of the Bruce Trail, Canada's longest and oldest marked footpath which is managed by the Bruce Trail Conservancy. The Bruce Trail Conservancy (BTC) has over 10,000 enthusiastic members who lead hikes, maintain trails, and can provide a wealth of knowledge about the trails. However, despite this obvious interest in the natural environment along the trails very little accessible geological information is available to BTC members or the public. Restrictions resulting from the COVID-19 pandemic have also taught us the value of experiences that can be obtained or augmented virtually to increase accessibility (Evelpidou et al. 2021; Whitmeyer and Dordevic 2021; Aaisyah et al. 2021; Peace et al. 2021; Gregory et al. 2022).

Motivations

Several motivations are involved in the development of the GeoTrails including: 1) the integration of scientific information from a variety of expert sources not usually accessible to the public, 2) geoscientific outreach to local communities, 3) recruitment of geoscience students, and 4) building leadership skills in students at all stages of their careers. Our GeoTrails incorporate a variety of geoscience perspectives from geologists, paleontologists, hydrogeologists, geomorphologists, and engineers, showcasing the benefit of using integrated approaches to better understand our environment. This multifaceted approach also allows the GeoTrails to engage an audience with diverse backgrounds and interests. Overall, the main

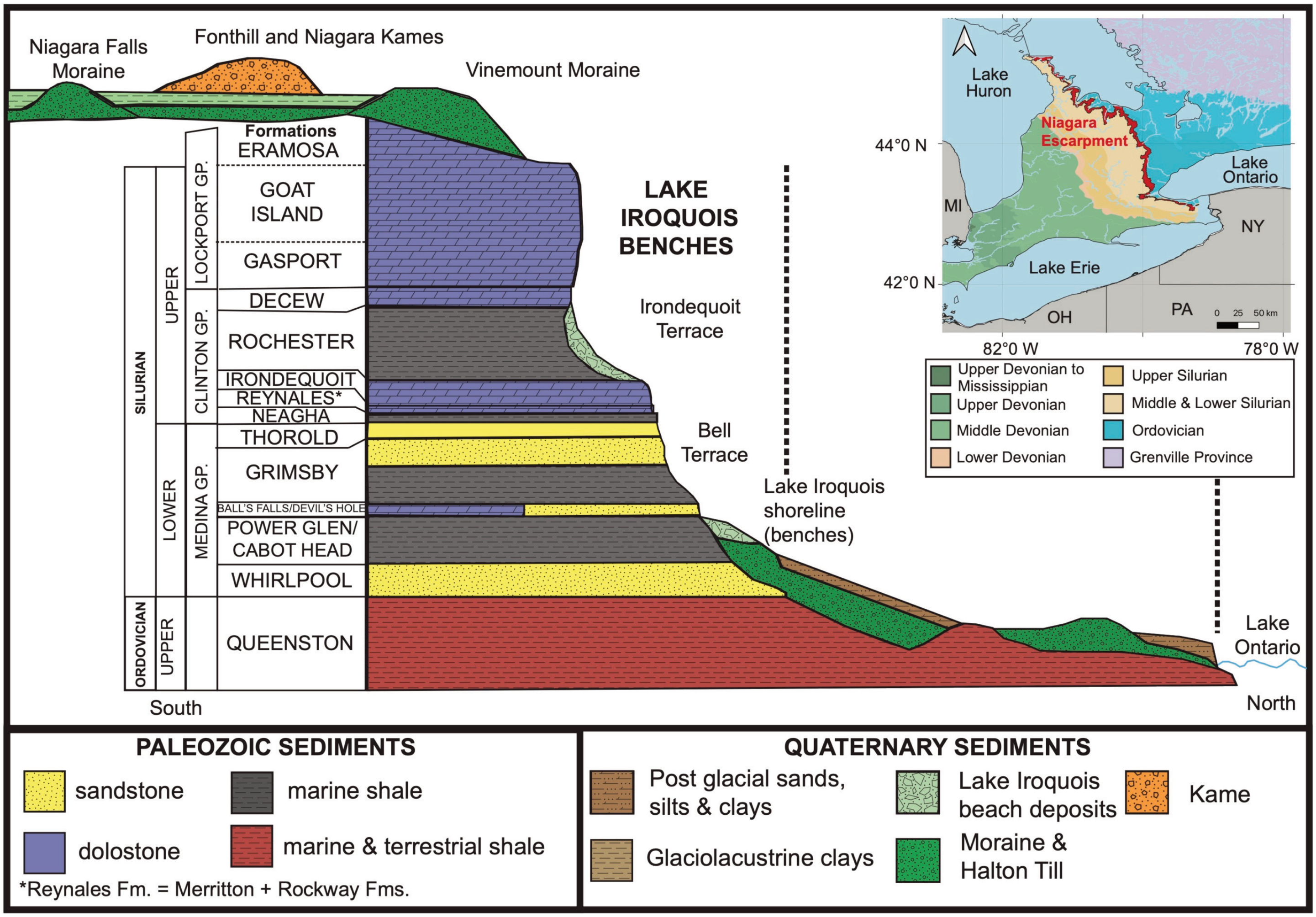

Figure 1. Niagara Escarpment general stratigraphy in Niagara Region, Ontario, Canada (adapted from Steele and Haynes 2000; Brunton and Brintnell 2020). Inset Map shows the Niagara Escarpment in southern Ontario and an overview of the Paleozoic geology (Armstrong and Dodge 2007).

goal of the GeoTrails is to provide geoscience information to the public in an exciting and inclusive format. GeoTrails also inform members of the local community about the types of geoscientific investigations and research projects being conducted in the area and why these are important. This information can empower community members and allow more informed decisions to be made about critical environmental issues. As natural disasters related to climate change increase in Canada (Weber 2023), members of the geoscience community are obliged to become leaders in ensuring that accurate information about Earth processes is available to educators and the public.

GeoTrails can also serve as a recruitment tool to attract students into geoscientific professions. The earth science curriculum is not mandatory in local high schools and these GeoTrails allow students to not only learn about the fascinating story of the formation of our planet but also about relevant career opportunities. The creation of the GeoTrails is student-driven, with undergraduate students conducting much of the field data collection independently while mentored by graduate students, postdoctoral fellows, and faculty. Students take on leadership roles by identifying points of geological interest along each trail and managing field data (e.g. GPS points, photos, videos, notes). These experiences provide students with valuable field training, practice in communicating geoscience to different audiences, and an opportunity to explore their own research interests.

Study Site

The Niagara Escarpment is bordered by Lake Ontario and Lake Erie and the Niagara River marks the international border between Canada and United States (Tovell 1992; Steele and Haynes 2000; Brett et al. 2018; Fig. 1). In the Niagara Region, urban and industrial expansion has, to some extent, been controlled by its geographic setting (Haynes 1995). The Great Lakes moderate the local climate (Scott and Huff 1996), making the region an appropriate place to grow various fruits (e.g. peaches, grapes) and even allow the growth of Carolinian forests which are typically restricted to the southern United States. Land use planning along the Niagara Escarpment is complex because it must respect Indigenous traditional territory (Hayward 2021; Ryan-Davis and Scalice 2022) while also

Table 1. GeoTrails (for map, see https://geoscienceinfo.com/geotrails/).

	Distance (km)	Duration (hours)	Description
Ball's Falls GeoTrail (Lincoln, Niagara)	1.5	1.5	Take a short hike from Upper Ball's Falls to Lower Ball's Falls and learn about an early settlement that utilized the local geological resources.
Cave Springs GeoTrail (Campden, Niagara)	1	1	Visit the trails here to see the famous Ice Cave and search for hidden rivers that appear at the surface as springs.
Niagara Gorge GeoTrail (Niagara Falls)	1	1	Hike the trail near the Niagara Gorge to learn how the powerful Niagara River changed the landscape we see today.
Chedoke Radial Trail GeoTrail (Hamilton)	1	1	Explore this section of the Bruce Trail to see how the Niagara Escarpment has helped shape the city of Hamilton as both an obstacle to development and important resource.
Sulphur Springs GeoTrail (Dundas, Hamilton)	3.4	1.5	Located in the Dundas Conservation Area, following this trail will lead you to the famous sulphur spring, the Hermitage, and the Griffin House.
Tiffany Falls GeoTrail (Ancaster, Hamilton)	0.35	0.5	Take a short walk to the spectacular Tiffany Falls and learn about active slope and valley processes along the way.

considering the requirements for industry, urbanization, agriculture, tourism, outdoor recreation and nature conservation (Haynes 1995). Over 1.3 million people live near the Niagara Escarpment and require effective geoscience information to help evaluate these competing interests in an age of increasing urbanization (UNESCO 2018). The Niagara Escarpment has also become a popular recreational attraction with hiking trails (e.g. the Bruce Trail) leading to conservation areas and the many waterfalls that cross its face, and offering seasonal opportunities for downhill and cross-country skiing. Hence, the Bruce Trail and its side trails along the Niagara Escarpment have provided exceptional study sites to develop and test the first series of GeoTrails. Bruce Trail hike leaders have been able to provide valuable feedback on the first GeoTrails to help us improve their construction and accessibility. We are open to suggestions for improvement of the GeoTrails and will continue to seek opportunities for feedback from trail users, teachers, geoscience educators and conservation experts.

The Niagara Escarpment is well suited for geoscience education based on its proximity to major urban centres and the rocks exposed along its length have been well documented since the mid 1800s (Hall 1852; Grabau 1908; Williams 1919; Bolton 1957; Brett 1983; Brett et al. 1990; Brunton 2009; Brett et al. 2018; Brunton and Brintnell 2020). Rocks exposed along the escarpment formed from the Late Ordovician to the middle Silurian periods when the Niagara region was covered in a shallow sea that extended across much of Laurentia and was home to a diverse number of invertebrate species (Brett 1983; Brett et al. 1990; Brunton 2009; Brett et al. 2018; Brunton and Brintnell 2020). Hence, a mixed siliciclastic–carbonate succession of sedimentary rocks accumulated in the basin creating a stratigraphy that continues to shape the modern landscape with the rock types providing a primary control on the topography of the region.

The Niagara Escarpment is vulnerable to differential erosion with fractured dolostone units overlying recessive shale layers which are exposed along major roads that cross the escarpment in the city of Hamilton, Ontario (Formenti et al. 2022; Gage et al. 2022). These differential erosion processes are not well understood and are the focus of ongoing research by undergraduate students at McMaster University. The GeoTrails we have created showcase this active research to the local community, including research constraining fracture patterns (e.g. distribution, conductivity; Formenti et al. 2022) and thermal change influencing winter weathering of fractured dolostone (Gage et al. 2022). Researchers are also investigating the influence of expanding urbanization and climate change on active processes along the Niagara Escarpment, which can put pressure on local rivers, increasing flooding and erosion risks (Ramharrack-Maharaj and Davies 2023). Identifying, evaluating and mitigating these risks is important since the Niagara Escarpment is an area of considerable ecological importance and was designated as a UNESCO World Biosphere Reserve site in 1990 (Niagara Escarpment Biosphere Reserve).

DEVELOPMENT OF GEOTRAILS

A total of six GeoTrails (Table 1) along the Niagara Escarpment were developed and released to the public on the geo-

Table 2. Urban GeoTrails (for map, see https://geoscienceinfo.com/urban-geotrails/).

Urban GeoTrail	Created by	Description
University of Toronto	University of Toronto team	Discover how the University of Toronto and the city of Toronto grew together from the historic building stones on campus.
Downtown Toronto: Union Station to the Royal Ontario Museum	University of Toronto team	Explore downtown Toronto and learn about the building stones that shaped the city.
McMaster Building Stones	McMaster team	View the historic buildings and architecture to learn about the beginnings of the campus and its expansion over the last century.
McMaster Rock Garden	McMaster team	Visit the rock gardens on the McMaster campus to learn about the different rock types and campus history.
Laurentian Campus	Laurentia team and Ontario Geological Survey	Wander through campus to explore local rocks with out-of-this-world features, including shatter cones and the Sudbury Breccia.

scienceINFO.com website between April 2022 and January 2023. This was done in partnership with the APGO Education Foundation, whose mandate is to support students and internationally trained geoscientists, and to promote a greater understanding of geoscience to the public (APGO: https://www.apgoedfoundation.ca/). The APGO Education Foundation provided technical support for the construction and publication of the StoryMaps and consulted with community groups to identify how the GeoTrails could aid in meeting their mandates. Collaborations with members of the Bruce Trail Conservancy and the Niagara Peninsula Aspiring Global Geopark helped guide site selection by identifying sites that are accessible, popular with the public and geologically significant. We have also launched an urban equivalent to our Niagara Escarpment GeoTrails called "Urban GeoTrails" (Table 2), which offer short geologically themed tours in urban settings, showcasing the geologic history of features of 'urban outcrops' such as building stones, rock gardens, and local parks.

Data Collection, Materials, and Resources

Data collection was led by teams of undergraduate students, who did multiple reconnaissance trips along selected trails to identify sites of geological interest and potential GeoTrail stops. Field data collection included digital photos, 3-D LiDAR models (Scaniverse using iPad Pro), digital 360° images, drone imagery, GPS points, and other field-based observations. Several logistical considerations had to be addressed during GeoTrail development, including site selection, time of data collection and accessibility. Site selection was based on numerous factors including accessibility, safety, geological points of interest, proximity to population centres and proximity to public transportation hubs. Data collection was significantly limited by seasonal time constraints; snow-covered outcrops and icy trails rendered sections of the trails unsafe until April. By mid-July, many of the outcrops were again covered by extensive vegetation, therefore the most useful imagery was captured in May and June.

GeoTrail text was developed based on field observations, peer-reviewed journal articles (e.g. Brett 1983; Cramer et al. 2011) and detailed reports by the Ontario Geological Survey, New York State Geological Survey, Niagara Parks, Hamilton Conservation Authority and the Bruce Trail Conservancy. Innovative research from these reports was integrated with research published in academic journals and knowledge from experts in the community. For example, a retired McMaster professor, Dr. Gerry Middleton, published a series of open access articles related to building stones and urban geology for a local publication called "Raise the Hammer" (Middleton 2011). This resource was particularly useful as it provided reliable information about local features that are not usually documented in textbooks or academic journals. In addition, historical records were investigated to provide perspective about how early settlers utilized the local geology to establish viable settlements starting in the 18th century (Haynes 1995). These settlements, which mostly lie below the Niagara Escarpment, were protected from extremely cold climate conditions and used natural hydropower created by waterfalls formed by rivers flowing over the Niagara Escarpment. Preserving community geoscience knowledge, including traditional ecological knowledge from Indigenous communities (Gewin 2021), and making that information accessible to the public is a major goal of these GeoTrails. For example, Indigenous peoples were the first to recognize the importance of natural resources including chert nodules found in the capstone dolostone beds that were used to create early tools. The GeoTrails will continue to improve as we build stronger relationships by listening to and learning from local Indigenous communities.

Choice of Dissemination Medium

Virtual field data can be hosted on many different platforms including ArcGIS and Google Earth (Whitmeyer et al. 2012 and references therein; De Paor et al. 2016; Bitting et al. 2018; Whitmeyer and Dordevic 2021). We chose to build the GeoTrails using ArcGIS StoryMaps as it is a user-friendly platform

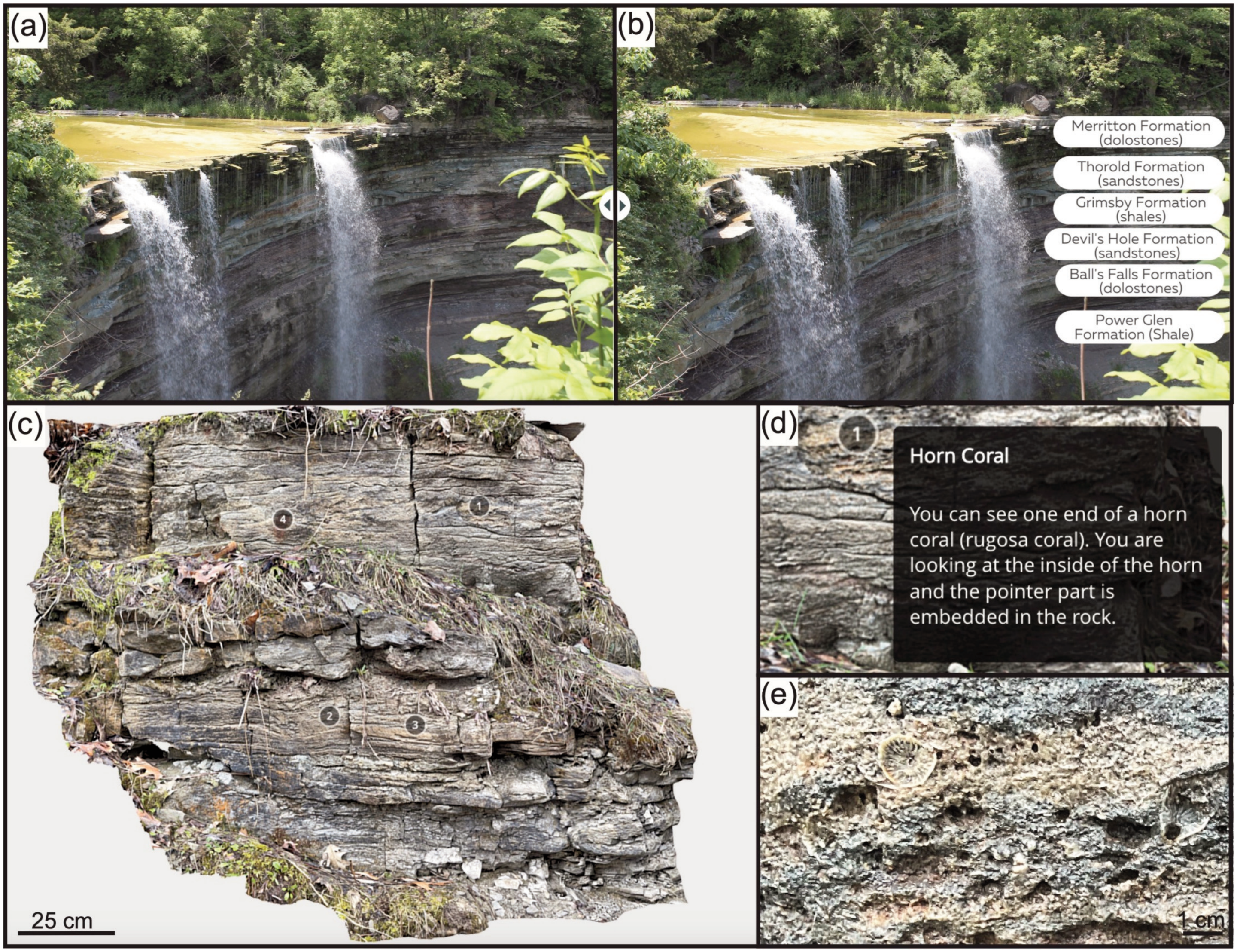

Figure 2: GeoTrails Data. (a) The lower waterfall at Balls Falls is presented in the GeoTrail using a slider. (b) GeoTrail users can move the slider to reveal the stratigraphic nomenclature and lithology of exposed units (e.g. parts of the Medina Group in Figure 1). (c) Example of a 3-D model hosted in Sketchfab; the numbers represent interesting features described using pop-up text boxes (see (d)). (d) Description of feature 1, a horn coral identified on the 3-D model shown in c. (e) High resolution photograph of fossils that can be viewed in the 3-D model. (a, b) Ball's Falls GeoTrail link: https://experience.arcgis.com/experience/c39fea16e5994697844239ba5a2f2e84/. (c–e) Chedoke Radial Trail GeoTrail link: https://experience.arcgis.com/experience/e8ffe313977d489aa91134b881c5f1df/.

and compatible with a variety of devices including phones, tablets, and desktop computers. The flexibility and ease of updating ArcGIS StoryMaps allows the GeoTrails to be living documents that can be updated as we learn more about the geology of our region and showcase active research. In order to ensure that they may be enjoyed by as many people as possible, numerous display methods are used to ensure that these GeoTrails are accessible and appeal to different learning styles. As users scroll down the page, each brief section of text is accompanied by a media component to better illustrate what is being discussed. Types of media used are still photos, figures, 360° interactive photos, slide bars to allow for easy comparison between two photos (Fig. 2a, b), video clips, drone footage, and interactive 3-D LiDAR imaging (Fig. 2c–e). Audio bars are also included that narrate all text to accommodate users with visual impairment. By providing a diverse array of interactive learning materials, we hope to stimulate interest in the reader and promote further learning.

GeoTrail Structure

The GeoTrails follow a consistent structure to make it easy for users to find similar information at each site (Fig. 3). Each GeoTrail contains a summary page that includes an introduction to the site with logistical considerations including safety warnings, parking information and costs, and trail accessibility. The introductory text includes a description of the site, a connection between the area and the regional geology of the Niagara Escarpment, a brief overview of each stop and an interactive map showing the location of each stop (Fig. 3b). Land acknowledgements are included to recognize the meaningful history and connection Indigenous people have with the land as well as to emphasize the lessons we can learn from Indige-

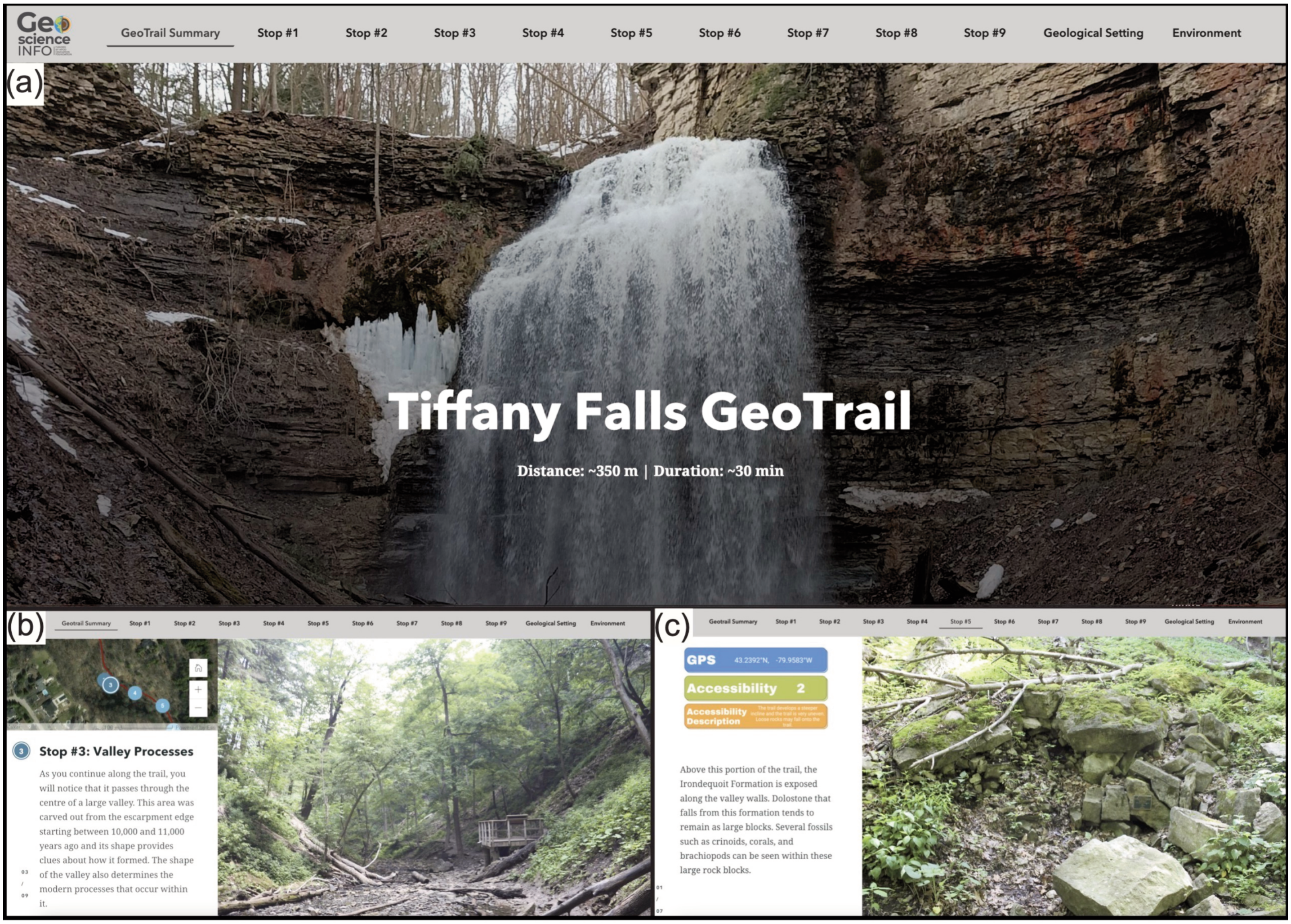

Figure 3. GeoTrail layout construction. (a) Example of a summary page for Tiffany Falls with the stops, geological setting and environment tabs shown across the grey bar at the top of the page. (b) A map on the summary page shows the location of each stop along the trail with a short summary of features and a photograph. (c) Each stop starts with information about the location (e.g. GPS coordinates), accessibility and an accessibility description. The text beside it describes the corresponding media while the number of slides is indicated in the bottom corner. Tiffany Falls GeoTrail link: https://experience.arcgis.com/experience/c0b10d68480444ebacde08432b5076b8/.

nous worldviews about sustainability and stewardship (Whitmore and Carlson 2022). A land acknowledgement is included at the beginning of every GeoTrail to remind users that we are on the traditional territory of the Indigenous communities. For example, the Hamilton and Niagara Regions are located on the traditional territory shared by the Haudenosaunee Confederacy and the Anishinaabe nations, which was acknowledged in the Dish with One Spoon Wampum belt. This Wampum belt uses the symbolism of a dish to represent the territory, and one spoon to represent that the people are to share the resources of the land and only take what they need (Seneca College 2022). In this spirit, in all of our GeoTrails, we strongly encourage the public to treat these lands with respect and to leave them in their natural state.

Each stop along a GeoTrail has its own page (Fig. 3c), which can be accessed via a series of tabs at the top of the page when using a laptop, or a drop-down menu when using a mobile device. Every stop begins with an accessibility rating and access description for the location. Accessibility was ranked for each stop along the GeoTrail from 1 (fully accessible for wheelchairs and strollers) to 3 (limited accessibility including stairs and uneven paths). Descriptions for the accessibility of each site are also provided with detailed information about the trail conditions. For example, an accessibility description could include whether the path is paved or unpaved, steep, or gently sloping, and the presence of rocky terrain and/or tree roots.

As you scroll down the page for each stop, you will find relevant geological, environmental and historical information depending on the point of interest. In addition, every GeoTrail includes a geological setting and environment page. The text in these two pages remains consistent among GeoTrails and provides additional information about the formation of the Niagara Escarpment as well as its influence on the modern environment. The geological setting page describes the geology of southern Ontario as an informal series of 4 units including Precambrian, Paleozoic, Pleistocene glaciations and present-day landscape. The history and formation of the Niagara

Escarpment rock units during the Paleozoic is described by characterizing each of the formations and briefly describing how each represents changes in the paleoenvironment through time reflecting tectonic events. The process of differential erosion is discussed in relation to the formation of the Niagara Escarpment and its many waterfalls including Niagara Falls. The Pleistocene glaciations are documented through glacial landforms that shape the modern landscape above and below the Niagara Escarpment.

The environment page of each GeoTrail focuses on answering the following question: "Why do we need to understand the local geology?" in a series of short paragraphs with corresponding figures. These sections feature examples of how the Niagara Escarpment and local geology influence people's daily lives including agriculture, groundwater, rivers, climate, ecology, economy, transportation and tourism. For example, the construction of the Welland Canal was necessary to bypass Niagara Falls and connect the St. Lawrence Seaway to the rest of the Great Lakes, allowing access to major ports in Cleveland, Detroit, Milwaukee and Chicago. Another example is the thriving wine industry in Niagara that is possible due to a combination of diverse glacial soils and the unique climate controlled by the Great Lakes and the Niagara Escarpment (Shaw 2005).

Urban GeoTrail Structure

Urban GeoTrails follow a similar structure to the GeoTrails, however, the formatting is more flexible based on the available information and targeted audience. For example, the University of Toronto campus and Downtown Toronto Urban GeoTrails feature two new pages - Building Stones and Rock Descriptions. The Building Stones page provides a map with the locations and descriptions of quarries where the building stones were sourced (Hewitt et al. 1964; Kemp et al. 1998) while the Rock Description page provides an overview of the rock types featured on the Urban GeoTrail. This is valuable information to help users understand how far some of the stones have been transported; however, clear documentation of the quarries where building stones were sourced is often unavailable. On the McMaster campus, local stones from the Niagara Escarpment are easy to spot, but the sources of metamorphic or igneous stones remain unknown. The Laurentian Campus Urban GeoTrail describes building stones, rock gardens, and outcrops on and near campus demonstrating another method to showcase Ontario's rich and complex geologic history.

DISCUSSION

The process of creating GeoTrails in collaboration with the APGO Education Foundation has led to numerous learning opportunities, not only for the public who use them, but also for geoscientists at various career stages who helped create them. Early career faculty (following the Natural Sciences and Engineering Research Council of Canada (NSERC) definition of individuals holding their first independent academic position within the last five years) had the opportunity to engage in science communication for the public and to network with community environmental leadership. Postdoctoral fellows and senior graduate students had the opportunity to improve their writing, field supervision and mentorship abilities. Undergraduate students scouted field sites, collected data and presented GeoTrails to community members during guided hikes. These opportunities enriched their careers by providing field and research experiences to students as early as during their first year of study. Students were also encouraged to practice their presentation skills to become effective scientific communicators to different audiences (e.g. their peers, scientists, community stakeholders). Future research could continue to assess students' perspectives on how involvement in the GeoTrails project has influenced their career trajectory.

Developing Opportunities for Geoscience Teaching

Fieldwork is fundamental to understanding the processes that have shaped our planet (Elkins and Elkins 2007; Petcovic et al. 2014; Whitmeyer and Dordevic 2021; Evelpidou et al. 2021). Field activities are understood to increase students' interest and enjoyment in a topic compared to traditional labs (Kern and Carpenter 1984), while they also enhance students' ability to understand and use the acquired information (Kern and Carpenter 1986; Elkins and Elkins 2007). Digital field tools (e.g. virtual field trips, virtual outcrops) allow educators to bring the field into the classroom, complementing fieldwork (Arthurs 2021; Peace et al. 2021; Whitmeyer and Dordevic 2021; Marshall and Higley 2021; Gregory et al. 2022). Many of these tools are not new (De Paor 2016), but their usage has skyrocketed with remote learning conducted during the COVID-19 pandemic (Peace et al. 2021; Evelpidou et al. 2021; Larsen et al. 2021; Arthurs 2021; De Paz-Álvarez et al. 2022; Gregory et al. 2022). Additional usage of digital field tools highlighted their importance in making the field more accessible and inviting to all students as geosciences continue to strive to improve diversity, equity and inclusivity (Arthurs 2021; Peace et al. 2021).

Urban GeoTrails in cities and on campuses can be utilized in undergraduate courses (Peebles and Johnson 1984; Wetzel 2002; Guertin 2005; Perez-Monserrat et al. 2013) and published for community outreach (Hannibal and Schmidt 1991; Horenstein 2008). These virtual tours can provide information about environmental, engineering, architectural and geoheritage influences that direct the type of stone used for these applications (Peebles and Johnson 1984; Hannibal and Schmidt 1991; Brocx and Semeniuk 2019). For example, Indiana limestone was selected for ornamental trimmings on Knox College (University of Toronto St. George Campus) while most of the building stones are of local Whirlpool sandstone that can be observed in outcrop along the Bruce Trail (Rogers 2019). Limestone better preserves the sharp edges and ornate details of the masonry work based on its crystalline structure, instead of individually cemented grains. Additionally, building stones reflect the history of the city and its resources with many buildings relying on local stones, which were often more affordable (Peebles and Johnson 1984; Eyles 2002). Examining building stones (Hoskin 2000; Wetzel 2002; Guertin 2005; Perez-Monserrat et al. 2013) and rock gardens (Dillon et al.

2000; Waldron et al. 2016) in urban settings helps students make connections between geology and social drivers, as well as gain confidence and understand geological processes recorded in more rural field areas (e.g. GeoTrails along the Niagara Escarpment). Urban GeoTrails make the field more accessible to students who feel more comfortable in, or are restricted to, urban settings (Birnbaum 2004; d'Alessioa 2012) and place-based learning has been shown to be remarkably effective in urban undergraduate student populations (Kirkby 2014).

Strategies to Make the Geoscience Accessible to the Public

The GeoTrails we have created thus far are an example of effective collaboration between a registered charity (e.g. APGO Education Foundation) and university students and faculty (e.g. McMaster University, University of Toronto) to promote geoscience and its environmental influence on the community. The non-profit partner benefits from the universities' expertise while the universities gained support to fund students and access to resources (e.g. online platforms, staff support). In addition, the non-profit partner provides a user-friendly website that permanently hosts the GeoTrails and Urban GeoTrails, and regularly promotes the website at public events across Ontario. These partnerships are essential to build on the work community organizations have initiated (e.g. conservation efforts by Bruce Trail Conservancy), to break down the image of the 'ivory tower' by showcasing active research that is being conducted at the local university and to increase transparency regarding government-funded research by sharing research findings with the public (Yin et al. 2022).

Improving the accessibility of popular local trails and conservation sites is one of the goals of the GeoTrails and Urban GeoTrails. It is necessary to ensure that the relevant geoscientific information is not only communicated in an accessible format that everyone can understand, but that the experience of exploring the trail is also inclusive. These GeoTrails provide a novel way to make geology more accessible for people with limited mobility as well as to those in the international community. The 360° images and 3-D models included in the GeoTrails allow the users to explore their virtual surroundings at their own pace. Labels on the 3-D models point out features of interest, and the high-resolution imagery supports further investigation of features such as fossils, vegetation, and sedimentary structures. By providing these GeoTrails virtually, anyone can access the information to learn more about Canadian geoscience and explore famous tourist destinations such as the Niagara Gorge that might otherwise be cost prohibitive.

GeoTrails can provide educational opportunities for all ages and aid in the development of resources for conservation organizations (e.g. Bruce Trail Conservancy). Geotrails and Urban GeoTrails are useful learning tools for use in primary or secondary education classrooms. They are easily accessible guides that will allow teachers to take students into the field and learn about local geology without having to secure a trained geoscientist as a guide. Alternatively, teachers who cannot bring their students to the field (e.g. cost, location, accessibility) are encouraged to access these virtual tours in the classroom. Our multi-media approach is intended to provide as immersive an experience as possible, allowing students to get a feeling for what exploring the area is like without having to visit in person. GeoTrails and Urban GeoTrails, supplemented with educational materials for teachers, can help educators discover the potential of resources in their own backyards (Kean and Enochs 2001; Kean et al. 2004). We are hoping to reach more teachers with our upcoming Niagara Escarpment illustrated children's book and teacher's guide featuring activities involving the GeoTrails. In addition, these GeoTrails help to raise awareness about the impacts of climate change and/or land use on the local environment (Haynes 1995). The opportunity to learn about the environmental consequences of lifestyle choices can help community members understand their role in influencing global change.

FUTURE DIRECTIONS

The effectiveness of the GeoTrails to (1) build student leadership, (2) recruit students and (3) provide resources for local communities will continue to be assessed over the next five years. We plan to document the learning experiences of students who have participated in the development of the GeoTrails and to determine how their involvement has influenced their career choices. This will help identify which skills they developed during their work on the GeoTrails were most valuable to them. We would also like to host workshops aimed toward educators and community stakeholders (e.g. Curriculum Connections at GACMAC 2023) to showcase the GeoTrails and gain information about how to improve the GeoTrails to enhance student recruitment and better serve community needs. We are actively seeking feedback on the GeoTrails and look forward to creating additional resources (e.g. illustrated book, podcast, trail signs) to supplement these educational tools.

We will continue to create additional GeoTrails to showcase regional geological differences across southern Ontario and the influence of geoscience on our everyday lives. The involvement of additional university groups in the future will allow GeoTrails to expand to other regions of Ontario, such as the Rideau Trail (between Ottawa and Kingston, Ontario) and urban park trails within the City of Toronto. Ongoing testing of emerging digital field tools will allow us to determine their suitability and effectiveness to capture and present field data to a variety of audiences. Drone-based photogrammetry created using open-source software could also be incorporated in the GeoTrails to create 3-D surfaces for users to explore. The current GeoTrails feature drone photography, but drone-based photogrammetry will be necessary to provide perspective when access to parts of the trails may be problematic. Gamifying the GeoTrails to create additional opportunities for virtual reality engagement could also be a future direction for this project. Video game-style virtual field experiences provide an excellent opportunity to improve field accessibly for both the public and students (Mani et al. 2016; Needle et al. 2022).

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Incorporating downloadable formats of the information including the audio descriptions provided in the GeoTrails is a future target.

The GeoTrails we have created would also benefit from the incorporation of additional opportunities for consultation with Indigenous leadership, community feedback and citizen science. Current feedback from community groups continues to help us enhance GeoTrail methodology and accessibility and inclusivity. However, the incorporation of user observations into the GeoTrails would help build local datasets for geoscientists and empower citizens to take ownership of their environment (Roche et al. 2020). There are logistical challenges to integrating public input into active research; however, this is an opportunity to generate new knowledge that needs to be explored. We are excited about the opportunities the expansion of the GeoTrails project provides and the potential to significantly enhance public awareness and appreciation of geoscience.

DATA AVAILABILITY

All GeoTrails are publicly available through Geoscienceinfo.com.

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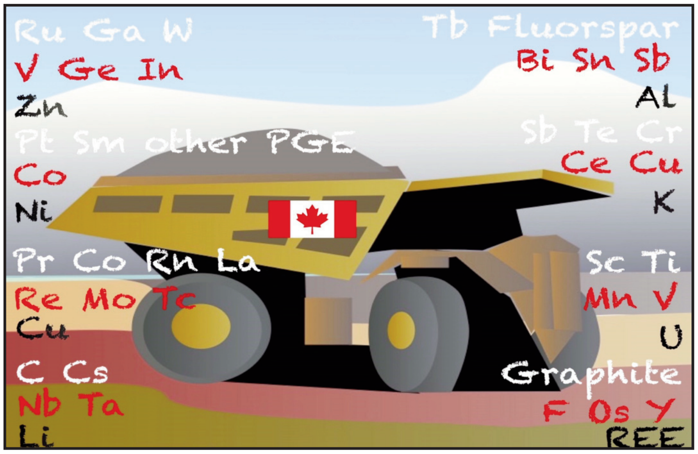

Critical Minerals in the Context of Canada: Concepts, Challenges and Contradictions

Andrew Kerr

Department of Earth Sciences
Memorial University
St. John's, Newfoundland and Labrador, A1B 3X5, Canada
Email: akerr@mun.ca

SUMMARY
Increased use of renewable energy, coupled with electrification of the economy, is considered important in efforts to limit future climate change. This quest for such commodities is now a persistent theme for the resource industry and emerging government policies. This review for non-specialists explains several key concepts but also explores some challenges and apparent contradictions in the context of Canada.

Canada now has a list of 31 critical minerals, but this includes some major commodities for which domestic production is significant and supply risk is low. The differences between our list and those of other jurisdictions reflect our more specific definitions. Most other commodities on Canada's list are also identified by other countries and some are specifically linked to the energy transition. These include cobalt, lithium, manganese, nickel, graphite and vanadium (used in electric vehicle batteries and static energy storage), rare earth elements (REE; used for magnets in EV motors and wind turbines) and some rarer elements (e.g. germanium, gallium, indium and tellurium) used in photovoltaic (solar) energy systems. Some of these are potential primary products (e.g. lithium, graphite and REE) but many others (e.g. cobalt, platinum group elements and the photovoltaic elements) are byproducts from the production of major commodities, notably nickel, copper and zinc. The REE represent coproducts that are closely associated in nature and very hard to separate from each other; they are produced as a group.

There are some specific challenges in exploring for and developing critical mineral resources. The end-use technology driving demand evolves on a timescale of years, but mineral exploration and development now typically take multiple decades. Material substitutions and unpredictable developments in technology complicate the exact prediction of future demands. The forecasts of overall relative demand growth are impressive, but for some key commodities global production will remain small in absolute terms, which may limit the potential for new discoveries. Simple measures of grade and tonnage are not always guarantees of viability, because deposits of some commodities (e.g. the REE) are mineralogically complex. Byproduct commodities cannot be produced in isolation, and many of these are only extracted in smelting and refining. Domestic production of these commodities is effectively lost if concentrates are exported for processing. The emissions and environmental impacts associated with production of critical mineral resources will also become important if such activity is to be linked to wider climate goals. This may present challenges in northern Canada, where renewable or low-carbon energy options are limited. Most draft land use plans in the north presently emphasize large-scale land conservation, which could limit future exploration access before resource potential is fully assessed. Given the strong divisions of opinion about resource development, especially in the north, controversy and polarized debate will not easily be avoided.

There are no simple answers to challenges that are political or jurisdictional rather than technical, but there is definitely a need for more public geoscientific information. This will help to identify areas of greatest potential, evaluate known deposits and contribute to future sustainable development. For many of the commodities on our critical mineral resources list, data for Canada remains incomplete, especially in more remote regions that are generally considered to have the highest potential.

RÉSUMÉ
L'utilisation accrue des énergies renouvelables, associée à l'électrification de l'économie, est considérée comme étant

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essentielle dans les mesures visant à limiter les changements climatiques futurs. Cette transition énergétique devrait accroître la demande de certaines matières premières, dont bon nombre sont maintenant qualifiés de minéraux critiques. La quête de telles matières premières est désormais un thème persistant pour l'industrie des ressources et les politiques gouvernementales émergentes. Cette revue à l'intention des non-spécialistes explique plusieurs concepts clés, mais explore également certains défis et contradictions apparentes dans le contexte du Canada.

Le Canada dispose désormais d'une liste de 31 minéraux critiques, mais celle-ci inclut certaines matières premières majeures pour lesquelles la production nationale est importante et le risque d'approvisionnement est faible. Les différences entre notre liste et celles d'autres juridictions reflètent nos définitions plus spécifiques. La plupart des autres matières premières de la liste du Canada sont également identifiées par d'autres pays et certaines sont spécifiquement liées à la transition énergétique. Il s'agit notamment du cobalt, du lithium, du manganèse, du nickel, du graphite et du vanadium (utilisés dans les batteries de véhicules électriques et le stockage statique de l'énergie), des éléments des terres rares (ETR ; utilisés pour les aimants dans les moteurs de véhicules électriques et les éoliennes) et de certains éléments plus rares (comme le germanium, le gallium, l'indium et le tellure) utilisés dans les systèmes d'énergie photovoltaïque (solaire). Certains d'entre eux sont des produits primaires potentiels (comme le lithium, le graphite et les ETR), mais beaucoup d'autres (comme le cobalt, les éléments du groupe du platine et les éléments photovoltaïques) sont des sous-produits de la production de matières premières majeures, notamment le nickel, le cuivre et le zinc. Les ETR représentent des coproduits étroitement associés dans la nature et très difficiles à séparer les uns des autres; ils sont produits groupés.

L'exploration et le développement de ressources minérales critiques présentent des défis spécifiques. La technologie d'utilisation finale qui stimule la demande évolue sur une échelle de temps de quelques années, mais l'exploration et le développement miniers prennent désormais généralement plusieurs décennies. Les matériaux de substitution et les développements imprévisibles de la technologie compliquent la prévision exacte des demandes futures. Les prévisions de croissance relative globale de la demande sont impressionnantes, mais pour certaines matières premières clés, la production mondiale restera faible en termes absolus, ce qui pourrait limiter le potentiel de nouvelles découvertes. Les mesures simples de teneur et de tonnage ne garantissent pas toujours la viabilité car les gisements de certaines matières premières (comme les ETR) sont minéralogiquement complexes. Les matières premières secondaires ne peuvent pas être produites isolément, et bon nombre d'entre elles ne sont extraites que lors de la fusion et du raffinement. La production nationale de ces matières premières est effectivement perdue si les concentrés sont exportés pour être transformés. Les émissions et les impacts environnementaux associés à la production de ressources minérales critiques deviendront également importants si cette activité doit être liée à des objectifs climatiques plus larges. Cela peut présenter des défis dans le nord du Canada, où les options d'énergie renouvelable ou à faible émission de carbone sont limitées. La plupart des projets de plans d'utilisation des terres dans le Nord mettent actuellement l'accent sur la conservation à grande échelle des terres, ce qui pourrait limiter l'accès à de futures explorations avant que le potentiel en ressources n'y soit pleinement évalué. Étant donné les fortes divergences d'opinion concernant le développement des ressources, en particulier dans le Nord, la controverse et les débats polarisés ne seront pas facilement évités.

Il n'y a pas de réponses simples aux défis qui relèvent davantage de la politique ou de la juridiction que de la technique, mais il est certainement nécessaire de disposer de plus d'informations géoscientifiques publiques. Cela aidera à identifier les domaines à plus grand potentiel, à évaluer les gisements connus, et à contribuer au développement durable futur. Pour bon nombre des matières premières de notre liste de ressources minérales critiques, les données pour le Canada demeurent incomplètes, en particulier dans les régions plus éloignées qui sont généralement considérées comme ayant le potentiel le plus élevé.

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INTRODUCTION

The Context of the Modern Critical Minerals Discussion

The third decade of the 21st century began turbulently, with a disruptive global pandemic followed by disturbing armed conflicts. Disruptions to supply chains from such circumstances, including impacts on mineral resources availability, illustrated the vulnerability of integrated international economies to natural and human influences. The topic of so-called *critical minerals* is one small part of a much wider discussion about energy and resource futures. Critical minerals are in the media on almost a daily basis and addressed by formal documents from the federal government (Government of Canada 2022) and individual provinces (Government of Quebec 2020; Government of Ontario 2022a). These documents emphasize expanded and/or new mineral resource extraction and more efficient utilization of existing resources to meet demands anticipated as part of the so-called *energy transition*. Such needs are predicted by studies that attempt long-range predictions of supply and demand to 2100. The most widely quoted of these 'scoping studies' are by the World Bank (2017, 2020) and the International Energy Agency (IEA) in 2020 and 2022. The IEA released an updated report in July 2023 that analyzes the growth in demand and supply for such commodities. This review article outlines key critical minerals concepts in a general sense and explores present discussions in the context of Canada. It does not include detailed geological treatments of every commodity, although this is certainly needed. It also touches on some wider issues, including challenges and potential contradictions that are not always discussed in scientific papers. It is intended to inform readers who lack specialized knowledge, which include many in the geoscience community. There is no shortage of promotional corporate material related to exploration, and more nuanced policy documents from governments will inevitably be tabled, but widespread media misconceptions underline the need for jargon-free explanatory material. There is also a pressing need for systematic geoscientific information about many of these commodities on a national scale, but this is no small task.

What are Critical Minerals and Why Might They Prove Controversial?

As geoscientists, we know that non-renewable natural resources are a cornerstone of modern industrial society, although this is not always recognized by the public. Simplistic estimates of the annual per-capita usage of key commodities in current decades by the United States Geological Survey (USGS) illustrate this vividly (Fig. 1). If such consumption rates are sustained over human lifetimes, the demand for materials is truly immense. Such guesstimates apply to the USA and other industrialized countries, but most people on Planet Earth consume far less than this. However, the peoples of the world understandably aspire to enjoy living standards akin to those of industrialized countries, so resource usage will only grow, even if global populations stabilize or even diminish.

The concept of critical minerals arose long before this century, but some of its tenets are now altered. The first list of 'war minerals' was compiled by the USA during World War I (Nicholls 2022), and control of strategic resource supplies was certainly critical in World War II, as illustrated by uranium (Zoellner 2011). During the ensuing "Cold War" western nations worried about disruption of strategic resource supplies, so they prioritized such materials and some maintained physical stockpiles. Such policies lapsed for most commodities in the late 20th century, but returned in the early 21st century, in part because of China's increasing dominance in the minerals sector. Critical minerals are now foremost on the agenda of most industrialized countries in the form of 'critical minerals lists' and specific policies to reduce dependence on imports. However, this revival is not universally welcomed, as it amplifies divergence between advocates of resource extraction and those concerned with environmental impacts and land conservation (e.g. Lee et al. 2020; Lèbre et al. 2020; Crawford and Odell 2022). Linking potential new mining developments to global efforts to limit the impacts of climate change is controversial in this context, and some (e.g. Environmental Justice Atlas and MiningWatch Canada n.d.; see also Deniau et al. 2021) contend that it is a distraction from the greater need to reduce material usage and emissions. A recent analysis of media discussion around critical minerals extraction related to electric vehicles (EVs) by Agusdinata and Liu (2023) shows that issues related to environmental and social impacts receive far more coverage than any technical matters. The degree to which media coverage actually reflects the balance of opinion is of course subject to discussion, but there is no denying its potential influence.

The most common questions about critical minerals are as follows. First, what are they and how exactly are they defined? Second, why do the critical minerals lists of various jurisdictions differ in important respects? Third, how reliable are demand forecasts by the World Bank, IEA and other agencies

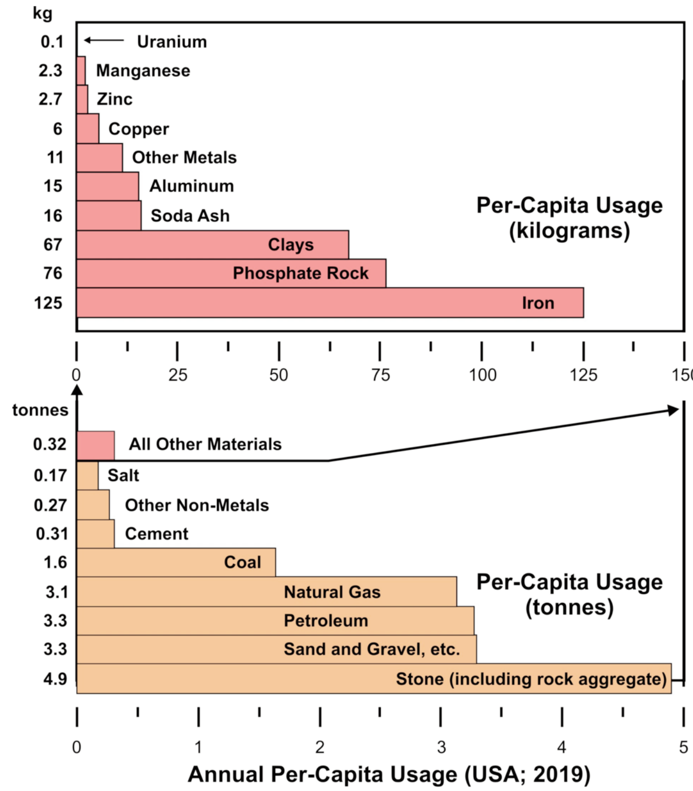

Figure 1. An illustration of per-capita annual resource demands for the United States in the early 21st century, as compiled by the United States Geological Survey in 2019. For the purposes of representation, petroleum products are recalculated into tonnes on the basis of an average density of 0.9 g/cc, and natural gas is converted from cubic feet assuming that a cubic foot weighs 0.15 kg (i.e. about 5 kg/m^3; or 0.005 g/cc). The horizontal scales for the upper and lower parts of the figure are adjusted to represent the wide range of values.

for such commodities? Fourth, are there substitutes for such materials, and could existing sources augmented by recycling instead suffice? A more complex question brings these themes together to ask if the purported criticality of a mineral deposit might justify its more rapid development, and/or setting aside some environmental concerns. Another closely linked question asks if emissions involved in developing and processing such resources discount or negate long-term climate benefits. Some of the commodities involved in this debate are now labelled as "green minerals" or referred to in phrases such as "*mining for clean energy*" (e.g. Clean Energy Canada 2017) or "*climate-smart mining*" (World Bank 2020). To phrase these questions in another way, are such labels truly accurate, or are some commodities being misrepresented or 'greenwashed' by those with a vested interest in their extraction?

Sources of Technical Information about Critical Mineral Resources

In Canada, public geoscientific information is presently incomplete for many commodities now labelled as critical minerals, especially those that lack previous exploration interest. Some entries on Canada's list are familiar major commodities (although the criteria for their inclusion are debatable; see later discussion) but existing resources may not suit new uses, so new technical information is still needed. Canada has a reputation as a resource-rich jurisdiction and a leader in minerals research and exploration financing, but other jurisdictions (e.g. the USA, UK, EU countries and Australia) have to date been more active in gathering, compiling and disseminating technical geoscience information.

A massive compilation of technical information by the USGS (Schulz et al. 2017) provides geological and geochemical data for more than 20 commodities, including information on markets, processing and environmental aspects. These provide useful background information on resources and environments in Canada. The British Geological Survey (BGS) provides excellent reports on multiple commodities with a wider scope, although with some focus on Africa, seen as a prospective region closest to Europe (e.g. Petavratsi et al. 2019; Mitchell and Deady 2021; Goodenough et al. 2021). Geoscience Australia also provides summary information and detailed accounts for specific commodities and more general analyses (e.g. Skirrow et al. 2013; Mudd et al. 2019, Huleatt 2019). Specific commodities in parts of Canada are discussed in reports issued by provincial geoscience agencies (e.g. Kerr et al. 2009, 2013; Simandl et al. 2012) but these lack national context and some are now outdated. The critical minerals strategies tabled by federal and provincial governments contain limited geoscientific data and focus more on the wider economic potential of these commodities, including the development of vertically integrated supply and production chains.

Broad statements that Canada is a *"storehouse of critical minerals"* (or words to that effect) abound in strategy documents and much corporate literature, but supporting data remain limited. Such statements partly reflect a modified definition of criticality adopted by Canada, through which several well-established commodities that we produce are included on our list, as discussed in the next section. A recent CBC news item (Panetta 2021) pointed out that our reserves of other critical mineral resources are actually small on a global scale even if there is perception of untapped wider potential. A more recent newspaper article (The Globe and Mail 2022) stated that *"Canada's ambitions are the right ones, at least on paper. The trick is moving beyond blueprints"*. One of few documents that are easily available on government websites is the report of the House of Commons Standing Committee on Natural Resources (Maloney 2021). An earlier document of this type (Anonymous 2014) is specifically related to rare earth elements (REE). Both include submissions from diverse industry experts, and the lack of technical information emerges as a common theme. These committee reports are not technical geoscience documents, although they contain opinions from geoscientists, but they provide interesting insights into political and ideological viewpoints that will likely influence geoscience research efforts. The Government of Ontario (2022b) provides information on specific commodities in that province, but only at a general level. The Ontario Mining Association (2022) provides more detailed information on production, markets and forecasts, outlining the concerns of industry, but their compilation is not geoscience oriented. The recent paper by Simandl et al. (2021) in *Geoscience Canada* discussed commodities linked specifically to energy applications in more detail, and was a useful source for this paper, but is not specifically Canadian in focus. A more recent summary by Simandl (2023) discusses more specific issues related to Canada's critical minerals list and strategy, and also touches upon some of the themes in this paper.

CRITICAL MINERALS AS VIEWED IN THE 21st CENTURY

Critical Minerals versus Critical Materials or Critical Mineral Resources

The term critical mineral(s) is established but inaccurate because it includes elements, groups of elements, minerals, gases, and other organic raw materials. The minerals that are processed to extract chemical elements, or used directly, are the real topic under discussion and some entries (e.g. helium) have no connection to minerals. Some treatments prefer *critical materials* as a term, but this might be construed to include synthetic substances. Although it is difficult to avoid 'critical mineral' entirely, the more precise definition should be kept in mind, and the term *critical mineral resources* is preferred here. Helium (He) is present on several lists, including Canada's, but this is excluded from discussion here.

Definitions and Modified Definitions

The term critical mineral first appeared following World War II, although the concept is much older. Nicholls (2022) mentions a terse anonymous quote that simply said, *"it's stuff you need that you can't get,"* and this is the essence of the concept. It is applied to mineral resources from geographic areas deemed vulnerable to natural disasters, military conflicts or political upheavals. In other words, mineral resources considered vulnerable to supply risk are deemed as critical. Consideration is also given to another loosely defined parameter termed economic importance (or similar wording) that measures industrial or strategic value. Criticality then becomes a combination of the two measures, such that a critical mineral resource is defined largely by high economic importance and elevated supply risk (e.g. Graedel et al. 2015). Usually, a numerical 'score' is assigned to supply risk and economic importance, as shown in Figure 2 (adapted from Skirrow et al. 2013). The criteria used to derive these scores are only partly quantitative, so some divergence among critical mineral resources lists should be expected, especially where countries also have some domestic production. It is also important to remember that the ranking of a given critical mineral resource is subject to change over time; for example, Figure 2 (which is 10 years old) did not categorize lithium (Li) as critical, but this would not apply today. Supply risk is also defined in different ways; for example, some jurisdictions (such as the USA) use 'single-point-of-failure' exclusions such that even if domestic production is significant, the commodity is considered at risk if the source is unique. The methods and reasoning used in definitions of criticality are discussed in much more detail elsewhere (e.g. Graedel et al. 2015; Simandl et al. 2021), but the key point is that there is no single rigorous definition, and the approaches of various jurisdictions may be inconsistent.

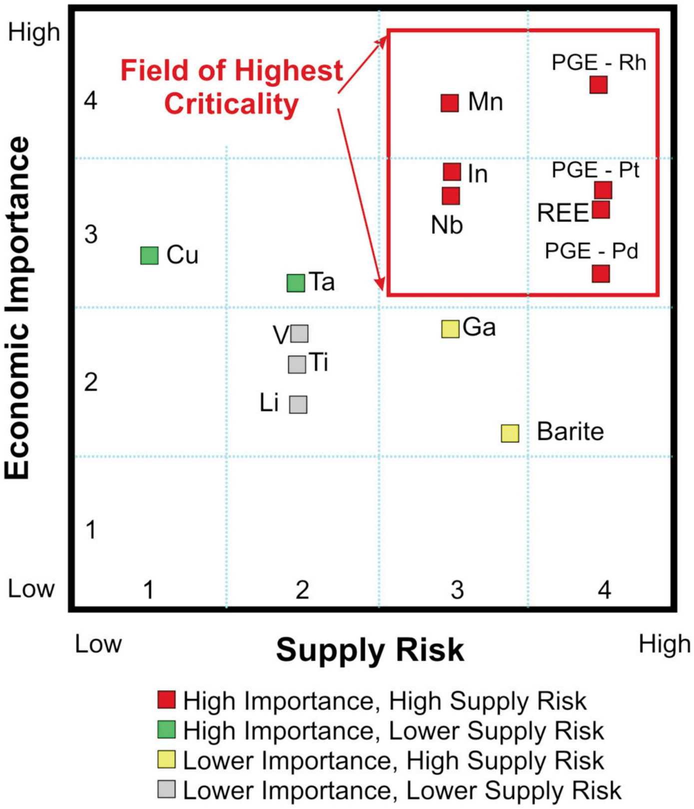

Figure 2. An illustration of how critical minerals are defined in terms of their perceived importance to industry and perceived risks to their supplies. Modified after Skirrow et al. (2013).

Some mineral resources are excluded even though they seem to have obvious relevance to the energy transition. For example, uranium (U) was removed in 2021 from the US critical mineral resources list because it was considered an "energy mineral". This decision proved politically controversial (e.g. Mining Newswire, November 2021). In other cases, mineral resources that lack obvious supply risk are defined as critical, as in the case of Canada's current critical minerals list, as discussed below, and also by Simandl (2023).

Lists and Changing Lists

The critical mineral resources lists maintained by Canada, USA, the EU and Australia are not identical, but they have much in common. They can be visually represented using the periodic table, even though some are not strictly chemical elements (Fig. 3; following Emsbo et al. 2021). Most commodities are found on two or more of these lists, and some are present on virtually all. Figure 3 also illustrates an important facet of Canada's list; it includes several major commodities (aluminium (Al), nickel (Ni), copper (Cu), zinc (Zn), potash (KCl)) and also U, which are generally not listed by the other jurisdictions. The Government of Canada strategy document (2022) tabulates a wider selection of such lists, including Japan, South Korea and the United Kingdom, but these are not incorporated in Figure 3. A patriotic 'Maple Leaf' graphic illustrates our list in strategy documents (Government of Canada 2022). This is included here to highlight differences from lists maintained by the USA, EU and Australia (Fig. 4a). As noted above, Canada's list includes some commodities that do not have obvious supply risk in our context. Nickel was added to the USA list at the same time as U was dropped. Canada was the world's largest source of potash and its second-largest source of U in 2022. Our production of copper, nickel and zinc is also significant over many decades, although our world share has declined. In 2022 we ranked sixth for Ni, eleventh for Zn and twelfth for Cu. We also produce many other commodities on our list, such as cobalt (Co), titanium (Ti), molybdenum (Mo), niobium (Nb) and platinum group elements (PGE). Canada does not mine any ores of Al, as raw materials (bauxite) are all imported, but aluminum production is important economically in Quebec and British Columbia. Simandl (2023) also pointed out that several entries on Canada's critical mineral resources list are not obviously subject to supply risks. This contrast between Canada's list and those of others reflects slightly different definitions of criticality. The Government of Canada (2022) also includes commodities that are *"....a sustainable source of highly strategic critical minerals for our partners and allies....".*

Simandl et al. (2021) discussed this issue in general terms and suggested that it reflects the desire to promote domestic production and exports. Simandl (2023) provided additional discussion in a Canadian context and suggested that some commodities are included on the basis of their importance to the economies of provinces and territories, rather than according to supply risk. Among the commodities that contribute most of the more than $40 billion value of mineral production in Canada in 2021 (Natural Resources Canada 2022; excluding coal, iron ore and construction materials) only gold and diamonds are actually excluded from the critical mineral resources list. On the basis of the current list, close to one third of the total value of Canada's mineral production is represented by critical mineral resources.

The differences between our list and those of others illustrate the influence that the precise definition of criticality has upon which commodities are included on such lists. Although our inclusion of some major commodities is fully consistent with the reasoning employed, it could cause some complications. First, when references are made to total Canadian reserves and resources, these include (and are in fact dominated by) such commodities. Second, if the development of critical mineral resources is to be prioritized or financially encouraged in some way, proposals involving these commodities could be challenged by opponents of development, because they do not have obvious supply risk and are not classed as critical by others. Proposals to develop uranium deposits would probably be the most likely to awaken controversy on this basis, based on numerous historical precedents. Presently, only Canada and South Africa include uranium as a critical mineral.

However, it is important to note that commodities that lack obvious supply risk may indeed be important in the context of the energy transition (e.g. Cu, Ni and perhaps U), in efforts to reduce emissions (e.g. Zn) or for global food production (e.g. potash). Aluminum plays a vital role across all industries, including energy technology. Copper is important because

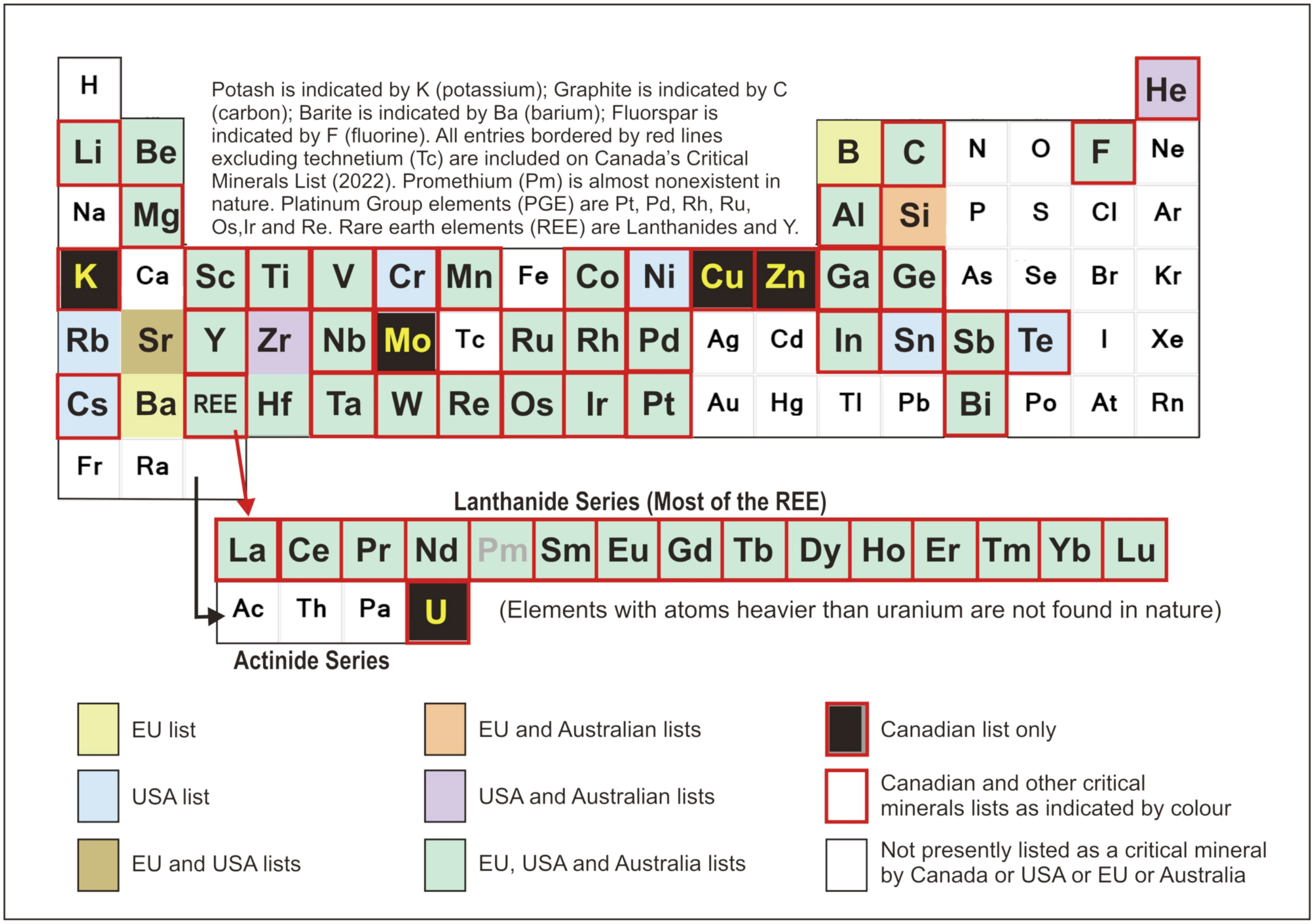

Figure 3. The periodic table of the elements, showing the critical minerals defined by four jurisdictions (USA, Canada, European Union and Australia) using a colour-coding system. Potash is illustrated using potassium (K), fluorspar is illustrated by fluorine (F) and graphite is illustrated by carbon (C). Elements denoted in negative format (black fill and yellow letters) are those categorized as critical by Canada, but not by most other jurisdictions. Modified after a similar diagram by Emsbo et al. (2021). Note that the critical minerals lists do change with time.

renewable energy generation requires much greater transmission capacity. Nickel and Zn also have existing and potential roles in energy technology, although this is not their most important usage.

Most other entries on Canada's critical mineral resources list (Figs. 3, 4a) have geographically restricted sources, although we do produce some. The supply risk for many has increased since 2000, and China now dominates some, to the extent of controlling most supply and downstream processing. This is most extreme for the rare earth elements (REE) but it applies to other commodities, such as antimony (Sb), graphite and tungsten (W). Whenever a single entity – be it a nation or a corporation – controls most sources and most availability, it effectively controls pricing, so this is part of the supply risk assessment. This aspect is downplayed in many critical minerals strategies (for example, Canada's document refers to "non-like-minded countries" and avoids any identification) but concern is more overt in documents that have a political context (e.g. Anonymous 2014; Maloney 2021) and in equivalent analyses from the USA (e.g. Humphries 2019). Russia's important reserves of some critical mineral resources (e.g. PGE, vanadium (V) and potash) are undoubtedly of more recent concern. As geoscientists, we naturally prefer to focus on technical information, but there are definite nationalistic and competitive dimensions to the current interest in critical mineral resources.

Groupings of Critical Minerals and their Importance

Canada's present list of 31 critical mineral resources (Figs. 3, 4) is also summarized in Table 1. Note that it includes two groups, REE and PGE, that comprise multiple chemical elements. The individual elements in each of these groups are not all critical in their own right, but rather occur together in nature, and may be difficult to separate.

The REE include 15 individual elements, comprising the lanthanide series (La to Lu in the periodic table; Fig. 3) and the chemically similar element yttrium (Y). Scandium (Sc) is also commonly grouped with the REE, although there is no geochemical basis for this. The PGE include iridium (Ir), platinum (Pt), palladium (Pd), osmium (Os), rhenium (Re), rhodium

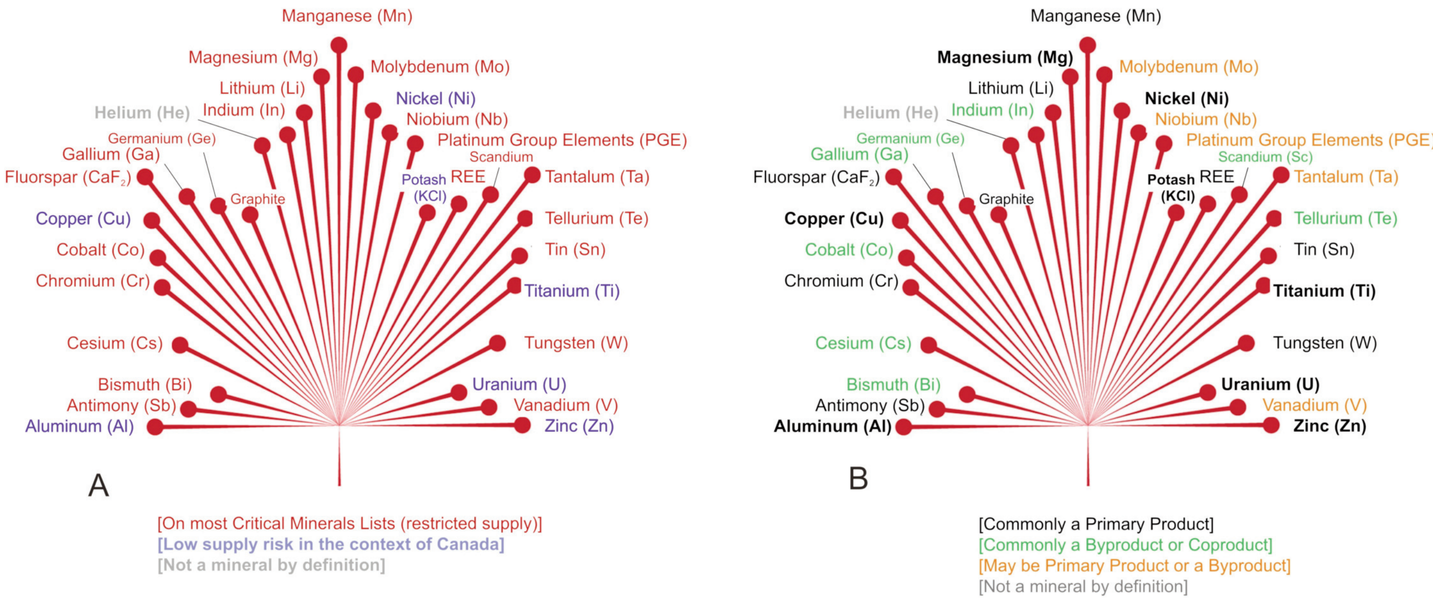

Figure 4. Canada's present list of critical minerals in graphical form, structured to provide the outline of a maple leaf, as in our flag, modified after Government of Canada (2022); (A) colour-coded version to highlight commodities for which Canada's definition of critical also includes factors other than supply risk; see text for discussion. (B) A colour-coded version to highlight primary products versus byproducts and coproducts. Note that the REE are mutual coproducts, but commonly are mined as a collective primary product.

(Rh), and ruthenium (Ru). The elements within the REE and PGE groups each exhibit similar geochemical behaviour and each element group occurs in distinct geological settings. The affinities between individual PGE are looser than those between individual REE; for example, it is possible to identify Pd-rich deposits that contain little Pt, or vice versa. In contrast, REE deposits dominated by only a single individual element simply do not exist. REE with lower atomic numbers ('light REE') are more abundant in absolute terms than those with higher atomic numbers ('heavy REE'). Note that the conventional scientific method of graphically representing REE patterns, by normalizing data to chondritic meteorite data, does not actually represent absolute abundances; the heavy REE are much rarer than the light REE. Weng et al. (2015), Goodenough et al. (2018) and Jowitt (2022) provided additional discussion around "REE Balance". The REE are effectively coproducts, at least at the mining and processing stages of supply chains, and this also generally (but not always) applies to the PGE.

Several commodities on Canada's list are important transition metals associated with the steel industry, such as Mo, V, W, chromium (Cr), and manganese (Mn). Chromium and Mn are major commodities based on their large annual global production, but Canada is presently dependent on imports. Other transition metals on Canada's list include Co, Nb, bismuth (Bi), and tantalum (Ta). Some of these (notably Co, Mn, Ta and V) have important applications in energy technology, as discussed below. Lithium and cesium (Cs) are alkali metals (Group 1 in the periodic table; Fig. 3) but have rather different geochemical properties and natural abundances. Lithium is especially important in modern battery technology (see later discussion).

Critical Mineral Resources and the Energy Transition

Current discussion about critical mineral resources focuses on materials that have roles in renewable energy (e.g. solar power, wind power and other innovations) and energy storage technology (i.e. batteries). Most industrialized countries now have policies to decarbonize transportation within the coming decades. Electric vehicles (EVs) need efficient motors and lightweight batteries with high energy densities, i.e. able to function for long periods before recharge. Wind power needs lightweight and efficient generators, which have much in common with EV motors. Photovoltaic technology (i.e. direct conversion of solar radiation to electricity) is moving from relatively inefficient silicon-based panels to so-called 'thin film' technology that is more efficient. Research in the energy sector is especially active and dynamic (see Simandl et al. 2021, 2023 for more details; also, Goodenough et al. 2018; Gunn and Petavratsi 2018; Bloodworth 2019; McNulty and Jowitt 2021). The treatment here is confined to a brief overview of essentials.

Important battery minerals include Co, graphite (a mineral formed of elemental carbon), Li, Mn, Ni and V. Although Ni is on Canada's list and is used in batteries, its main applications are in other sectors, such as steel. This is also true for Mn, which has many uses. Some of the REE (notably La, Ce and Y) and also lead (Pb) and cadmium (Cd) have battery sector applications, but the latter two elements are omitted from Canada's present list. Future V demand growth is projected if vanadium-redox batteries (VRBs) are extensively deployed (e.g. Simandl and Paradis 2022). Many other storage battery systems are in research stages, so the final shape of this sector is very hard to predict (Simandl et al. 2021, 2023). The greatest pres-

Table 1. Listing of critical minerals presently identified by Canada, with brief comments on their attributes.

Material	Symbol	Comments
Aluminum	Al	Important major commodity, but not mined in Canada. Produced from imported bauxite ores processed in QC and BC.
Antimony	Sb	Now supplied from China, but deposits in NB and NL have produced; resources remain in NL. Also associated with gold or base-metals veins, but generally at low grades. A pathfinder for gold.
Bismuth	Bi	Byproduct from some base-metal and gold deposits. Future production from NWT (NICO deposit) possible. Subeconomic deposits in NB associated with W, Mo and In (Mount Pleasant)
Cesium	Cs	Byproduct typically associated with Li- and Ta-Nb-bearing pegmatites. Produced in small amounts from Tanco, MB; largely used to make Cs-formate brines, but has other uses.
Chromium	Cr	Major commodity, typically found in layered mafic intrusions. Large undeveloped deposit (Black Thor) in the "Ring of Fire" area, northern ON. Smaller deposits associated with ophiolite suites (BC, QC, NL)
Cobalt	Co	Byproduct from some Ni-Cu sulphide deposits, but major global source is from Cu deposits in central Africa. Produced from several deposits in Canada, and associated with many undeveloped deposits.
Copper	Cu	Important major commodity mined from porphyry deposits (BC), in some cases with byproduct Mo. Also obtained from Ni-Cu sulphide deposits and VMS deposits all across Canada.
Fluorspar	CaF_2	Industrial mineral used in steel/chemical sectors. Mined in NL since the 1930s, Other Canadian deposits are minor, with limited past production. Usually in vein-type settings related to granite.
Gallium	Ga	Rare trace element, byproduct from smelting of some zinc ores, but also enriched in bauxite (aluminum) ores, although not easily extracted from these. Important photovoltaic applications.
Germanium	Ge	Rare trace metal element, byproduct from smelting of some zinc ores. Currently extracted at smelters in Canada and elsewhere. Semiconductor important in computer technology.
Graphite	C	Soft form of elemental carbon, in massive or microcrystalline form, usually found in metamorphic terranes. Supply dominated by China and Africa, but several deposits exist in QC and ON.
Helium	He	Inert gas extracted from hydrocarbons. Not a true mineral by definition, and absent from natural minerals. Not discussed in this article.
Indium	In	Rare trace element, byproduct from smelting of some zinc ores. Canada is an important producer. Associated with Cd and Ge, locally with Ga. Possible byproduct from Mt Pleasant deposit in NB
Lithium	Li	Critical in battery sector. Obtained from pegmatite deposits and salar brines in South America. Li-rich pegmatites are well-known in the Canadian Shield. Some production from Tanco (MB).
Magnesium	Mg	Not currently produced in Canada. Previous production from carbonate deposits in BC. Increasing usage in low-density alloys, with Al, other metals. Deposits in BC are being re-evaluated.
Manganese	Mn	Former byproduct from discrete zones in iron-ore deposits (QC, NL). Potentially large sedimentary Mn deposits known in NB and Maine (USA). Present supply is mostly from southern Africa.
Molybdenum	Mo	Byproduct from porphyry copper deposits (BC), but locally the primary commodity. Smaller granite-related deposits are known in NB and NL. Locally associated with U deposits.
Nickel	Ni	Important major commodity mined from Ni-Cu sulphide deposits in Canada, notably Thompson, Sudbury, Raglan and Voiseys Bay. Important for byproduct Co or PGE production from some.
Niobium	Nb	World supply largely from Brazil (90%), followed by Canada (10%). Associated with carbonatite in QC, but found locally in pegmatites (with Ta) and in various REE deposits.
*Platinum Group Elements	PGE	Trace elements associated with Ni-Cu sulphide deposits in Canada (Thompson, Sudbury, Raglan). Generally byproducts, but can also be a primary commodity, with byproduct Cu and Ni.
Potash	KCl	Industrial mineral used in fertilizers and chemicals. Canada is the world's largest producer, dominated by several mines in SK. Lesser intermittent production from southern NB.
*Rare Earth Elements	REE	Trace elements, associated with primary deposits in unusual granite and carbonatite bodies in Canada, but with diverse associations worldwide. Canada has significant resources, but limited production.
Scandium	Sc	Extraction and use limited by extreme rarity of deposits, but could have wide application in alloys. Byproduct from some REE mining in China, and recently from Ti deposits in QC.
Tantalum	Ta	Trace element associated with Nb in carbonatite and with Li, Cs in rare pegmatites. Previously mined in Tanco, MB. Important in electronics; varied supply includes aritisanal mining in Africa.
Tellurium	Te	Rare trace element, byproduct from smelting of zinc ores or refining of copper; also found as a byproduct in some Au-Ag deposits.
Tin	Sn	One of the very first critical minerals in the Bronze Age. Associated with hydrothermal deposits in high-level granite bodies. Low-grade deposits in NS and NB, locally enriched in VMS deposits.
Titanium	Ti	Important commodity produced from deposits in QC with very large ilmenite resources. Metallurgically suitable Ti deposits may yield byproduct vanadium, some are also enriched in Sc.
Tungsten	W	Similar geological habitat to tin, but also forms large skarn deposits, previously mined in YT/NWT area. Deposits known in NL and NB, including high-grade veins and large disseminated deposits.
Uranium	U	Energy mineral produced in Canada from several deposits in SK. Canada was once world's largest producer but now ranks sixth. Potential resources in NWT, NU and NL.
Vanadium	V	Generally a byproduct from steel industry or iron-ore mining, also extracted from heavy oil and coal ash. Primary deposits are associated with mafic intrusions, with resources in QC and ON.
Zinc	Zn	Major commodity mined across Canada, from sedimentary- and volcanic-hosted sulphide deposits. Increased usage in galvanization anticipated. Potentially important for byproduct Ga, Ge, In.

NOTES: Some entries (e.g., Al, Cu, potash, Ni, U and Zn) are generally not identified as "critical" by other jurisdictions, and Canadian production for these is significant, although raw material sources may be elsewhere, as for Al. Canada also produces cobalt, molybdenum, niobium, Platinum-Group Elements (PGE), titanium, indium, fluorite, germanium and REE, although for some of these production is minimal. Aside from niobium, fluorite, titanium and REE, Canadian production of these minor commodities is as byproducts.

* A group of related and chemically similar elements. PGE group includes Ru, Rh, Pd, Re, Os, Ir and Pt (ascending atomic number). REE group includes Y, La, Ce, Pr, Nd. Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu (ascending atomic number), and may include the unrelated element Sc (atomic number 21) in some discussions. See Figure 3 for periodic table information.

ent exploration interest is for Li, graphite and Co. There are numerous combinations of these (and other) materials used in electrodes, electrolytes and other battery components (see Bloodworth 2019 and Simandl et al. 2021). Although their performance varies, these recipes all fulfil the basic functional requirements, so there is wide scope for substitution in these applications if a given material is unavailable or prohibitively expensive.

Magnet materials contribute to high-strength, lightweight permanent magnets needed for wind turbines and many EV motors. However, not all EV motor designs require permanent magnets, although these offer performance advantages (Goodenough et al. 2018; Simandl et al. 2021). Interestingly, the German manufacturer BMW recently stated that their next generation of electric vehicles will be powered by motors that do not require REE (Banner 2022). There is considerable flexibility in proportions of component materials, as in the battery sector. The REE are very important, because the addition of REE to alloys (also involving iron, boron, cobalt and other elements) increases field intensity with minimal density increase. Neodymium, praseodymium (Pr), samarium (Sm), dysprosium (Dy) and terbium (Tb) are the most important and valuable of the REE, but others also have utility. The choice depends to some extent on the application and the operating environment. Simandl et al. (2021) provided a useful account of existing and potential magnet types and the wide variety of material requirements that might be anticipated from their use but cannot be accurately predicted.

Photovoltaic materials are those connected to direct solar power generation. Large-scale implementation of solar energy (of any type) also demands energy storage capacity (i.e. batteries) and extensive transmission networks. Thin-film photovoltaic systems are more efficient than silicon-based equivalents, but some have yet to demonstrate commercial feasibility. These involve several metals and semi-metals including Cd, gallium (Ga), germanium (Ge), indium (In) and tellurium (Te). Other elements, such as Mo and tin (Sn) may also have important future roles (e.g. Simandl et al. 2021, 2023). With the exception of Cd, all are listed as critical by Canada and other jurisdictions (Fig. 3; Table 1). All these commodities, with the local exception of Mo and Sn, are mined as byproducts or coproducts, most typically from zinc or copper deposits. They are recovered during smelting and refining operations, rather than being separated at sources. The byproduct status of these materials (and many others) adds significant complications in assessing possible sources, and for any efforts to increase production and recovery (see later discussion).

Primary Products, Coproducts and Byproducts

Only a few of the materials on Canada's critical minerals list are primary products from existing mining operations, and these are mostly the major commodities that lack obvious supply risk. Table 2 summarizes important relationships between byproducts and associated primary products. Figure 4b shows Canada's list in 'maple leaf' format and indicates primary products, byproducts and also a few entries that can come in either form. A visual representation of some of the links between commodities is provided in Figure 5, modified and simplified from the more comprehensive original by Mudd et al. (2019).

Some product–byproduct links are well known. For example, Mo is generally produced from large (porphyry-type) copper deposits although it may locally be the primary product in Mo-rich subtypes. As discussed earlier, the entire REE group are coproducts; they will commonly all occur in a single mineral or in a small selection of minerals. The PGE are mostly associated with magmatic Ni-Cu sulphide deposits (like Sudbury, Ontario) and extraction is usually dependent on Ni and (or) Cu production. But this is not always the case; in some instances PGE are the primary commodity, with Ni and Cu as byproducts. This is the case for the world's largest PGE producer, the deposits of the Bushveld Intrusion in South Africa.

Several important elements are linked to Cu and Zn, including many of those used in photovoltaic technology (Ga, Ge, In, Te and Cd). Cobalt was mined historically as a primary commodity in Ontario but is today largely a byproduct from Ni-Cu sulphide deposits (many areas worldwide) or sedimentary-hosted copper deposits in central Africa. These are all cases where a critical mineral resource is linked to another commodity that may have a different demand profile. Increasing the availability of Ga (which is enriched in some ores of aluminum) by processing more bauxite is obviously not feasible unless demand for aluminum grows hugely, but developing Ga recovery from existing operations may be. However, predictions of increased demand for Ni and possibly Zn (see later discussion) may be a route to increasing supplies of Co and the photovoltaic elements.

Niobium, Ta and Cs are all linked to pegmatites, which are late-stage segregations of fluid-enriched granitoid magmas, and this is also a noted geological environment for Li, which is generally a primary product in hard-rock mining. However, a large part of the global Li supply comes from brine extraction, notably in South America. Niobium and Ta are also enriched in many carbonatite bodies, and these represent the most important sources of present Nb supply (Simandl et al. 2018). Canada is the second largest global producer of Nb, but pales in comparison to Brazil, which accounts for nearly 90% of supply (Simandl et al. 2018; USGS sources).

In summary, if we exclude the major commodities included on Canada's critical mineral resources list (Al, Cu, Ni, Zn, potash) and also U, only a few other entries are likely to be primary products (Fig. 4). These are Cr, Li, graphite and fluorspar, although Mo and Nb may possibly have this status. Manganese is in some cases the primary product from Mn-enriched zones in larger iron ore deposits, but Mn extraction would not generally be viable without the infrastructure related to iron ore. The byproduct or coproduct status of many critical mineral resources holds significant implications for their exploration and development.

CHALLENGES IN EXPLORING FOR AND DEVELOPING NEW CRITICAL MINERAL RESOURCES

General Information

Strategies related to critical mineral resources from the Government of Canada (2022) and other jurisdictions all discuss

Table 2. Primary products, byproducts and coproducts as applied to Canada's critical minerals list. See also Figure 5 for visual representation of these relationships.

Primary Commodity	Commonly Associated Commodities	Less Commonly Associated Commodities	Comments and Qualifications
Copper (Cu)	Molybdenum (Mo) Tellurium (Te) Rhenium (Re) Gold (Au)	Cobalt (Co) Zinc (Zn) Selenium (Se) Silver (Ag)	Mo, Re, Te and Au are commonly (but not always) associated with porphyry-type settings, but may not be recoverable. Cobalt is found largely in sedimentary Cu deposits (Africa).
Nickel (Ni)	Cobalt (Co)	Platinum (Pt) Palladium (Pd) Other PGE (Ru, Rh, Ir, Os)	Cobalt is generally associated with deposits that also show Cu enrichment. Pt is more abundant in Ni-rich varieties compared to Pd but some deposits essentially lack PGE.
Zinc (Zn)	Cadmium (Cd) Indium (In) Germanium (Ge)	Tin (Sn) Gallium (Ga) Selenium (Se) Telluriun (Te)	Zn-rich sulphide deposits carry a wide variety of associated minor elements but their occurrence is hard to predict.
Lead (Pb)	Bismuth (Bi) Antimony (Sb)	Tellurium (Te) Fluorite (CaF_2)	Other base metals, e.g. Zn and Cu also occur sporadically in Pb-rich veins.
Iron (Fe)	Manganese (Mn) Vanadium (V)	Scandium (Sc)	Vanadium only found in iron-ores of igneous origin; Mn-rich zones are typically discrete.
Gold (Au)	Various base-metals (notably Cu)	Silver (Ag) Tellurium (Te) Arsenic (As) Antimony (Sb)	Byproducts are rarely recovered from Au deposits, aside from Ag, as their processing prioritizes Au recovery and byproducts add little value.
Aluminum (Al)	Gallium (Ga)	Vanadium (V)	Byproduct recovery is rare (and difficult).
Rare Earth Elements (REE)	Zirconium (Zr) Niobium (Nb) Thorium (Th)	Beryllium (Be) Uranium (U)	Byproducts may be difficult to recover without affecting REE recovery. Some elements (U, Th) are problematic.
Lithium	Tantalum (Ta) Niobium (Nb)	Cesium (Cs) Rubidium (Rb)	Spatial associations of Ta, Nb and Cs are commonly hard to predict in pegmatites.

exploration to define new resources. Northern regions are emphasized, because resource development has long been seen as a route to economic growth (e.g. Sherlock et al. 2003). Broader mineral strategies for Nunavut and the Northwest Territories (NWT) stress the economic impacts of mineral production and the need to maximize benefits from development (Government of Nunavut 2007; Government of Northwest Territories 2014). Government geoscience programs such as the *Targeted Geoscience Initiative and Geo-mapping for Energy and Minerals* by the Geological Survey of Canada provide mapping and other information, to complement work by provincial and territorial agencies. However, despite this widespread support from government and industry, opinions on mining developments in the North remain polarized. Strong voices advocate instead for a strategy of large-scale land conservation, reflected in draft land use plans, notably in the case of Nunavut (Nunavut Planning Commission 2021) and the NWT (Government of Northwest Territories 2022). Northern Canada is known as prospective for world-class gold, base metal and iron ore deposits but the information base for critical mineral resources remains incomplete. There are also wider challenges to the exploration and development of such resources, even in areas with better infrastructure or more plentiful geoscience data. Parts of the following discussion amplify points made previously by Goodenough et al. (2018) and Simandl et al. (2021, 2023) for the REE and other energy-related commodities, but the general considerations apply to all critical mineral resources, with the exception of some major commodities included on Canada's list.

The Timescales of Innovation and Resource Development

Critical minerals are widely labelled as "*vital resources for modern technology*", or words to this effect. Predictive studies (e.g. World

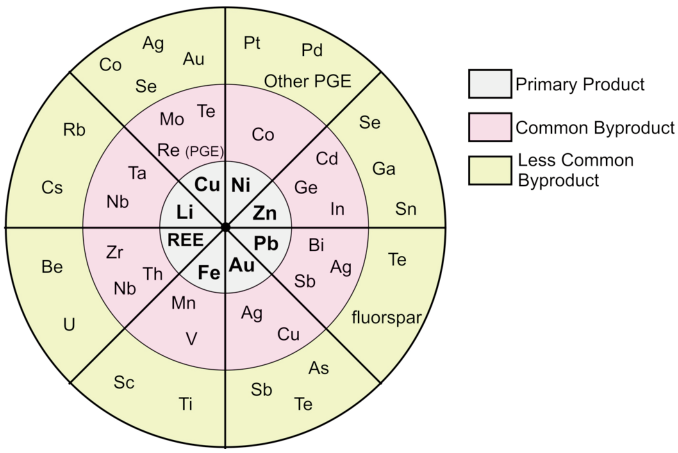

Figure 5. An illustration of the relationships between selected primary products or product groups (Cu, Zn, Ni, Pb, Fe, REE and Li) and the associated byproducts or coproducts, which include also some elements not presently ranked as critical. See also Table 2, as not all relationships can be indicated in this manner. Simplified from a more comprehensive graphic presented by Mudd et al. (2019).

Bank 2020; International Energy Agency 2022) build a persuasive narrative of unique attributes, immediate needs and strong growth potential. However, this view does not always consider order-of-magnitude contrasts in the timescales of technical innovation and resource development.

As anyone beyond middle age knows, the pace of technological innovation is fast and bewildering. Such changes can rapidly impact demands for commodities or change future expectations. Successful material substitutions can suddenly downgrade the importance of a given commodity, and research may create new demands for another commodity that may be hard to obtain. However, not all substitutions or innovations prove commercially feasible, so such changes are unpredictable. The timescale of technological innovation is typically measured in years, but the timescale for development of any mineral deposit (not including the preceding exploration effort) typically involves decades. It took only 5 years to advance Voisey's Bay (Labrador) from a gossan to a world-class Ni-Cu-Co discovery, but twice as long to finally break ground at the site (Goldie 2005). Most industry analysts would class Voisey's Bay as a rapid success in the context of northern development. Other discoveries took longer to develop, and some never completed their journey. The Kiggavik uranium deposit in Nunavut was first discovered over 30 years ago (Fuchs and Hilger 1989) but remains undeveloped following recent regulatory decisions. Development of Windy Craggy, a world-class volcanogenic Cu-Co-Ag-Au deposit in a remote area of British Columbia, was halted in 1993 following establishment of a provincial wilderness park. The present status of cobalt as a critical mineral has led to calls for this decision to be revisited (e.g. Downing and Van Nieuwenhuyse 2020) but there are few precedents for this.

This contrast in timescales has important implications. Established companies are hesitant to engage in any sudden exploration rush for materials that may have unpredictable futures. Those with greater capacity to apply expertise and knowledge may understandably conclude that it is better to let others take those risks. There is no obvious solution to this disconnect between timescales. Geoscience data that aid in exploration will help, but most research emphasis remains towards more familiar base metals and gold. The interval between research and the availability of integrated data is also often several years, which adds to the timescale contrasts. Industry groups advocate for simpler permitting and assessment procedures that could fast-track development (see Maloney et al. 2021 for many examples). Recent critical mineral resources strategies (e.g. Government of Canada 2022) make reference to this problem, and the wider idea of 'one project, one assessment' but this is not easily achieved when there are multiple stakeholders, each with defined rights. Such fast-tracking initiatives are seen in a different light by groups focused on large-scale land conservation, which is a prominent theme in draft land use plans for northern regions (e.g. Nunavut Planning Commission 2021; Government of Northwest Territories 2022). Land claims agreements with Indigenous peoples across Canada include strong provisions for consultation and environmental assessment. These principles are also strongly emphasized in critical mineral resources strategies (e.g. Government of Canada 2022), so there is presently some inconsistency in this area. It is unlikely that opposition to mining developments, and associated delays, will evaporate simply because a commodity is now labelled as 'critical'.

The Constraints of Small Markets

Huge amounts of raw materials are extracted every year to support industrial society, but most of this represents a small group of major commodities. We might think that we are well into the Space Age, but the Iron Age is alive and well. Figure 6, based on a graphic used by Bloodworth (2019) with updated data from Simandl et al. (2021) and USGS sources, illustrates the gross global annual 'balance of production', excluding energy minerals and construction materials.

Resource extraction is massively dominated by iron ore (~84%) followed distantly by phosphate (~8%) extracted for fertilizers (Fig. 6a). Among major commodities, Al, potash, Cr, Cu, Mn and Zn collectively amount to just over 7% of annual global extraction, or about 200 million tonnes. All other commodities, including most designated as critical mineral resources, add up to only 1.2%, or around 35 million tonnes (Fig. 6a). Figure 6b and 6c illustrate the total production of most of these in 2020, but the total amounts of some (e.g. Ta, In, PGE, Ga, Ge, and Sc) still cannot be shown on such a scale. Excluding the major commodities that lack significant supply risk (as discussed above) most of the entries on Canada's critical mineral resources list have global annual production below 1 million tonnes, and many qualify as 'specialty materials' (less than 0.25 Mt annually; Simandl et al. 2021, 2023).

The small absolute production of some well-known commodities (e.g. gold, and also PGE), is offset by extremely high unit prices, but other small-volume commodities do not benefit to the same extent. It is very difficult to constrain prices for minor commodities, as these reflect longer term supply contracts rather than spot prices on metal exchanges and are more

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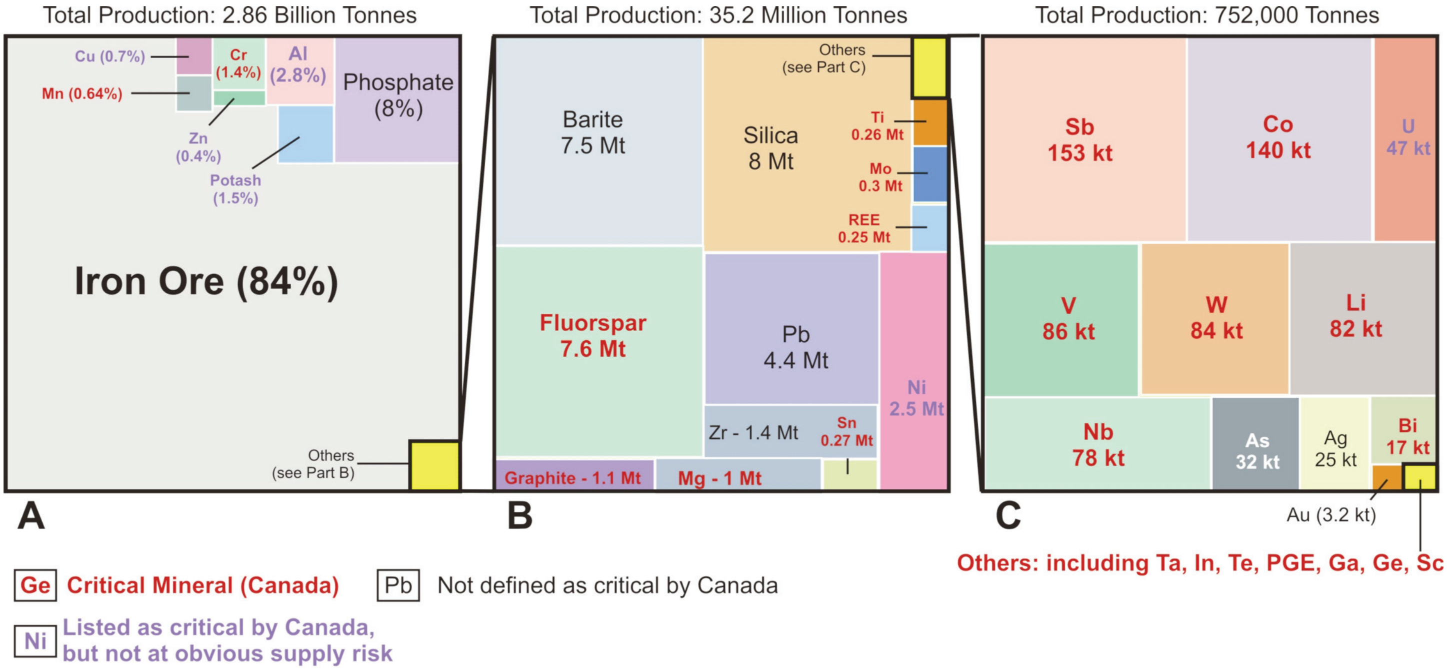

Figure 6. An illustration of global mineral resource production, based on a similar graphic used by Bloodworth (2019), with data from Simandl et al. (2021) and recent USGS sources for the same period. (A) major commodities, with global annual production greater than 12 million tonnes (Mt) (B) commodities with global annual production between 0.25 Mt and 12 Mt, including some classed as critical minerals; (C) commodities with global annual production less than 0.25 Mt, which includes many entries on critical minerals lists.

volatile on short time scales. A plot of production versus price estimates (Fig. 7a; data from Simandl et al. 2021 and USGS sources) shows that these are negatively correlated but also reveals considerable scatter. Crude estimates of total market values are better appreciated from Figure 7b, which shows them in order of increasing market size (i.e. value). This is a very crude method of assessment, but it shows that the total production values of most critical mineral resources are orders of magnitude less than those of major commodities. The difficulty of assigning price estimates lends considerable uncertainty to this, and different assumptions would likely alter the ranking, but would have little impact on the orders-of-magnitude differences. Similarly, large proportional increases in the production of minor commodities cannot erase such differences. Simandl et al. (2021) and Simandl (2023) also emphasized this point, and concluded that economies of scale, which favour larger low-grade deposits with lower per-unit production costs, generally will not apply. Simply defining a large resource at an attractive grade cannot guarantee its development, as any large-scale production would depress prices. Developing smaller deposits is hampered by the higher ratio of capital costs compared to total asset value, which increases the unit cost of long-term production. Increased output from already active deposits will generally be a more attractive option, especially given the time and effort needed to negotiate permitting and development. Simandl et al. (2021) discussed specific examples and concluded that incentives or subsidies may be important for successful development. These conclusions seem to be well founded, although they may not always apply where deposits have truly exceptional features. Critical mineral resources strategies (e.g. Government of Canada 2022) do indeed make reference to incentives aimed at encouraging development of domestic deposits or more efficient extraction of desired commodities.

Absolute and Proportional Measures of Demand Growth

Analyses of future demand for critical minerals (World Bank 2020; International Energy Agency 2022) emphasize percentage growth over absolute quantities. This makes data easier to comprehend but can also lead to misunderstanding. The World Bank (2020) predicts that requirements for graphite, Li and Co could quadruple by 2050, and those for other critical minerals (e.g. In, V and REE) could double by then. There are noted uncertainties in such forecasts, related largely to the scale and type of renewable energy infrastructure. But even if results exceed assumptions, the annual global production of many materials will remain small in absolute terms, and their market values may not grow proportionally if prices decline. An additional complication is that some forecasts of proportional demand growth express increased use of a commodity in the energy sector, rather than increased use across all sectors. For example, if demand for something from the energy sector is predicted to double, this does not necessarily mean that the total demand will double, because most commodities have other important end uses. This distinction is not always expressed clearly in graphs and tables.

Simandl et al. (2021) suggested that for new discoveries only those with the highest grades and lowest production costs will succeed in the long run. This is exactly what every explorationist wants to find, but also the least likely outcome for most exploration projects. Even if tonnage–grade statistics seem ideal, some other challenges remain.

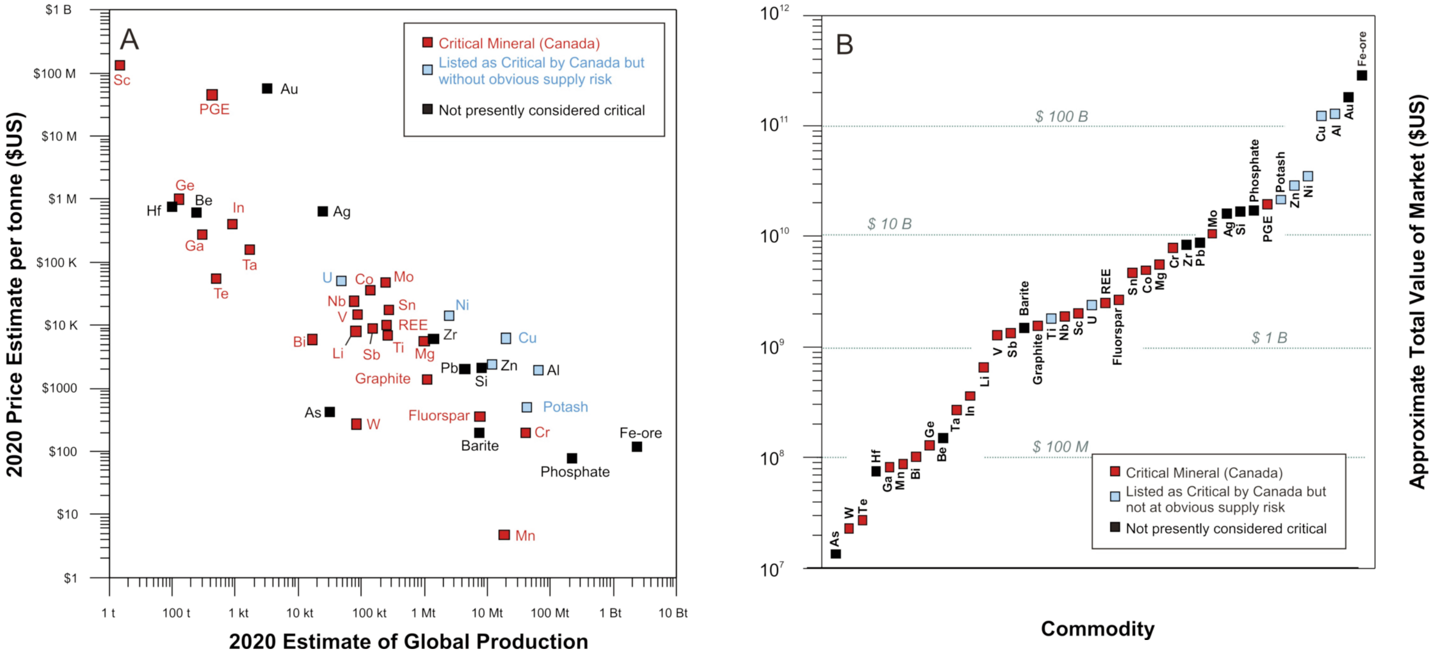

Figure 7. Relationships between global production, estimated average prices and total size of markets, as crudely indicated by multiplying production and price. Data are derived from Simandl et al. (2021) and recent USGS sources. Note that there is considerable uncertainty in assigning prices to many small-volume commodities, so these are general indications only. (A) logarithmic plot of annual production and average price, showing a general (but poor) inverse correlation of these measures. (B) total market values for commodities shown in ascending order from left to right, showing the orders-of-magnitude contrasts between major commodities and most of the commodities presently listed as critical. Although different price assumptions would affect individual calculations and would likely change the ranking of some, these shifts would not be significant in the bigger picture of contrasting markets.

Mineralogical and Metallurgical Complications

The chemical elements that dominate critical mineral resources lists must be extracted from true minerals (i.e. natural inorganic compounds that contain them), but details vary by commodity. For most major commodities, minerals of interest are separated from those of no value at the mining site (termed beneficiation), and then processed elsewhere by smelting and refining. Processing, smelting and refining are very energy-intensive, especially for low-grade high-tonnage operations. Every step in this process is influenced by the mineral assemblage, i.e. the nature, grain size, relative abundance and textural associations of minerals. This will often determine the viability of a deposit just as much as tonnage and grade. In a wider sense, we often depend on supergene (near-surface) processes to make some resources economically viable. For Al in bauxite, and for Ni from laterite deposits, we basically rely on Mother Nature to do most of the work over many thousands or millions of years.

For most major commodities, certain host minerals are favoured, and only a few minerals represent feasible sources. Sulphides are important for base metals because they are dense (easily concentrated) and easily decomposed at low and high temperatures, allowing supergene enrichment and ease of processing. Oxide and hydroxide minerals host most iron, Mn and Al resources and are also amenable to natural supergene processes. Mineralogical factors for deposits of major commodities vary little, and adaptation of existing extraction technology is routine. Some of the commodities on critical mineral resources lists are also like this. For example, molybdenite (MoS_2) is the most common host for Mo, and Cr comes almost exclusively from the oxide mineral chromite (Fe_2CrO_4); both are widely processed. There are also established processing routes for Li from the silicate minerals spodumene ($LiAlSi_2O_6$) and petalite ($LiAlSi_4O_{10}$) found in pegmatite deposits. Graphite processing is largely a matter of physical separation from associated silicate minerals. However, textural features and grain or flake size distributions are very important and the economic feasibility of a graphite deposit is as much a function of metallurgy as grade (e.g. Mitchell and Deady 2021).

Many of the other critical mineral resources (e.g. Table 1) have diverse and complex mineralogy. For example, the PGE may substitute in common sulphide minerals such as pentlandite and chalcopyrite, but can also form unusual sulphide, sulphosalt and telluride minerals, or tiny metal alloy grains. In most cases, the PGE are only actually extracted at the smelting and refining stage, so their production is not necessarily linked to the mine site or its host country. The REE occur in a seemingly endless list of diverse minerals, including oxide, hydroxide, phosphate, titanate, carbonate, fluorocarbonate and silicate phases (e.g. Weng et al. 2015; Van Gosen et al. 2017; Goodenough et al. 2018). Many REE deposits, especially in igneous rocks, contain several discrete REE-bearing minerals, some of which may be rare or unique. For example, the large Strange Lake deposit in Quebec and Labrador contains an unusual Ca-Y-REE silicate known as gerenite, known from only one other location in the world, but its REE inventory also includes other unusual minerals (e.g. Kerr 2011; Dostal 2016). Other REE deposits in Canada, such as Kipawa (Quebec) and Nechalacho (NWT) also have great mineralogical diversity (Currie and van Breemen 1996; Bakker et al. 2011). Extraction of REE from such varied minerals may be possible at a laboratory scale, but large-scale commercial feasibility is another matter.

The potential for REE deposits in Canada, especially in the Precambrian Shield, is well documented, and significant resources are defined. However, after decades of exploration, the only Canadian REE production comes from a small high-grade pod within the larger Nechalacho deposit (NWT). This limited area contains the REE-bearing carbonate bastnaesite (essentially $[REE]CO_3F$), which is easily processed. Deposits such as Strange Lake or the main Nechalacho deposit appear promising in terms of total resources (Kerr 2011; Bakker et al. 2011), but development, extraction and processing are not simple. Another complication related to REE is the extreme concentration of refining capacity in China. A small REE refinery facility now operating in Saskatchewan is an important factor in the viability of current small-scale production in the NWT (Connelly 2021, see also Vital Metals, https://vitalmetals.com/). Goodenough et al. (2018) noted that the industry 'demand profile' for REE closely matches the REE distribution of clay-rich surficial weathering deposits that currently account for much of Chinese (i.e. global) production. These deposits are another example of how we rely on very slow natural processes to initially process valuable minerals for our use.

Other materials contained in Canada's critical mineral resources list have specific mineralogical or metallurgical complications that relate to their coproduct or byproduct status. These affect Co, Sc, Cs and also elements linked to photovoltaic technology (Ga, Ge, Te, In). Cobalt typically occurs in low concentrations (< 0.3%) in magmatic Ni-Cu sulphide ores. Like the PGE, it is commonly extracted during smelting, rather than at mine sites. The photovoltaic elements (Ga, Ge, In, Te) are typically closely associated with common sulphide minerals as tiny discrete mineral inclusions or in solid solution, so the same constraints apply.

The Separation of Mine Production and Metal Extraction

As discussed above, many rarer elements are extracted during smelting and refining, rather than being concentrated at mining sites. Mineral concentrates have long been transported within Canada for smelting, but shipment distances are now greater and destinations are international. Smelting and refining capacity has also shifted away from Europe and North America over time, notably to Asia. The remaining smelting operations in Europe and North America are increasingly scrutinized for their environmental and human health impacts. Smelters are not generally seen as desirable neighbours by communities, but they are important for many of these commodities.

Outsourcing smelting and refining beyond Canada will effectively result in the loss of potentially valuable domestic resources of byproduct elements because concentrates from multiple sources are mixed, and some of these elements may not even be recovered. Maintaining or expanding existing domestic smelting and refining capacity is the most obvious solution, but such an effort would probably encounter opposition in most developed western countries, including Canada. Critical mineral resource strategies note this challenge, and financial assistance and incentives were important in establishing the REE refinery that aids in the exploitation of high-grade material from Nechalacho (Connelly 2021; Vital Metals, https://vitalmetals.com/). There is also an important geoscience question involved in this because there is presently limited information about the trace elements contained in ores of Cu, Pb or Zn distributed across Canada, especially for exploration-stage projects that might represent future production. These data were of limited interest in the past, but now assume greater importance.

The Climate Impacts of Critical Minerals Extraction

The connection between mineral resources and limiting climate change is by far the strongest theme in discussion of critical mineral resources. *Mining for Clean Energy* (Clean Energy Canada 2017) is just one of many documents that present this reasoning. If so-called climate-smart mining is to be validated and (more importantly) gain public acceptance, the emissions of increased extraction and processing need to be closely audited. This includes those associated with starting a mine and also the final stages of mineral resource developments (closure, rehabilitation, etc.). The studies by the World Bank (2020) and International Energy Agency (2022) concluded that associated emissions footprint would be only a small fraction of those from continued extraction and usage of fossil fuels. Such assessments always generate discussion about figures and exactly what is included or excluded, but this general premise seems sound.

The extraction and processing of mineral resources makes a significant contribution to CO_2 emissions, from 4 to 7% of global emissions and perhaps as much as 11%, depending on what is included (World Bank 2020). The crushing and grinding of raw materials are a big part of the energy budget for typical operations, especially for large-tonnage, low-grade deposits. Energy usage per unit of production has probably grown over time and will likely continue to do so. New or expanded operations will obviously benefit if their emissions footprint is low and (or) if they employ the same technology that extracted resources are claimed to support. It is suggested by some that assessment of resource developments in the 21st century must involve a much wider analysis where lifetime energy and environmental footprints are considered as much as tonnage, grade and metallurgy (e.g. Lee et al. 2020; Pell et al. 2021). This departs from conventional thinking, which emphasizes short-term economics, and such an approach will probably be seen as idealistic or at least unrealistic by the minerals industry. Nevertheless, questions about energy usage and emissions are bound to enter future debates concerning critical mineral resources.

In more remote parts of Canada where minerals are extracted, links to existing energy transmission networks are not feasible. Diesel power generation is the norm for many mines unless local hydroelectric potential exists. However, only larger developments could sustain the high costs of the latter, which is not entirely free of environmental consequences. Finding feasible renewable energy sources in northern regions with seasonal darkness is likely to provide challenges. Partially wind-based energy systems already exist, such as the hybrid wind-diesel system at the Diavik Mine in the NWT (Romero et al. 2016; Clean Energy Canada 2017), but wind cannot alone power a mine on a 24/7 basis. The use of modular nuclear reactors as power sources for remote mining was explored in a recent discussion paper (Government of Canada 2021) and was also assessed by Froese et al. (2020) but there is as yet no clear demonstration of feasibility and no regulatory framework. Ironically, the very regions of northern Canada that are generally identified in strategy documents as having the greatest future critical mineral resources potential are also those that will most challenge low-carbon energy technology.

Critical Mineral Resources and the Concept of a 'Just Transition'

In this article, the energy transition is discussed mostly from the perspective of natural resources development, where it is viewed in a generally positive light. However, this view is not shared by all, and advocates of environmental protection concerned with global inequity see it through a different lens. There are thus calls that any future energy transition must also be a 'just transition'. This term has multiple definitions, but a common theme is that nations with minimal historical carbon footprints (i.e. most of the Global South) are disproportionally affected by climate change and so should not pay a retroactive price for continued consumption and emissions by industrialized nations (the Global North). A related consideration is that benefits from any future 'green' economy should be more equally shared. There is some fear that the rush to develop critical mineral resources will result in rapid development and extraction from lower income countries that cannot maintain environmental standards, resulting in additional ecosystem damage. This outcome is not emphasized in documents advocating 'climate-smart mining' conducted with strict environmental standards, but it is certainly possible, and some think it very probable (e.g. Environmental Justice Atlas and MiningWatch Canada n.d.). This particular challenge is the most difficult to discuss because it is more ideological than technical.

The counterargument to the premise that increased mineral extraction is needed to limit climate change is that any energy transition should instead prioritize sustained reductions in energy and material usage, particularly in the developed industrial nations. This is linked to calls for a fully circular economy, in which recycling and reuse are emphasized. This view diverges from that of industry and most governments, which acknowledge the need for better use of existing resources but seek ways to maintain our energy-intensive society yet at the same time avoid consequences of emissions. There is an obvious philosophical divergence here, and the pages of *Geoscience Canada* are not the place for a lengthy discussion. When I started to write this article, I did not expect to include a quote from *MiningWatch Canada*, who stand firmly on one side of this divide. However, their short discourse entitled *Mining for the Energy Transition in the Americas* (Environmental Justice Atlas and MiningWatch Canada n.d.) includes a thought-provoking statement:

> *"A transition that heavily depends on mining new materials without considering materials and energy for what, for whom and at what socio-environmental costs will only reinforce the injustices and unsustainability that have led us to the climate crisis in the first place. Improved efficiency and recycling of materials are necessary components in the transition, but these strategies alone will not address the growing demand for these materials. Significant reductions in material and energy consumption, particularly in the Global North, are a key component to a just transition."*

This is a quote, and not necessarily my opinion, but it raises interesting points. A lengthier analysis from the same organization outlines this perspective in more detail (Deniau et al. 2021). These agree with the World Bank (2020) and the IEA (International Energy Agency 2022) that recycling alone cannot yet meet expected demands. The same World Bank study also stated that mining related to the energy transition could provide:

> *"...new economic benefits to resource-rich but poor countries that also hold significant solar energy potential to use in production"* and "*....contribute to efforts to combat climate change*".

This seems to imply that mineral resources needed for the energy transition should indeed be, in part, outsourced as a form of economic development. Canada's critical mineral resources strategy (Government of Canada 2022) similarly frames one of its purposes as reconciliation with Indigenous peoples by their participation in related economic development. This reads very much like the same concept, although admittedly within one nation. In the resource industries, we tend to interpret historical aspects of the mining industry as part of nation-building, in the broad sense of the word, but other treatments (e.g. Sandlos and Keeling 2021; Angus 2022) offer different interpretations. These aspects also lie well beyond the scope of this article, but their emergence in future discussions about critical mineral resources should be anticipated. They are already illustrated by some of the responses to the initial draft that preceded the release of the current Canadian strategy document late in 2022, by the Wildlife Conservation Society Canada (2022) and also by the International Council on Mining and Metals (2022) which is an industry-led group. These submissions, and others, emphasized the need to ensure a just transition. A recent article in the online journal *The Narwhal* (Struzik 2023) explores these issues in the specific context of Arctic Canada.

The point here is not one of a specific interpretation or world view being right or wrong, but rather that efforts to develop resources for the much-heralded energy transition will inevitably be discussed and judged within this concept of a just transition. This would certainly be the case if such developments are across the world in low-income countries, but very similar reasoning can be applied within Canada, where northern regions are economically disadvantaged, disproportionally affected by climate change and view much of their history in terms of sustained exploitation and injustice. We should be fully prepared for these less-tangible issues to become prominent in northern Canada wherever new resource developments are promoted as a vital part of the energy transition. Current strategies place great emphasis on sustainability and environmental protection, and more widely frame such efforts as part of reconciliation with Indigenous peoples and community development, but not all stakeholders will be convinced of such links. This is one of several challenges recently noted in a recent commentary by Tortell et al. (2023) on behalf of the *Institute for Research on Public Policy*, an independent Canadian research group.

SUMMARY AND DISCUSSION

Writing this article proved to be far more difficult than I ever expected at the outset. The topic of critical mineral resources is extraordinarily broad and does not only involve technical information. It inevitably spills over into politics, economics and divergent philosophical views about natural resources, which become hard to separate from geoscience in any discussion.

Canada's "storehouse of critical minerals", as it is often termed, still remains to be fully defined in detail. The modified definition that includes some major commodities that most other jurisdictions exclude supports such statements because we do indeed hold significant reserves and resources of Cu, Zn, potash, Ni and U. However, the inventory is less clear for many other commodities on Canada's critical mineral resources list, although significant resources of the REE are already defined. Northern Canada is widely regarded by the minerals industry as an underexplored region of significant potential, as shown by its important and diverse mineral deposits. It is equally well known as one of the largest remaining intact wilderness areas in the Northern Hemisphere, and as one of the Earth's great reservoirs of carbon storage. Developing mineral resources in this setting in the past was never simple, and it left some difficult environmental and social legacies. On the other hand, resource development provides important economic benefits and it employs many people in the North. Critical mineral resources may unlock this potential more in decades to come, as envisaged in various government strategies, but elements of past and present controversies will not disappear simply because a resource is designated 'critical'.

It is no surprise that the World Bank (2020) and the International Energy Agency (2022) concluded that the 21st century will see increased demand for familiar mineral resources and unconventional resources that have experienced relatively minor exploration interest in the past. The conclusions from the World Bank (2020) and the IEA (2022) seem well founded and in many respects represent common sense, given current per-capita resource consumption, growing populations, and increasing urbanization. The deployment of material-intensive renewable energy and electrification infrastructure will surely add to and change these demands, even if the exact details are hard to forecast. Finding these materials is one task in this greater challenge, but perhaps the easier part, as significant global resources already exist for most of them, even if presently defined reserves for some might seem sufficient for only a few decades (e.g. Simandl et al. 2021). The greater part of the challenge will be to extract and process such mineral resources without excessive ecosystem damage or increases in associated emissions, and also to gain acceptance for such increased activity.

I hope that this article illustrates that although many basic concepts around critical mineral resources seem straightforward, some aspects remain poorly defined, and the discussion becomes more complex and tangled when Canada's geography, history and geopolitics are considered. Some may consider parts of this article to have a discouraging tone, but I resist such judgment. It is intended to inform those without detailed geoscience knowledge but must also acknowledge some challenges that are beyond our control and others that are rooted in institutions and governance structures. If the energy transition is to unfold as envisioned, with Canada assuming a prominent role in supplying vital resources, and enjoying related economic benefits, these many linked challenges need to be recognized and addressed. The need for better geoscientific knowledge is an important part of this. Such information will better define the regional potential for specific commodities and assist future decisions about targets. Nevertheless, geoscience is only one part of this equation, as more significant challenges are linked to politics and jurisdiction. Critical mineral resources strategies so far released emphasize long-established policies for environmental protection, land conservation and recognition of Indigenous rights. These guiding principles are stressed in their pages just as much as the perceived need to expedite development pipelines and give proponents more confidence in successful outcomes. There is no overt conflict in this, but responses to initial strategy discussions (e.g. Wildlife Conservation Society Canada 2022; Kneen 2022; International Council on Mining and Metals 2022) imply that contradictions can be read between their lines. Strong provisions for impacts and benefits agreements and environmental assessment all across the North were not easily achieved and are highly valued. Although present geoscience data are incomplete, it is clear that many areas perceived as having significant potential for future critical mineral resources are already covered by such frameworks or await their formal definition. Land use plans for Nunatsiavut (Labrador), Nunavut and the NWT have yet to be finalized, despite years of discussion, but the drafts for all emphasize extensive protected areas where mineral exploration and mining would essentially be prohibited. Ambitious land conservation targets were also an important outcome of the recent UN Biodiversity Conference COP15 in Montreal aimed at protecting nature and biodiversity. If Canada's commitment to these initiatives is to be met, the extent of protected areas will need to at least double in coming decades. If difficult choices about lands are to be made in the years ahead, it is important to do so in the light of geoscientific information and systematic evaluation of mineral potential.

Canada is blessed with large tracts of underexplored Precambrian crust across much of its north, and global analogues suggest potential for a wide range of critical mineral resources.

Despite this broad perception, our geoscience knowledge remains incomplete, especially in the far north, where exploration over the last two decades focused largely on gold and diamonds. Aside from the REE, for which several significant but so far undeveloped concentrations are defined, we have limited information for many entries on the critical mineral resources list. Regional geological mapping and dissemination of broad-based geoscience data need to be emphasized for many regions that are labelled as "highly prospective" but in reality are poorly known. Some of these include defined base metal and gold deposits, so this provides some baseline information. However, some commodities (e.g. graphite and Li) are more likely to occur in plutonic rocks or high-grade metamorphic terranes that previously received less attention. The 'high science' aspects of economic geology research, such as theories of deposit genesis, detailed classifications, or links to plate tectonic evolution models may be useful in the long term (and they are certainly very interesting) but the greater short-term need is for descriptive, tangible, measured data that can assist exploration. For many areas, surficial exploration programs using geochemical or indicator mineral methods may be the first priority given the prevalence of thick glacial deposits. The mineralogical complexity of some critical minerals deposit types suggests that these aspects should also be stressed in examination of known mineralization. The success or failure of a project may ultimately rest with these parameters, rather than just its tonnage and grade. This technical knowledge side of the equation can be addressed, although the investment is large and will critically depend on finding highly qualified professionals, especially for field-based research. The latter is already known as a significant challenge for the mineral exploration sector.

New information and discussions concerning critical mineral resources appear constantly. When this article was in final revision for publication, the IEA released its first 'progress report' (International Energy Agency 2023) on global efforts to increase production and diversify supplies of key commodities. Some key points from their analysis are relevant to this discussion. The IEA reports that strong growth in deployment of clean energy technology since 2017 increased demand for Li, Co and Ni, and the total markets for these and other commodities grew significantly. Policy initiatives that seek to diversify supplies of critical minerals in industrialized countries were widely developed, of which Canada's strategy is just one example. However, over the same period many resource-rich countries introduced measures intended to restrict exports of such materials. Investment in development of and exploration for critical mineral resources grew by 30% and 20% respectively in 2022 alone, which illustrates strong interest in the sector and confidence in its future. The IEA expressed confidence that projected supplies could meet global demands to around 2030, but still predicts significant supply constraints in later decades. The efforts to diversify supplies over the last five years were judged to have had limited real-world success and, in some cases, the geographical concentration of supply (and processing capacity) actually worsened. The IEA's verdict on progress towards sustainable and environmentally responsible extraction of materials is similarly mixed, noting increased water usage and little change in associated emissions. It was also noted that China (already the principal source for many commodities) continues to invest heavily in securing supplies from elsewhere for its own import needs. For example, this investment in global Li projects since 2018 was twice as much as that from the USA, Canada and Australia combined. Overall, the new IEA report shows that critical mineral resources will retain a high profile in years to come and will likely continue to generate controversy. The need to address such challenges is presumably behind the IEA's initiative to hold the first-ever *International Summit on Critical Minerals*, projected for September 2023; see https://www.iea.org/events/iea-critical-minerals-and-clean-energy-summit for more details.

It is always easier to point out complications and obstacles than to formulate solutions, and I accept criticism of this article in such light. The questions raised in it, and in other specialized treatments such as the new IEA report, do not have simple answers, but hopefully practical and equitable solutions will be found. In closing, successfully meeting the mineral resource requirements of any successful and sustainable energy transition in Canada (or elsewhere) will require a great deal of reconciliation, but in its broadest possible sense, which is one of balance. I hope that this article might in some way assist in finding ways to overcome the challenges to what may be one of the most important tasks ever undertaken by the mineral resources industry.

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ABSTRACTS

GAC-MAC-SGA 2023 Sudbury Meeting: Abstracts, Volume 46

Introduction

The 2023 Joint Annual Meeting of the Geological Association of Canada, Mineralogical Association of Canada, and Society for Geology Applied to Ore Deposits was hosted by the Harquail School of Earth Sciences at Laurentian University in Sudbury on 24–27 May 2023 with pre- and post-meeting field trips and workshops.

Sudbury is one of the world's largest, oldest, and best-exposed meteorite impact sites; it contains some of the largest Ni-Cu-PGE deposits on Earth and is the world's largest mineral exploration – mining – service cluster; it straddles the boundaries between Archean igneous/metamorphic rocks of the Superior Province, volcanic/sedimentary/glaciogenic rocks of the Huronian Supergroup, and Paleozoic platform carbonate deposits; and it is only a few hours drive from some of the world's best-preserved Archean geology and largest Cu-Zn-(Au) massive sulphide and orogenic Au deposits.

The theme of the meeting was *Discovering Ancient to Modern Earth,* reflecting the location of Sudbury at the intersection of the Archean and Proterozoic provinces, and Paleozoic–Quaternary cover sequences. The meeting was attended by 712 participants (68 of whom participated virtually) from all provinces and territories of Canada, 18 American states, and 13 other countries. There were 337 oral presentations and 102 poster presentations in 7 Plenary Lectures, 5 Symposia, 21 Special Sessions, and 7 General Sessions, as well as 7 Field Trips, 2 Workshops, and 1 Short Course, covering a broad spectrum of geoscience disciplines. There were 20 exhibitors; panel discussions on Indigneous Relations, Women in Geosciences, and the Canadian Arctic; a public outreach event on Mineral Identification; and tours of the Ontario Geoscience Laboratories and Environmental Geology of the Laurentian University campus.

The Schedule and Program remain accessible to the public and the Abstracts and some presentations/posters remain accessible to registrants at http://event.fourwaves.com/Sudbury2023.

The Local Organizing Committee is very grateful to all of those who proposed, organized, and chaired the technical sessions, organized and led the field trips, and organized and delivered the workshops and short course; to Julie Ceming (Business Development), Bill Sanders (Audio Visual), Marie-Lynne Michaud, Lynn Laird, and JoAnn Wohlberg (Marketing), Jameson Fletcher (Printing Services), Luc Roy and Dan Robidoux (IT Services), and Pedro Jugo and Roxane Mehes (Harquail School of Earth Sciences) of Laurentian University for their capable and enthusiastic assistance; to Deanne van Rooyen, Alwynne Beaudoin, and Karen Dawe (GAC), Johanne Caron, Dan Marshall, and Andrew Conly (MAC), and Garth Graham and Georges Beaudoin (SGA) for their support and counsel; to all of the many Financial Sponsors; and, of course, to all of those who attended the meeting, field trips, workshops, and short course.

The abstracts preserved in this volume record the state-of-the-art in our continuing quest to understand *Ancient to Modern Earth*.

Sudbury 2023 Local Organizing Committee
Michael Lesher, chair
Stéphane Perrouty, vice-chair and webmaster
Douglas Tinkham, vice-chair and audiovisual coordinator
Cathryn Nadjiwon, event manager
Bruno Lafrance, Evan Hastie, and Riley Mulligan, field trips
Noëlle Shriver, exhibits and posters
Tobias Roth and Lynn Bulloch, social media
Olga Brinkman, guest program

Introduction

La conférence annuelle conjointe de 2023 de l'Association Géologique du Canada, de l'Association Minéralogique du

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Canada et de la Société de Géologie Appliquée aux Gisements Minéraux fut accueillie par l'École des Sciences de la Terre Harquail à l'Université Laurentienne de Sudbury du 24 au 27 mai 2023 avec des excursions sur le terrain et des ateliers pré- et post-conférence.

Sudbury est l'un des sites d'impact de météorites les plus grands, les plus anciens et les mieux exposés au monde; il contient certains des plus grands gisements de Ni-Cu-EGP sur Terre et constitue le plus grand pôle de services d'exploration et d'exploitation minière - au monde ; il chevauche les frontières entre les roches ignées/métamorphiques archéennes de la Province du Supérieur, les roches volcaniques/sédimentaires/glaciaires du Supergroupe de l'Huronien et les gisements de carbonates de la plate-forme paléozoïque; et il n'est qu'à quelques heures de route de certaines des géologies archéennes les mieux préservées au monde et des plus grands gisements de sulphures massifs à Cu-Zn-(Au) et d'Au orogénique.

Le thème de la conférence était *Découvrir la Terre Ancienne à Moderne*, reflétant l'emplacement de Sudbury à l'intersection des provinces archéennes et protérozoïques et des séquences de couverture paléozoïque-quaternaire. La conférence a réuni 712 participants (dont 68 ont participé virtuellement) de toutes les provinces et territoires du Canada, 18 états américains et 13 autres pays. Il y a eu 337 présentations orales et 102 présentations par affiches dans 7 conférences plénières, 5 symposiums, 21 sessions spéciales et 7 sessions générales, ainsi que 7 excursions sur le terrain, 2 ateliers et 1 cours intensif, couvrant un large éventail de disciplines géoscientifiques. Il y avait 20 exposants; des tables rondes sur les Relations Autochtones, les Femmes en Géosciences, et l'Arctique Canadien ; un événement de sensibilisation du public sur l'Identification des Minéraux; et des visites des Laboratoires Géoscientifiques de l'Ontario et de Géologie Environnementale du campus de l'Université Laurentienne.

Le calendrier et le programme restent accessibles au public, et les résumés et certaines présentations et affiches restent accessibles aux participants sur https://event.fourwaves.com/fr/Sudbury2023/pages.

Le comité d'organisation local est très reconnaissant à tous ceux qui ont proposé, organisé et présidé les sessions techniques, organisé et dirigé les excursions sur le terrain, et organisé et animé les ateliers et le cours intensif; à Julie Ceming (développement commercial), Bill Sanders (audio-visuel), Marie-Lynne Michaud, Lynn Laird et JoAnn Wohlberg (marketing), Jameson Fletcher (services d'impression), Luc Roy et Dan Robidoux (services informatiques), et Pedro Jugo et Roxane Mehes (Harquail School of Earth Sciences) de l'Université Laurentienne pour leur aide compétente et enthousiaste; à Deanne van Rooyen, Alwynne Beaudoin et Karen Dawe (AGC), Johanne Caron, Dan Marshall et Andrew Conly (AMC) et Garth Graham et Georges Beaudoin (SGA) pour leur soutien et leurs conseils; à tous les nombreux sponsors financiers, et, bien sûr, à tous ceux qui ont assisté à l'assemblée, aux excursions sur le terrain, aux ateliers et au cours intensif.

Les résumés conservés dans ce volume capturent l'état des connaissances de pointe dans notre quête continue pour comprendre *la Terre Ancienne à Moderne*.

Le Comité d'Organisation Local de Sudbury 2023
Michael Lesher, président
Stéphane Perrouty, vice-président et webmestre
Douglas Tinkham, vice-président et coordonnateur audiovisuel
Cathryn Nadjiwon, gestionnaire d'événements
Bruno Lafrance, Evan Hastie et Riley Mulligan, excursions de terrain
Noëlle Shriver, expositions et affiches
Tobias Roth et Lynn Bulloch, médias sociaux
Olga Brinkman, programme d'invité(e)s

GEOLOGICAL ASSOCIATION OF CANADA
ASSOCIATION GÉOLOGIQUE DU CANADA

MINERALOGICAL ASSOCIATION OF CANADA
ASSOCIATION MINÉRALOGIQUE DU CANADA

SOCIETY for GEOLOGY APPLIED to MINERAL DEPOSITS

ALPHABETICAL LISTING OF ABSTRACTS

ROLE OF LATE TRANSVERSE FAULTS IN GOLD MINERALIZATION IN THE SUPERIOR PROVINCE: A CASE STUDY FROM THE MASKINONGE LAKE FAULT, MICHIPICOTEN GREENSTONE BELT, ONTARIO

Zachary Adam[1], Shoufa Lin[1], Chris Yakymchuk[1], Carl Nagy[2]
[1]University of Waterloo, [2]Alamos Gold.
E-mail: *zvadam@uwaterloo.ca*

Orogenic gold deposits in the Superior Province are characteristically hosted in Archean greenstone belts and are fundamentally controlled by their structural environment. The majority of these deposits are recognized as syn-tectonic with the formation of the Superior Province between 2.8–2.6 Ga and are strongly controlled by east-west-striking shear zones. The Island Gold deposit, hosted in the Goudreau Lake Deformation Zone of the Michipicoten greenstone belt, is consistent with this genetic model. Gold deposits occurring in transverse faults at a high angle to these major shear zones have been observed but overlooked in exploration frameworks in the past and as such, the genesis and timing of these deposits are poorly understood. The Maskinonge Lake fault, a late northwest-trending brittle-ductile structure east of the Island Gold deposit, is one of these transverse structures and is populated with zones of high-grade mineralization along its strike. The historic Pine-Breccia gold showing along this fault encompasses 2750–2700 Ma metavolcanic rocks that have undergone pervasive silica alteration. This silicification is structurally associated with the fault and hosts the majority of gold mineralization, suggesting that the Maskinonge Lake fault was a potential conduit for gold-bearing hydrothermal fluids. Results of detailed outcrop-scale mapping and structural analyses have led to the recognition of two distinct stages of deformation with opposing sense of shear along a steeply dipping fault plane in a dominantly strike-slip regime. Sinistral movement is documented predominantly by the substantial displacement of stratigraphy and vein array analysis whereas dextral motion is identified by the rotation and ductile drag of felsic dykes and regional ENE-striking shear zones towards a NNW-SSE orientation. The coincidence of fluid infiltration with these events coupled with constraints on mineralization provide more insights into the significance of these structures on a local scale, and the results of this study may be used to aid in future exploration around similar structures that are at a high angle to major east-west shear zones in the Superior Province.

VOLCANIC STRATIGRAPHY AND HYDROTHERMAL ALTERATION AT THE PALEOPROTEROZOIC KAY MINE VOLCANOGENIC MASSIVE SULPHIDE DEPOSIT, BLACK CANYON CITY, ARIZONA, USA

Aaron J. Adsit[1], Thomas Monecke[1], Mark D. Hannington[2], Miranda R. Lehman[1], Ben Somps[3], David Smith[4]
[1]Colorado School of Mines, [2]University of Ottawa, [3]Ethos Geological, [4]Arizona Metals Corporation.
E-mail: *aadsit@mines.edu*

The Kay Mine, located ~70 km north of Phoenix in central Arizona, is a volcanogenic massive sulphide deposit that contains a historic estimate of resources and reserves of 5.8 million tonnes grading 2.2% Cu, 3.03% Zn, 54.9 g/t Ag, and 2.8 g/t Au at a cut-off grade of 2% Cu equivalent. The Kay Mine is hosted by the highly prospective 1.79–1.76 Ga bimodal volcaniclastic Townsend Butte Formation of the Black Canyon Creek Group, which forms part of the Proterozoic Yavapai Supergroup. The bimodal host succession of the Kay Mine has been overprinted by greenschist-facies metamorphism and been isoclinally folded. Primary volcanic textures are poorly preserved due to footwall and hanging wall hydrothermal alteration and effects of high-strain deformation. Detailed core logging revealed that the lower part of the volcanic succession is composed of fine-grained mafic-intermediate volcaniclastic rocks. The favourable interval at the Kay Mine is marked by graphitic mudstone that occurs immediately below coherent to brecciated rhyolite or rhyodacite. Contacts between felsic to intermediate flows and intrusions with the mudstone are commonly marked by the occurrence of mudstone-matrix monomict rhyolite or rhyodacite breccia, interpreted to be peperite. Textural evidence suggests that the massive sulphides at the Kay Mine may have largely formed by subsea-floor infiltration and replacement. The stratigraphic hanging wall to the massive sulphides is dominated by mafic-intermediate volcaniclastic rocks and basalt that forms massive or pillowed flows. The main massive sulphide lens at the Kay Mine is underlain by a zone of intense chlorite alteration that is accompanied by chalcopyrite stringers. Hanging wall alteration includes widespread gray sericite alteration. Dolomite and ankerite are abundant throughout the alteration halo and occur as nodular masses with semi-massive and massive sulphides. Selected drill core is analyzed to establish the chemostratigraphy of host rock succession and to unravel geochemical and mineralogical gradients around the massive sulphides that could be used for future exploration targeting. This includes continuous X-ray fluorescence analysis using a fully automated Minalyze core scanner and short-wave infrared imaging employing a Hyspex laboratory core scanner. Recent software developments allow acquisition of fully co-registered geochemical and mineralogical data on the core to complement more traditional analytical methods on thin sections including optical and scanning electron microscopy.

METAL IMMOBILIZATION IN SECONDARY CEMENTS AT A HISTORIC GOLD MINE

Sana Ahmad, Jenine McCutcheon
University of Waterloo.
E-mail: *s76ahmad@uwaterloo.ca*

The production of acid mine drainage (AMD) by acidophilic microorganisms is an environmental concern at many of the > 10,000 abandoned mine sites in Canada. While some sites have been targeted by past remediation efforts, others have been left untreated and continue to produce AMD long after mining activities have ceased. One such site is the Cordova Gold Mine, located near Peterborough, ON, which has been abandoned for several decades and contains numerous tailing piles still actively generating AMD. Mine sites with AMD contamination often have hardpan formation occurring adjacent to the tailing piles. Previous studies suggest that these hardpans may have formed as a result of microbial mineralization processes in which microbes encourage the precipitation of secondary mineral phases through their metabolic activity. This study examines how microbial weathering of minerals in tailings impacts metal mobilization, and the extent to which microbes are contributing to the immobilization of dissolved metals through secondary mineral precipitation in hardpans. Samples collected from the site included tailings from four depth profiles, hardpans, and surface waters. Tailings mineralogy will be determined using X-ray diffraction (XRD) and linked to the microbial communities present in the tailings as determined using 16S rRNA sequencing. Hardpan samples will be characterized using XRD, and petrography and back-scattered electron scanning electron microscopy (BSE-SEM) of polished thin sections to identify the presence of microfossils and their association with metals. Ion chromatography (IC) and inductively coupled plasma optical emission spectroscopy (ICP-OES) will be used to

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measure the concentration of dissolved ions in the surface water samples. X-ray fluorescence (XRF) analysis of the tailings identified transition metals including Ca, Mg, Na, etc., and it is anticipated that the hardpan mineralization will be enriched in these same metals immobilized by microbial activity (both past and present). Lastly, studies conducted at similar sites found that the hardpans were cemented by iron oxide minerals. As such, it is expected that iron oxidizing bacteria (e.g. Acidithiobacillus ferrooxidans) will be found within the Cordova tailings and hardpans. Collectively, this study will provide information about microbial weathering of tailing minerals and associated transition metal immobilization in secondary cements. These findings inform how microbes could be used to reduce the impact of dissolved metals in mining environments and help characterize historic sites that may experience renewed interest due to increasing demands for metals for use in low carbon technologies.

RELEVANCE OF AQUEOUS THIOLATED ARSENIC IN MINE WASTE SYSTEMS

Jaabir D. Ali[1], Adriana Guatame-Garcia[1], Matthew I. Leybourne[1], Anna L. Harrison[2], Bas Vriens[1]
[1]Queen's University, [2]University of Bern.
E-mail: *20jda@queensu.ca*

The biogeochemical cycling and mobility of arsenic (As) in wetlands, groundwater, and hydrothermal systems can be heavily influenced by the presence of aqueous thiolated As species. Many mine waste systems are enriched in As and harbour the same neutral-to-alkaline and sub-oxic conditions that favour the production of thiolated As. However, quantitative data on the existence and mobility of thio-As in these environments is lacking. Importantly, thiolated As behaves differently from its fully oxidized oxyanionic counterparts: thiolated As species have a lesser tendency to adsorb or co-precipitate with secondary minerals and may therefore explain anomalous As loading rates observed in the field. We investigated thiolated As in mine waste systems using laboratory column experiments with waste rock and tailings from the Antamina (Peru) and Montague (Nova Scotia, Canada) mines and through field sampling at various legacy mine waste sites in Canada, including at Cobalt, Ontario, and Montague and Goldenville, Nova Scotia. First, our laboratory experiments involved accelerated weathering of material with As hosted in As-bearing enargite (Antamina) and arsenopyrite (Montague) that were run under oxic versus sub-oxic conditions. We found a wide range of total dissolved As concentrations (1–7000 μg/L) in the drainage across the different mine waste types, with up to 13 μg/L of As (~5%) present in the thiolated form (predominantly mono-thiolated As). Higher proportions of thiolated-As were generally observed in the drainages from enargite-bearing materials over those from arsenopyrite-rich materials, as well as under Fe-poor and sub-oxic conditions. Next, our fieldwork involved collection of surface water samples, porewater, and cores from exposed and submerged mine waste sediments, with analysis of the aqueous As speciation and mineralogy of the tailings throughout. In comparison to the laboratory experiments, initial analysis of the field samples indicated higher concentrations of total As in the porewater, mainly in historic tailings rich in realgar and arsenopyrite. We found higher proportions of thiolated As (~12%) present in comparison to the laboratory experiments, as well as higher degrees of thiolation (di- and tri-thiolated As), possibly related to elevated dissolved suphfide levels. Currently, we are investigating the controls of the prevailing redox conditions and mineralogy on the observed As thiolation dynamics. Overall, our results show that aqueous thiolated As species may occur in mine waste systems of varying As-mineralogy, and can play a significant role in the biogeochemical cycling and mobility of As.

REE-MINERALIZED AND BARREN GRANITIC PEGMATITES IN THE AREA BETWEEN NORTHWESTERN TROIS-RIVIÈRES AND LAC SAINT-JEAN, CENTRAL GRENVILLE PROVINCE - PRELIMINARY RESULTS

Pedro Alves[1], Bertrand Rottier[1], Abdelali Moukhsil[2], Crystal Laflamme[1]
[1]Université Laval, [2]Ministère des Ressources naturelle et des Forêts.
E-mail: *pedro.alves@ggl.ulaval.ca*

Granitic pegmatite dyke swarms of Ottawan and Rigolet ages are widespread in the hinterland of the central Grenvillian orogen. These pegmatite dykes were emplaced into medium-pressure terranes metamorphosed under amphibolite- to granulite-facies conditions, i.e. the allochthonous Medium-Pressure Belt (aMP Belt). Over the last two decades, the geological mapping conducted by the Ministère des Ressources naturelles et des Forêts du Québec (MRNFQ) revealed significant REE mineralization hosted in these pegmatites. In this contribution, eight REE-mineralized and barren granitic pegmatite occurrences were investigated in a ca. 100 x 300 km area between northwestern Trois-Rivières and Lac Saint-Jean region, in the central Grenville Province. The decimetre- to metre-scale (up to 10 m thick) pegmatite dykes are undeformed and intruded a large range of rock types, including orthogneisses of the Mékinac-Taureau domain, deformed gabbroic rocks of the Roc suite, paragneisses of the Wabash and Barrois complexes, mangerite of the Pope suite, and anorthosite of the Lac-Saint-Jean suite. Most of these wall rocks are partially melted, displaying in situ leucosomes that crosscut and are injected along the tectonic foliation. The pegmatites have monzo- and syenogranitic to alkali feldspar granitic composition. In addition to quartz, K-feldspar, and plagioclase, biotite, amphibole, magnetite, and locally garnet compose the main rock-forming assemblage, whereas allanite, apatite, xenotime, pyrite, columbite, zircon, and thorite are accessory phases. Allanite is commonly medium- to coarse- and very coarse-grained (up to 7 cm crystal size) and hosts most of the total REE content of these pegmatites. The dykes are unzoned to simply zoned and display ubiquitous porphyritic textures and eventual graphic intergrowth. Unequivocal field evidence of parental intrusions genetically linked to the pegmatite dykes was not identified. In fact, there is an ongoing debate as to whether they represent residual melts of differentiated granite magmatism or direct products of anatexis. These pegmatites are slightly metaluminous to predominantly peraluminous (weakly, ASI = 1.0–1.1), magnesian to mostly ferroan, and high-K calc-alkalic to alkalic. Despite the widespread occurrence of barren dykes in the region, total REE + Y contents of REE-enriched samples range from ~3000 to ~28,000 ppm, particularly controlled by LREE. A few samples also display Nb and Zr contents up to ~2100 ppm and ~6800 ppm, respectively. Most samples display REE patterns characterized by sloping LREE, flat HREE, and Eu negative anomalies. Multielement diagrams commonly display Ti, Sr, P, Nb, and Ta negative anomalies and nearly all samples display low Be, Cs, and Rb contents.

INVESTIGATION OF BIOCHEMICAL METHODS TO ASSIST IN EXPLORATION FOR LITHIUM-CESIUM-TANTALUM (LCT) PEGMATITES

Ethan Amyotte
Ontario Geological Survey.
E-mail: *ethan.amyotte@ontario.ca*

A pilot study was initiated by the Ontario Geological Survey to examine the utility of biogeochemical techniques to assist in the exploration for lithium-cesium-tantalum (LCT) pegmatites. Biogeochemical techniques sampling vegetation are widely used as an exploration tool for mineralization covered by overburden, but have largely been focused towards exploration of gold, silver, zinc, nickel, copper, uranium and molybdenum. While the vegetation species and sample media for the exploration of these elements is relatively well understood, the vegetation uptake characteristics of LCT pegmatite pathfinder elements are not well studied. This pilot study involved the collection of 113 vegetation samples from black spruce and grey alder over two LCT pegmatites and their metasedimentary host rocks in the Georgia Lake pegmatite field: Nama Creek Main Zone North and the Jackpot. The goal of this study is to determine if inductively coupled plasma mass spectrometry (ICP-MS) trace element analysis of the vegetation samples could be used to interpret the presence of the mineralized pegmatites under overburden cover. Results from ICP-MS analyses of the vegetation show lithium, beryllium and tantalum anomalies associated with the pegmatites. When comparing lithium, cesium and beryllium values from samples taken above LCT pegmatites with those take above metasedimentary host rocks, results show mean values from samples taken above pegmatites to be above one standard deviation higher than the mean of samples collected above metasedimentary host rocks. Black spruce twig and bark analysis appear to present the most consistent lithium, beryllium and tantalum anomalies. Analysis of grey alder twigs and leaves show significant scatter in lithium values, potentially due to the mobility of the element and the plants' shallow root system and rapid growth cycle. Preliminary investigations into biogeochemical techniques have demonstrated the potential to aid in the exploration for LCT pegmatites given the clear and present anomalies observed in this study. Additional work is required to refine which medium is best suited for this technique as well to assess if the extent of the geochemical halo in the host rock is visible with the biogeochemical technique.

CARBONATITE AND SALT MELTS CAN DO WEIRD THINGS LIKE IOAS, IOCGS, AND FERROCARBONATITES

Michael Anenburg
Australian National University.
E-mail: *michael.anenburg@anu.edu.au*

Silica-dominated magmatic-hydrothermal systems are generally well understood. A viscous silicate magma solidifies to rock and exsolves a separate aqueous fluid, which can itself separate into a vapour and a dense brine phase and cause hydrothermal alteration. This distinction is not as clear in magmatic systems which lack silica, instead being dominated by salts such as chlorides, fluorides, sulphates, carbonates, and phosphates. Often, hydrous salt melt inclusions can be misinterpreted as fluid inclusions. Salt melts can remain continuously liquid to temperatures below the solidus of any silicate system. They are highly reactive and corrosive, and instead of solidifying into a solid mass, salt melts are more likely to metasomatize rocks that they come into contact with, just like hydrothermal fluids. Confusingly, they often exsolve a real hydrothermal phase which can potentially be trapped alongside the salt melts. Salt melts are proposed to be excellent carriers of iron in both oxidation states, as well as many economic metals. This, together with their reactivity, permits them to form enigmatic metasomatic rocks which appear "hydrothermal" but are unlike any rock formed by silicate magmatic-hydrothermal system. They often consist of elements which are seldom elevated in silicate melts, and poorly soluble in silicate-derived hydrothermal fluids. Fluid inclusions in iron oxide-apatite (IOAs) and iron oxide-copper-gold deposits (IOCGs) may record these melts, often misinterpreted as "fluids". Unfortunately, minerals crystallizing from salt melts are soluble and are not preserved in the geological record. Therefore, identification of their former presence is challenging. Current research into salt melts is in its infancy. How common are salt melts? Are they really responsible for IOCGs and IOAs, or is there an alternative explanation? If they are so reactive, how do they form in the first place? There are very few experimental studies on natural-like compositions, and their possible interactions with the wide range of crustal rocks. Carbonatite melts are a special case of salt melts in which the dominant anion is carbonate. They are much better studied than chloride-dominated salt melts, and rocks that crystallize from them are better preserved in the geological record. Ferrocarbonatite bodies are often ore-bearing, and their formation from melts is mostly understood. Non-ferrous mineralized carbonatite systems are also instructive. The study of carbonatite systems and their related mineralization can be used as a strategy guide in approaching the wider questions in salt melts.

GEOSCIENCE OF GREEN ENERGY AND THE DIGITAL ECONOMY: OVERVIEW OF A NEW COURSE AT THE UNIVERSITY OF SASKATCHEWAN

Kevin Ansdell
University of Saskatchewan.
E-mail: *kevin.ansdell@usask.ca*

The University of Saskatchewan, like many other universities in Canada, has a significant focus on sustainability practices with the development of a forward-looking strategy to 2030 that is designed to consider the United Nations Sustainable Development Goals. One of the goals is to reduce greenhouse gas emissions by 45% from their 2010 levels by 2030, and to have net-zero emissions by 2050. The university has several academic and research initiatives that are focused on the development of energy policies, and the development of green energy and digital technologies and materials, some of which are linked to the signature research area of "Energy and Mineral Resources for a Sustainable Future". As we all know, the transition to green, clean, sustainable energy sources is considered to be vital to meet greenhouse gas emission targets in Canada. In addition, we know that to meet these targets will require increasing amounts of a variety of critical geological materials. However, non-geoscientists typically do not appreciate this connection. The new undergraduate course at the University of Saskatchewan, which was first offered in 2021, is designed to be accessible to non-geoscience students, as well as geoscientists. The aim is for the course to attract students from across disciplines to spark discussion and provide different perspectives, and so the rationale was for a senior level course so that the students have already obtained a breadth of knowledge through their university career. Graduate students can also take the course. The course examines the definition, location, and importance of green energy sources, such as solar, wind, geothermal, hydroelectric, tidal, and nuclear. The geological characteristics of these energy sources are considered, along with the use of resources and other issues associated with the generation, storage, and distribution of the energy produced, and the importance of recycling, waste disposal, and the circular economy. Local, national, and global examples are provided in order to emphasize that an understanding of geology is important to the success of green energy initiatives. The course format consists of lectures combined with student-led discussion of selected articles, texts, and relevant national and global news and policy announcements. This provides a direct link between geoscience and up-to-date news items. For example, in 2021 one discussion session focused on the connections between a Human Rights Watch article on issues linked to the manufacturing of electric vehicles, a coup in Guinea, an election in Iceland, and Quebec. What is the link?

UNCONFORMITY-RELATED URANIUM DEPOSITS ASSOCIATED WITH THE ATHABASCA BASIN, CANADA: VIEW ON DEPOSIT FOOTPRINTS AND RELATIONSHIP TO GENETIC MODELS AND THE URANIUM ORE SYSTEM

Kevin Ansdell
University of Saskatchewan.
E-mail: *kevin.ansdell@usask.ca*

The aim of this presentation is to provide a personal view of the salient features of the uranium ore system and genetic models that are potentially relevant for the development of a footprint for unconformity-related uranium deposits in the Athabasca Basin, with a focus on results from the Geological Survey of Canada EXTECH IV, TGI4, and TGI5 projects, and the NSERC-CMIC Footprints project. Much of this work has focused on deposits related to the Wollaston-Mudjatik transition zone (WMTZ: McArthur River, Cigar Lake, Millennium) in the east, and the Patterson Lake Corridor (PLC: Arrow, Triple R) in the southwest of the basin. The Athabasca Basin hosts the world's highest-grade uranium deposits. They are spatially associated with structures that crosscut the unconformity between the sedimentary rocks of the Paleo/Mesoproterozoic Athabasca Supergroup and the underlying Archean-Paleoproterozoic basement rocks, but can be hosted in the basement, or close to the unconformity. Fundamentally, the development of a footprint to these deposits, which is a present-day snapshot of the effects of pre-, syn- and post-mineralization processes, is focused on identification of fertile structures, understanding the complexity of these structures, and determining the extent of the alteration and geochemical haloes, and related physical property variations, around the deposits. Primary mineralization is considered to have formed at ca. 1.6 Ga, potentially related to reactivation of older structures sparked by the collision of proto-Australia with Laurentia. Crustal-scale structures, often recording significant pre-basin alteration, appear to be more important than the composition of host rocks, based on the differences between the rocks in the WMTZ and PLC. The siting of deposits, and associated alteration, is thus related to the combination of appropriate structural traps and available depositional mechanism, akin to orogenic gold systems. Uraninite, and clay minerals, also record younger ages, indicative of the presence of fluids throughout the basin history, and these fluids may destroy deposits, or redistribute U-related elements to form an important component of a footprint. Geological, geochemical, and geophysical data along the structural corridors in the WMTZ have been used to constrain the footprint of deep (~500 m) deposits. For example, molar ratios (K, Mg, Al) in sandstones, and the presence of fractures and lithogeochemical 'chimneys', provide evidence for dispersion of specific elements and radiogenic lead towards the glacial deposits at surface. In contrast, the footprint around basement-hosted deposits is tighter to the structures, and more complex, as the rocks are more impermeable and compositionally variable.

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AGE AND PETROGENESIS OF DEVONIAN PLUTONIC ROCKS IN THE EASTERN MEGUMA TERRANE, NOVA SCOTIA, CANADA

Donnelly Archibald[1], Sandra Barr[2], Chris White[2], Shae Nickerson[3], Richard Stern[4], Yan Luo[4], Robert Creaser[4], Graham Pearson[4]
[1]St. Francis Xavier University, [2]Acadia University, [3]Brunswick Exploration, [4]University of Alberta.
E-mail: *darchiba@stfx.ca*

The eastern Meguma terrane is characterized by a 7750 m-thick succession of Cambrian–Ordovician metasedimentary rocks representing the upper part of the Goldenville Group and lower part of the Halifax Group that were intruded by abundant Middle to Late Devonian granitoid plutons. Less voluminous intrusions of diorite-tonalite and minor gabbro are associated with plutons along the northern margin of the terrane (Trafalgar plutonic suite, Cranberry Lake pluton, Bull Ridge pluton, Lost Lake pluton). The mafic-intermediate intrusions contain abundant metasedimentary xenoliths and show magma mingling textures with their adjacent granitic plutons. Mafic-intermediate rocks do not appear to be associated with larger plutons (e.g. Halfway Cove, Larrys River, Queensport, Sherbrooke, Canso) in the easternmost part of the terrane at the present level or erosion. The mafic-intermediate rocks have calc-alkalic chemical characteristics consistent with origin in a continental margin magmatic arc, thus, providing constraints on the tectonic setting of the spatially and temporally associated granitic magmatism. The granitoid plutons are peraluminous granite to granodiorite, contain abundant metasedimentary xenoliths and have "S-type" geochemical characteristics including high SiO_2 concentrations (> 65 wt.% SiO_2), primary muscovite, and garnet. Whole-rock geochemical data from granitoid plutons and related pegmatite dykes show similar major, trace element and rare-earth element compositions. New U–Pb zircon data indicate coeval emplacement of mafic-intermediate plutons and granitic plutons in the Devonian (ca. 385–370 Ma). However, inherited zircon domains are numerous and range from Palaeoproterozoic to Devonian. Zircon oxygen isotopic data are between + 7.2‰ and + 9.3‰ and indicate melting of a metasedimentary source rock. Zircon hafnium isotopic data have epsilon Hf(t) values between – 6.0 and + 2.1 which support whole-rock epsilon Nd(t) values that are between + 1.9 (quartz diorite) and – 8.1 (biotite granite). The new geochemical data together with the new zircon U–Pb, O and Hf isotopic data from plutons in the eastern Meguma terrane are indistinguishable from published data from the South Mountain Batholith. Taken together, this suggests subduction-related magmatism was more extensive in the Meguma terrane during the Middle to Late Devonian than previously recognized.

THREE-DIMENSIONAL (TETRAHEDRAL) MAJOR ELEMENT ANALYSIS OF REDOX-VARIABLE CHEMICAL WEATHERING TRENDS

Michael G. Babechuk[1], Christopher M. Fedo[2]
[1]Memorial University of Newfoundland, [2]University of Tennessee.
E-mail: *mbabechuk@mun.ca*

The utility of major elements in the study of siliciclastic sedimentary petrogenesis expanded rapidly ~30–40 years ago with the development of molar chemical weathering indices and accompanying ternary plots, most prominently the chemical index of alteration (CIA) and the Al_2O_3-CaO*+Na_2O-K_2O (A-CN-K) plot. Different ternary plot arrangements emerged to isolate and analyze other weathering and physical hydrodynamic trends, such as those adding Fe and Mg (FM) to examine mafic mineral effects. However, limitations from fixed-element arrangement across 3 poles have remained a barrier to visualizing some critical sedimentary processes in these ternary plots since their inception. For example, combining CNK on one pole of FM-bearing plots inhibits combined analysis of plagioclase vs. K-feldspar weathering and prevents the K-metasomatism correction possible in the A-CN-K plot. A strategy more common to igneous and metamorphic petrology, but rare in sedimentary petrology, is the use of 3-dimensional (tetrahedral) compositional space for major element analysis. Tetrahedral plots allow separation of elements across 4 poles and thus maximum visual resolution of more processes influencing whole-rock sediment/sedimentary rock compositions. This presentation provides an overview of recently developed tetrahedral plots in the Al_2O_3-CaO*+Na_2O-K_2O-$FeO_{(T)}/Fe_2O_{3(T)}$-MgO(-SiO_2) system(s) with a focus on in situ (source rock) chemical weathering trends from Archean to present. Iron-loss in tandem with mobile elements, as observed in metasomatized paleosols formed prior to ~2.2 Ga, is visualized effectively in the new A-CN-K-FM tetrahedral plot, with separation between mafic mineral and feldspar weathering effects. The modern-like retention of Fe in oxide minerals in contrast to mobile elements, as observed in metasomatized paleosols formed after ~2.2 Ga, is visualized effectively in the new AF-CN-K-M tetrahedral plot, with separation between mafic mineral and feldspar weathering effects. The isolation of K on one pole in both aforementioned tetrahedral plots allows tracking and correction in 3-D space for the K-addition resulting from diagenesis/metasomatism. In most weathering indices/ternary plots established to date, Si loss is not tracked in parallel with other mobile major elements (Ca, Na, K, Mg). The new A-CNKM-F-S tetrahedral plot makes this bridge and, with the sacrifice of mineral-specific and metasomatism effects, helps examine trends across a full spectrum of chemical weathering stages. All these new tetrahedral plots incorporate existing weathering indices directly into 3-D tetrahedral space or onto some of their projected ternary faces.

DISTRIBUTION OF RARE EARTH ELEMENTS AND YTTRIUM IN THE VARIOUS MINERALIZED ZONES OF THE MOUNT PLEASANT W-Mo-Bi AND Sn-Zn-In-Cu DEPOSITS, SOUTHWESTERN NEW BRUNSWICK

Saeid Baghban Asgharinezhad[1], David Lentz[1], Kathleen Thorne[2], Neil Rogers[3]
[1]University of New Brunswick,
[2]New Brunswick Department of Natural Resources and Energy Development,
[3]Geological Survey of Canada.
E-mail: *saeid.baghban@unb.ca*

The Late Devonian, granite-related Mount Pleasant deposits are located along the southwest margin of the Mount Pleasant Caldara complex in southwestern New Brunswick. Mineralization is associated with three episodes of highly evolved, A-type granites intruded into the Mount Pleasant volcano-sedimentary sequences, producing three distinct mineralized areas. These zones constitute a high-tonnage, low-grade W-Mo-Bi ore related to an early fine-grained equigranular granite (Gr-I) in the Fire Tower Zone; a limited-tonnage, high-grade Sn-Zn-Cu-In ore associated with aplitic to porphyritic granite (Gr-II) in the North Zone; and the small W-Sn-Zn-In occurrence in the Saddle Zone that is linked to the intersection of Gr-I and Gr-II. A barren, medium-grained, equigranular granite (Gr-III) crosscuts the earlier granitic phases at depth. The distribution of rare earth elements (REE) and yttrium (Y) are characterized for different styles of mineralization by whole-rock geochemistry, micro-X-ray fluorescence (µXRF), and shortwave ultraviolet (UV) light. Yttrium-rich phases (e.g. fluorite, monazite, xenotime, zircon, rutile, and titanite) are strongly associated with the mineralized zones and are most prevalent within the matrix of brecciated zones. Based on µXRF analysis, these minerals contain elevated LREE+Y and some HREEs (including Gd, Dy, and Er). The enriched Y content of fluorite with oscillatory to chaotic zoning was identified by shortwave UV and µ-XRF. The intergrowth of zircon, monazite, and xenotime was also detected in the mineralized zones. Additionally, ferberitic wolframite exhibits elevated contents of Eu and HREEs (e.g. Tb, Er, Yb, and Lu). Based on whole-rock geochemical data, these granites are extremely enriched in fluorine, incompatible trace elements, and REEs, with very low Zr/Hf, K/Rb, and Nb/Ta ratios, implying an important role for fluid fractionation in late-stage magmatic differentiation. Furthermore, the mineralized zones exhibit elevated Y concentrations. The granitic rocks and the mineralized zones exhibit flat chondrite-normalized REE patterns with pronounced negative Eu anomalies. Several key high-field strength elements (HFSE) are enriched in these deposits, including Zr, Ti, Hf, Nb, and Ta. High fluorine was also detected in the mineralized zones (up to 7%), which is consistent with a shallow emplacement of the granitic suites and the subsequent low-pressure conditions during mineralization. Based on principal component analysis, monazite and rutile for LREEs, and zircon and xenotime for HREEs are pathfinder minerals in the Mount Pleasant deposits. In conclusion, the Mount Pleasant deposits have a very high potential for economically viable Y and HFSE mineralization, which could potentially be extracted as by-products to the primary Sn-Zn-Cu-In and W-Mo-Bi ores.

PARENTAL MAGMAS, TECTONIC SETTING, AND MAGMATIC EVOLUTION OF THE LAC DES ILES INTRUSIVE SUITE

Wyatt Bain[1], Peter Hollings[2], Lionnel Djon[3], Matthew Brzozowski[1]
[1]British Columbia Geological Survey, [2]Lakehead University, [3]Impala Canada.
E-mail: *wyatt.bain@gov.bc.ca*

The Archean (~2.69 Ga) Lac Des Iles (LDI) mafic-ultramafic system in northwestern Ontario is a world-class platinum-group element (PGE) deposit and North America's premier Pd resource. The LDI intrusion is one of several mafic-ultramafic intrusions that form a ring-shaped array (the LDI intrusive suite; LDI-IS) situated near the eastern boundary of the Wabigoon Subprovince of the Superior Province near the boundary with the Quetico Subprovince. Intrusions within the LDI-IS are geochemically similar to the Mine Block Intrusion of the Lac Des Iles deposit, suggesting a similar level of prospectivity for PGE mineralization. These shared features potentially arise from similarities in the processes driving melt fractionation, parental magma compositions, and contributions of mantle and crustal components. Here, we present new age dates, Sm–Nd isotopes, and modeled parental melt trace-element compositions for several intrusions within the LDI-IS, including the Tib Lake, Legris Lake, Wakinoo Lake, Demars Lake, Dog River, and Buck Lake intrusions. Zircon U–Pb ages from the Wakinoo Lake (2696.6 ± 0.8 Ma), Legris Lake (2690.6 ± 0.8 Ma), Buck Lake (2698.1 ± 1.5 Ma), and Tib Lake (2685.9 ± 1.6 Ma) demonstrate that the various intrusions of the LDI-IS are coeval with one another and the Mine Block Intrusion of LDI. Calculated parental magma trace-element compositions for each of the intrusions exhibit highly fractionated REE profiles, moderately negative Ta-Nb and Zr-Hf anomalies, and strong enrichment in the large ion lithophile elements. Taken together, the common ages and similar parental magma compositions suggest that the individual intrusions in the LDI-IS were likely derived from a common melt reservoir at depth. However, both Tib Lake and the northern ultramafic centre of the Lac Des Iles complex contain physically distinct intrusive units that are geochemically more primitive than the majority of the rocks in the LDI-IS. This is likely a result of variable mixing with a more mafic magma during the formation of the intrusions that form the northern boundary of the LDI-IS. The Wakinoo Lake, Tib Lake, Legris Lake, and Lac Des Iles intrusions have overlapping Sm–Nd isotope signatures that are consistent with progressive assimilation of Wabigoon tonalite gneiss and hornblende tonalite with increased distance from the Wabigoon-Quetico suture zone. This crustal assimilation likely drove sulphide immiscibility at depth, but variable degrees of sulphide liquid entrainment during emplacement resulted in variable volumes of sulphide mineralization in each of the intrusions.

REE, Th, AND HFSE MOBILIZATION VIA CIRCULATION OF SECONDARY CARBONATE-SULPHATE-CHLORIDE AQUEOUS SOLUTIONS: A KEY PROCESS FOR UPGRADING OF CRITICAL METAL MINERALIZATION IN IRON OXIDE-APATITE SYSTEMS

Wyatt Bain[1], Matthew Steele-MacInnis[2], Matthew Severs[3], Yannick Bussweiler[4], Xinyue Xu[2]
[1]British Columbia Geologic Survey, [2]University of Alberta, [3]Stockton University, [4]University of Cologne.
E-mail: *wyatt.bain@gov.bc.ca*

In a number of Kiruna-type iron oxide-apatite (IOA) deposits in Europe and Asia, rare earth element (REE) and high field strength element (HFSE) enrichment appears to form as a result of the secondary mobilization of REEs and HFSEs during late-stage hydrothermal overprinting. However, key questions remain as to the character of the fluids involved in this process and how their genesis and circulation relate to the processes involved in the initial formation of IOA ore bodies. Here we present textural, geochemical, and inclusion data from ore-stage apatite in the Buena Vista (Nevada, USA) and Iron Springs (Utah, USA) magnetite-apatite deposits. Previous work shows that primary IOA mineralization in both systems was likely precipitated by Fe-rich carbonate-sulphate melts that are preserved as melt inclusions in primary apatite crystals. However, primary apatite from Buena Vista contains zones of secondary apatite which are strongly depleted in REEs, Th, Hf, and Fe and rimmed by secondary carbonate minerals that envelope the outer edge of a chemical front along which REEs and HFSEs are progressively mobilized. These zones of secondary apatite commonly surround coarsely crystalline REE-rich minerals and contain abundant assemblages of carbonate-sulphate-chloride brine inclusions. In contrast, apatite from Iron Springs lacks these secondary features and contains far fewer carbonate-sulphate-chloride brine inclusions relative to Buena Vista, but displays REE, Th, and HFSE concentrations uniformly in excess of primary apatite from Buena Vista. These observations demonstrate that a secondary stage of hydrothermal upgrading involving carbonate-sulphate-chloride brines is responsible for the mobilization of REEs, HFSEs, and Fe from IOA ore bodies in the Buena Vista system. This is consistent with numerous experimental studies that characterize SO_4^{2-} and CO_3^{2-} as strong complexing agents for REEs, Th, and Fe in aqueous solutions. Moreover, systems that lack the secondary features described here (i.e. Iron Springs) likely lack significant REE mineralization. Thus, critical element enrichment in IOA deposits occurs in two phases: 1) REEs and HFSEs are incorporated as trace elements in the primary mineralogy of IOA orebodies precipitated by carbonate-sulphate melts and, 2) carbonate-sulphate-chloride brines, exsolved from primary carbonate-sulphate melts, mobilize and concentrate REEs and HFSEs as major elements in discrete mineral phases. This model accounts well for the common observation of overprinting hydrothermal features in many notable IOA localities and is likely a key throughline linking genetic mechanisms in metasomatic iron and alkali-calcic (MIAC) systems, IOA and iron oxide copper-gold (IOCG) deposits, and REE-rich ferrocarbonatite systems worldwide.

THE KINETICS OF MELT INCLUSION PRESERVATION DURING COOLING OF MAGMATIC SYSTEMS

Don R. Baker
McGill University.
E-mail: *don.baker@mcgill.ca*

Melt inclusions in crystals provide one of the best windows into the composition and evolution of magmatic systems. The preservation of melt inclusions as glasses requires rapid cooling to prevent crystallization and depends upon the kinetics of nucleation and crystal growth. Understanding the conditions necessary for melt inclusion preservation can provide new insights into magma chamber dynamics. The combination of experimental measurements of crystal growth rates with calculations of nucleation delay in small volumes allow us to constrain the time-temperature cooling paths necessary to preserve melt inclusions as glasses. Crystal growth rates in magmatic composition melts have been measured in multiple studies during the past ~100 years, providing the ability to estimate the time necessary for a crystal to grow to a specified size. But growth of new crystals in inclusions does not occur immediately following supersaturation of a melt with a crystalline phase, instead the melt will reside at supersaturated conditions for a finite duration before the first crystals appear. The nucleation delay in magmatic systems can range from durations of less than a second (ultramafic melts) to millions of years (silicic melts). Through comparison of experiments and calculations it has been demonstrated that nucleation delay for the rock-forming minerals in anhydrous basaltic melts (olivine, clinopyroxene, plagioclase), and hydrous rhyolitic melts (alkali feldspar, quartz) can be predicted by classical nucleation theory to better than an order of magnitude. Combination of these results with the theory of crystallization in confined volumes provide the constraints needed to investigate the cooling times necessary for the preservation of melt inclusions as glasses. The calculations demonstrate the strong control of melt composition, including water concentration, and inclusion size on glass preservation during cooling. Modelling indicates that dry basaltic melt inclusions of 50 micrometres in diameter need to cool to temperatures of near 773 K within ~40 years to prevent nucleation and growth of new crystals. On the other hand, metaluminous rhyolitic melt inclusions with ~4 wt.% water of the same size must cool to similar temperatures within ~400 years. In both cases, increases in water concentration in the melt can decrease these times by many orders of magnitude; for example, a basaltic melt inclusion with 6 wt.% water must cool to ~773 K in less than ~180 days to prevent nucleation and crystal growth.

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ORE BODY ARCHITECTURE IN SNOW LAKE: METAMORPHOSED AND DEFORMED VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS

Sheila Ballantyne[1], Melissa Anderson[1], Margaret Stewart[2]
[1]University of Toronto, [2]Mount Royal University.
E-mail: *sheila.ballantyne@utoronto.ca*

Ore body architecture of ancient volcanogenic massive sulphide (VMS) deposits is the result of both primary volcanic environments and overprinting metamorphism and deformation, which modify the primary geometry of the ore lenses. This study reviews the microscale and mesoscale structural features commonly observed in VMS ore bodies in the Snow Lake District and their controls on the distribution of base and precious metals. The Snow Lake arc assemblage (SLA) is host to six known economic VMS deposits (Chisel, Chisel North, Ghost, Lost, Lalor, and Photo Lake deposits). This district is at the eastern margin of the Flin Flon-Snow Lake Belt, which belongs to the Paleoproterozoic Trans-Hudson Orogen. The VMS mineralization is the result of hydrothermal processes related to volcanism in a pericratonic arc outboard of the Superior Craton. Following VMS deposit formation, the SLA underwent four deformation events from 1.84–1.77 Ga, resulting in peak almandine-amphibolite facies metamorphism (~5–6 kbar, 550–600°C) at ca. 1.81 Ga and strongly influencing the architecture and spatial relationship between VMS deposits. Primary, syn-volcanic modification of VMS deposits can be significant and often challenging to distinguish from post-volcanic events. Syn-volcanic modification of VMS deposits includes vertical stacking of ore bodies buried by progressive volcanic and volcaniclastic rock sequences, hydrothermal alteration of ore and host rocks, and metal zonation due to the thermal evolution of VMS systems. Regional syn-volcanic tectonics also affect VMS ore body architecture, particularly before and during subsidence of VMS centres, resulting in localized truncation, offset of units by faulting, and thickening of ore lenses and related host volcanic and volcaniclastic sequences. Metamorphism and deformation of the VMS ore bodies in the SLA, as well as the variably hydrothermally altered surrounding host rocks, have created unique architecture and spatial relationships. Massive sulphide bodies are rheologically weaker than their host volcanic and volcaniclastic units and, apart from pyrite, sulphide minerals behave in a ductile manner under most metamorphic conditions. Significant ore remobilization is common. Modes of metal transfer during metamorphism include mechanical cataclasis or ductile flow, solid-state or hydrothermal diffusion, and melting. This competency contrast creates identifiable features in the ore bodies such as cups, piercement veins, and sulphide breccias. Foliation is also common, expressed by alternating silicate and sulphide bands or other mineralic banding. Understanding the syn- and post-depositional features of VMS ore bodies aids in interpretation of VMS ore body formation, modification, and preservation and advances the development of mineral exploration targets.

MINOR AND TRACE ELEMENT CONTENTS OF CHROMITE FROM KOMATIITES AND PICRITES AS PETROGENETIC INDICATORS

Sarah-Jane Barnes[1], Eduardo T. Mansur[2], Dany Savard[1], Philippe Philippe Pagé[3]
[1]Université du Québec à Chicoutimi, [2]Geological Survey of Norway, [3]IOS Services Géoscientifiques.
E-mail: *sjbarnes@uqac.ca*

Chrome, Ni and platinum-group element ore deposits are all found in association with mafic and ultramafic rocks. Olivine followed by olivine plus chromite are the first minerals to crystallize from the magmas that form these rock types. The Ni content of olivine has long been used in exploration programs, but olivine is readily altered in transport and this limits its use as an indicator mineral. Chromite appears to be more robust and Zn, Ni and Ru contents of chromite have been suggested as possible tracers of ore formation. However, most ultramafic and mafic rocks contain only a small amount of chromite and post-crystallization processes such as re-equilibration during cooling, metamorphism and weathering could change their compositions. In order to consider the effects of fractional crystallization and cooling on the composition of chromite we have determined the minor and trace element content of chromite from the Emeishan High- and Low-Ti picrites (China) and from komatiite flows of Alexo (Abitibi, Canada), to assess the degree to which the chromite compositions reflect the melt compositions. The concentrations of elements with a charge 3+ or greater (Al, Sc, Ti, V, Ga, Zr, Nb, Sn, Hf and Ta) appear to reflect the melt compositions in that they correlate with the whole rock compositions and have empirical partition coefficients similar to those determined in experiments. The concentrations of all these elements increase with crystal fractionation, despite the fact that Al, V and Ga are compatible with chromite. This is because the cotectic proportions of olivine to chromite is 98 to 2 or less and thus the bulk partition coefficients are less than one. Vanadium concentrations indicated fO_2 in –2 to 0 range for the Emeishan rocks and –1 to 0 in the komatiites. The elements with a 2+ charge (Mg, Mn, Fe, Co, Ni and Zn) partition into olivine and hence their concentrations are controlled by olivine rather than chromite. In addition, the concentrations of these elements are different in chromite included in olivine to those in the matrix. Both appear to have re-equilibrated and are therefore not as reliable indicators of magmatic conditions, although Ni concentrations of chromite from massive Ni-rich sulphides in komatiites are distinctly lower. Ruthenium concentrations are high in all the chromite, except those from massive Ni-rich sulphides. The crystallization of chromite produces negative Ru anomalies in PGE patterns of fractionated rocks.

MINOR AND TRACE ELEMENT CONCENTRATIONS IN CHROMITE FROM LAYERED INTRUSIONS: IMPLICATIONS FOR THE FORMATION OF MASSIVE CHROMITE LAYERS

Sarah-Jane Barnes[1], Eduardo T. Mansur[2], Wolfgang D. Maier[3], Stephen A. Prevec[4]
[1]Université du Québec à Chicoutimi, [2]Geological Survey of Norway, [3]Cardiff University, [4]Rhodes University.
E-mail: *sjbarnes@uqac.ca*

The origin of massive chromite layers in layered intrusions is much debated because the layers contain more than fifty percent chromite, whereas cotectic crystallization from primary magmas would only be expected to produce two percent chromite. Various models have addressed this problem, including: a) A rapid change in an intensive variable (pressure, fO_2 or a sudden change in composition of the magma possibly due to magma mixing), which led to only chromite crystallizing; b) Physical separation of chromite from the silicate minerals during transport in a slurry, aided by differences in specific gravity; c) Partial melting of a cotectic chromite-silicate cumulate resulting in a chromite-rich residue. Which if any of these processes occurred is important from the point of view of understanding and exploring for Cr and platinum-group element (PGE) deposits, because massive chromite layers supply almost half of the world's Cr and some massive chromite layers contain PGE deposits. Indeed, the largest PGE ore deposit in the world is found in a massive chromite layer - the UG2 of the Bushveld Complex, South Africa. By examining the minor and trace element contents of chromite from three intrusions which contain PGE and Cr deposits, the Bushveld Complex (South Africa), the Stillwater Complex (USA) and the Great Dyke (Zimbabwe) and comparing these chromite compositions to those of chromite from magmas from which the intrusion could have formed (komatiites and picrites) we observed the following. The chromites from the lowest levels of the intrusions could have crystallized from komatiite liquids that have been contaminated with continental crust. The Great Dyke chromites have the highest Cr# and lowest incompatible element contents and could have formed from a liquid close to komatiite. All the chromites, except those of the Dunite Succession of the Great Dyke, have equilibrated with a liquid that had also crystallized pyroxene. The Great Dyke and Stillwater chromites show a narrower range in composition than the Bushveld chromites. Titanium, V, Sc and Ga contents of the chromites increase both across the whole stratigraphy and across individual layers. The increase of V and Ga across layers contradicts models based on a sudden change in an intensive variable leading to crystallization of only chromite, because V and Ga are compatible with chromite and thus should decrease up-section. We conclude that models based on physical accumulation of chromite during transport best fit the observations.

NEW CONCEPTS IN GENETIC MODELS FOR THE NORILSK-TALNAKH Ni-Cu-PGE DEPOSITS

Stephen Barnes[1], Giada Iacono-Marziano[2], Margaux Le Vaillant[1], Marina Yudovskaya[3]
[1]Commonwealth Scientific and Industrial Research Organization (CSIRO), [2]National Centre for Scientific Research (CNRS), [3]University of Witwatersrand.
E-mail: *steve.barnes@csiro.au*

The supergiant ore deposits of the Norilsk-Talnakh camp contain over a trillion dollars worth of metals and continue to fascinate researchers. Genetic models must take account of multiple constraints and paradoxes. The host chonoliths are probably closed tubes rather than flow-through conduits, but PGE mass balance requires that sulphides reacted with a volume of magma at least ten times larger than that of the host intrusions. S isotopes are strongly indicative of a source in the evaporites of the enclosing stratigraphy but assimilation of anhydrite requires dissolution of sulphate; additional assimilation of a strong reductant is also required to generate sulphide. The sulphide globules characteristic of the orebodies are mostly too big to have been carried any great distance by basaltic magma. Textural evidence indicates that these globules originated as liquid droplets physically attached to gas bubbles, and that a "bubble rafting" mechanism may have been involved in their transport. Injection of volatile-saturated magma is further indicated by the widespread brecciated skarns and intrusion breccias in the country rocks. It is likely that volatile saturation of the magmas was initially induced by pre- and syn-emplacement assimilation of country rock. These observations can be reconciled with a model of explosive emplacement of a magma already carrying finely dispersed sulphide droplets, at least in part rafted on vapour bubbles. A further mechanism is suggested by analogue experiments showing that a sudden pressure drop occurs in overpressured magmas at sill-dyke transitions, such as must have characterized the initial emplacement of the chonoliths. The pressure drop would have caused a sudden further burst of vesiculation, country rock fragmentation and enhanced rates of assimilation of marginal rocks to form taxites. The emplacement process hence generates a lot more vapour, which "harvests" fine sulphide droplets and drives their coalescence to make droplet-bubble pairs as shown in recent experiments. Large sulphide droplets with relatively small gas bubbles sink to make the lower globular sulphide layers. Gas bubbles with minor amounts of attached sulphide, which float rather than sink, occupy the top parts of the sills and degas extensively, resulting in loss of most of the S and formation of low-S, high-PGE ores. Rapid supercooling during degassing of the overpressured magma accounts for the dendritic and sub-skeletal olivine commonly observed in the "picrodolerite" layers that host the globular ores. As the sills inflate during continuing magma injection the interiors are filled with sulphide-poor uncontaminated magma making internal gabbrodolerite layers.

MULTIPLE SULPHUR ISOTOPES USED ON VMS DEPOSITS TO DETERMINE THE ISOTOPIC SIGNATURE OF ARCHEAN OCEANIC SULPHATES

Guillaume Barré[1], Crystal LaFlamme[1], Georges Beaudoin[1], Jean Goutier[2], Pierre Cartigny[3]
[1]Université Laval, [2]Consultant, [3]Institut de Physique du Globe de Paris.
E-mail: *guillaume.barre.2@ulaval.ca*

Seawater sulphate is one of the major sulphur reservoirs in Earth's history and plays a critical role in controlling the sulphur cycle. The presence of sulphate in the Archean Ocean is debated; nevertheless, recent studies have shown that it contained significant amounts of sulphate. The analysis of sulphur isotopic signatures is a powerful tool to track the influence of sulphate in different geological settings. Typically, evaporite minerals are used as a tracer of the isotopic signature of seawater sulphate over geologic time, and the lack of an evaporitic record in the Archean makes it difficult to determine the isotopic record. To fill this gap, we used multiple sulphur isotopes analysis ($\delta^{34}S$, $\delta^{33}S$, $\delta^{36}S$) on volcanogenic massive sulphide (VMS) deposits, resulting from large-scale hydrothermal circulation of seawater in the oceanic crust, to precisely determine the sulphur isotopic signature of Archean seawater sulphate. Indeed, these deposits are known to partially record the isotopic signature of seawater sulphate in massive sulphide lenses. To better constrain the influence of seawater in Archean VMS, we analyzed different types of well-preserved deposits, including sub-seafloor replacement VMS, seafloor VMS, and exhalates, all from the ca. 2.7 Ga Abitibi greenstone belt (Quebec). Each type presents a specific isotopic signature, yielding magmatic (sub-seafloor replacement VMS) and seawater sulphate-rich (exhalites) endmembers. In seafloor VMS deposits, sulphide minerals record a mixing between the isotopic signature of seawater sulphate and magmatic-derived fluids (generated directly from magma or from the leaching of oceanic crust sulphide minerals). We used the seafloor VMS isotopic signatures in a two-component mixing model with that of the magmatic reservoir to determine the isotopic signature of the seawater sulphate. For this, the proportion of sulphate incorporated into the VMS is required. It has been estimated at 15% based on a compilation of VMS data over time (from modern to Paleoproterozoic) and previous mass balance calculations. The two-component mixing model using Noranda's VMS isotopic signature led to estimate values of $\delta^{34}S = 9.01‰ \pm 3.19$ and $\delta^{33}S = -0.97‰ \pm 0.30$ for oceanic sulphate at ca. 2.7 Ga. Our findings shed new light on the isotopic signatures of ancient oceans and offer new insights for future research.

CHARACTERIZATION OF BRECCIA-HOSTED Ni-Cu-PGE MINERALIZATION IN THE CRYDERMAN DEPOSIT, SUDBURY IGNEOUS COMPLEX, ONTARIO

Sandra Baurier Aymat[1], C. Michael Lesher[1], Chris Hicks[2]
[1]Laurentian University, [2]Vale Canada Limited.
E-mail: *sbaurier_aymat@laurentian.ca*

The basal contact of the Sudbury Igneous Complex (SIC) is lined by discontinuous magmatic and anatectic breccias, which occur primarily/exclusively within embayments/troughs/funnels along the basal contact and host the majority of the Ni-Cu-PGE-bearing contact ores. Sublayer norite (SLNR) and footwall breccia (FWBX) consist of polymictic, matrix- to clast-supported breccias containing heterometric inclusions: a) anteliths from the overlying melt sheet, b) local xenoliths from surrounding country rocks, and c) exotic xenoliths derived from mid-crustal ultramafic intrusions. SLNR is characterized by a cumulate noritic matrix, whereas FWBX contains an anatectic felsic to intermediate matrix, both of which may contain variable amounts of sulphide phases. Most studies on SLNR and FWBX have been carried out in the North Range, which is characterized in most locations by granitic to granodioritic footwall rocks. However, little work has been done in the South Range, which is characterized by greater abundances of mafic metavolcanic footwall rocks. The footwall rocks of the Cryderman deposit, located in the southeastern corner of the SIC, consists dominantly of greenschist- to amphibolite-facies massive, amygdaloidal, and pillowed metabasalt with minor interlayered arkose/wackes of the Stobie Formation, matrix-supported conglomerate rocks of the Ramsey Lake Formation, and gabbro-anorthosite bodies of the East Bull Lake-type Falconbridge Intrusion, all of which are crosscut by Nipissing gabbro/diorite bodies and NW-trending olivine diabase dykes. This deposit lies at a major inflection in the Sudbury basin and is bounded by two major NW-SE displacement faults. The basal contact of the SIC is vertical to overturned, but most of the deformation has been partitioned into shear zones, leaving large domains of footwall and Main Mass rocks essentially undeformed. Mineralization occurs as disseminated, inclusion semi-massive, and massive sulphides (Po-Pn > Ccp) in brecciated basalt at the SIC-Footwall contact and within fault zones. Inclusions are heterometric, subangular to rounded, and are dominantly derived from the adjacent footwall rocks. Petrographic studies and coarse-beam SEM analyses of breccia matrices suggest that they are Opx-rich mafic norite, indicating that the host rock is SLNR rather than FWBX. The absence of FWBX suggests that the temperature of the SIC melt during formation of the brecciated basalt was below the amphibolite solidus (825–950°C), and thus the mineralized breccia resulted from predominantly mechanical erosion of brecciated footwall rocks by dense, low-viscosity sulphide melt rather than by thermomechanical erosion.

GEOCHEMISTRY AND PARAGENESIS OF MAGNETITE-BEARING GABBROS FROM THE LAC DES ILES MINE, NORTHERN ONTARIO

Sergio Bautista[1], Peter Hollings[1], Sarah Dare[2], Lionnel Djon[3]
[1]Lakehead University, [2]Université du Québec à Chicoutimi, [3]Impala Canada.
E-mail: *sbautis1@lakeheadu.ca*

The Lac des Iles suite intrusion comprises several late Archean layered mafic to ultramafic intrusive bodies; one of them, the mafic to ultramafic Lac des Iles Complex (LDIC) consists of the North and the South LDI complexes. The South LDI Complex was emplaced during a regional collisional orogeny involving the Wabigoon-Marmion terrane and the Abitibi Wawa terrane and is made up of four main magmatic domains (gabbronorite, norite, breccia and norite), with palladium resources known from the norite domain and the breccia domain, which host the Lac des Iles palladium mine, a structurally controlled disseminated magmatic sulphide deposit. This study is investigating the magnetite-rich segments of the gabbronorite domain from fourteen samples in two drill holes. Fe-Ti oxide mineralization is dominated by fine- to medium-grained and anhedral magnetite, that is interstitial to pyroxene, which has been altered to chlorite, actinolite and talc, and plagioclase that has been altered to sericite and epidote. Petrography of the magnetite has identified sandwich and granular exsolution textures of ilmenite and some exsolutions of hercynite. The vanadium content of magnetite varies between 6647 and 12,934 ppm. LA-ICP-MS data of magnetite samples along a stratigraphic section show that vanadium and chromium are highest at the base and present lower concentrations towards the top, consistent with a more evolved magma towards the top.

THE SOURCE OF AURIFEROUS FLUIDS ALONG THE CADILLAC LARDER LAKE FAULT ZONE

Georges Beaudoin, Benoît Quesne, Christophe Scheffer, Guillaume Raymond
Université Laval.
E-mail: *georges.beaudoin@ggl.ulaval.ca*

The oxygen and hydrogen isotope compositions of orogenic gold-bearing veins along the Cadillac Larder Lake Fault Zone (CLLFZ) between Val-d'Or and Kirkland Lake were documented in detail to unravel the fluid sources and evolution in this classic orogenic gold vein field. Coexisting vein minerals show common oxygen isotope equilibrium, which yields temperatures between ~250 and ~550°C, typical for orogenic gold deposits. This enables calculation of the O-H composition of the hydrothermal fluids in equilibrium with the vein minerals. Equilibrium temperature covariation with fluid O and H isotope compositions demonstrates mixing of higher temperature (> 500°C), deep-seated metamorphic fluids with high $\delta^{18}O_{H_2O}$ of > 9‰, low δD_{H_2O} < –40‰, with lower temperature (< 250°C) upper crustal fluids having lower $\delta^{18}O_{H_2O}$ of < 4‰ and higher δD_{H_2O} that ranges from 0 to 30‰. Along the Augmitto-Bouzan segment (Rouyn-Noranda), the vein minerals document a vertical temperature gradient of 30°C per 100 m. Temperature decreases from 420°C at 700 m depth, to 230°C at 100 m depth, showing the vertical ascent of the deep-seated metamorphic fluid and mixing with the upper crustal fluids along the CLLFZ. The metamorphic fluid end-member along the CLLFZ can be subdivided in two slightly different reservoirs, mixing with a common upper crustal fluid reservoir. Along the eastern part of the CLLFZ (Val-d'Or to Malartic) the metamorphic fluid has $\delta^{18}O_{H_2O}$ isotope composition of 9–10‰, whereas west of Malartic to Kirkland Lake, the metamorphic end-member has a heavier composition, with $\delta^{18}O_{H_2O}$ between 11–13‰. The change in metamorphic fluid reservoirs occurs where the CLLFZ has an inflection in strike, suggesting it controlled fluid reservoir segmentation. At this location and that of the world-class Canadian Malartic deposit, both fluid reservoirs overlap; a tantalizing observation. The higher $\delta^{18}O_{H_2O}$ of the Malartic-Kirkland Lake metamorphic fluid end-member likely reflects a higher proportion of sedimentary rocks in the fluid source area, compared to the eastern Val-d'Or-Malartic segment. The study shows that the source of the deep-seated metamorphic fluid can vary along the strike of a crustal shear zone. Mixing occurs along the strike of the CLLFZ with upper crustal fluids, likely seawater trapped in country rock pores with a history of water-rock isotope exchange that cannot be distinguished despite differences in composition of the country rocks hosting the orogenic gold deposits.

TRANSITION FROM ARCHAEAN UNSTABLE STAGNANT LID CYCLE TO PLATE TECTONICS DURING THE PROTEROZOIC: DO MASSIF ANORTHOSITES RECORD DESTRUCTION OF FOSSIL ARCHAEAN OCEANIC LITHOSPHERE?

Jean Bédard
Geological Survey of Canada.
E-mail: *jeanh.bedard@nrcan-rncan.gc.ca*

In Archean cratons, granite-greenstone terrains show marked differences to the products of Phanerozoic Wilson cycles (no ophiolites, no high-P metamorphic rocks, no passive margins, no blueschists and no evidence for uniformitarian subduction). This has led to alternative unstable stagnant lid interpretations, where periodic mantle overturns generate large volumes of primitive juvenile melt that rework and remelt overlying crust, forming tonalite-trondhjemite-granodiorite and high-temperature pyroxene-tonalite plutons. Overturn cells may rift and disaggregate existing cratons and episodically set deep-rooted cratonic blocks in motion, leading to leading-edge accretion of unsubductable crust-dominated Archean-style oceanic lithosphere (ASOL). Compressional thickening of ASOL can generate syn-compressional TTGs and corresponding eclogitic restites. Late Archean continent-derived sedimentary rocks may also be underthrust, generating late-tectonic sanukitoid-type magmas from metasomatized subcontinental lithospheric mantle (SCLM). After the paroxysmal cratonizing overturns at 2.7 and 2.5 Ga, Earth lapsed into a stagnant lid phase (Siderean quiet period), with emergent continental blocks forming extensive passive margin deposits. At about 2.2 Ga, a mantle overturn broke the lid and set cratonic blocks in motion again, but with significant differences from previous overturns, as rift zones on a now colder world evolved into spreading ridges fed by passive depleted mantle upwellings, yielding modern type oceanic lithosphere that thickens and becomes denser with age, a prerequisite for the formation of active subduction zones at convergent margins. These characteristic plate tectonic environments slowly linked up into a world-girdling system during the Proterozoic, but at the start, most of Earth was likely still covered by near-unsubductable ASOL. Trace element inversion models applied to Proterozoic anorthosite massifs suggest they were derived from extensive garnet-field melting of a basaltic source. Plausible source compositions include depleted arc tholeiites and typical Archean greenstone successions (i.e. ASOL). This suggests that massif anorthosites may be by-products of the destruction of ASOL through subcretion and melting beneath drifting continents. When most of the ASOL was consumed (about 1 Ga), plate tectonic processes would have accelerated markedly, allowing accretion of ophiolite belts and formation of blueschists.

A NEW TYPE OF OPHIOLITIC CHROMITE DEPOSIT?

Jean Bédard[1], Alana Hinchey[2], Dogan Paktunc[3], Carl Guilmette[4], Azam Soltanmohammadi[1]
[1]Geological Survey of Canada,
[2]Geological Survey of Newfoundland and Labrador, [3]CanMet, [4]Laval University.
E-mail: *jeanh.bedard@nrcan-rncan.gc.ca*

Much of the world's chromite ore comes from ophiolites. Chromium is a Critical Mineral needed for metallurgical production. The Canadian Appalachian ophiolite belt has considerable potential for Cr and may also have PGE potential. Ophiolitic chromite deposits are subdivided into 5 types. The first three occur within the Thetford-Mines ophiolite and were mined for Cr ore during the two world wars. Types 4 and 5 are developed in the lower crust of the Bay of Islands ophiolite complex (BOIC) of Newfoundland. Type 1 nodular to massive chromite channel deposits developed within intra-mantle dunitic feeder pipes and are the most common type of ophiolitic chromitite worldwide. Type 2 stratiform chromitite-dunite cumulates at the base of the crust were deposited within small sill-like magma chambers. Type 3 PGE-rich metasomatic chromitites were injected into higher-level cumulate rocks. The Hall deposit fills breccias within a discordant metasomatic dunite pipe. At Starchrome, chromitite occurs together with prominent dunitic dykes and orthopyroxenite reaction rims against host websterites. Such deposits likely form by fault-guided migration of PGE-Cr-bearing fluids expelled from solidifying boninitic sills in the lower crust. Type 4 are high-Cr/Al reaction rims developed by incongruent dissolution of pyroxene into melts saturated only in olivine + chromite. They are concentrated near the MOHO along the top of the lowermost crustal pyroxenites and are thickened in fold noses. Volumes are small. Type 5 spinel-rich feldspathic peridotites have not yet been recognized as a Cr ore, but recent observations suggest this facies may be economic. The low-Cr/Al spinel forms by incongruent dissolution of plagioclase into melt that is saturated only in olivine + chromite. Field evidence shows that many BOIC olivine gabbro and feldspathic peridotite bodies are hybrids generated when hot primitive replenishments inject into older gabbroic rocks and mix with them. Anhedral inclusion-filled spinel occupies dissolution pits in plagioclase and can make up almost 10% of some rocks. Centimetre-scale chromitite schlieren likely represent disaggregated reaction rims. The spinel is relatively coarse and could easily be separated from gangue. As Type 5 generally occurs stratigraphically above Type 4, progressive maturation of this system could generate ghost stratigraphies (e.g. Philippine deposits). Similar spinel-rich facies are also present at Table Mountain, Blow-me-Down, and Lewis Hills. The volume of potential Type 5 Cr ore may be significant.

SCANDIUM: ORE DEPOSITS, MINERALIZING PROCESSES, AND EXPLORATION TARGETS

Caitlin M.J. Beland, Anthony E. Williams-Jones
McGill University.
E-mail: *caitlin_beland@iamgold.com*

Due to numerous technological advances in the aerospace and automotive sectors and concerns about supply, scandium is now considered a critical metal, making it the target of significant exploration activity. Scandium is classified as a rare earth element (REE) but has a much smaller ionic radius than the lanthanides and yttrium, and therefore behaves compatibly, particularly in ferromagnesian minerals. Nonetheless, scandium is concentrated by a variety of processes involving magmas, hydrothermal fluids, and surface waters. Indeed, the three deposits in the world that currently produce scandium (as by-products), Kovdor and Tomtor (Russia) and Bayan Obo (China), are either magmatic (carbonatite or phoscorite) or formed from fluids released by carbonatitic magmas. Economic levels of scandium at these deposits range from ~150 to 800 ppm Sc, and the ore mineralogy is highly variable. There has also been minor historic production from niobium-yttrium-fluorine (NYF) pegmatites in Madagascar and Norway. Currently, laterite-hosted scandium deposits are an important focus of exploration, specifically in Australia. A new scandium resource was recently discovered in ferrodiorite of the Kiviniemi mafic intrusion, Finland, with an average grade of 163 ppm Sc. Apart from this deposit, and those in NYF pegmatites, there are no examples of scandium deposits hosted by alkaline igneous rocks. The newly discovered, Crater Lake syenite-hosted scandium deposit, in northern Quebec, is the first scandium deposit to have been discovered in Canada, and the first known scandium deposit in a syenite complex anywhere. Hedenbergite is the main scandium mineral at Crater Lake, but subordinate proportions of scandium are also hosted by hastingsite. These minerals are concentrated in a cumulate facies of ferrosyenite. Fractional crystallization from an Fe-enriched parental liquid, and physical segregation of hedenbergite and hastingsite, were the main ore-forming processes. Scandium mineralization at the Crater Lake deposit indicates that alkaline igneous rocks are a largely overlooked but viable exploration target for this critical metal.

LOCAL OR GLOBAL OCEAN REDOX SIGNAL? COMPARISON OF THALLIUM WITH THE MOLYBDENUM AND URANIUM ISOTOPE SYSTEMS IN THE UPPER DEVONIAN KETTLE POINT FORMATION, ONTARIO

Natasha Bell, Brian Kendall
University of Waterloo.
E-mail: *ncbell@uwaterloo.ca*

Thallium (Tl) isotope data from black shales have been utilized to infer global ocean redox changes during some Phanerozoic ocean anoxic events and associated mass extinctions, but it is not well understood how environmental changes within a sedimentary basin can influence shale ε^{205}Tl. In this study, authigenic Tl concentrations and isotope ratios were measured for black shales of the Famennian Kettle Point Formation and compared with the molybdenum (Mo) and uranium (U) isotope paleoredox proxies. An inverse correlation between Mo and U isotope compositions was previously described for these shales and attributed to changes in dissolved sulphide levels in the deep waters of the Chatham Sag sub-basin. Additionally, the previous comparison of U and Mo enrichment factors indicated some connection between the sub-basin and open ocean throughout deposition. The stratigraphically lowest shales have higher ε^{205}Tl, lower δ^{238}U, higher δ^{98}Mo and lower concentrations of these trace metals, suggesting deposition from locally strongly euxinic bottom waters in a more restricted basin. In the stratigraphically highest shales, the lower ε^{205}Tl, higher δ^{238}U, lower δ^{98}Mo and higher trace metals concentrations reflect locally weakly euxinic conditions and larger dissolved trace metals inventories in response to a decrease in basin restriction. The intervening shales have intermediate isotope ratios and trace metals concentrations, reflecting the transition from strong to weak euxinic environments. A strong inverse covariation ($R = -0.75$) is observed between ε^{205}Tl and Tl concentrations for the entire dataset. Using a decision tree previously developed with data from modern environments, we interpret the ε^{205}Tl of the Kettle Point shales to directly capture water column ε^{205}Tl. Because the inverse Mo-U isotope correlation precludes interpretation of a global change in ocean redox conditions, we propose that local and regional changes within the semi-restricted Chatham Sag sub-basin drove the inversely correlated stratigraphic trends in ε^{205}Tl and Tl concentrations. During deposition of the lower stratigraphic interval, relatively lower regional sealevel and infrequent replenishment from the open ocean caused low sedimentary Tl enrichment and high ε^{205}Tl, with the regional water column ε^{205}Tl reflecting the dominant Tl inputs from riverine sources into the more restricted Chatham Sag. Conversely, relatively higher sealevel enabled higher sedimentary Tl accumulation and lower ε^{205}Tl ratios that reflect a greater input of Tl from the open ocean. Our study emphasizes that variation in basin restriction can produce stratigraphic trends in the ε^{205}Tl of black shales that are not driven by changes in global ocean redox conditions.

ASSESSING THE ROLE OF CRYOTURBATION ON INDICATOR MINERALS IN TILL

Juan Bello Rodriguez[1], Georges Beaudoin[1], Isabelle McMartin[2]
[1]Université Laval, [2]Geological Survey of Canada.
E-mail: *jdber15@ulaval.ca*

In this study located at the Amaruq orogenic gold deposit in Nunavut, northern Canada, we investigate if the inner motion dynamics in mudboils could fractionate indicator minerals (IMs) in till profile. We sampled several vertical profiles down to ~1 m depth in two trenches ~1 km down-ice of the deposit, including two profiles in the central part of well-identified mudboils. Texture and geochemical profiles were also collected in the two clear-cut mudboils. One mudboil exhibits consistent matrix grain size along the profile, while the other varies with depth, showing a gen-

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eral trend of increasing silt content down to the permafrost. The geochemistry of major elements (SiO_2, Al_2O_3, and MgO) and trace metals (Cu, Zn, As, Pb) does not differ with depth in these two profiles. The heavy mineral concentrate fraction (< 2 mm) of all profile samples contains gold and scheelite. The abundance of these IMs shows vertical variations that are not consistent along and between all profiles. Likewise, the size and morphology of gold grains do not exhibit a consistent trend. Only the profile in the mudboil with a variation of the matrix grain size reflects a trend of decreasing gold grain abundance with depth, which coincides with decreasing proportions of gold grains < 15 µm, and of pristine-shaped gold grains. The chemical composition of gold (< 400 µm), as well as scheelite and chalcopyrite (0.25–2 mm), was determined by EPMA and LA-ICP-MS. Most of the gold, scheelite and chalcopyrite crystals are interpreted to be derived from the Amaruq gold deposit. None of them present systematic vertical trends in chemical composition. In summary, mudboils show variations in the IM properties (mineral abundance, morphology, size and mineral chemistry) at different depths as well as laterally without clear patterns. The study suggests that cryoturbation processes do not generate a uniform fractionation of indicator minerals in mudboils.

A NEW MODEL FOR THE TECTONIC EVOLUTION OF THELON TECTONIC ZONE, CANADA, BASED ON PETROLOGICAL MODELING LINKED WITH Lu–Hf GARNET AND U–Pb ACCESSORY MINERAL GEOCHRONOLOGY

Robert Berman[1], Jamie Cutts[1], Bill Davis[1], Alfredo Camacho[2], Mary Sanborn-Barrie[1], Matthijs Smit[3]
[1]Geological Survey of Canada, [2]University of Manitoba, [3]University of British Columbia.
E-mail: *jamie.cutts@nrcan-rncan.gc.ca*

Forming the boundary between the Archean Slave and Rae cratons, the Thelon tectonic zone (Ttz) represents one of the oldest sutures in the Canadian Shield. Longstanding controversy regarding whether the Ttz formed in a convergent margin or an intracratonic setting has been resolved via a GEM-supported transect across the central Ttz, with whole-rock geochemistry and oxygen isotopes demonstrating a convergent margin setting for the voluminous, 2.01–1.98 Ga Ttz plutonism. Significant questions regarding the timing and regional extent of metamorphic events, and the polarity of subduction during Paleoproterozoic evolution of the Ttz have been addressed by applying quantitative petrological modeling and multi-method geochronology (Lu–Hf garnet, U–Pb monazite, zircon, titanite) to mid-amphibolite to granulite-facies metamorphic rocks spanning most of the Ttz. A Grt-Sp-Sil diatexite records 2.02–2.01 Ga garnet and monazite growth during > 830°C contact metamorphism associated with convergent margin plutonism. The most widespread, 1.96–1.90 Ga metamorphism is associated with clockwise *P-T* paths, indicating it was driven by crustal thickening. Earlier (1.96–1.92 Ga) and lower temperature (630–730°C; 6–8 kbar) metamorphism in the eastern Slave craton contrasts markedly with ~860°C (7.5 kbar), 1.91–1.90 Ga diatexites in the central, plutonic rock-dominated, core of the Ttz. These differences are interpreted to reflect lower versus upper plate settings, respectively. A contribution of mantle heat (crustal thinning, ridge subduction?) is suggested by a counter-clockwise *P-T* path and 885°C (5.7 kbar) recorded by diatexite associated with ca. 1.9 Ga peraluminous leucogranite emplaced along the Ttz-Rae craton boundary. We propose a tectonic model wherein the Ttz evolved at an accretionary margin after Ttz microcontinent (mTtz) rifted off the western Rae craton at 2.2–2.1 Ga. Plutonism at 2.01–1.98 Ga formed via east-dipping subduction under mTtz. Following 1.97 Ga collision of the Slave and mTtz, west-dipping subduction produced 1.96–1.95 Ga plutonism in the composite Slave-mTtz upper plate. Collision of Rae craton with the composite Slave-mTtz at 1.95–1.94 Ga resulted in crustal thickening, widespread 1.91–1.90 Ga high-grade metamorphism and extensive crustal melting in the central Ttz and main leucogranite belt.

FUGITIVE DUST MONITORING AND CHARACTERIZATION NEAR AN ACTIVE GOLD MINE

Eleanor J. Berryman[1], Amy Cleaver[1], Christine Martineau[1], Nicole Fenton[2], Carrie Rickwood[1], Philippa Huntsman[1]
[1]Natural Resources Canada, [2]Université du Québec en Abitibi-Témiscamingue.
E-mail: *eleanor.berryman@nrcan-rncan.gc.ca*

Dust originating from mining operations can carry a significant amount of contaminants to the surrounding environment and communities. There are technical challenges facing available dust-monitoring and analytical techniques, which have limited information on the spatial distribution, mineralogical make up, and composition of mine dust. This information is necessary for mines to identify deleterious dust sources, allocate dust mitigation efforts, and to inform studies on environmental impacts. CanmetMINING's dust monitoring program expands on a broader study to trace mine dust signatures and their impacts on the ecological environment surrounding mines. This study utilizes Passive Dry Deposition Collectors (Pas-DDs), a relatively new monitoring method being evaluated for its ability to capture mine dust and measure atmospheric trace metal deposition around mine sites. The Pas-DDs captured dust along transects surrounding an active gold mine in northern Quebec. Polyurethane foam filters were used as the sampling medium and were collected biyearly over a two-year period. Samples were subsequently analyzed for total dust mass, reactive element chemistry, and major, minor and accessory mineral phases. Various sample preparation and analytical techniques were evaluated in the determination of both elemental and mineralogical compositions to ensure results properly represented the captured dust. To date, the results have provided information on 1) the relative volume of dust emissions at different locations around the mine; 2) the mine's dust footprint; 3) the flux of environmentally significant elements (e.g. As, Cu, Ni) to the near-mine environment; and 4) the mineral carriers of elements and their relative abundance in the dust. In addition to improving our ability to monitor fugitive mine-dust emissions, studies of this nature inform our understanding of mine dust characteristics and their role in delivering elements of concern into the ecosystem.

BACK-ARC BASINS: A COMPARISON BETWEEN THE MODERN OCEAN AND PURPORTED EXAMPLES FROM VENUS AND THE ARCHEAN EARTH

Erin Bethell, Alan Baxter, Christopher Galley, Mark Hannington
University of Ottawa.
E-mail: *ebethel2@uottawa.ca*

Back-arc basins are zones of crustal extension located behind the arcs of subduction zones. The tensional forces responsible for back-arc extension are thought to result from slab rollback, wherein the steepening angle of a subducting slab causes the hinge to migrate towards the subducting plate. On present-day Earth, back-arc basins are commonly found at collisional boundaries between two oceanic plates and are the sites of significant hydrothermal activity and associated metallogenic provinces. Back-arc basins have been suggested as potential paleo-environments for volcanic assemblages within Archean greenstone belts. However, the purported existence and nature of subduction on Earth during the Archean is a contentious topic. Arguments against Archean subduction commonly point to the effects of the hotter Archean mantle on lithospheric rheology and buoyancy. Venus, which has a surface temperature of 460°C and a hotter lithosphere than present-day Earth, has been used as an analogue for early Earth tectonics. While there does not appear to be an active plate tectonic system on Venus, observational and experimental evidence for subduction has been proposed for several sites across the planet. A notable example is Artemis Corona, a tectono-volcanic structure with a diameter over 2000 km. Analogue modeling, in combination with geological observations made using radar imagery, topography, and gravity data, have led some workers to propose a formation model involving mantle plume-induced subduction. The topography of Artemis is characterized by an arcuate trench bounded by an interior rise and outer flexural bulge. Artemis is associated with significant volcanism, manifested as volcanic flow fields and numerous discrete volcanic centres. Analysis of topography and structural lineaments visible on radar imagery suggests that the interior contains several rifts connected by transform faults, not dissimilar to the microplate mosaics observed in modern back-arc basins such as the Lau basin. Artemis may therefore represent an example of back-arc basin style tectonics associated with plume-induced subduction. The recognition of back-arc tectonics on Venus, whose hot lithosphere may be analogous with Archean Earth, would support the interpretation of subduction tectonics and related crustal signatures in Archean greenstone belts. In this contribution, we compare the geology of the Lau basin, an example of a modern oceanic back-arc basin, with Artemis Corona on Venus and discuss the implications with respect to greenstone belts in the Superior Province of Canada.

REMOTE PREDICTIVE MAPPING OF GOSSANS IN THE MUSKOX FEEDER DYKE, NUNAVUT

Erin Bethell[1], Marie-Claude Williamson[2], Éloïse Brassard[3]
[1]University of Ottawa, [2]Geological Survey of Canada, [3]Université de Sherbrooke.
E-mail: *ebethel2@uottawa.ca*

Geological mapping in Canada's North often includes analysis of satellite imagery as part of remote predictive mapping (RPM) in advance of fieldwork. In large igneous provinces (LIP), it is possible to resolve smaller features of the local geology using imagery with sufficiently high spatial resolution (0.5–5 m) to reconstruct the magmatic history of the region. Gossans that form from weathering of sulphide and oxide minerals in the host bedrock can be detected in visible-near-infrared (VNIR) and short-wave infrared (SWIR) imagery. Most gossans form relatively small surface footprints but the distinctive yellow orange colours of the oxide cap make them easily recognizable on PRISMA and WorldView images, for example, depending on the size of the deposit. The Muskox Intrusion is a layered mafic-ultramafic intrusion located 90 km southeast of Kugluktuk, near the Coronation Gulf, that is part of the 1.27 Ga Mackenzie LIP. The intrusion was discovered by the Canadian Nickel Company in 1956 during an aerial reconnaissance survey that detected sulphide-rich gossans exposed along the footwall contacts. A recent study of the geomorphic attributes and spectral signatures of Baffin Island gossans completed in 2021 demonstrated the validity of using RPM to detect gossans on a regional scale. Here we use the same approach to investigate the gossans developed on a local scale along the Muskox feeder dyke in the Spider-Eider Lakes (SEL) area. The first step in our analysis is to delimit the bedrock exposures along the feeder dyke using Esri World Imagery and available geological maps. We then test several image processing methods to map gossans that were documented in the published literature, including those mapped in the SEL area at a scale of 1:10,000. WorldView-2 images (0.5 m/pixel) allow more accurate observations of the deposits at a spatial resolution 2.5 times better than provided by Esri World Imagery. Our goals are: (1) to determine the spectral features of the gossans on a local scale; (2) to subsequently extend the RPM approach to the entire feeder dyke area (400 km^2); and (3) to determine if this approach is applicable to gossans mapped in areas south of the Muskox Intrusion. The anticipated result is a first order classification of the SEL gossans based on geomorphic attributes and spectral signatures that is integrated with published geochemical data on both fertile and barren gossans. This approach provides a first order exploration tool in areas with high Ni-Cu-PGE potential, such as the Muskox Intrusion.

CHARACTERIZATION OF THE ORMAQUE DEPOSIT IN VAL-D'OR, QUEBEC

Shalaila Bhalla, Bruno Lafrance, Ross Sherlock, Kirk Ross
Laurentian University.
E-mail: *sbhalla@laurentian.ca*

The Ormaque deposit is a new orogenic gold discovery within the renowned Val-d'Or mining camp in the Archean Abitibi greenstone belt, Quebec. Ormaque is located 4 km north of the Larder Lake Cadillac Deformation Zone and is in close proximity to the historic Sigma-Lamaque mines, where the fault-valve model for orogenic gold deposits was first proposed. Ormaque differs from other deposits in the camp by its host lithology, the relative abundance of extensional veins and fault-fill veins, their orientation, and associated alteration. The deposit is hosted in a porphyritic diorite intrusion and consists of E-W flat-lying quartz-tourmaline-carbonate (QTC) extensional veins adjacent to both north- and south-dipping high-angle ductile reverse shear zones. The QTC veins are surrounded by 2 m wide alteration halos of tourmaline, calcite, ripidolite, phengite, pyrite ± chalcopyrite, and gold, which are overprinted by 50 cm wide alteration zones of albite, phengite, calcite, ripidolite, pyrite ± chalcopyrite, and gold. Two generations of chlorite are present: an early regional metamorphic clinochlore and brunsvigite composition and a late hydrothermal chlorite of ripidolite composition adjacent to the veins. In the tourmaline alteration zone, gold occurs as micro-inclusions within pyrite and as small gold grains in fractures associated with Ag and Bi tellurides. In the albite-phengite alteration zone, gold occupies fractures across albite grains. Two generations of pyrite are present within the tourmaline alteration halo: inclusion-rich Py-I in the core and inclusion-free Py-II in the rim. Py-I is enriched in Bi, Te, Se, Pb, Co, Ag, and Au both within inclusions and in its crystal lattice and is interpreted to have precipitated from a fluid rich in those metals. Py-II is depleted in those trace metals and is interpreted to have formed during the growth of a new pyrite around Py-I. The abundance of extensional veins and near absence of fault-fill veins suggest that the reverse shear zones were not reactivated as brittle faults during the restoration of differential stresses and fluid pressures across the shear zones due to intense chlorite alteration, which weakened the shear zones and prevented the build-up of high differential stresses. As fluid pressures became buffered by the formation of extensional veins, the shear zones slipped ductilely under the same low-differential stress conditions that resulted in the formation of extensional veins. The results of this study demonstrate the critical mechanical role played by the host rocks in the formation of extensional and fault-fill vein systems in the Val-d'Or camp.

MOBILIZING 'IMMOBILE' ELEMENTS: IMPLICATIONS FOR CRITICAL METAL TRANSPORT IN SALINE SYSTEMS IN THE CENTRAL AFRICAN COPPERBELT

Anna Bidgood[1], Murray Hitzman[1], Dave Chew[2], Helen Twigg[1], Richard Unitt[3]
[1]Irish Centre for Research in Applied Geoscience, [2]Trinity College Dublin, [3]University College Cork.
E-mail: *akbidgood@gmail.com*

Kyanite, the high-pressure Al_2SiO_5 polymorph, is traditionally considered a high-pressure, high-temperature mineral. Common kyanite-forming reactions such as pyrophyllite or chlorite dehydration take place at ~400°C and > 600°C, respectively. In this study, kyanite is observed within low temperature (sub-greenschist facies) carbonate and carbonaceous siliciclastic lithologies hosted in post-evaporitic breccia. Kyanite occurs within hydrothermal kyanite-quartz-magnesite-chalcopyrite-monazite veins, within fractures associated with quartz + pyrite, and as porphyroblasts in host rock lithologies. The occurrence of kyanite in low pressure-temperature rocks indicates unusual conditions of kyanite growth. Cathode luminescence, laser ablation mass spectrometry, raman spectroscopy, and U–Pb monazite dating are used in this study to unravel the complex vein paragenesis and characterize the multiple textural generations of kyanite. The Central African Copperbelt (CACB) is the world's primary source of copper and cobalt, producing about 70% of the metal which is critical for the production of batteries needed to help decarbonize our societies. Highly saline fluids are associated with extensive mineralization and alteration in the CACB. Intimate association of kyanite-bearing veins and Cu-sulphide mineralization indicates that the unusual thermodynamic conditions facilitated the mobility of traditionally immobile elements such as Al, Ti, and Ge, as well as mobilizing technology metals such as Cu, Co, and Ni. Understanding the paragenesis of kyanite in relation to Cu, Ni, and U mineralization at Menda, as well as the unusual thermodynamic conditions required for low-temperature kyanite growth and Al-mobilization, has implications for the exploration for technology metals in the CACB, as well as metal mobility in highly saline systems. Additionally, the interpretation of the vein kyanite-copper-bearing assemblages in the higher grade metamorphic Domes region of the Zambian Copperbelt is called into question.

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QUANTIFICATION OF QUARTZ, FELDSPAR, SILLIMANITE, AND CORUNDUM NUCLEATION DELAY IN A PERALUMINOUS GRANITIC MELT

Maude Bilodeau, Don R. Baker
McGill University.
E-mail: *maude.bilodeau@mail.mcgill.ca*

The most accepted model for the formation of pegmatites is that they crystallized from melts undercooled by hundreds of degrees Celsius, but much debate still surrounds their genesis. Having a better understanding of their formation could provide insight into the processes of magmatic crystallization and may help target potential deposits of critical metals found in some pegmatites. Peraluminous pegmatites are common in nature and are mainly composed of sodic plagioclase, K-feldspar, and quartz. It was therefore surprising when crystallization experiments performed on a peraluminous granite composition with aluminum saturation index (ASI) = 1.45 (Mt. Mica pegmatite composition from Maine, USA) produced aluminosilicates and corundum crystals. Crystallization experiments were performed in a piston cylinder apparatus at 630 MPa by first melting a glass powder (made from the rock) with 4.5 wt.% H_2O at 1100°C for 24 h then cooling below the liquidus to temperatures between 750 and 1000°C and holding the samples at those conditions for 0.3 to 211 hours. Experimental run products were investigated by SEM microscopy, with EDS analyses of crystalline and quenched liquid phases, and compared to a theoretical nucleation delay model based on classical nucleation theory equations, which show agreement within a factor of 3. These experiments produced corundum and an aluminosilicate mineral, which is thought to be sillimanite due to the range of pressures and temperatures at which the experiments were performed, and their presence is possibly due to reaction relationships between these minerals and the melt, as seen in the Na_2O-Al_2O_3-SiO_2 and K_2O-Al_2O_3-SiO_2 systems. The natural rock lacks these aluminum-rich minerals but peraluminous melts of lower ASI than our composition have, however, been known to produce stable aluminosilicates in nature. Experiments performed at the quartz and feldspar liquidus temperature and durations exceeding 115 hours also produced quartz and spherulites of sodic plagioclase. These results contrast with previous work in our lab on a metaluminous granitic composition with an ASI = 0.96 where quartz and plagioclase nucleated within 24 hours at similar undercoolings to those used here. The nucleation delays for peraluminous melts are therefore greater than for metaluminous melts, although the presence of twice as much K_2O in the metaluminous melt may also affect the nucleation delay. These results demonstrate that compositional differences in high-silica melts can have an important influence upon nucleation delay times which can have an important impact and these delays may substantially affect the magmatic evolution of pegmatitic melts.

WASTE MINING: INVESTIGATING THE ELEMENTAL COMPOSITION OF LATE CARBONIFEROUS COPROLITES FROM THE JOGGINS FORMATION

Nikole Bingham-Koslowski[1], Melissa Grey[2], Peir Pufahl[3], James Ehrman[2], Ashley Strauss[3]
[1]Geological Survey of Canada, [2]Mount Allison University, [3]Queen's University.
E-mail: *nikole.bingham-koslowski@nrcan-rncan.gc.ca*

Coprolites have the potential to offer unique insights into ancient ecosystems and the organisms that inhabited them. The Joggins Fossil Cliffs UNESCO World Heritage Site (Joggins, Nova Scotia, Canada) contains a plethora of Late Carboniferous (Pennsylvanian) terrestrial and aquatic fossils, the latter of which have been historically understudied, including abundant fish coprolites in the limestones of the Joggins Formation. Previous work on specimens from the Joggins Formation classified the coprolites into six morphotypes (conical, cylindrical, irregular, large, small, and spiral), and these morphotypes were then associated with four trophic levels. As the various morphotypes represent different trophic levels, and therefore potentially different diets, we hypothesize that the elemental composition of the coprolites should show a measurable change between morphotypes, and that this should be reflective of the dissimilar dietary requirements. Our geochemical investigations to date have employed scanning electron microscopy - energy dispersive X-ray spectroscopy (SEM-EDS) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to look for elemental discrepancies across the morphotypes with the aim of developing novel methodologies for paleontological research, and to provide additional information on the poorly understood Carboniferous aquatic realm at Joggins. SEM-EDS, conducted on 42 coprolites including representatives of each morphotype, detected the presence of three main compounds in some of the coprolites and the surrounding substrates: FeS_2, $BaSO_4$, and ZnS. Of these, FeS_2 and $BaSO_4$ were noted more frequently than ZnS, and the sulphates/sulphides are not mutually exclusive of one another. The sulphates/sulphides occur commonly (but not exclusively) near the boundaries of the coprolites, which could suggest a possible sulphur-based diagenetic crust. Furthermore, rare occurrences of zircon (substrate) and TiO_2 (substrate and coprolite) were identified in some samples during the analyses. An overall examination of the results has produced no obvious relationship between the presence of FeS_2, $BaSO_4$, and ZnS and morphotype/trophic level. From the 42 samples, 7 were selected to undergo LA-ICP-MS analysis to measure REE and Y concentrations. Each sample was ablated 15 times and 79 elements were tested for. The geochemical data underwent statistical reduction via stochiometric normalization and by normalizing the REE and Y measurements against Post-Archean Average Shale (PAAS). Preliminary interpretations suggest that certain samples registered significantly elevated concentrations of REEs and Y, which may be reflective of different diets, supporting our original hypothesis. However, due to the limited sample size, additional analyses are needed to verify these results.

A SEQUENCE STRATIGRAPHIC FRAMEWORK FOR THE OMBOMBO SUBGROUP IN NORTHWESTERN NAMIBIA

Ajani Bissick[1], Galen P. Halverson[1], Joshua H.F.L. Davies[2]
[1]McGill University, [2]Université du Québec à Montréal.
E-mail: *ajani.bissick@mail.mcgill.ca*

The ca. 775–745 Ma Ombombo Subgroup in the Kaokoveld region of northwestern Namibia was deposited during an early extensional phase in the development of a sedimentary basin on the southwestern margin of the Congo craton during the fragmentation of Rodinia. Deposition of this mixed clastic-carbonate unit was strongly influenced by episodic uplift of the inferred "Makalani Ridge", at the southern outcrop limit of the Ombombo Group. Though characterized by its classic shallowing upward carbonate cycles, recent work in northwestern Namibia has led to the suggestion that the Devede Formation, the thickest and middle of three formations in the Ombombo Subgroup, may have been deposited in two distinct environments: the typical shallow to peritidal environment seen in the southern part of the basin, and a deeper subtidal setting to the north. In an effort to clarify the early history of this basin, we have initiated a combined lithostratigraphic, chemostratigraphic, and geochronological study of the pre-Sturtian Devede Formation of the Otavi Group in northwestern Namibia. The sequence stratigraphic framework of the Devede Formation shows the waning and ultimate disappearance of the lower clastic unit towards the north, consistent with the hypothesis of a southern source. Carbon isotope data from stratigraphic sections measured from south to north in the Kaokoveld can generally be correlated with confidence, but the correlations break down in the northern-most studied sections. Here, we use detailed measured sections to develop a sequence stratigraphic framework for the Devede Formation and correlate the exposures across the Kaokoveld region, which serves as a template for constructing a composite carbonate $\delta^{13}C$ profile. These results may help to understand the regional tectonic context in which the Devede Formation was deposited. Moreover, as a series of tuff beds also occur in the upper Devede Formation—one of which has previously been dated—our results may also contribute to the calibration of the Neoproterozoic carbon isotope record.

CO_2 INTERACTION WITH FRACTURED ORGANIC-RICH SHALES: IMPLICATIONS FOR CO_2 STORAGE

Majid Bizhani[1], Omid H. Ardakani[1], Yihuai Zhang[2], Martin J. Blunt[3]
[1]Geological Survey of Canada, [2]University of Glasgow, [3]Imperial College London.
E-mail: *omid.haeriardakani@nrcan-rncan.gc.ca*

Depleted oil and gas reservoirs and saline aquifers are prime reservoirs for CO_2 storage; however, recent studies showed that unconventional resources such as organic-rich shales (e.g. Bakken, Marcellus, and Barnett shales) have significant CO_2 storage capacities ranging from 2 to 10 Gt. Shales, due to their abundance and adsorption capacity, can be a suitable CO_2 storage reservoir. As CO_2 in shales stores in an

adsorbed state, it significantly reduces the CO_2 leakage possibility. However, the major challenges for CO_2 sequestration in shales are injectivity and reactivity. While shale fracturing is required to overcome injectivity problem in shales, CO_2 reaction with shale at the fracture surface and effect on porosity remains controversial. Different shales with diverse mineralogical composition and organic matter content react differently with CO_2. In this study the reaction of organic-rich shale samples from the Early Mississippian Lower Bakken Formation, one of the major unconventional resources in North America, with CO_2 was investigated. The reaction of fractured shale samples with injected CO_2 and brine under high pressure and temperature conditions was the focus of this study. Non-destructive micron-resolution three-dimensional X-ray imaging was used to visualize the interaction under in situ conditions. X-ray diffraction and programmed pyrolysis were performed to better understand mineralogical and organic matter content and maturity of samples. Our results indicate that CO_2 reacts strongly with the host rock causing swelling of the matrix close to the fracture and manifesting in loss of permeability. High illite and total organic carbon (TOC) contents of the samples are likely to be the main contributors to the reactivity of the samples with CO_2. Fracture volume decreased nearly 61% after 36 hours of CO_2 injection. However, the overall resolvable pore size distribution was unchanged, indicating limited penetration of CO_2 into the matrix. For the second shale sample, we first injected a 1.5 wt.% NaI brine, followed by CO_2. The results show reactivity is significantly reduced in a water-saturated sample. The results of this study show that in clay-rich shales, interaction with CO_2 is likely to lead to matrix swelling and the closure of fractures with a loss of permeability, which is detrimental to storage in the shale itself; on the other hand, the shale could provide a good caprock for storage, where fractures close on contact with CO_2, preventing leakage.

USING AI TO ADVANCE VHMS EXPLORATION

Britt Bluemel, Michael Cain
ALS GoldSpot Discoveries.
E-mail: *britt@goldspot.ca*

Geodata science is an emerging field that combines the art of geoscience expertise with the (data)science of artificial intelligence and machine learning (ML). The mining industry is critical to successfully accelerating the Green Transition to a low-carbon economy and reversing climate change, and volcanic-hosted massive sulphide (VHMS) deposits are particularly important because they contain high concentrations of critical metals such as copper, zinc, silver, and cobalt, among others. The pace and volume of data acquisition is rapidly increasing in mineral exploration campaigns, at mining operations, and in near-mine environments. Conventional data processing methods must therefore become more sophisticated to efficiently manage this deluge of data, as well as efficiently synthesize and re-evaluate historic data. Machine learning workflows and machine-assisted modelling will become routine in the mining value chain; integrating traditional geoscience knowledge with data science expertise will be critical to successful management of data, algorithm deployment and most importantly the discovery of mineralized zones. The most important components of any successful mineral exploration campaign are a robust geological map and a realistic geological model that represent the synthesis of field observation and interpretation of fundamental datasets. Advances in cloud computing have allowed significant improvements in the field of geophysical data interpretation. Multi-component electromagnetic survey data can be challenging to interpret with laborious manual anomaly detection and the typically complex natural responses of known deposits; innovative ML tools, which use cloud computing processing power, allow rapid line-by-line peak detection and anomaly matching. Geophysical techniques are highly effective for locating buried massive sulphide deposits, therefore advances in processing and interpretation of geophysical data can contribute a step change in our exploration success for VHMS systems. This presentation will showcase various tools, techniques, and case studies where Artificial Intelligence, Data Science, and expert geoscientific approaches are combined to enhance our ability to explore for, and discover, VHMS deposits.

THE ROLE OF EDUCATION AND OUTREACH PROGRAMS FOR CHANGING THE NARRATIVE AROUND THE GEOSCIENCES IN CANADA

Katherine Boggs
Mount Royal University.
E-mail: *kboggs@mtroyal.ca*

As geoscientists, we know that our expertise is important for designing effective mitigation strategies critical for addressing the existential threat of climate change and the stressors created by increasing population. In Canada, two early earthquake warning systems are being developed for the west coast of British Columbia and southern Quebec/eastern Ontario; regions with the largest cities in Canada. The west coast is now within the 300–500 year cycle for the next mega-thrust earthquake. More GPS instrumentation is needed along coastal regions to monitor glacial isostatic adjustment to determine which communities will need to have infrastructure built to protect from rising sea levels due to melting glaciers. Critical minerals are desperately needed for reaching NetZero GHG by 2050, while some elements have significant socio-economic stressors such as Co, Nd and other REEs. Yet the number of undergraduate geoscience students in Canadian universities dropped by 42% from 2014 to 2021, and shows no signs of increasing, while the numbers of environmental sciences students remains constant. These dwindling numbers of geoscience students reflect the general public's impression and understanding of the geosciences, which are perceived as being poor cousins to physics, chemistry and biology (which for education students are teachables, whereas geology is not), and not really as viable careers. The decrease in undergraduate geoscience students is a concern for our professional accreditation body (Geoscientists Canada) because this is already impacting the geoscience workforce. Here, it is proposed that we geoscientists need to take control of the narrative about our discipline, perhaps framing our discipline as "Geoscientists - the stewards of our planet". Traditionally, Canadian geoscientists have not focused on effective communication strategies, however, education and outreach programs (EOP) are foundational for each of the five components of the proposed model, which requires a general shift towards giving EOP more funding and respect. The model includes: i) Professional Development - Bridges to Education and General Public (design conferences more purposefully to include non-geoscientists with specific EOP); ii) Engage Politicians and Policy-Makers (design EOP to welcome these non-geoscientists to conferences, talks and other events); iii) Strategic Plans (include EOP as integral components such as in the developing National Geoscience Research Plan), iv) Community and Outreach Programs (EOP in UNESCO Geoparks, World Geoheritage sites, museums, national-territorial-provincial parks to engage families and recruit the geoscientists of the future), and v) Post Secondary Programs (scientific theatre, summer geoscience camps, promote our "Rock Stars").

PETROGENESIS OF THE NEOARCHEAN BARLOW PLUTON (SUPERIOR PROVINCE, CANADA): AN INTRUSION BETWEEN TWO SUBPROVINCES

Esther Bou[1], Dominique Genna[1], Michel Jébrak[2], Jean-François Moyen[3], Lucie Mathieu[1]
[1]Université du Québec à Chicoutimi, [2]Université du Québec à Monréal,
[3]Université Jean-Monnet.
E-mail: *esther.bou1@uqac.ca*

In the southern part of the Superior Province, Canada, the contact between the Abitibi greenstone belt and the Opatica plutonic subprovince is underlined by the Barlow pluton. The petrogenesis of this intrusion located on a transcrustal structure has been little studied. The Barlow pluton was emplaced after the series of shortening events of the Kenoran orogeny. Its elongated shape in E-W trend and the magnetic signature tend to reveal a synform structure. The Barlow pluton displays the characteristic mineralogy and whole rock chemistry of tonalite-trondhjemite-diorite

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suites. This type of magmatism has been previously reported in the region, for example in the Chibougamau pluton. Rocks are composed of amphibole, clinopyroxene, biotite, plagioclase, rare K-feldspar and quartz. They are sodic (Na_2O/K_2O = 0.35) and have fractionated REE patterns ($(La/Yb)_N$ = 40). The magmatism of the Barlow pluton occurred over 5 to 10 million years according to new zircon dating. The deformed northern rim of the pluton points to a $^{207}Pb/^{206}Pb$ weighted mean age of 2703.9 ± 1.1 Ma which is slightly different from the previous age of 2696 ± 3 Ma on the easternmost part of the intrusion. Preliminary results of geobarometry on amphibole display a range of mean pressures between 246 to 496 MPa ± 72 MPa corresponding to the core and the northern rim of intrusion. We conclude that the Barlow pluton seems to use a transcrustal structure to ascend toward the upper crust in several pulses and accommodate the deformation. Future work will use mineral chemistry to constrain the fO_2 and volatile content of magma and will estimate its gold content to evaluate the role played by Neoarchean intrusions in the fertilizing of the gold- endowed Abitibi subprovince.

FORMATION OF PGE- AND SULPHIDE-BEARING CHROMITITES AND ASSOCIATED ANORTHOSITIC ROCKS IN LAYERED INTRUSION BY INFILTRATION OF REACTIVE, Cl-RICH FLUID

Alan Boudreau
Duke University.
E-mail: *boudreau@duke.edu*

Models for chromite + platinum-group element (PGE)-sulphide associations in layered intrusions range from conventional magmatic to those that envision a substantial role by high temperature fluids. A chromatographic interpretation was previously presented by Marsh and co-workers, who suggested that chromite can precipitate at a reaction front as a Cr-bearing (gabbro)norite protolith reacts with a Cl-rich aqueous fluid that became progressively undersaturated in pyroxene, leaving an anorthositic residue, as it moved into the hotter parts of the crystal pile. Chromium dissolved into the fluid re-precipitates as chromite at a moving reaction front between the anorthosite and the norite owing to liberation of Mg and Cr from pyroxene. The chromatographic model for chromitite formation by Marsh and co-workers has been updated to include sulphide as a possible participating phase. In the model, the liberation of Fe during the dissolutions of orthopyroxene can drive concurrent sulphide saturation. Chromium is dissolved largely as a divalent ion in the CrCl(OH)0 complex at expected temperatures and pressures, whereas chromite Cr is trivalent. Thus, precipitation of chromite would require an oxidation step in the precipitation reaction, which can involve S species. An example of the co-precipitation of pyrrhotite and chromite via redox reactions involving solution species including $FeCl_2$, SO_2, and H_2S: $6CrCl(OH)0 + 4FeCl_2 + SO_2 + 4H_2O = 14HCl + 3FeCr_2O_4 + FeS$. If the reaction front encounters an orthopyroxenite, the model produces a first-order approximation for the Merensky Reef stratigraphic sequence of anorthosite to chromite + sulphide to orthopyroxenite. In addition, MELTS modelling shows that the isothermal addition of Cr_2O_3 alone to a nearly solid (gabbro)norite assemblage increases the amount of both chromite and liquid at the expense of other silicate minerals owing to the liberation of Ca, Na, and Si, the latter two acting as additional fluxing agents. A constitutional zone refining model is presented in which the Critical Zone magma of the Bushveld Complex, initially saturated in orthopyroxene + plagioclase ± chromite, undergoes a progressive series of hydration melting and chromatographic segregations to produce the various orthopyroxenite, chromitite and anorthosite layers over time.

HOW OLD ARE DIAMONDS BENEATH PROTEROZOIC CRATONS? ANSWERS FROM THE STATE LINE KIMBERLITE DISTRICT, WESTERN LAURENTIA

Melissa Bowerman[1], Suzette Timmerman[2], Thomas Stachel[1], Graham Pearson[1]
[1]University of Alberta, [2]University of Bern.
E-mail: *bowerman@ualberta.ca*

The close association of diamonds and Archean crustal terranes has led to most scientific research and exploration being focused on these regions. One exception to this association is the diamondiferous State Line Kimberlite District of Colorado, situated in the Paleoproterozoic Yavapai province. The age of the mantle lithosphere beneath the Yavapai province and its tectonic history has been long debated. These issues bear on the broader problem of the nature of diamond formation in Proterozoic cratons and have important implications for understanding the diamond potential of these terranes. Here, using radiometric dating of silicate inclusions in diamond from the George Creek kimberlite, we show that diamonds formed in the Mesoproterozoic likely in response to a tectonothermal event and with the involvement of an Archean source component. A suite of inclusions in diamonds from the George Creek kimberlite yield a Sm–Nd isochron age of circa 1290 Ma, with 3 inclusions from a single diamond defining an identical isochron age. This diamond growth age is within error of extensive tectonothermal activity across southern Laurentia, including the 1.5–1.38 Ga Picuris Orogeny and widespread intrusions of granite at 1.4 Ga. The unradiogenic initial isotopic composition (ε_{Ndi} = –7.5) documents a contribution from an ancient, enriched component to the mantle protolith where these diamonds formed. These results confirm a phase of Mesoproterozoic diamond formation in the mantle lithosphere of the Yavapai province, likely from a mixed source containing recycled Archean crustal material and younger mantle. Together, these findings highlight the importance of Proterozoic diamond formation and provide a new paradigm for diamond exploration in Proterozoic crustal terranes.

TRACE ELEMENT GEOCHEMISTRY, QUANTITATIVE ANALYSES, AND ORIGINS OF SPODUMENE AND QUARTZ INTERGROWTH TEXTURAL GROUPS AT THE TANCO PEGMATITE, MANITOBA

Catriona Breasley[1], Lee Groat[1], Tania Martins[2], Robert Linnen[3], Desmond Moser[3], Emilie Landry[3], Aaryn Hutchins[4], Claude Deveau[4], Ivan Barker[3]
[1]University of British Columbia, [2]Manitoba Geological Survey, [3]Western University, [4]Tantalum Mining Corporation of Canada Ltd.
E-mail: *cbreasley@eoas.ubc.ca*

The Li-Cs-Ta (LCT) Tanco pegmatite in southeastern Manitoba represents one of the most economically important and fractionated pegmatitic bodies in the world. Tanco is one of Canada's two current lithium-producing mines; spodumene is the main targeted ore at the deposit and is typically found as spodumene and quartz intergrowths (SQUI). SQUI is typically thought to have formed via the breakdown of parental petalite. Evidence of variable spodumene to quartz ratios, iron-enriched spodumene in SQUI, and the notable lack of significant preserved petalite at Tanco all indicate that this hypothesis is not sufficient to explain all SQUI origins seen in the deposit. Thin section petrography, cathodoluminescence (CL), scanning electron microscopy (SEM), laser ablation inductively coupled mass spectrometry (LA-ICP-MS), X-ray computed tomography (micro-CT), and electron backscatter diffraction (EBSD) all provide complementary insights which aid in assessing the origins of SQUI at Tanco. Thin section petrography revealed five distinct textural groups of spodumene existing at Tanco: 1) classic SQUI (the most abundant textural variety in the deposit) as shown by elongated unidirectional texture; 2) micro SQUI with symplectic radial texture, replacing the classic SQUI; 3) equant SQUI, which forms larger, stubby, equant interlocking crystals; 4) primary platy spodumene that is not necessarily associated with quartz; and 5) spodumene that has been remobilized within the aplitic albite unit. CL imaging revealed a complex internal zonation not seen in backscatter imagery within the classic SQUI and chaotic internal zonation visualized in equant SQUI. CL also showed that micro SQUI represents a second generation of SQUI crystallization. LA-ICP-MS results show that the classic and micro-SQUI are geochemically similar, whereas equant SQUI has a highly variable trace-element composition. Additionally, LA-ICP-MS results show that the recrystallization of classic SQUI into micro SQUI involves Cs enrichment and Mn and Sn depletion. Micro-CT quantitative analyses revealed a highly variable spodumene to quartz ratio within all SQUI groups. EBSD results highlighted the strong crystallographic orientation of planar spodumene and quartz in classic SQUI and radial symplectic fans in micro SQUI. The origins of classic SQUI are still debatable, but this intergrowth could either represent a breakdown of primary petalite or simply a rapidly crystallized oriented growth completely unrelated to petalite. Based on the textural features observed and CL, EBSD, and LA-ICP-MS results, micro-SQUI is hypothesized to have formed via a post-crystallization reactive hydrothermal fluid. Equant SQUI is hypothesized to represent a primary eutectic phase of mineralization due to its geochemical variability.

CALIBRATING THE WISCONSIN: A REVISION OF THE CHRONOSTRATIGRAPHY OF THE SCARBOROUGH AND BOWMANVILLE BLUFFS

Michael E. Brookfield
University of Texas at Austin.
E-mail: *mbrookfi44@gmail.com*

The eastern Great Lakes late Quaternary chronology is based on thermoluminescence (TL) and uncalibrated radiocarbon dates from the extensive sections along the north shores of Lake Ontario. Though the relative stratigraphy of the various units, based on superposition and cross-cutting relationships is well established, chronostratigraphic assignments for < 55 ka are simply too young. Calibration of the radiocarbon dates with IntCal20 to 55 ka, gives consistent dates that become progressively older with time, and which now fit the TL and new optically stimulated luminescence (OSL) dates reported here. These calibrated events also fit the climatic fluctuations of the Greenland Ice Core Project (GRIP) plots. Along the north shore of Lake Ontario, the supposed Sangamon interglacial Don beds (~80 to 67 ka) can now be assigned to the warm interstadials of the early Wisconsin Oxygen Isotope Stages (OIS) 5a (as can the younger phase of the type Sangamon paleosol, OSL dated as 74 to 58 ka), and the underlying York Till to OIS 5b. The overlying Scarborough Formation delta (~60 to 50 ka), Sunnybrook diamicts (~50 to 40 ka), and Thorncliffe sands (~40 to 30 ka) with their incised channels and local tills can be assigned to the fluctuations of OIS 4 and 3. Further OSL and calibrated radiocarbon dating are needed to establish an accurate Quaternary stratigraphy for these classic large and extensive exposures.

THE ORDOVICIAN METEORITE EVENT IN NORTH AMERICA

Michael E. Brookfield
University of Texas at Austin.
E-mail: *mbrookfi44@gmail.com*

The Ordovician meteor event (OME) was a dramatic increase in the rate at which meteorites impacted the Earth during the Middle Ordovician at a hundred times greater rate than at present. This peak is marked by abundant fossil meteorites in Swedish basal Darriwillian Ordovician limestone (467.5 ± 0.28 Ma) and enhanced concentrations of ordinary chondritic chromite grains in contemporary sedimentary rocks. It slightly postdates the fragmentation of a 100–150 km-wide asteroid at 468 ± 0.3 Ma, in the biggest asteroid collision in the last 3 Ga, which showered the inner solar system with debris; one third of all meteorites hitting the Earth today come from this one source. This influx may have triggered the start of the Great Ordovician Biodiversification Event (GOBE) during the Darriwilian, when global marine species richness tripled, by seeding the surface of the oligotrophic oceans with inorganic nutrients. Although firmly established in Scandinavia, the OME was unrecognized in North America until recently. But many Ordovician impact craters occur, though no-one has found impact ejecta or meteorite fragments or investigated chondrite chromite distributions in sedimentary rocks (perhaps because they were not looking - now some people are). Many impact craters give inconsistent ages, due to post-impact hydrothermal and other effects. Dating their ejecta blankets, which are subject to rapid cooling and less hydrothermal alteration, using both biostratigraphic and isotopic methods, might be more promising, but the ejecta blanket deposits need to be identified.

SNOWBALL EARTH AND CAP CARBONATE DEPOSITS IN SOUTHEASTERN BRITISH COLUMBIA: WHERE ARE THEY?

Melinda M. Brugman
Monashee Mountains Institute.
E-mail: *brugmanm@telus.net*

In southeastern British Columbia, glacially derived diamictites from Neoproterozoic snowball Earth events have been mapped, but so far cap carbonate deposits from the subsequent hothouse Earth flip-flop events have not been identified despite their occurrence elsewhere around the world. This paper will review where snowball Earth deposits exist in southern British Columbia and what is currently known about them. The Association for Woman Geoscientists (AWG) visited several snowball Earth deposits and examined evidence for cap carbonate rocks in southeastern British Columbia during a 2022 geology field trip. The Monk Formation and conglomeratic Toby Formation of the Windermere Supergroup and underlying unconformity in the Selkirk and Purcell Mountain ranges, likely were derived from two Neoproterozoic snowball Earth events between about 720 to 635 Ma ago. The sand-sized "grit" described for the upper Windermere is interbedded with discontinuous carbonate- and conglomerate-containing units, which together may reflect progressive deglaciation caused by varying Earth orbital characteristics. The Windermere "grit" may have originated from increased erosion of barren unvegetated and freshly exposed deglaciated landscapes due to increased rainfall and storminess. Abundant angular to subrounded carbonate clasts are exposed in the upper Monk Formation conglomerate. However, carbonate clasts also exist in the lower Toby Conglomerate, suggesting erosion of an underlying carbonate layer during each snowball Earth event. Neoproterozoic deposits of the Windermere above the Monk Formation conglomerate may record the transition from a full snowball event. There are several overlying potential cap carbonate layers. So far, no cap carbonate deposits have been documented in southern British Columbia. Distinctive Precambrian deposits exposed in southeastern British Columbia—and around the world—track the sensitive interplay between Earth systems, with a methane-charged CO_2 greenhouse alternating with icehouse events. Each climate flip-flop was preceded by a Great Oxidation Event which further helped determine the evolution of life and the composition of our atmosphere.

FOREST CARBON SEQUESTRATION ALONG A MAFIC-ULTRAMAFIC LITHOSEQUENCE

Jerry Burgess
Johns Hopkins University.
E-mail: *jerry.burgess@jhu.edu*

Eastern deciduous forests represent an important proportion of the North American forest carbon (C) stores and geology can play a major role in forest productivity. Although the distribution of ecosystem productivity is largely related to variations in temperature and precipitation, the influence of bedrock lithology can be a dominant control on both above ground and below ground carbon storage. Geologic control is an often overlooked variable to identify the carbon sequestration rate of various ecosystems and their uncertainty, stability, and sustainability. This work explored coupled forest inventory data at a local scale, where ultramafic and mafic parent material are juxtaposed, from thirty random plots including measures of woody vegetation, edaphic factors, bedrock geochemistry, petrography, and outcrop fracture density to evaluate some of the community-structuring factors in an area where ultramafic and mafic bedrock are juxtaposed in the mid-Atlantic area. We investigated the coevolution of requisite biotic (vegetation dynamics) and abiotic (bedrock and soil properties) variables that occur over an environmental gradient in the Mid-Atlantic, USA where multifaceted drivers and mesophication are accompanying afforestation. Here the bedrock consists of a northeast trending group of undifferentiated serpentinite and other metamorphosed mafic-ultramafic bodies that may be an extension of the Baltimore Mafic Complex that were tectonically emplaced into the metasediments of the Wissahickon Formation. Forest carbon accumulation on mafic units was more similar to other eastern US forests than ultramafic parent material. The bedrock geochemistry as well as the fundamental bedrock structure (fracture density) functioned as a regulator of wood species productivity resulting in differential aboveground and belowground biomass and calculated carbon storage. These findings suggest that bedrock geology is an important factor to consider when evaluating ecosystem carbon pools at the regional level. When examining strategies for forest carbon sequestration, incorporating potential influences of lithology on forests into management plans may help in meeting carbon policy targets.

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DISTAL FLOW DEPOSITS: CHARACTERIZING LANDSCAPE MODIFICATION AND EXTENDED EJECTA ON MARS

James Burley, Livio Tornabene, Gordon Osinski
Western University.
E-mail: *jburley6@uwo.ca*

This work characterizes landscape modification associated with well-preserved impact craters on Mars that are often found well beyond the zone of proximal ejecta in the form of surface flow features [here defined as Distal Flow Deposits/DFDs]. Prior observations and interpretations of ejecta emplacement suggest that the vast majority of ejecta deposition, and extensive impact-induced landscape modification, occurs within the proximal ejecta range (~≤ 5 crater radii of source craters). However, recent high-resolution imaging reveals that within a region of continuous deposits surrounding well-preserved craters, beyond what is generally defined as the continuous ejecta blanket, there appears to be abundant localized flow features. Thus far, DFDs appear to occur beyond the range of the continuous ejecta and both respond to and modify target terrains which surround primary craters. First identified at Hale crater, distal flow features have since been described at a total of 4 craters, namely Noord, Resen, and an unnamed ~9 km crater in Noachis Terra (-29.405°N, 351.319°E). While radially extensive distal ejecta deposits have been reported around other craters based on radar and other datasets, these studies utilized image resolutions too coarse for comprehensive DFD characterization. Due to the ubiquitous nature of impact cratering as a planetary surface process, recognizing and constraining the extent of deposition and modification produced by impacts is necessary to ensure the accuracy of any geomorphological assessments made on cratered surfaces. Therefore, we have sought to expand the identification of DFDs for further characterization. This work uses visible/near-infrared (VNIR) from HiRISE, CaSSIS, and CTX, as well as thermal infrared images from THEMIS to characterize and determine the nature, extent and origin of these DFDs. We have expanded DFD identification and analysis to 4 new candidate craters (~3 km, 0.83º, 319.77º; ~11.5 km, –35.2º, 201.6º; ~12 km, 4.45º, 106.8º; ~19 km, 4.95º, 21.78º). In addition to morphologic characterization and detailed mapping of distal flows using visible and thermal infrared images, slope data derived via stereo photogrammetry helps determine modes of emplacement and the state/conditions of a substrate at the time of mobilization. DFDs consistently express one of two morphologies at all candidate sites observed to date; both types are consistent with outward [from candidate crater] mobilization of material as diffuse ground flows and are inconsistent morphometrically with gravity-dominated dry flow regimes (e.g. dust avalanches resultant form seismic shaking). The results of this work expand our understanding of impact processes and the evolution of surfaces on Mars.

ANALYTICAL CHALLENGES OF CRITICAL MINERAL EXPLORATION: REFERENCE MATERIALS AND THE DEMONSTRATION OF ACCURACY

Marcus Burnham, Evan Hastie
Ontario Geological Survey.
E-mail: *marcus.burnham@ontario.ca*

The research and exploration for Critical Minerals presents numerous analytical challenges, both for whole-rocks and constituent minerals. Most obviously, the suites and concentrations of many of the elements of interest are outside those of routine lithogeochemical analysis and many elements can be present in hard to dissolve phases, at concentrations beyond the proven solubility limits of preparation techniques, or in association with elevated concentrations of interfering components. Less considered, but potentially more important, is the difficulty in proving the accuracy of many Critical Mineral analyses owing to the paucity of inter-laboratory reference materials with assigned concentrations and/or matrices that match Critical Mineral exploration samples and the failure of many inter-laboratory proficiency tests to assign values for many trace Critical Minerals in either routine or mineralized samples. Whereas this issue is acute for analyses of elements such as Cs, Ga, Ge, Sc, and possibly Zr, for which there are no more than a handful of inter-laboratory reference materials whose concentrations or matrices approach those in mineral deposits, it could be considered critical for Te, for which the most enriched materials available (two CANMET Cu concentrates with 60–70 ppm Te) fall short of the > 100–200 ppm production levels in some deposits. To demonstrate accuracy during the analysis of Te at elevated levels in gold and/or base-metal mineralized samples collected as part of the Ontario Critical Minerals Strategy, a round-robin characterization was carried out using selected Te-rich Mineral Resource Branch (MRB) in-house quality control materials and an in-house quality control material prepared from newly collected Te-rich Au ore (MMTe-1). Because the matrices and Te contents of these materials represent those expected in a range of different deposits, they allow validation and/or quality control of methods to considerably higher concentrations (> 350 ppm Te) and in a variety of mineralization styles.

ENVIRONMENTAL AND MINERALOGICAL CONTROLS ON BIOSIGNATURE PRESERVATION IN MAGNESIUM CARBONATE SYSTEMS ANALOGOUS TO JEZERO CRATER, MARS

Teanna Burnie[1], Ian Power[1], Carlos Paulo[1], Hülya Alçiçek[2], Luisa Falcón[3], Yongjie Lin[4], Siobhan Wilson[5]
[1]Trent University, [2]Pamukkale University,
[3]Universidad Nacional Autónoma de Mexico, [4]University of Cambridge,
[5]University of Alberta.
E-mail: *ianpower@trentu.ca*

Jezero Crater on Mars is a paleolacustrine environment where Mg-carbonates may host evidence of ancient life. To elucidate the environmental and mineralogical controls on biosignature preservation, we examined samples from five terrestrial analogues: Lake Salda (Turkey), Lake Alchichica (Mexico), Qinghai-Tibetan Plateau (China), Mg-carbonate playas (British Columbia, Canada), and a mine with fine-grained ultramafic tailings (Yukon, Canada). Samples ranged from aragonite ($CaCO_3$) to hydromagnesite [$Mg_5(CO_3)4(OH)_2 \cdot 4H_2O$] dominated. Aragonite-rich samples from Alchichica, the Mg-carbonate playas, and the ultramafic mine contained an abundance of entombed microbial biomass, including organic structures resembling cells, whereas hydromagnesite-rich samples were devoid of microfossils. Aragonite often precipitates subaqueously where microbes thrive, thereby increasing the likelihood of biomass entombment, while hydrated Mg-carbonates typically form by evaporation in subaerial settings where biofilms are less prolific. Magnesite ($MgCO_3$), the most stable Mg-carbonate, forms extremely slowly, which may limit the capture of biosignatures. Hydrated Mg-carbonates are prone to transformation via coupled dissolution-precipitation reactions that may expose biosignatures to degradation. Although less abundant, aragonite is commonly found in Mg-carbonate environments and is a better medium for biosignature preservation due to its fast precipitation rates and relative stability, as well as its tendency to form subaqueously and to lithify to form rock. Consequently, we propose that aragonite be considered a valuable exploration target on Mars.

EXAMINING MICROSTRUCTURES ALONG THE MURRAY FAULT ZONE FROM BLIND RIVER-MASSEY, ONTARIO, CANADA: POSSIBLE IMPLICATIONS FOR REGIONAL DEFORMATION

Maxwell J. Cain[1], Evan C.G. Hastie[2], Alexander L. Peace[1]
[1]McMaster University, [2]Ontario Geological Survey.
E-mail: *cainm2@mcmaster.ca*

Despite the decades of research and mapping within the Southern Province of the Canadian Shield, the evolution of the Murray Fault Zone (MFZ) and its relationship with regional deformation and metamorphism remains elusive. Characterized as being steeply south-dipping and trending WNW near Sault St. Marie to ENE near Sudbury, the MFZ is a prominent structure in the Southern Province that has likely undergone a complex, polyphase evolution. Peak metamorphic conditions and primary reworking of major structures within the Southern Province have long been attributed to the 1890 to 1830 Ma Penokean Orogeny. However, evidence of large-scale deformation events both pre- and post-Penokean recorded in the Southern Province suggests a complex tectonometamorphic timeline in the region requiring further investigation. Additionally, it has been postulated that the influence of the Penokean Orogeny in the Southern Province has been overestimated. Particularly, there is a lack of definitive evidence linking the Penokean to activity along the MFZ. As such, it is important to reconsider how the MFZ has evolved through time to increase our understanding of the regional geology. Here, we systematically identify styles of deformation using data collected from outcrops along the MFZ and samples at multiple scales. Four roadside outcrops of the McKim Formation of the Huronian Supergroup were selected along Highway 17 between Blind River and Massey in Ontario, Canada. Kinematic indicators observed at the outcrops suggest both an oblique dip-slip event and a dextral strike-slip event. These findings are consistent with previous interpretations of the MFZ being a listric thrust fault which was then reactivated as a dextral strike slip fault. The maximum compressive stress directions obtained from observations across all samples suggest NW-SE, SW-NE, and W-E shortening. A bulk shortening direction of NW-SE is consistent with previous independent observations. The other observed compressive directions possibly provide new insights into deformation experienced along the MFZ. These results are important as they help to constrain our understanding of the deformational history of the MFZ. Further, understanding the deformation history in this region of the Canadian Shield may facilitate locating economically significant ore deposits as deformation episodes may provide both spatial and temporal constraints on key mineralization events.

STRUCTURAL EVOLUTION OF THE MAGINO GOLD MINE, WAWA SUBPROVINCE, ONTARIO: AN OVERPRINTED ARCHEAN INTRUSION-RELATED DEPOSIT

Ian Campos, Bruno Lafrance, Ross Sherlock
Laurentian University.
E-mail: *icampos@laurentian.ca*

The Magino gold mine is located approximately 40 km northeast of the town of Wawa, within the Michipicoten greenstone belt of the Archean Wawa subprovince. It is a past-producing underground mine being redeveloped as a large tonnage open pit gold deposit with proven and probable reserves of 2.4 Moz of gold at a grade of 1.15 g/t Au. Gold mineralization at Magino is primarily hosted in the Webb Lake stock, a steeply dipping ca. 2724 Ma tabular multi-phase tonalitic intrusion. The Magino deposit underwent three episodes of ductile deformation (regional D_2, D_3, and D_4) and two pre- to syn-tectonic auriferous alteration events (Au_1 and Au_2; respectively). N-S-directed shortening during the D_2 event produced a steeply dipping WSW-ENE-striking flattening regional cleavage (S_2) which overprints the deposit. The D_3 event resulted in localized dextral shear zones and reactivation of D_2 fabrics, whereas the D_4 event produced recumbent F_4 folds and associated axial planar, flat-lying crenulation cleavage (S_4). The Au_1 event comprises early intrusion-related, disseminated phengite/muscovite-quartz-pyrite alteration and associated sheeted to stockwork-style, molybdenite-bearing sugary quartz (SQ) veins (pre-regional D_2 event). The intrusion-related SQ veins are cross-cut by quartz-feldspar-phyric dykes, which are both transposed and boudinaged along S_2. The Au_2 event comprises N-S-trending orogenic quartz-carbonate-tourmaline (QTC) veins with albite-paragonite-ankerite-pyrite selvages (syn-regional D_2 event). The orogenic QTC veins cross-cut Au_1 veins and the S_2 foliation. QTC veins were emplaced syn- to late-D_2, and are deformed within D_2 high strain zones, D_3 dextral shear zones, and D_4 high strain zones. These structures are overprinted by metamorphic minerals, suggesting that alteration and mineralization formed prior to peak metamorphism. Late, sinistral E-side-up faulting along Matachewan(?) diabase dykes further modify and offset mineralization. Magino is an excellent example of a paragenetically complex Archean intrusion-related system which has been overprinted by deformation, orogenic-style mineralization, and metamorphism.

MULTIPLE PERIODS OF STRUCTURALLY CONTROLLED EXHUMATION IN THE NONACHO LAKE AREA OF THE SOUTHWESTERN RAE CRATON, NORTHWEST TERRITORIES

Rebecca Canam[1], Dan Gibson[2], Dawn Kellett[3], Edith Martel[1]
[1]Northwest Territories Geological Survey, [2]Simon Fraser University,
[3]Geological Survey of Canada.
E-mail: *rebecca_canam@gov.nt.ca*

The structural and thermal evolution of the southwestern margin of the Rae craton, exposed in the Nonacho Lake area of the southeastern Northwest Territories, is poorly understood due to a paucity of previous geological mapping and study. Detailed bedrock mapping, microstructural analysis, U–Pb zircon geochronology, U–Pb titanite and apatite petrochronology, and $^{40}Ar/^{39}Ar$ thermochronology were used to constrain the kinematics and timing of deformation of major structures in the Nonacho Lake area, as well as to document the exhumation history across the southwestern Rae craton. Field observations and microstructural analysis indicate two distinct groups of shear zones in the Nonacho Lake area: the "Western" group, comprising the King, Magrum and Noman shear zones, and the "Eastern" group, consisting of the Tejean, South Gray, and Gray Lake shear zones. The Western shear zones dip steeply to the northwest and display a sinistral sense of shear, whereas the Eastern shear zones dip steeply to the southeast and display dextral shear sense. The integration of microstructural and geochronological constraints highlights two major periods of deformation localized along the shear zones in the Nonacho Lake area. An early Paleoproterozoic episode at ca. 2290–2160 Ma is recorded in the King and Magrum shear zones and a late Paleoproterozoic ca. 1830–1790 Ma transtensional shearing event is recorded in all the shear zones analyzed in this study. $^{40}Ar/^{39}Ar$ thermochronological results indicate that cooling in the Nonacho Lake area was domainal but generally occurred from ca. 1890–1790 Ma, with the exception of a few domains that also record an earlier ca. 2400–2200 Ma cooling history. The temporal coincidence of shear zone movement and cooling across the southwestern Rae craton supports a model of structurally controlled cooling and exhumation. The two periods of structurally controlled exhumation are broadly coincident with the late- to post-Arrowsmith Orogeny and the late stages of the Trans-Hudson Orogeny.

GREENPEG'S EUROPEAN SPECTRAL LIBRARY: CONTRIBUTIONS TO PEGMATITE EXPLORATION

Joana Cardoso-Fernandes, Douglas Santos, Cátia Rodrigues de Almeida, Alexandre Lima, Ana C. Teodoro
University of Porto.
E-mail: *joana.fernandes@fc.up.pt*

To face the current global challenges, there is a need for new approaches to identify critical mineral commodities, essential for the energy transition, while reducing the impacts of exploration. Pegmatites can be exploited for strategic mineral commodities such as high-purity quartz to be used in optics, fibers, semiconductors, solar energy, and lithium for electric mobility/renewable energy storage. The spectral database was built in the frame of the GREENPEG project (https://www.greenpeg.eu/) which aims to develop multi-method exploration toolsets for the identification of European, buried, small-scale pegmatite ore deposits of the Nb-Y-F (NYF) and Li-Cs-Ta (LCT) chemical types. The GREENPEG project also aims to enhance European databases of petrophysical and reflectance properties, for example adding new data on the properties of pegmatites and their green raw materials, including their spectral signature obtained through reflectance spectroscopy studies. The spectral reflectance database presents several advantages and high added value when compared with the already available datasets: (i) it is the first database of this kind built at a European scale; (ii) it includes samples from distinct pegmatites with different mineralogy, structure, host-rocks, and genesis (anatectic and granite-related); and (iii) it is the first open database providing data on pegmatites of the NYF chemical type. Samples include LCT- and NYF-type pegmatites and host rocks from pegmatite locations in Austria, Ireland, Norway, Portugal, and Spain. The database contains the reflectance spectra (raw and with continuum removed), sample photographs, and main absorption features automatically extracted by a self-proposed Python routine. Whenever possible, spectral mineralogy was interpreted based on the continuum-removed spectra. The reflectance spectra stored in the database can therefore be utilized for satellite image processing such as image classification in the early stages of pegmatite exploration. Currently, the spectral library is being used for the processing of Worldview-3 images over the Tysford (Norway) case study. The reported spectral mineral assemblages can also be of interest when considering resource estimation or ore processing. Thus, it is expected that this open dataset, available on the Zenodo platform, (https://doi.org/10.5281/zenodo.6518319), will be a reference for distinct types of users ranging from academia to industry.

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UNRAVELING THE GEOLOGICAL HISTORY OF THE FENELON GOLD DEPOSIT, QUEBEC

Joy Carter, Daniel Gregory
University of Toronto.
E-mail: *joy.carter@mail.utoronto.ca*

The Abitibi Greenstone Belt is the most important gold-producing area in Canada and one of the most important globally. Until recently, the primary focus of exploration endeavors has been in the southern Abitibi due to abundant rock exposure at surface. Increasing effort is now being expended to explore the northern Abitibi, which has a high probability of containing undiscovered mineral wealth. The Fenelon Gold deposit, situated along the Sunday Lake Deformation Zone in the northern Abitibi, is the focus of this research project. This study utilizes a combination of geochronology, whole-rock geochemistry, and sulphide mineral chemistry to characterize and unravel the timing of the formation of the host rocks and the mineralization at the Fenelon Gold deposit. TIMS and LA-ICP-MS analyses of zircon were used to date the Jeremie Diorite and the surrounding sedimentary rocks which are the main hosts to the gold mineralization. A gold-bearing vein was age dated using Re–Os techniques. LA-ICP-MS analysis of pyrite from the mineralized zones established a relationship between sulphide and gold precipitation. These results were combined to propose a genetic model for the Fenelon Gold deposit. The results of this study enhance the geological understanding of the Fenelon Gold deposit and will significantly contribute to its resource expansion and exploration in the surrounding belt.

SULPHIDE REPLACEMENT BY OXIDES: MOBILIZATION OF Ni AT THE CRAWFORD DEPOSIT, NORTHERN ONTARIO

Nathan Carter, Pedro Jugo
Laurentian University.
E-mail: *ncarter1@laurentian.ca*

The Crawford deposit, located within the 2730–2724 Ma Deloro Assemblage of the Abitibi greenstone belt, contains nickel, cobalt, and PGE mineralization. The deposit is located 42 km north of Timmins. It is hosted by a partially serpentinized dunite-peridotite body that lacks surface exposure and was identified through geophysical surveys and drilling. The deposit is divided into two zones by a steep regional NNW-trending strike-slip sinistral fault. The main west zone trends west-northwest and is 1.9 km long and 280–580 m wide, whereas the east zone trends east-west and is 2.6 km long and 200–350 m wide, both extending to ca. 800 m depth. Both zones have complex sulphide, oxide, Ni-alloy, and PGM mineral assemblages. The study aims to understand the mineral assemblages' paragenesis and textural relationships determine the effect of the fault on alteration and metal distribution, and identify characteristics that can be used to advance exploration of similar deposits. Sixty-eight samples from five drill holes were collected, representing the deposit's main lithologies (fifty-three dunite, eight peridotite, two pyroxenite, four talc-ultramafic rocks, and one gabbro). The samples were selected based on the contrast between the most and least mineralized horizons per drill core. Petrography, SEM, and LA-ICP-MS are being used to study alteration, mineralogy, textures, mineral associations, and mineral chemistry. Preliminary results show that the dunite is composed of adcumulate olivine, with less than 5% pyroxenes and primary oxides, that have undergone serpentinization ranging from 30% to 100%. Samples near the fault are the most serpentinized, whereas samples distal to the fault have abundant primary olivine, with iddingsite alteration mostly around cracks, but are much less serpentinized. Preservation of sulphide assemblages is consistent with the degree of serpentinization and displays a progression from mostly primary sulphides to sulphides that are corroded and replaced by secondary magnetite near the fault, leaving isolated residual sulphide pockets within secondary magnetite as well as magnetite rims on primary oxides (chromite). Awaruite and native copper have been documented in the property during core logging, and the suite of samples collected has more awaruite than native copper, as rims of variable thickness replacing primary sulphides or as micrometre-scale disseminations in serpentine. Reconstruction of the desulphurization reactions and their proximity to the fault, degree of serpentinization, and grade distribution will help understand the mineralization's origin at Crawford and provide guidance for exploring similar deposits in the district.

COMMODITY OVERVIEW OF CRITICAL MINERALS IN VMS DEPOSITS

Tarryn K. Cawood, Jan M. Peter
Geological Survey of Canada.
E-mail: *cawood.tk@gmail.com*

Volcanogenic massive sulphide (VMS) deposits are primarily exploited for Cu, Pb, and Zn, along with Au and Ag in some cases. However, they are also potentially significant sources of the critical minerals (CMs) Bi, Co, Ga, Ge, In, Sb, Sn, and Te, and are known to host the CMs Mn, Mo, and Ni. These CMs, however, are rarely included in production data or resource estimates, and are typically only recovered during processing, by which time concentrates from multiple deposits across the globe may have been combined for smelting. There are thus few data available regarding the total resources of CMs hosted by VMS deposits, in Canada and elsewhere, or their distributions between and within districts and deposits. Estimating the total resources of CMs in VMS deposits will require new, bulk analytical data for numerous deposits, augmented by proxy estimates based on known resources and CM contents of host minerals. In addition, because many CMs were not traditionally targeted during mining, and their recovery was not prioritized during ore processing, significant quantities may be present in the mine waste of some deposits. Resource estimates for these tailings should, therefore, also be considered. Estimating what amount of these CMs are potentially economically extractable will require in-depth, representative deportment studies to understand their distribution and occurrence in various mineral hosts. For example, indium in VMS deposits may occur in sphalerite or chalcopyrite, whereas Co is hosted primarily by pyrite, with lesser amounts in pyrrhotite or sphalerite, or in rare Co-rich phases such as cobaltite. Within their host minerals, CMs may occur as lattice substitutions or micro- to nano-scale mineral inclusions, with implications for the processing required to extract them: metallurgical extraction using hydro- or pyrometallurgy for the former, or sufficiently fine milling for the latter. Furthermore, CMs from VMS deposits are typically produced as by-products, so their availability will be governed by demand for their associated main-product elements. For example, the supply of Ge is linked to the demand for Zn, because Ge is predominantly hosted by sphalerite, and only extracted as a by-product of sphalerite processing. Finally, targeted exploration for specific CMs will require knowledge of the controls on their district- to deposit-scale distributions. For example, existing data suggest that In may reach greater values in VMS deposits with a significant magmatic input, whereas Co is highest in deposits formed at high temperatures (> 300°C) and hosted by mafic to ultramafic lithologies.

BIOGEOCHEMICAL CHARACTERISTICS OF POLYACRYLAMIDE-TREATED THICKENED TAILINGS AT AN OIL SANDS MINE

Emily Champion[1], Matthew Lindsay[1], Anya Batycky[2], Ania Ulrich[2]
[1]University of Saskatchewan, [2]University of Alberta.
E-mail: *emily.champion1996@gmail.com*

Fluid tailings are a by-product of bitumen extraction at oil sands mines in northern Alberta, Canada. The slow settlement and dewatering behaviour of these clay-rich tailings has prompted development of various treatment technologies intended to accelerate dewatering and facilitate progressive reclamation, thereby curbing industry-wide growth of fluid tailings inventories. Although polyacrylamide (PAM) is commonly used to accelerate dewatering, little is known about the biogeochemical implications of this flocculant within treated tailings deposits. Previous studies have observed that organic carbon and nitrogen contributed by PAM stimulates microbial activity, which could thereby influence water chemistry and gas production. Our research integrates geochemical, isotopic, mineralogical, and microbiological techniques to examine biogeochemical implications of PAM addition within a commercial scale treated tailings deposit. We obtained samples of PAM-treated tailings from eight locations along two transects of this deposit. Within an anaerobic chamber, we extracted pore-water at ~0.3 m depth intervals over the ~5 m deposit and collected corresponding solids for analysis. We immediately measured various parameters (i.e. pH, Eh, EC, alkalinity, NH_3-N, NO_3-N, NO_2-N, and H_2S) and collected samples for elemental (i.e. PAM, inorganic anions, major elements, trace elements), gas (i.e. $CO_{2(aq)}$, $CH_{4(aq)}$), and isotopic (i.e. δ^2H-H_2O, δ^{18}O-H_2O, δ^{13}C-DOC, δ^{13}C-DIC, δ^{34}S-SO_4) analyses. Our results indicate that pore water within these treated tailings is generally consistent with fluid tailings deposits, which typically exhibit alkaline pH (i.e. 8–9) and slightly elevated concentrations of major elements (e.g. Na, Cl). Dissolved H_2S and CH_4 concentrations were generally low and PAM concentrations were consistently below method detection limits. Isotopic and geochemical analyses provide additional insight into carbon and nitrogen cycling within these treated tailings. Although δ^{13}C-DOC and δ^{13}C-DIC values suggest PAM contributes to porewater DOC, variations are generally within the range previously reported for the McMurray formation. While dissolved nitrogen species typically occur at low concentrations, the presence of measurable NO_2-N, NO_3-N, and NH_3-N may reflect complex nitrogen cycling. Our results offer new insight into biogeochemical processes in PAM-treated tailings deposits at oil sands mines in northern Alberta, Canada.

SEDIMENTARY MANGANESE DEPOSITS AS A RECORD OF LATE PALEOZOIC OCEANIC ANOXIA

Fangge Chen[1,2], Peir K. Pufahl[2], Edward J. Matheson[3], Qingfei Wang[1]
[1]China University of Geosciences, [2]Queen's University, [3]Cape Breton University.
E-mail: *fc27@queensu.ca*

Many marine Mn deposits are composed of rhodochrosite ($MnCO_3$) and kutnohorite ($CaMn[CO_3]_2$). These Mn carbonates are traditionally interpreted to form through the diagenetic reduction of depositional Mn-oxides. Such oxides are interpreted to reflect bottom water oxygenation, whether transient in restricted basins or due to a rising redoxcline in shelf environments. In this study, we propose that the enrichment of the relatively uncommon Mn calcite ($Ca_xMn_{1-x}CO_3$, x > 0.5) provides previously unrecognized insights into the origin of Mn deposits, particularly the redox conditions under which they form. Our results suggest that Mn carbonates accumulated under low oxygen levels, not the previously interpreted oxygenated conditions. As such, the relation of these Mn deposits to regional oceanic anoxic intervals merits renewed investigation, especially during periods of Mn carbonate deposition in well-oxygenated global oceans, such as the late Paleozoic. Late Devonian (~360 Ma), Early Carboniferous (~350 Ma), and Early Triassic (~250 Ma). Mn deposits in the South China Block were studied to address this. Ce anomalies combined with V, U, and Mo enrichments suggest that the Mn carbonates precipitated under suboxic to anoxic conditions. The Mn calcite encases dolomite rhombs (< 10 μm) or aggregates, indicating a heterogenous nucleation, supported by similar lattice parameters of both minerals with small lattice mismatch (< 2.1%). Dolomite nuclei show peaks near D and G bands (1350 and 1580 cm^{-1}), indicating an organogenic origin. This is consistent with δ^{13}C values (averaging –2.65 ‰) that are slightly lower than coeval seawater (~0 ‰), suggesting incorporation of ^{12}C during microbial respiration of sedimentary organic matter. The Mn carbonates generally accumulate on distal shelves and are interbedded with lime mudstone and heterozoan carbonates. This geochemical and sedimentologic evidence suggests coastal upwelling that delivered nutrient-rich and manganous deep-water to the shelves. The absence of Mn in shallow facies excludes terrestrial Mn. Instead, Eu/Eu* ratios (< 1.5) suggest long-range transport of hydrothermal Mn, during which hydrothermal signals were muted due to mixing with ambient seawater. The transport of hydrothermal Mn to shelves indicates that at least the regional deep oceans at the time must have been suboxic to anoxic, as Mn^{2+} would be easily oxidized and become insoluble under oxic conditions, preventing its long-distance transport. Hence, these Mn deposits record at least regional recurrent deep-ocean oxygen-depletion during the late Paleozoic and Early Triassic. The recognition that this periodic anoxia was broadly coeval with anoxia-related biotic crises suggests a potential relationship between the two, a possibility that merits further evaluation.

MESO-NEOPROTEROZOIC MAFIC MAGMATISM INDICATES TECTONIC TRANSITION FROM CONTINENTAL RIFTING TO SUBDUCTION IN THE SOUTHWESTERN YANGTZE BLOCK, SOUTH CHINA, DURING RODINIA ASSEMBLY

Fenglin Chen[1,2], Xiaozhuang Cui[3], Shoufa Lin[2], Jian Wang[4]
[1]Chengdu University of Technology, [2]University of Waterloo,
[3]China Geological Survey, [4]Southwest Petroleum University.
E-mail: *f28chen@gmail.com*

The late Mesoproterozoic to early Neoproterozoic (1.2–0.9 Ga) is a critical time for the global-scale assembly of the Rodinia supercontinent. To better understand the tectonic processes of South China with respect to the assembly of Rodinia, an integrated dataset of geochronology, whole-rock geochemistry and Sr-Nd-Hf isotopic compositions for late Mesoproterozoic to early Neoproterozoic mafic rocks in the southwestern Yangtze Block is herein presented. The mafic rocks consist of two groups. Group 1 gives zircon U–Pb ages between 1167 and 1138 Ma. They are tholeiitic basalts in composition, slightly enriched in LREE with $(La/Yb)_N$ ratios of 2.87–3.99, and show E-MORB-like trace element patterns with positive Nb-Ta anomalies. They exhibit positive zircon $\varepsilon_{Hf(t)}$ values from + 9.4 to + 13.7 and whole-rock $\varepsilon_{Nd(t)}$ values from + 3.4 to + 4.0. These results suggest that they may have undergone negligible crustal contamination during the magma evolution and were most likely generated from partial melting of a depleted asthenosphere mantle source. They have high Ti/V (38–46) and Zr/Y (3.36–5.23) ratios, typical of within-plate basalts. These results, as well as the existence of contemporary A-type granites and alkaline basalts in the same region, indicate that intense continental rifting most likely occurred in the southwestern Yangtze Block during the late Mesoproterozoic. Group 2 mafic rocks give zircon U–Pb ages between 946 and 918 Ma, and they possess Nb = 12.3–30.5 ppm, Nb/U = 19.99–37.06, Nb/La = 0.78–1.05, $(Nb/Th)_N$ = 0.44–0.80, and $(Nb/La)_N$ = 0.75–1.02, geochemically resembling those of typical Nb-enriched basalts. They are enriched in light rare earth elements (LREE) with weak negative Eu anomalies (Eu/Eu* = 0.75–0.96) and show E-MORB-like characteristics with slight to moderate Nb-Ta depletion. The samples show zircon $\varepsilon_{Hf(t)}$ values ranging from + 5.8 to + 10.3 and whole-rock $\varepsilon_{Nd(t)}$ values from + 0.5 to + 0.9. These elemental and isotopic characteristics suggest that the 0.95–0.92 Ga mafic rocks were derived from an E-MORB-like magma source with the injection of metasomatized slab melts, and likely originated from a back-arc basin. Integrating previous studies with our results, we propose that the southwestern Yangtze Block evolved from an intracontinental rift to a passive continental margin in the late Mesoproterozoic, followed by the development of an earliest Neoproterozoic continental arc-back-arc basin system analogous to the Northern Okinawa Trough. During 0.95–0.90 Ga, the northern and southern parts of the Yangtze Block may have been dominated by intra-oceanic and oceanic-continental subduction tectonics, respectively, followed by their final amalgamation that corresponded to the assembly of the Rodinia supercontinent.

DISTRIBUTION OF RADIATION-INDUCED DEFECTS IN QUARTZ AT THE ACKIO URANIUM PROJECT, ATHABASCA BASIN, SASKATCHEWAN: TRACING URANIUM-BEARING FLUIDS

Ka Long Cheung[1], James Sykes[2], Cameron MacKay[2], Yuanming Pan[1]
[1]University of Saskatchewan, [2]Baselde Energy Corporation.
E-mail: *mjv940@usask.ca*

The Athabasca Basin in northern Saskatchewan hosts the highest-grade uranium deposits in the world and is an excellent natural laboratory for studying radiation-

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induced defects in minerals. This contribution reports the results of an electron paramagnetic resonance (EPR) spectroscopic study of radiation-induced defects in quartz from the ACKIO uranium exploration project at the eastern edge of the Athabasca Basin. Detailed EPR analyses of quartz in both the Athabasca Group sandstones and basement rocks from 16 diamond drill holes reveal a suite of well-known silicon-vacancy hole centers, formed from the bombardment of alpha particles emitted from radioactive decay of uranium, thorium, and their unstable daughter isotopes. The intensity differences in the EPR signals of these silicon-vacancy hole centers indicate that quartz grains recorded different accumulative doses of alpha particles within the ACKIO project. A three-dimensional distribution model of the EPR signal intensities has been constructed. This model shows that the distribution of these silicon-vacancy hole centers is not uniform in sandstones close to the sandstone-basement unconformity but can be correlated with regional faults, defining and tracing the pathways for the migration of ancient uranium-bearing fluids. This study demonstrates the application of radiation-induced defects in quartz as a new vector for the exploration of uranium deposits.

WHAT CONTROLLED THE FORMATION AND LOCALIZATION OF WORLD-CLASS UNCONFORMITY-RELATED U ± REE MINERALIZATION IN THE ATHABASCA BASIN? - TOWARD A UNIFIED SOURCE-PATH-TRAP MODEL

Guoxiang Chi[1], Eric Potter[2], Morteza Rabiei[1], Yumeng Wang[1], Victoria Tschirhart[2], Jeremy Powell[2], Duane Petts[2]
[1]University of Regina, [2]Geological Survey of Canada.
E-mail: *guoxiang.chi@uregina.ca*

The Proterozoic Athabasca Basin hosts numerous world-class uranium deposits, many of which also contain high concentrations of rare earth elements (REE), with few (if any) counterparts that are comparable in terms of tonnage and grade. These deposits are mainly located near the basal unconformity of the basin and are referred to as unconformity-related uranium (URU) deposits, although some of the orebodies may be located as far as 1 km below the unconformity. Key questions related to the genesis of these deposits include: (1) Why is this basin so special in terms of U ± REE mineralization? Is it related to the fertility of the basin or the basement, or both? (2) What controlled the fluid flow and transport of metals? and (3) What controlled localization of orebodies with respect to the unconformity and along faults when major portions of the same faults are barren? Answers to these questions have direct implications for exploration and evaluating the U and REE potential of this basin. Studies conducted under the Targeted Geoscience Initiative have made significant progress towards these questions. First, discovery of U- and REE-rich fluid inclusions in quartz overgrowths in the sandstone indicates widespread development of U- and REE-rich basinal fluids. This suggests that most of the U and REE in the URU deposits were derived from the basin, although variable contributions from the basement cannot be discounted. According to this model, the Athabasca Basin is rich in U and REE mineralization because of a fertile basin rather than an especially fertile basement. Furthermore, it implies that the unconformity and upper part of the basement underneath the entire basin are prospective. Second, recognition of the hydrostatic fluid pressure regime, shallow-burial mineralization environment and fluid convection pattern recorded by regional distribution of quartz cementation and dissolution in the sandstone, further explain why the Athabasca Basin was especially favourable for developing U- and REE-rich diagenetic fluids. Thirdly, evidence of fluid boiling indicating episodic fluid pressure drops, together with spatial changes in graphite properties and implications for its role as the source of reducing agents at depth, supports coupled fault-valve (at depth) and suction-pump (near the unconformity) mechanisms as controls on the flow of both U ± REE-rich basinal fluids and reducing-agent-rich basement fluids. Economic mineralization occurred in certain segments of the faults where these fluids met and mixed for prolonged periods of time. Recognition of such fault segments requires joint efforts of geology, geochemistry, and geophysics.

PETROGRAPHY AND GEOCHEMISTRY OF DISCOVERY HILL IMPACT MELT POND, KAMESTASTIN (MISTASTIN) LAKE IMPACT STRUCTURE

Neeraja Chinchalkar, Gordon Osinski
Western University.
E-mail: *neerajac14@gmail.com*

Impact melt and endogenous igneous melt have similar physical and textural properties, making it difficult to differentiate between them. Additionally, impact melts have been proposed to be superheated with respect to their endogenic igneous counterparts, based on observations from natural and experimental studies. Recent evidence of superheated impact melt at Kamestastin (a.k.a. Mistastin) Lake impact structure highlighted the crater's importance as a site for understanding thermal evolution of impact melt. Mistastin offers the opportunity to study a variety of impactite units in situ through its well-exposed and relatively unaltered outcrops. Discovery Hill is an impact melt unit that is about 80 m in thickness, located in the terraced crater rim region, and interpreted as a melt pond that formed part of the impact ejecta. In this work, we sought to investigate the textural and geochemical variations in the Discovery Hill impact melt unit over a vertical section. In 2021, sample collection was carried out by G. Osinski by rappelling/abseiling over the west face of the hill. Petrographic analyses show that the clast content of the melt decreases upwards, with the base of the melt rock unit being clast-rich and the upper portion clast-poor but not clast-free. Near the base of the transect, the melt rocks have a glassy groundmass with spherulites in the early stages of development, indicating potential devitrification of the glass. Moving up from the base, the matrix transitions to hypocrystalline, i.e. glass and crystallites, and the degree of crystallinity as well as grain size increase upwards. Compositionally, the crystalline groundmass remains generally consistent throughout the unit, with the dominant component being plagioclase feldspar, and some anhedral pyroxene. A notable feature of the melt rocks is the diversity of plagioclase textures. Plagioclase occurs as angular subhedral to anhedral clasts throughout the melt rocks, and in the groundmass, it occurs in two distinct size fractions: as larger, blocky/tabular euhedral crystals of 80–100 μm along the longest dimension, and as smaller, elongated laths with sizes < 50 μm < 70 μm. We also obtained major oxide content of the plagioclase in the groundmass, and barring subtle differences, no significant trends could be identified in the composition. It is evident that the thermal evolution of the Discovery Hill melt is complex, and to better interpret the cooling history, we plan to implement a quantitative approach as a next step for characterizing the texture of this unit.

VOLATILE COMPOSITIONS OF FLUID INCLUSIONS FROM THE DISCOVERY-ORMSBY PROPERTY IN THE YELLOWKNIFE GREENSTONE BELT, NWT

Vivian Cho[1], Hendrik Falck[2], Merilie Reynolds[3], Pilar Lecumberri-Sanchez[1]
[1]University of Alberta, [2]Government of Northwest Territories,
[3]Northwest Territories Geological Survey.
E-mail: *vcho@ualberta.ca*

The Yellowknife Greenstone Belt (YGB) is host to several world class orogenic gold deposits that have collectively produced over 13 million ounces of gold since 1938. The mineralizing fluids in orogenic gold deposits are most commonly aqueous-carbonic fluids. However, several studies most notably from the Ashanti Belt in Ghana, have reported fluid compositions dominated by CO_2 with little to no aqueous component. Although the mineralization style within the YGB is highly variable, the presence of high-pressure volatiles in the belt has been identified as an indicator of gold mineralization. Similarly, the physicochemical properties of fluid inclusions may help differentiate between mineralized and barren samples. The Discovery-Ormsby property, which includes the former Discovery Mine, is in the northern portion of the YGB. Mineralization in this area is largely hosted within the metavolcanic rocks of the Discovery and Ormsby Members. Raman analyses of individual fluid inclusions reveal the presence of three main volatile components (CO_2, CH_4, N_2) which appear in various proportions. Graphite-bearing inclusions are also present in varying quantities; such inclusions have also been observed in other areas of the YGB such as the Quyta-Bell property where there is some evidence that graphite and gold precipitation were coeval. In this study, we evaluate the relationship between the composition of volatile-rich fluid inclusions, host rock lithology, and relative position with respect to mineralization and discuss the possible implications for gold precipitation.

GENESIS AND CURRENT UNDERSTANDING OF THE ca. 2697 Ma INTRUSION-RELATED WINDFALL AU DEPOSIT, URBAN-BARRY GREENSTONE BELT, QUÉBEC, CANADA

Brandon Choquette[1], Daniel J. Kontak[2], Édouard Côté-Lavoie[1]
[1]Osisko Mining Incorporated, [2]Laurentian University.
E-mail: *brandonchoquette1@gmail.com*

The Neoarchean Windfall Au deposit, hosted in the Urban-Barry greenstone belt of the Abitibi Subprovince (Québec, Canada), represents an emerging and significant Au deposit with a current resource of 7.4 Moz of Au. It is hosted in ca. 2717 Ma bimodal volcanic rocks that are cut by several generations of calc-alkaline quartz-feldspar porphyry (QFP) dykes separated into: (1) a 2697.6 ± 2.6 Ma group spatially related to Au mineralization; and (2) a 2697.6 ± 0.4 Ma group that truncates the earlier dykes and the Au mineralization. The Au mineralization, present as free gold inclusions in pyrite, and invisible Au in arsenian pyrite occurs (1) in grey quartz veins and stockworks with pyrite and subordinate carbonate and tourmaline and (2) in pervasive to patchy sericite-silica-pyrite-carbonate ± tourmaline ± fuchsite alteration zones. The Au zones are localized proximal to the contacts of the early QFP dykes and form thin, subvertical and elongate lenses plunging 35°ENE. The Au mineralization and associated hydrothermal alteration, along with all the host rocks, are overprinted by D_2-related deformational features that include the main regional penetrative foliation and the regional scale Mazères deformation zone. The spatial and temporal association of the QFP intrusions with the Au mineralizing event at the Windfall Au deposit, along with its elemental associations (Ag, As, Sb, S, Se, Bi, Te, ± Zn, Cu, Pb, Mo, and W) suggests an intrusion-related model. However, the deposit has been modified and remobilized by an overprinting syn-orogenic event which is attributed to the formation of bonanza high-grade Au zones (e.g. 90,700 g/t Au over 0.3 m), thus making Windfall a polyphase system. These interpretations have important implications both locally and regionally for Au exploration in Archean greenstone terranes.

STRUCTURAL ANALYSIS OF FLETCHER CREEK FOLD, SOUTHERN ONTARIO: IS IT NEOTECTONIC IN ORIGIN?

Abigail Clark, Alexander Peace, Ethan Davies
McMaster University.
E-mail: *clarka78@mcmaster.ca*

Neotectonism in an intraplate setting is generally not well documented and understood, despite its significance for seismic hazards in parts of Eastern Canada and elsewhere. This study aims to provide an in-depth structural analysis of a potential pop-up structure in southern Ontario to constrain the processes involved and extent to which neotectonism may have impacted the region. Fletcher Creek is a former quarry, now a small ecological preserve, located near Puslinch, Ontario, and the location of a small-scale, previously unexplained, dome-like structure. Local bedrock is comprised of the Guelph formation, an Ordovician and Early Silurian dolostone unit, that contains two distinct fracture patterns, perpendicular and concentric. Perpendicular fractures strike NNE-SSW and WNW-ESE, while the concentric fractures appear to be associated with the folding event. The dome-like structure itself is not easily discernable without measurements, as bedding dip is near horizontal only ranges from 0–15°, with the steepest dips being on the dome feature and shallowest dips being along flat bedrock around the preserve. Several analytical methods were used to constrain the structure of the dome at Fletcher Creek, and thus determine its origin including DJI Phantom 4 Pro drone surveys followed by photogrammetry in Pix4D and Drone2Map, ground-based structural measurements using FieldClino, fracture attribute quantification using FracPaq, and statistical and geomorphic analysis using ArcGIS Pro and MOVE including generation of rose diagrams, slope and aspect maps, and a topographic profile. Perpendicular fracture orientations correlate with lineament and fracture data previously collected in southern Ontario. Concentric fractures at Fletcher Creek crosscut the perpendicular fractures found at the site and across southern Ontario. We interpret the documented structure at Fletcher Creek as a stress release feature associated with rock removal at the site. The dome-like structure located at Fletcher Creek has comparable size and description to other well-documented pop-ups. To reach this conclusion, local stratigraphy was also considered extensively to rule out the possibility that the feature may represent a bioherm-type feature. However, we conclude this to be unlikely due to the lack of highly fossiliferous deposits in the region, as well as the documentation of concentric fracture sets. This study adds to a growing list of literature documenting neotectonic activity in southern Ontario, and a first-time documented stress-related structure at Fletcher Creek Ecological Preserve.

DETRITAL ZIRCON AGE DISTRIBUTION CORRELATIONS BETWEEN THE SNOWCAP ASSEMBLAGE SUBSTRATE OF THE YUKON–TANANA TERRANE AND PROTEROZOIC TO DEVONIAN STRATIGRAPHY OF THE LAURENTIAN MARGIN

Nathan Cleven[1], Jim Ryan[1], Dawn Kellett[1], Bill McClelland[2], Alex Zagorevski[1], Nancy Joyce[1], Jim Crowley[3], Andy Parsons[4]
[1]Geological Survey of Canada, [2]Iowa State University, [3]Boise State University, [4]Oxford University.
E-mail: *nathan.cleven@nrcan-rncan.gc.ca*

Reconstruction of the earliest tectonic history of allochthonous pericratonic terranes such as the Yukon–Tanana in the northern Canadian Cordillera is limited by the variably deformed, metamorphosed nature, and poor exposure of their basements or substrates. This study demonstrates that detrital zircon U–Pb geochronology techniques can provide inter-terrane stratigraphic correlations that help define the origins and nature of the earliest tectonostratigraphy. Detrital zircon data from 20 samples of Snowcap assemblage, the metasedimentary substrate within the Yukon–Tanana terrane, and its lithostratigraphic equivalents from twelve different regions are presented. Additionally, detrital zircon data from 9 samples of Devonian–Mississippian units, 7 samples of Mississippian-Permian units, and 3 samples of Parautochthonous Laurentian margin White River assemblage were included to evaluate late Paleozoic terrane evolution, sediment recycling, and mixing. Statistical comparisons, using multi-dimensional scaling techniques based on Kolmogorov-Smirnov similarity tests, were made between Snowcap Assemblage and compiled reference data of Proterozoic through Devonian Laurentian passive margin strata. The Snowcap assemblage detrital zircon age distributions show similarity to those of some Neoproterozoic units from British Columbia to Arctic Canada, except that Neoproterozoic units exhibit a wider variety of age components. Cambrian Laurentian margin strata age distributions from the Pacific Northwest region have qualitative similarities implying Snowcap assemblage may have deposited in a similar time or tectonic setting. However, Pacific Northwest region units lack one key age component, ca. 2000 Ma, found consistently in Snowcap assemblage. Ordovician Laurentian units are similar to Snowcap Assemblage but are homogeneous along the length of the margin. Devonian Laurentian units and parautochthonous units in northern BC, Yukon and Alaska show strong similarities to a subset of Snowcap assemblage samples; they have similar major and minor age components and are therefore a good possible stratigraphic correlation for a portion of Yukon–Tanana terrane. The key 2000 Ma age component is seen as a strong indicator of provenance from the Taltson magmatic zone in central Canada and is only found in Snowcap Assemblage and northern BC, Yukon, and Alaska Laurentian margin units. This implies that the Yukon–Tanana terrane substrate originated as a pericratonic fragment rifted from the Laurentian margin in the north, close to its estimated location of accretion in Permian–Triassic.

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PETROGENESIS OF SYN- TO POST-TIMISKAMING GRANITOIDS FROM THE KIRKLAND LAKE REGION: IMPLICATIONS FOR MAGMATIC-HYDROTHERMAL MINERALIZATION IN THE ABITIBI

Michael Cloutier[1], Bertrand Rottier[1], Ross Sherlock[2], Georges Beaudoin[1], Jonathan Sutton[2,3], Olivier Côté-Mantha[3]
[1]Université Laval, [2]Laurentian University, [3]Agnico Eagle Mines Ltd.
E-mail: *michael.cloutier.2@ulaval.ca*

Magmatic-hydrothermal deposits are scarce in Archean terranes compared to the Phanerozoic. It is uncertain if this scarcity is due to differences in geodynamics and/or physiochemical conditions. The Kirkland Lake–Larder Lake camp, located in the southern Abitibi subprovince in Ontario, Canada, is an ideal location to test these hypotheses as it is host to several distinct intrusive complexes with some of these complexes being related to known magmatic-hydrothermal mineralization (Au-Cu-Mo, Au-Te-Mo, Sb-Cu). The region is predominantly comprised of volcanic rocks of the ca. 2710–2704 Ma Tisdale assemblage and the ca. 2704–2695 Ma Blake River assemblage. These volcanic rocks are unconformably overlain by sedimentary and alkaline volcanic rocks of the ca. < 2679 – < 2669 Ma Timiskaming assemblage. All three supracrustal assemblages are cut by intrusive bodies that pre-date the regional D_3 deformation event (> ca. 2640 Ma). Whole rock geochemistry for these syn- to post-Timiskaming intrusions, filtered for alteration, reveal that the intrusions are intermediate to felsic (53–70% SiO_2) and calc-alkaline to alkaline in composition. Samples range in aluminum saturation from metaluminous to strongly peraluminous (A/CNK = 0.67–1.25). Trace element signatures of moderately to strongly fractionated REE patterns, small Eu anomalies, negative Dy/Yb vs SiO_2 trends, elevated Sr/Y, and enriched LILE with depleted Nb and Ta are consistent with melting of a hydrated source and fractionation being driven by amphibole. On a A/CNK, Na_2O/K_2O, FMSB ternary diagram, samples predominately plot in the "TTG-type" and "sanukitoid-type" fields with a single "biotite-type" signature suggesting that the syn- to post-Timiskaming intrusives were primarily sourced from metasomatized mantle and hydrated basaltic crust, and rarely from felsic crust (i.e. biotite-type). Intrusive complexes with predominant sanukitoid-type affinities are spatially associated with Au ± Mo-Cu-Te-Pb mineralization (Bidgood, and Morris deposits). The Upper Beaver intrusive complex, with a geochemical signature consistent with mixing between TTG- and sanukitoid-type magmas, is spatially and temporally associated with Au + Cu + Mo mineralization (Upper Beaver deposit). The biotite-type intrusion is spatially associated with Sb + Cu mineralization. This study presents new U–Pb, Lu–Hf and trace element data from zircon for these syn- to post-Timiskaming intrusives. These data place the development of these differing magma types and associated mineralization styles into the tectonic framework of the southern Abitibi subprovince.

LATE ORDOVICIAN MAGMATISM ALONG THE DAWSON FAULT CORRIDOR: EVIDENCE FOR REACTIVATION OF LITHOSPHERIC-SCALE STRUCTURES

Rose Cobbett[1], Luke Beranek[1], Stephen Piercey[1], Maurice Colpron[2]
[1]Memorial University of Newfoundland, [2]Yukon Geological Survey.
E-mail: *Rosie.Cobbett@yukon.ca*

Lower Paleozoic continental margin facies define a zig-zag pattern along the eastern parts of the North American Cordillera from Yukon to Nevada. Platformal carbonate and coeval basinal shale and siltstone are offset along proposed rift transfer faults, including the Liard Line, St. Mary-Moyie transform, and Snake River transfer. It is proposed here that the Dawson fault in central Yukon is a similar rift transfer fault because: (1) it coincides with an offset in continental margin facies; (2) there is a sharp contrast in geophysical properties across it; and (3) alkaline rocks are concentrated along the fault corridor. Zircon U–Pb dates from mafic volcanic rocks and gabbro, and macrofossil ages from interbedded sedimentary rocks, constrain the timing of magmatism along the Dawson fault to Miaolingian (Mid- to Late Cambrian) and Late Ordovician. Whole-rock trace element and Nd–Hf isotope geochemical data indicate that these rocks formed by low degree partial melting of subcontinental lithospheric mantle where garnet was stable in the residue (> 75 km). New bedrock mapping and facies analysis of mafic igneous rocks exposed north of the Dawson fault near Castle Mountain provide a detailed framework for geochronological, paleontological and petrological analysis and unravelling the early to mid-Paleozoic geological history of the northern Cordillera. The age of submarine eruptions near Castle Mountain is constrained by U–Pb zircon dates and fossils to the Late Ordovician (ca. 453–445 Ma). Magmatism was preceded by deposition of silty limestone and chert and followed by carbonate buildup and development of a carbonate platform. These facies occur within a bend in the Dawson fault where the trace shifts from an E-W trend to a NW-SE orientation. It is proposed that this bend developed during Late Ordovician strike-slip reactivation of the Dawson fault and local extension accommodated the deposition of deeper-water silty limestone and chert and emplacement mafic igneous rocks. Post-rift, Late Ordovician strike-slip reactivation of the Dawson fault coincides with counter-clockwise rotation of Laurentia indicated by paleomagnetic data. Late Ordovician continental rotation may be an important factor controlling post-rift extension and magmatism along western Laurentia.

ASSESSING REE-MINERALIZATION IN THE FEN ALKALINE-CARBONATITE COMPLEX (TELEMARK, SOUTHERN NORWAY) USING VNIR-SWIR HYPERSPECTRAL IMAGING

Nolwenn Coint, Tobias Kurz, Jasmin Schoenenberger, Ying Wang
Geological Survey of Norway.
E-mail: *nolwenn.coint@ngu.no*

The Fen alkaline-carbonatite complex, a 4–5 km^2 large intrusion emplaced around 580 Ma through the Sveconorwegian Precambrian basement, hosts one of the largest carbonatite-related rare earth element (REE) deposits in Europe. The Ce-dominated mineralization, associated with the Fe-dolomite carbonatite, consists of bastnäsite, parasite and subordinate monazite. In 2018, the Norwegian government funded the drilling of two cores down to a depth of 1000 m and 700 m respectively to assess the distribution of the mineralization. The cores were scanned using two hyperspectral cameras measuring within the spectral range between 400 and 2500 nm, often described as visible to near-infrared and short-wave infrared (VNIR-SWIR) and between 7700 and 12,300 nm, described as long-wave infrared (LWIR). One-metre sections of Fe-dolomite carbonatite and associated lithologies were analyzed for major and trace elements content, a total of 1522 analyses. This unique dataset allows us to assess the capability of hyperspectral imaging in identifying and semi-quantifying the amount of REE present in the cores. Rare Earth Elements, and Nd in particular, produce a series of distinctive, diagnostic absorption features, the most important ones occurring at 740 and 800 nm. While absorption features in the reflectance spectra indicate the presence of Nd, their depth is correlated to the abundance of the element. In this study, we processed the data to highlight the presence of the feature in the reflectance spectra for each pixel and constructed colour-coded maps of the core boxes highlighting the spatial distribution of REE-mineral as well as their relative abundance. Correlations between the amount of Ce, Nd or total REE in the cores and the depth of the absorption features at 740 and 800 nm were witnessed through scatterplots, and further confirmed by linear regression analysis. The depth of the 800 nm absorption feature shows the best correlation with REE concentrations compared to the 740 nm one, with Pearson's correlation coefficients of 0.67 for Nd and 0.7 for both Ce and total REE. Subdivision of the dataset based on the lithologies shows that the correlation best holds for the coarser-grained Fe-dolomite carbonatite (0.72) compared to fine-grained laminated Fe-dolomite carbonatite (0.57), revealing the importance of the image resolution, here 1 × 1 mm. This study confirms that hyperspectral imaging provides an objective, non-destructive method for core logging of complex rocks such as carbonatites. Maps generated can be used to guide core sampling campaigns, providing the prospecting industry with a powerful tool.

THE ROLE OF SILICATE-LIQUID IMMISCIBILITY IN THE PETROGENESIS OF Fe-Ti-P-RICH ROCKS AND NELSONITES ASSOCIATED WITH THE MONZONITIC TO SYENITIC RAFTSUND INTRUSION, VESTERÅLEN-LOFOTEN AMCG SUITE, NORTHERN NORWAY

Nolwenn Coint[1], Eduardo Mansur[1], Jakob K. Keiding[2]
[1]Geological Survey of Norway, [2]Geological Survey of Denmark.
E-mail: *nolwenn.coint@ngu.no*

The role of silicate-liquid immiscibility in the evolution of tholeiitic magmas remains partly controversial. The process has been documented in tholeiitic dry mafic systems, however the late entrance of the melt in the two liquid field and the limited ability of the Fe-rich melt to pond suggest that the process is non-efficient and plays a marginal role for the formation of large Fe-Ti-P deposits of magmatic origin. In addition, Fe-rich liquids produced experimentally in relevant conditions never contain less than 30 wt.% SiO_2, failing to explain the genesis of nelsonites, rocks nearly deprived of silicates. Some intrusive systems of intermediate to felsic composition, however, widen the possibilities for silicate-liquid immiscibility as an ore forming process for Fe-Ti-P deposits. Published work show that the monzonitic to syenitic Raftsund intrusion of the Lofoten-Vesteraalen AMCG (anorthosite-mangerite-charnockite-granite) suite shows evidence of extensive silicate-liquid immiscibility. Scattered occurrences of Fe-Ti-P-rich rocks occur throughout the intrusion. In some units, they reach up to 50 × 120 m large lenses, whereas in others they form cm-thick features at the contact with mingling monzonites. In addition, nelsonite locally occur as decametric-scale bodies. Fe-Ti-P-rich rocks consist of inverted pigeonite and/or Fe-rich olivine, augite, titanomagnetite, ilmenite and apatite, which is an assemblage crystallizing from a high temperature and dry magma. Evidence of liquid immiscibility in the Raftsund intrusion results from a combination of observations in the field where contacts between the Fe-Ti-P-rich rocks are sharp but undulating. In addition, Fe-rich mineral clusters show evidence of disequilibrium with the surrounding monzonite in the form of resorption features and development of symplectite at the contact between the two rock types. Furthermore, accessory minerals such as apatite and zircon, occurring locally in large abundance, are restricted to Fe-rich mineral clusters, features difficult to explain by simple fractionation or accumulation. Finally, whole-rock data show that Fe-Ti-P-rich rocks are enriched in both compatible (e.g. REE, Co, V, and Zn) and incompatible elements compared to their host monzonite or syenite. Trace element content of titanomagnetite and ilmenite in the Fe-Ti-P-rich rocks and the nelsonite record enrichments in elements behaving compatibly and incompatibly in an evolving magmatic system (e.g. Mg, Al, Sc, V, Mn, Zn, Zr, and Hf) compared to the same minerals in the monzonite and syenite, supporting the liquid immiscibility hypothesis. The transition from Fe-Ti-P-rich rock to a nelsonite remains, however, poorly constrained and needs further experimental investigation with appropriate composition for such systems.

THE PYRITE TO PYRRHOTITE DEVOLATILIZATION REACTION ACROSS METAMORPHIC ZONES FROM THE NEOARCHEAN PONTIAC SUBPROVINCE (SUPERIOR CRATON): IMPLICATIONS FOR OROGENIC GOLD FLUID GENERATION

Bruna Coldebella[1], Crystal LaFlamme[1], Isaac S. Malta[1], Carl Guilmette[1], Guillaume Barré[1], Georges Beaudoin[1], Laure Martin[2], Dany Savard[3]
[1]Université Laval, [2]University of Western Australia,
[3]Université du Québec à Chicoutimi.
E-mail: *bruna.coldebella.1@ulaval.ca*

It is well-known that sulphur is released to metamorphic fluids through the pyrite (FeS_2) - pyrrhotite ($Fe_{(1-x)}S$) devolatilization reaction along with aqueous fluids triggered by chlorite breakdown amid prograde metamorphism of sedimentary basins. Metamorphosed sedimentary basins become progressively depleted in Au, As, and other metals (e.g. Se, Te, Bi, and Sb) at higher metamorphic grades. However, it remains unclear what controls the increase and depletion of these elements at mineral scale and how it relates to fluid release. To further constrain this process and its relevance to orogenic gold fluids, we investigate in situ the metal redistribution and multiple sulphur isotope signatures through the pyrite-to-pyrrhotite transition along a Barrovian-like sequence within the Pontiac metasedimentary subprovince (Superior craton, Canada). Samples were selected across different metamorphic zones, with increasing grade from the biotite, garnet, staurolite, kyanite, to sillimanite zones. Pyrite occurs in the biotite, garnet, and staurolite zones in two generations: Py_1 early, fine-grained, disseminated or clustered sub- to anhedral grains; and Py_2 late, fine to coarse-grained, euhedral to subhedral cubes or clusters, often overgrowing Py_1. Only Py_2 is observed in samples from the kyanite and sillimanite zones. Pyrrhotite occurs as blocky, irregular-shaped or stretched grains parallel to foliation and throughout the matrix in samples from all metamorphic zones. Prograde pyrite to pyrrhotite reaction texture is identified in rocks from the biotite and garnet zones, where corroded Py_1 is replaced by pyrrhotite. Py_1 and pyrrhotite coexist in the staurolite zone without a clear textural relationship, while in the kyanite and sillimanite zones, Py_1 is completely absent, with pyrrhotite being the main sulphide. LA-ICP-MS analysis reveals a significant decrease in trace metals such as As, Ag, Te, Co, Bi, Se, and Cu, which is associated with the prograde replacement of Py_1 by pyrrhotite. In situ SIMS multiple sulphur isotope analysis shows small sulphur isotope fractionations between Py_1 and product pyrrhotite at all metamorphic zones ($\delta^{34}S$ shift = 1.5‰), but an important shift of about 0.46‰ on the $\Delta^{33}S$ signature. These fractionations can be associated with the desulphidation process of pyrite-to-pyrrhotite, which releases light H_2S, causing an increase in the $\delta^{34}S$ of reaction pyrrhotite. Thus, we suggest that the pyrite-to-pyrrhotite devolatilization reaction plays a critical role in mobilizing Au, As, and other metals into hydrothermal fluids and, if it is synchronous with the release of fluids and deformation, it can control metal endowment in the Earth's crust.

THE FORMATION OF STRATABOUND V-RICH MINERALIZATION AT THE ROD PROPERTY, YUKON TERRITORY

Daryll Bien Concepcion
University of Toronto.
E-mail: *daryll.bien@concepcions.us*

As the world's economies transition to become more environmentally friendly, critical minerals such as vanadium will see an increase in demand. To supply forecasted demand, we must start looking at unconventional deposits, like hyper-enriched black shales (HEBS). One such deposit is found in the Rod Property, located in the central Yukon Territory, Canada. Before utilizing these deposits though, we must first delve into how they were created. There are two competing models for their formation, the most popular of which is the "direct seawater precipitation" model. This model argues that it is through a combination of direct metal precipitation, high primary productivity, and Fe-Mn-oxyhydroxide shuttling that the HEBS are extremely V-rich. On the other hand, the other model argues for a hydrothermal fluid and/or hydrocarbon source of the V-enrichment. In this study, we used bulk rock geochemistry, laser ablation-ICP-MS, and sequential extraction analyses to show that the Rod Property is less likely to have been formed as a result of direct seawater precipitation.

GEODYNAMIC SETTING OF PROTEROZOIC MASSIF-TYPE ANORTHOSITES IN THE EASTERN CANADIAN SHIELD

David Corrigan
Independant Researcher.
E-mail: *david.corrigangeo@gmail.com*

Proterozoic-age massif-type anorthosites were historically considered to be a product of anorogenic magmatism. That said, a large number, globally, are now recognized as having formed in active tectonic settings. The eastern Canadian Shield hosts a large number of the world's known massif-type anorthosites (AMCG complexes), ranging in age from ca. 1650 Ma to 1018 Ma. They were emplaced in four distinct pulses, corresponding in time (but not exclusively in space) with accretionary and collisional phases of the southeastern margin of Laurentia. These include the ca. 1.7 to 1.6 Ga Labradorian orogeny (Mealy Mountains anorthosite), the ca. 1.5 to 1.35 Ga Pinwarian orogeny (Michikamau, Harp, Pentecôte, de la Blâche, and Nain AMCG suites), the ca. 1.18 to 1.12 Ga Shawinigan orogeny (Lac-St-Jean, Morin, Marcy, Magpie, and Parry Sound AMCG suites), and the ca. 1.08 to 1.00 Ga Ottawan and Rigolet phases of the Grenville orogeny (Rivière Romaine, Havre St-

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Pierre, and Labrieville AMCG suites). The earlier Labradorian and Pinwarian phases were contemporaneous with accretionary tectonics and continental margin arc magmatism and were accompanied by high- to ultrahigh-T and moderate P regional metamorphic conditions. The later Shawinigan and Ottawan/Rigolet phases of massif-type anorthosites coincided with collisional tectonics, in particular with regions of syn-collisional extension within the Grenville Province. Given that all four phases of massif-type anorthosite emplacement occurred in tectonic environments that are similar to those encountered in Phanerozoic orogens, it begs the question as to why they are nearly unique to the Proterozoic. One of the widely recognized and primary conditions necessary for the formation of massif-type anorthosites is the ponding of very large volumes of mantle-derived basaltic magma at the base of lower continental crust. We speculate that higher mantle temperatures, as well as greater abundance of fertile mantle during the Proterozoic (versus neo-Archean sub-continental mantle lithosphere) may have provided a unique set of conditions, from an Earth evolution perspective, for the formation of massif-type anorthosites.

BEYOND AN IOCG-CENTRIC CLASSIFICATION FOR METASOMATIC IRON-RICH ALKALI-CALCIC MINERAL SYSTEMS AND THEIR CRITICAL AND PRECIOUS METAL DEPOSITS

Louise Corriveau[1], Jean-François Montreuil[2]
[1]Geological Survey of Canada, [2]MacDonald Mines Exploration.
E-mail: *louise.Corriveau@canada.ca*

Metasomatic iron-rich alkali-calcic (MIAC) mineral systems can form giant mining districts and their iron oxide-copper-gold (IOCG) and affiliated critical and precious metal deposits have known mineral resources of Ag, Au, Bi, Co, Cu, Fe, Mo, Ni, P, Pb, REE, U, W, and Zn. At the regional-scale, MIAC systems form through successive fluid-rock reactions between a hot (peaking ~900°C), hypersaline fluid plume and the upper crust. Fluid ingress adds metals to the plume as it ascends toward surface along and across geological discontinuities (e.g. transcrustal faults) in addition to metals leached from the multiple and compositionally diverse geological units thoroughly metasomatized by the plume. As the plume evolves in physicochemical conditions, it precipitates distinct alteration facies that couple and decouple co-precipitating elements and metals leading to predictable series of mineralization types with a wide range of iron enrichment and iron-bearing mineral assemblages. Currently, mining of polymetallic iron-oxide deposits (e.g. IOCG and iron oxide-apatite deposits) prevails but MIAC systems also generate zones of iron-rich mineralization in which iron silicates, iron sulphides and iron carbonates are the primary repositories of iron and where iron oxides are sparce or absent. MIAC systems also incorporate iron-poor mineralization associated with alkali-calcic alteration facies and variable quartz and carbonates. The classification framework for deposit types in MIAC systems must move beyond an IOCG-centric approach. Based on the diagnostic association between alteration facies and mineralization types and integrating the variations in the mineralogical expression and the intensity of iron metasomatism, two groups of end-member deposits, metasomatic iron (MI) and metasomatic alkali-calcic (MAC), are defined. Deposits are intrinsically polymetallic. Using the metal anticipated to be of primary economic interest in a mineral resource, MI deposits are subdivided into MI-W, MI-Fe, MI-REE, MI-Ni, MI-Co, MI-Cu, MI-U, and MI-Au deposit classes. The class MI-Cu groups IOCG and iron sulphide-copper-gold deposit types. The class MI-Fe groups skarn-Fe, iron oxide and iron oxide-apatite deposit types. The classification system also unravels the grouping for lesser constrained deposit types like albitite-hosted U, Au, Co, Cu, and Mo-Re based on the primary metal in mineralization zones and the attributes of Fe metasomatism. This framework provides new insights on the prospectivity of Canadian MIAC systems with potential for critical and precious metal deposits from the Great Bear magmatic zone and East Arm Basin (NT), Labrador Trough (QC, NL), Central Mineral Belt (NL), Wanapitei district (ON), Appalachian Orogen (NL, NB, NS), and the Grenville Province (QC).

THE PIKWITONEI GRANULITE DOMAIN, MANITOBA: A LARGE-HOT OROGEN ALONG THE NORTHWESTERN MARGIN OF THE SUPERIOR CRATON

Chris Coueslan
Manitoba Geological Survey.
E-mail: *chris.coueslan@gov.mb.ca*

The Pikwitonei Granulite Domain (PGD) is a zone of Archean granulite-facies rocks located along the northwestern margin of the Superior craton in Manitoba, where consistently high-grade metamorphic rocks are exposed over an area of roughly 24,000 km^2. The PGD is bounded to the northwest by the Paleoproterozoic Trans-Hudson Orogen while its southeastern boundary is defined by an orthopyroxene-in isograd, which crosscuts the suture between the North Caribou and Hudson Bay terranes of the Superior craton. Metamorphic grade increases westward, away from the orthopyroxene-in isograd, and towards the Superior margin. The PGD has been described as a tilted section of crust or a discrete block of uplifted lower crust, and the origins of the high-grade metamorphism are interpreted as the result of magmatic heat advection, magmatic underplating, or asthenospheric upwelling related to lithospheric delamination or post-collisional slab break-off. Outcrops in the PGD typically display an early S_1 gneissosity that is crosscut by orthopyroxene-bearing leucosome related to peak metamorphism (M_2). The leucosome and gneissosity are transected by a regionally penetrative S_2 foliation, which is axial planar to parasitic isoclinal folds. Peak metamorphic conditions are interpreted to have reached 800–900°C and 7–8 kbar near the orthopyroxene-in isograd and attained UHT conditions of 1025–1070°C and 8–9.5 kbar closer to the Superior margin. Mineral textures and assemblages indicate clockwise P–T paths following peak metamorphism. Uranium-lead zircon ages of ca. 2720–2640 Ma and metamorphic monazite ages of ca. 2690–2570 Ma indicate a prolonged period of crustal heating. These ages are interpreted to represent either multiple heating-cooling events or a single, long-lived event. Uranium-lead dating of rutile suggests relatively slow cooling rates (< 2.2°C/Ma). Mafic dykes that transect the S_1 gneissosity, and are overprinted by M_2 peak metamorphism, are exceedingly rare, and the majority of "enderbite" intrusions in the PGD predate the high-grade metamorphism and are more properly described as metatonalite. It is therefore unlikely that magmatic heat advection, underplating, or asthenospheric upwelling were the driving forces of high-grade metamorphism in the PGD. The prolonged period of heating, clockwise P–T paths, and relatively slow cooling rates suggests the PGD represents the core zone of a large-hot orogen that formed during the assembly of Kenorland. The occurrence of the highest-grade rocks close to the Superior margin suggests that the original extent of the orogen was much greater and was rifted apart during the breakup of the supercontinent.

THE TIMING AND ORIGIN OF HEMATITE IN RED BEDS OF THE UPPER HURONIAN SUPERGROUP

Ian Coxon[1], Michael G. Babechuk[1], Robert H. Rainbird[2], Nabil Shawwa[3], Amy Parkinson[1]
[1]Memorial University of Newfoundland, [2]Natural Resources Canada, [3]Carleton University.
E-mail: *inacoxon@mun.ca*

The 2.45–2.22 Ga Huronian Supergroup (HSG) is a mainly clastic sedimentary succession that records the Great Oxidation Event (GOE), a global-scale shift that marked the first stable rise of oxygen in Earth's atmosphere. Evidence of the GOE in the HSG is represented by oxic, hematite-bearing paleosols and red beds, both of which indicate oxygenation in terrestrial environments reached levels sufficient for Fe^{2+} oxidation to Fe^{3+}. Within the upper HSG (Cobalt Group), the GOE is also temporally associated with a climatic transition from icehouse conditions, represented by glacial deposits of the lower Gowganda Formation, to post-glacial greenhouse conditions, in deltaic and fluvial strata of the upper Gowganda and Lorrain formations, respectively. While the appearance of red beds is widely agreed to be a geological reflection of the GOE, direct evidence for syn-, or early post-depositional oxidation is rarely fully documented. How the hematite in red beds more specifically reflects environmental oxidation is therefore not well understood, as is the case for most units of the HSG. Furthermore, K- and Na-metasomatic events in the HSG speak to post-depositional fluid alteration being another possible pathway for hematite formation. Establishing clarity in Fe-oxidation pathways is an important stepping-stone towards better understanding the origin of red beds and their potential for exploitation as geochemical archives of post-GOE terrestrial oxidation. This work investigates the paragenesis of hematite formation in the Lorrain Formation and to a lesser extent from the underlying Gowganda Formation via petrography and whole-rock major-element and ferrous/ferric iron measurements. Focus is on samples of siltstone and sandstone from the upper Gowganda and Lorrain formations of the Cobalt and Bruce Mines regions of Ontario, Canada, with variable reddening. Comparison to closely associated non-red beds (grey to green clastic sedimentary rocks) is also undertaken. Textural and mineralogical associations indicate that there are different paragenetic sequences of hematite formation, some unambiguously early (likely syn-depositional) and others more ambiguous. Whole-rock major-element data are used to further assess mineralogy, grain size, and other mineral-chemical features developed from source weathering to deposition. These data are explored in 3-dimensional (tetrahedral) space thereby expanding upon traditional alteration/weathering proxies to better reveal the effects of metasomatism and sedimentary sorting, and test for chemical evidence of an association of reddening with both physical and chemical sedimentary processes. Ultimately, this work builds on our general understanding of Precambrian red bed formation and more specifically the oldest well-documented terrestrial red beds hosted in the HSG.

AN INVESTIGATION INTO LABORATORY SCALE KINETIC TESTS: MICROBIOLOGY AND GEOCHEMISTRY AT 4°C AND 22°C

Kaitlyn Crawford[1], Gary Schudel[2], Benoît Plante[2], Joyce McBeth[1]
[1]University of Regina, [2]University du Québec en Abitibi-Témiscamingue.
E-mail*: joyce.mcbeth@uregina.ca*

Laboratory-scale kinetic tests are often used to predict the onset of acid mine drainage (AMD) or contaminated neutral drainage (CND) by evaluating the release rates of metals and ions from mine waste materials. This information guides costly decisions on mine waste management and water treatment. However, there are still gaps in our understanding and interpretation of scaling-up effects in kinetic tests. Humidity cell tests are repeated cycles of wetting and drying tailings samples to accelerate weathering processes and determine drainage characteristics over time. Due to the known role of microorganisms in AMD metal cycling and sulphur oxidation, the objective of the present study is to examine changes in drainage chemistry and the microbial communities present in the tailings, and their relationship to one another during humidity cell experiments. In previous studies, culture-based work has been done on humidity cell tests; however, culture-based work does not capture the full picture in terms of diversity and temporal changes in the microbial communities present. Thus, we are using high-throughput amplicon sequencing at timepoints throughout our study to gain further insight on microbial community changes during the tests. Eight humidity cells were constructed with four tailings samples from two sites. The humidity cells were operated for 42 weeks, with one set of four cells at 4°C and the other at room temperature (~22°C). Leachates were collected weekly and analyzed for pH, electrical conductivity, and metal and anion concentrations. Leachates were also filtered every four weeks to collect samples for microbiological analyses. Small solid samples (~3 g) were collected from each humidity cell every four weeks. X-ray absorption spectroscopy (XAS) was used to identify changes in the chemical species and oxidation states of iron and arsenic. High-throughput sequencing of the 16S rRNA gene was performed on DNA extracted from the solid samples and filtered leachates to monitor changes in microbial communities over time. Preliminary geochemical analyses suggest that the leachates differ in key ion loadings between 4°C and ambient lab temperatures. Understanding the impact of temperature and microbiology on these tests can help to improve our understanding of scale effects. The results of this study will help to guide practitioners in interpreting the results of humidity cell tests, with the overall goal of better informed mine site planning.

SIMULATIONS OF RADIONUCLIDE PRODUCTION IN ANCIENT HYPERSALINE BRINES

Bianca Currie[1], Christopher Charles[1,2], Roberta Flemming[1], Aurelia Laxdal[2]
[1]Western Univiersity, [2]TRIUMF.
E-mail: *bcurri2@uwo.ca*

The rare short-lived nuclides 236-uranium (half-life = 23 M.y.), 129-iodine (half-life = 15 M.y.), and 36-chlorine (half-life = 300 kyr) were recently detected by accelerator mass spectrometry (AMS) in the world's oldest water at Kidd Creek Mine (KCM) in Timmins, Ontario. This ancient water (ca. ~2 Ga) is an ultra-deep hypersaline brine located at the –8000-ft level in an isolated subsurface fracture network of KCM. The presence of extant ^{236}U, ^{129}I, and ^{36}Cl with half-lives much shorter than the age of the brine is unexpected and must arise from the natural spontaneous fission of U and Th in the system (anthropogenic contamination has not occurred). This project will use FLUKA, a well-known particle interactions code, to develop a numerical simulation that (A) reproduces the measured AMS ratios of ^{236}U/U, ^{129}I/I, and ^{36}Cl/Cl at KCM, and (B) provides a tool to predict the presence and concentrations of other short-lived isotopes that may be present in ancient geologically isolated waters due to low-energy nuclear processes. Our FLUKA model accurately incorporates the mineralogy and geochemistry of the surrounding KCM geology and brine, geometry of the subsurface fracture network, and other geochemical processes (i.e. water-rock interactions) in the system. Outcomes include an improved understanding of low-energy radioactive decay and sequestration in the deep subsurface, refinements to FLUKA for introducing spontaneous fission relevant to geological systems, and improved knowledge of possible energy sources for isolated life in deep subsurface waters in the Earth and other planetary bodies (i.e. Europa, Mars, etc.).

USING MAJOR AND TRACE ELEMENT GEOCHEMISTRY FOR DOMAIN DEFINITION IN GRADE CONTROL MODELS, DETOUR LAKE MINE, ONTARIO

Sarah Davey
Agnico Eagle Mines Limited.
E-mail: *sarah.davey@agnicoeagle.com*

The Detour Lake Mine is an orogenic hydrothermal lode gold deposit located at the northern extent of the Abitibi Greenstone Belt, Superior craton, Ontario, Canada. Gold mineralization at the Detour open pit formed in at least two stages including a sulphide-poor vein stockwork focused along the Sunday Lake Deformation Zone and a sulphide-rich overprint in hanging wall lithologies. Complexities in gold mineralization style combined with challenges related to gold estimation (e.g. multiple mineralization trends and orientations, complex deformation history, and lack of visual controls) provide motivation to characterize and define geological domains with geochemistry in order to enable grade control modelling that reflects the complex gold distribution patterns present. Using a database of more than 65,000 major and trace element geochemistry samples collected from reverse circulation delineation drilling and comparison to rock samples collected from drill core, I report a step-by-step approach to geochemical interpretation for identifying unique geochemical domains. This workflow requires characterization of rock types using unconventional binary plots. For example, due to the absence of SiO_2 data, metals such as Ni and Co are used to distinguish mafic and felsic rocks. Overall, the approach aims to distinguish key patterns and trends important for grade estimation and geometallurgy such as ultramafic talc-bearing units, hydrothermal alteration types and mineralization.

ASSEMBLY OF THE SUPERIOR PROVINCE: THE BEGINNING OF PLATE TECTONICS?

Donald Davis
University of Toronto.
E-mail: *dond@es.utoronto.ca*

Archean plate tectonics has been debated for over 50 years despite the accumulation of ever larger amounts of data. The Superior province is the largest and best studied Archean craton. It consists of a number of Paleo-Mesoarchean terrains in the north

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and a series of E-W trending plutonic and greenstone dominated terrains separated by metawacke dominated belts to the south. These terrains contain Mesoarchean and Neoarchean aged domains mostly deposited over a short time span. There is no evidence for a craton-wide ancient basement. Most volcanics in granite-greenstone terranes are calc-alkaline or tholeiitic, derived from juvenile mantle and erupted under submarine conditions, primarily over the period 2.75–2.70 Ga. Metawackes were mostly deposited after 2.70 Ga with a provenance consistent with adjacent greenstone belts. They may represent foreland basins whose source rocks were uplifted above sea-level along early thrust faults, overriding the basins, and resulting in a laminated crust. This is now exposed as subprovince belts due to large-scale folding. Volcanic and sedimentary sequences were intruded over the period 2.70–2.68 Ga during regional deformation by sanukitoid suite plutons, whose geochemistry suggests derivation from melting of metasomatized mantle followed by crustal assimilation. The simplest interpretation is an arc followed by an accretionary period that culminated in collision followed by slab breakoff. The upwelling of hot asthenosphere into metasomatized mantle led to extensional uplift, recorded in late Timiskaming-type sedimentation and alkaline volcanism, along with plutonism, deformation and gold mineralization. Continued strain from the collision imposed an E-W trending dextral transpressional fabric along major regional faults. The most definitive evidence for plate tectonic accretion is the presence of this structural feature over a 1000 km-scale. This is not seen elsewhere in earlier crustal blocks where deformation appears dominated by vertical processes such as diapirism. Diapirism also operated in the Superior province, but it produces deformation at the scale of crustal thickness. To explain a consistent structural pattern over a plate scale requires plate tectonics almost by definition. It is probably not possible to decide the question of plate tectonics without studying regions at a scale approaching that of tectonic plates and many older cratons are too small. The Superior event may represent the earliest evidence for large-scale accretionary/collisional processes resulting from subduction.

SUBDUCTION-RELATED DIAMOND SUBSTRATES ALONG THE SW MARGIN OF THE SÃO FRANCISCO CRATON, BRAZIL

Luísa de Carvalho[1], Thomas Stachel[1], Graham Pearson[1], Suzette Timmerman[2], Richard Stern[1], Tiago Jalowitzki[3], Ricardo Scholz[4], Reinhardt Fuck[3]
[1]University of Alberta, [2]University of Bern, [3]University of Brasília, [4]Federal University of Ouro Preto.
E-mail: *luisa.carvalho@ualberta.ca*

The nature of the lithospheric mantle underpinning the Southwestern São Francisco Craton, in Brazil, is poorly constrained due to cover rocks obscuring the basement. Limited chemical depletion recorded in the dominant population of lherzolitic inclusions in diamonds indicates a likely post-Archean age for the lithospheric mantle beneath this part of the craton. The influence of subduction-related processes on the origin of diamonds in this area has been inferred from the presence and characteristics of eclogitic and websteritic diamonds. Here, carbon, nitrogen and oxygen stable isotope data are used to further constrain the link between subduction processes and diamond formation in the southwestern margin of the São Francisco Craton. The $\delta^{13}C$ compositions of diamonds cover a large range from –25.5 to +0.5‰. The ^{13}C-depleted and enriched portions of the distribution are clearly dominated by diamonds of known eclogitic/websteritic and lherzolitic paragenesis, respectively. Measured $\delta^{15}N$ values range from –14.2 to +20.9‰, with about 50% of the values being positive. While positive and negative $\delta^{15}N$ values occur equally near the $\delta^{13}C$ mantle value, $\delta^{13}C$-depleted diamonds have $\delta^{15}N$ skewed towards positive values. The $\delta^{18}O$ compositions of eclogitic garnet inclusions fall in a restricted range of values from +5.5‰ to +7.0‰. A negative coupling of $\delta^{18}O$ and $\delta^{13}C$ signatures of inclusions-host diamonds is observed. The stable isotope characteristics of diamonds in our study overlap the main modes observed for diamonds worldwide, but many deviate from typical mantle values. Globally, occurrences that contain a distinct tail to $\delta^{13}C$-depleted compositions are all in post-Archean geological settings associated either with subduction along craton margins or with thermally perturbed settings. The observation of coupled $\delta^{13}C$ depletion and $\delta^{15}N$ enrichment in diamonds provides clear evidence for the involvement of subducted organic material. The presence of both ^{13}C-depleted and -enriched compositions can be explained by carbon derived from reservoirs hosted in the upper sections of altered oceanic crust. Such reservoirs are paired with nitrogen incorporated during formation of low temperature (< 100°C) clays, which is characterized by positive $\delta^{15}N$ values. Low-T alteration also causes ^{18}O-enriched inclusion compositions. The minor presence of diamonds with depleted $\delta^{15}N$ likely indicates an additional contribution of deeper portions of oceanic crust, where high temperature clays may acquire low $\delta^{15}N$ values. In conclusion, we invoke a geochemical system that involves a mantle component and additional distinct reservoirs hosted in altered oceanic crust to explain the isotopic diversity of diamonds from the southwestern São Francisco Craton.

COMMUNICATING SPACE WEATHER IN CANADA: AURORA CHASERS, SOLAR CARTOONS, AND SPACE PHYSICS

Shona V.Z. de Jong
Queens University.
E-mail: *shona.dejong@queensu.ca*

Because of rapid terrestrial climate change, few humans are thinking about space weather and its potential impacts on the built environment. Yet, both terrestrial climate and space weather are affected by small changes as the Sun undergoes its 11-year solar cycle. Space weather is another phrase for "storms from the sun". The sun emits bursts of radiation - and high-speed protons and electrons - as solar flares, geomagnetic storms, solar radiation storms and coronal mass ejections. If a large burst is directed at the Earth, these storms have the potential to interfere with satellite operations, electrical power grids, airlines and much more. To illustrate, on the 13 March 1989, a spectacular northern lights/geomagnetic storm caused an electrical power blackout for the entire province of Quebec. This presentation provides a brief overview of space weather as a global natural hazard issue. Three case studies are offered to illustrate the role of university researchers - especially earth scientists - in addressing the associated risks. Space weather hazard risk communication examples are provided from: (a) local sky knowledge; (b) solar cartoons; and (c) solar and space physics. The space weather event impact patterns on electric power grids, communication technologies, satellite navigation and transportation systems underscore the need for interdisciplinary analysis. This study recommends interdisciplinary research teams to support space hazard risk science in policy dialogue and debate.

EARTHQUAKE EARLY WARNING EDUCATION (E3) PRACTICES, PROCESSES, AND PRIORITIES

Shona V.Z. de Jong[1,2], Glenn Dolphin[2]
[1]Queens University, [2]University of Calgary.
E-mail: *shona.dejong@queensu.ca*

Results of the Earthquake Early Warning Education (E3) Pan Canadian bilingual survey will be shared with generalists working with the Canadian alerting system. Nation-wide action is being encouraged to advance seismic science education. The point is to raise awareness of the importance of geoscience in crisis communication. In 2022, the E3 Project surveyed all Canadians to get a picture of seismic science - society interface. The University of Calgary (U of C) Conjoint Faculties Research Ethics Board approved this study (REB22-0966) and participation was confidential and voluntary. The entire Canadian population was randomly invited to complete the E3 survey: E3 Survey, Phase I - November 2022–January 2023; E3 Survey, Phase II - currently live. The U of C has not yet received results of the E3 Survey, Phase II. Results of the E3 survey (Phase I) have been analyzed and organized by the following themes: (a) Overall seismic science knowledge; and (b) Awareness and use of online seismic science information and services. Meaningful differences in responses among Canadian sub-groups - including Canadians who identify as ethnically diverse, Canadians who identify as LGBTQ2S+, Canadians with disabilities and new immigrant Canadians - are noted. We learned that expressing knowledge of earthquake intensity and earthquake magnitude was challenging for many Canadians. The survey data are being used to help: (a) Identify the most common misunderstanding of seismic science; (b) Improve a culture of seismic science in all aspects of the Canadian resilience to earthquake risk; and (c) Collaborators provide input into further actions the U of C E3 can take to promote E3 nationally and internationally.

EARTHQUAKE EARLY WARNING EDUCATION (E3) PARTNERSHIPS: A KNOWLEDGE TO ACTION INITIATIVE

Shona V.Z. de Jong[1,2], Yu-Yen Pan[3], Marie-Hélène Graveline[4], Glenn Dolphin[2]
[1]Queens University, [2]University of Calgary, [3]Simon Fraser University, [4]Université du Québec à Montréal.
E-mail: *shona.dejong@queensu.ca*

Partnerships with Earth Science for Society, the Canadian Federation of Earth Sciences and others have been critical for reaching the target audience of the Pan Canadian bilingual E3 Survey. Research partners also circulated our 2022 article entitled "A new earthquake warning system will prepare Canada for dangerous shaking" and its key message: "About 10 million people live in Canada's earthquake-prone zones. Yet few have practical knowledge of what to do with new early warning system alerts which aim to save lives and protect livelihoods". These partnerships also provide the structure for the distribution of the E3 survey final report to the Council of Chairs of Canadian Earth Science Departments and others. The primary aim of this presentation is to outline how our partners have helped us to research on three questions of national interest: (1) How do Canadians build their earthquake literacy? (2) What information is required to build Canadians' E3 geoliteracy levels? (3) How can Canada support E3 in disaster risk management activities and programs (and close the E3 Knowledge to Action gap)? We showcase how the Knowledge to Action framework analysis of E3 survey results reveals multiple aspects of E3 delivery that need to change. With evidence-based recommendations, new and existing partners can identify resource needs and pinpoint future interventions. Overall, we conclude that investment in future E3 products - via digital delivery - may revolutionize E3 geoliteracy levels and close the E3 Knowledge to Action gap.

THEY DO EXIST! A FIRST LOOK AT VOLCANIC ROCKS OF THE TALTSON ARC PRESERVED WITHIN THE WAUGH LAKE GROUP, SOUTHERN TALTSON OROGEN

Jordan Deane[1], Kathryn Bethune[1], Ken Ashton[2], Nicholas Montenegro[1]
[1]University of Regina, [2]Saskatchewan Geological Survey.
E-mail: *crashdeane@hotmail.com*

Arc-related volcanic rocks are rarely preserved within Paleoproterozoic orogens; instead, we commonly just see their deeper-level (intrusive) equivalents. The Waugh Lake group (WLg), a 2.02–1.97 Ga greenschist-facies supracrustal succession, is potentially one such rare occurrence. This group was previously interpreted as the remnant of an intra-arc basin, or alternatively a back-arc, that formed on the SW margin of the Rae craton during the 2.0–1.93 Ga Taltson orogeny. It is preserved in a small synformal outlier, bordering the Taltson magmatic zone spanning the Alberta-Saskatchewan border. Its lower sequence comprises a spatially extensive turbiditic package with locally observed younging reversals, unconformably overlain by a thin unit of strongly foliated polymictic conglomerate with flattened clasts of impure quartzite, granitoid rocks, rhyolite, and basalt in a schistose matrix. These are in turn overlain by the upper sequence, comprising two cycles of variably sheared pebbly arkosic subarenite units each overlain by units of intermediate-felsic volcanic-volcaniclastic rocks with discernible primary textures such as phenocrysts and lapilli. The two paired siliciclastic-volcanic cycles are separated by a distinctively green unit of mafic-intermediate tuff interbedded with lithic wacke. At the top of the upper sequence is a unit of mafic-intermediate volcanic rocks with local autoclastic breccia. All WLg units are intruded by a suite of ca. 1.97 Ga Taltson granitoid rocks and folded along NNE-trending axes. Preliminary geochemical analyses of upper sequence volcanic rocks indicate calc-alkaline affinity with compositions ranging from basalt to dacite. All units have strongly fractionated REE (La/Yb_N = 12.6–26.2) with a minimally to moderately negative Eu anomaly (Eu/Eu^* = 0.62–0.90) and more strongly fractionated LREE (La/Sm_N = 3.5–5.0) relative to HREE (Gd/Yb_N = 1.5–3.2). Furthermore, when normalized to N-MORB, all units exhibit high Th relative to Nb, Ti, Y, and Yb, and when plotted on tectonic discrimination diagrams, all are diagnostic of an arc environment. Based on the strongly arc-like geochemical character of volcanic rocks, the earlier interpretation of an intra-arc basin is preferred for upper WLg. Further, the basal unit of the upper sequence, marked by pebbly arkosic rocks, indicates a sharp change in depositional environment (i.e. increase in continentally-derived detritus) from lower sequence turbidites, and points to a continental arc setting. This, together with the early phase of folding in the lower sequence and variable, locally intense, strain in the upper sequence suggests contrasting tectonic histories, and a potential age gap. This will be tested with future geochronological and isotopic study.

THE UPPER CONTACT UNIT (ROOF ROCKS) OF THE SUDBURY IGNEOUS COMPLEX, NORTH RANGE, SUDBURY IMPACT STRUCTURE

Lindsay Debono, Gordon Osinski, Richard Grieve
Western University.
E-mail: *lindsaydebono@gmail.com*

The Sudbury Igneous Complex (SIC) represents the remnant of a crystalline impact melt sheet of the Sudbury impact structure. In addition to being the best example on Earth of a differentiated impact melt sheet, the SIC is historically, and presently, a strategic exploration target sustaining the region's prolific mining activities. In order to better understand the SIC, it is critical to investigate the chilled upper contact of the SIC - the Upper Contact Unit (UCU), which has historically received little attention. This unit has been previously erroneously referred to as the "Onaping Intrusion" and various other terms and considered part of the overlying Onaping Formation. Through field observations, whole-rock geochemistry, petrography, and electron microprobe analysis, we conclude that the UCU is extensive across the North Range of the SIC. Additionally, the geochemistry of the SIC units, offset dykes, and Upper Contact Unit of the SIC presented here demonstrates that the UCU roof rocks represent a more accurate proxy than the offset dykes for the initial composition of the SIC. Finally, this study indicates that the UCU lithology should no longer be considered an intrusive melt of the basal Onaping Formation breccias.

THE INCORPORATION OF GEOPHYSICAL, PETROPHYSICAL, AND GEOLOGICAL CONSTRAINTS IN GRAVITY MODELING TO RESOLVE STRUCTURES AT DEPTH

Fabiano Della-Justina, Richard Smith
Laurentian University.
E-mail: *fjustina@laurentian.ca*

Gravity modeling is an important tool for interpreting and understanding geological structures in the subsurface. In forward modeling or inverse modeling, the main goal is to modify a geophysical/geological model to accomplish an acceptable level of reproducibility of the model data with the observed data. However, due to the non-uniqueness of potential-field data, more than one model might fit the observed data. In order to reduce the number of acceptable models, constraints are commonly incorporated into the model. There are countless studies available in the literature demonstrating the necessity of constraining gravity and magnetic models. However, typically they do not demonstrate the individual enhancements that come as a consequence of integrating each constraint into the geophysical model. This study demonstrates how the model, either inverse or forward, is improved as new constraints are built into the modeling workflow. The constraints include information from a density compilation, high-resolution seismic sections, geological maps as well as geological interpretations. The mapped surface geology and the density of this surface data were important to explain the gravity variations associated with faults and to estimate the dip and the error in this dip estimation. The high-resolution seismic sections were helpful to identify reflective features that were most likely lithological contacts where there could be changes in density. Incorporating some of these deeper features and the gradual changes in depth evident in the seismic data resulted in changes in the thickness of the near-surface rocks that were more consistent along strike. Information from previous studies in the area, such as geological interpretations of seismic sections, were required to ensure the geological feasibility of gravity models.

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VOLCANIC AND TECTONIC SETTINGS OF VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS IN THE SLAVE CRATON

Michelle DeWolfe[1], Bernadette Knox[2]
[1]Mount Royal University, [2]Northwest Territories Geological Survey.
E-mail: *mdewolfe@mtroyal.ca*

Volcanogenic massive sulphide (VMS) deposits are an important source for base and precious metals globally. Though Phanerozoic rocks contain 72% of the world's VMS tonnage, the Archean Eon (8% of the world's VMS tonnage) was a prolific time interval for the formation of VMS deposits and the deposits formed during this time tend to have higher metal endowment. The Slave craton is composed of rock assemblages that span the period in Earth's history from ca. 4.05 to 2.55 Ga and has an area of ~300,000 km^2, covering much of the Northwest Territories and part of Nunavut, Canada. Yet, despite the known prospectivity of Neoarchean volcanic belts for VMS deposits (e.g. Superior craton contains 80% of the Archean VMS tonnage), those of the Slave craton remain understudied. The Sunrise VMS deposit is a banded, polymetallic Zn-Pb-Cu-Ag sulphide lens hosted by felsic volcanic rocks of the Neoarchean Beaulieu River volcanic belt in the western Slave craton in the Sunset Lake area of the Northwest Territories, Canada. With historic indicated resources of 1.52 Mt at 5.99% Zn, 2.39% Pb, 0.08% Cu, 262 g/t Ag, and 0.67 g/t Au it is the largest known VMS deposit in the Northwest Territories, and as such has the potential to add to our understanding of the complexity of Archean VMS deposits and their host terranes. Detailed lithofacies and geochemical analyses of the rocks that host the Sunrise deposit document subaqueous, bi-modal, effusive (highlighted by FIII lobe-hyaloclastite flows) to pyroclastic volcanism and concomitant subsidence. Volcanic stratigraphy and architecture, a contemporaneous mafic dyke swarm within the underlying Sleepy Dragon Complex, and the occurrence of a VMS deposit, combined with major and trace element geochemistry and Nd, Hf, and Pb isotopic data, indicate the volcanic rocks and the Sunrise deposit formed on rifted Mesoarchean crust. We interpret rocks of the Sunrise deposit area to have been erupted and deposited in a continental back arc basin because the volcanic lithofacies and geochemistry are consistent with those observed in modern arc or rifted arc settings. Our observations from the Beaulieu River volcanic belt, and the Sunrise deposit, challenge a previous idea that VMS deposits of the western Slave craton, which are underlain by older basement rocks and characterized by evolved Pb isotope values, are less well-endowed than those of the eastern Slave craton (e.g. Hackett River), which are characterized by younger basement and more juvenile Pb isotope ratios.

THE ROLE OF MAGMATIC VERSUS METASOMATIC PROCESSES IN Ta-Nb MINERALIZATION AT THE JIABUSI DEPOSIT, CHINA: EVIDENCE FROM TEXTURAL AND CHEMICAL FEATURES OF RARE METAL MINERALS AND MICA

Xi Diao[1], Mingqian Wu[2]
[1]China University of Geosciences (Beijing), [2]University of Windsor.
E-mail: *diaoxi0303@gmail.com*

The role of magmatic versus metasomatic processes in peraluminous Ta-Nb-mineralizing systems has received great attention yet remains an open question. Economic Ta-Nb-Li mineralization occurs in a lepidolite granite and an internally zoned marginal pegmatite (MP) that lies above the lepidolite granite. Principal Ta-Nb oxides at Jiabusi are columbite-group minerals (CGM) and pyrochlore-supergroup minerals (PSM) that occur in different mineral associations and exhibit different textural and chemical features. The CGM in the Fe-mica granite and the pegmatite portion of the MP developed penecontemporaneously with cassiterite and PSM, all of which are always in equilibrium with Fe-mica. These CGM generally exhibit gradual increases in Ta/(Ta+Nb) and Mn/(Mn+Fe) values from core to rim. On the other hand, the PSM can be further divided into two generations: an early crystallization of kenoplumbopyrochlore and a late crystallization of kenoplumbomicrolite. Textural and chemical evidence suggests that Fe-mica is magmatic, such that the co-precipitated CGM and PSM are also magmatic and represent the first stage of mineralization at Jiabusi. The following stage-II mineralization occurred in the lepidolite granite and the aplite portion of the MP and is manifested mainly by columbite-(Mn) overgrown by aggregates of Ta-Nb oxides, but also as individual crystals that are in equilibrium with snowball quartz and interstitial, anhedral fluorite that have a metasomatic origin. Stage III is represented by CGM overgrowths that have partially resorbed or replaced the Stage-II columbite-(Mn). These overgrowths have 2–3 times higher Ta/(Nb+Ta) values than the Stage-II columbite-(Mn), such that there is a clear compositional gap between Stage-II and Stage-III CGM. The Stage-IV PSM, which consists of an early crystallization of fluorcalciomicrolite and a late crystallization of hydromicrolite, occur as a partial replacement or overgrowth on the stage-III CGM aggregates and are in equilibrium with albite. Our observations suggest that the mineralizing stages of II to IV and the formation of snowball quartz, fluorite, lepidolite, Cs-rich lepidolite, and albite in the lepidolite granite and aplite are all governed by metasomatism. The Ta-Nb ore-forming processes governed by magmatic fractionation and multiple stages of metasomatism, revealed in this study, suggest that Nb-Ta oxides of different origins are distinct in mineral associations and textural/chemical features. Metasomatic processes are critical to economic Ta-Nb enrichment at the Jiabusi deposit.

Li-EXPLORATION AND PROCESSING: THE CASE STUDY OF SPODUMENE FROM THE BARROSO-ALVÃO FIELD, NORTHERN PORTUGAL

Filipa Dias[1], Alexandre Lima[1], Encarnación Roda-Robles[2], Tania Martins[3]
[1]Universidade do Porto, [2]University of País Vasco, [3]Manitoba Geological Survey.
E-mail: *filipa.dias@fc.up.pt*

To start identifying, analyzing, and developing methodologies to process spodumene from a new lithium (Li) deposit, such as the Barroso-Alvão (BA) field, a preliminary study should consist of the following: (1) spodumene texture (e.g. grain size); (2) spodumene paragenesis; and (3) spodumene geochemistry. In the BA field, spodumene can be found in the Li-rich aplite-pegmatites, both in aplitic zones (fine spodumene - micrometric to millimetric) and pegmatitic zones (coarse spodumene - centimetric). However, it becomes more complex. First, there are two types of spodumene-bearing aplite-pegmatites in the BA field: type A in which the main Li mineral is spodumene and type B where the main Li-minerals are petalite and spodumene (with varying proportions). Second, the aplite-pegmatites have been deformed and fine spodumene can also be found surrounding coarse spodumene and/or petalite in the pegmatitic zones. In the type A, the zones with higher Li concentrations can be: (1) single centimetric crystals of spodumene (rare texture); (2) centimetric spodumene intercalated with centimetric quartz; (3) zones with only micrometric to millimetric mixtures of spodumene and quartz; and (4) fine mixtures of spodumene and quartz surrounding millimetric to centimetric feldspars and quartz. In the type B, the zones with higher Li concentrations can be: (1) centimetric spodumene crystals intercalated with centimetric quartz (next, or not, to centimetric petalite); (2) centimetric bands of only micrometric to millimetric spodumene intergrown with micrometric to millimetric quartz; (3) micrometric to millimetric mixtures of spodumene and quartz inside, crosscutting, or surrounding centimetric petalite crystals. These fine mixtures can also crosscut and surround other minerals such as feldspar and quartz; (4) single crystals of petalite; and (5) centimetric to millimetric spodumene surrounded by micrometric petalite, which can also surround other minerals such as quartz and feldspars. The BA field has (I) Li-barren aplite-pegmatites mixed with the Li-rich and (II) Li-barren zones inside the Li-rich pegmatites; (III) similar Li-minerals (spodumene and petalite), and (IV) fine mixtures of spodumene and quartz sometimes invisible to the naked eye. A portable Laser Induced Breakdown Spectroscopy (LIBS) equipment has been calibrated with local selected samples of (a) spodumene; (b) petalite, and (c) mixtures of spodumene and quartz to help to identify them. Alijó and Adagói are the two aplite-pegmatites selected by the project CAVALI - Cadeia de Valor do Lítio (POCI-01-0247-FEDER-047728) to retrieve and concentrate spodumene ore. Alijó is an aplite-pegmatite of the type A with Li concentration in the form of 2-4; and Adagói is an aplite-pegmatite type B.

Nd ISOTOPE MAPPING: THE MISUNDERSTOOD KEY TO GRENVILLE GEOLOGY

Alan Dickin
McMaster University.
E-mail: *dickin@mcmaster.ca*

Recent isotopic studies of Precambrian orogenic belts show a tendency to the increasing use of Hf isotope analysis supported by in-situ U–Pb dating. This technique can give a very detailed picture of the geological history of a small number of samples, but high costs limit its ability to provide wide geographical control between sample localities. In orogenic belts with major supracrustal sequences, conventional field mapping may provide the necessary geographical control. However, collisional orogenies such as the Grenville Province typically cause deeper exhumation of the crust, creating large regions of high-grade gneisses with few distinctive geological features. In this situation, Nd isotope analysis allows detailed geographical mapping of crustal formation ages, and hence permits the precise delineation of terrane boundaries between widely separated U–Pb dating localities. However, the Nd model age dating method has been widely misunderstood, and its results disbelieved. This talk will give some examples of how detailed Nd isotope mapping can elucidate poorly understood structures in the Grenville Province, especially for the complex geology of the Ontario gneiss belt and the enigmatic geology of the 'composite arc belt'.

LAC DES ILES PGE-Cu-Ni DEPOSIT: CURRENT STATE OF KNOWLEDGE

Lionnel Djon, William D. Smith
Impala Canada.
E-mail: *ldjon@impalacanada.com*

Over 50 years of exploration and 30 years of mining at Lac des Iles (LDI) have generated a tremendous geoscientific database including over 875,000 assays and ~1,300,000 metres of diamond drill core. This database underpins several immutable facts related to various aspects of the LDI. Incidentally, highlights of this contribution regarding the PGE-Cu-Ni resources within LDI include: (a) The ~2.69 Ga mafic-ultramafic LDI Complex emplaced during a regional collisional orogeny that affected the Wabigoon and Quetico cratonic domains; (b) The South LDI Complex parental magma is a volatile-rich basaltic andesite based on mineral chemistry and thermodynamic modelling, consistent with the composition of local mafic-intermediate dykes; (c) Coexistence of olivine and orthopyroxene indicates batch crystallization and only locally developed feldspathic cumulates are consistent with fractional crystallization; (d) The most important distinguishing features of the LDI deposits compared to peer-group PGE-Cu-Ni deposits are the greater thickness and vertical extent of high-tenor disseminated sulphides, typically exceeding several hundred ppm Pd in 100% sulphide; (e) Grade distribution predominantly reflects the primary structural control on magma flow and sulphide accumulation; (f) The highest Pd grades, although principally located along an inferred pre-magmatic regional feeder fault, locally follow other major faults as well as lithological contacts; (g) The consistent observed increase in Pd:Pt and Pd:Au ratios with increasing Pd grade is not typically seen in other PGE deposits; (h) Palladium mineralization is commonly, but not universally, associated with disseminated Fe-Cu-Ni sulphide mineralization with total sulphide mineral abundances of 0.5 to 2%; (i) Palladium principally occurs in Te-, Bi- and S-bearing platinum-group minerals displaying a wide range of textures and mineral associations but having similarities to Pd-bearing minerals documented from other PGE deposits; (j) The South LDI Complex was affected by syn- to post-magmatic faulting that has complicated the interpretation of primary ore-forming processes and the pre-faulting configuration of ore zones. The most important of these structures, Offset and the parallel Camp Lake Fault, divide the main deposit into three structural blocks (Roby, Offset, and Camp Lake); (k) Hydrous alteration and ductile deformation were focused in the Roby-Offset central domains, converting mineralized norite to chlorite-actinolite schist, but not significantly modifying the primary precious and base metal grades. The LDI deposits are truly unique amongst the family of magmatic PGE-Cu-Ni sulphide deposits. Although a huge amount of knowledge has been gained over a half century of exploration, there remains much more to learn from this world class Pd resource.

RESEARCHING PUBLIC UNDERSTANDING OF EARTHQUAKE MAGNITUDE AND INTENSITY IN PREPARATION FOR CANADA'S FORTHCOMING EARTHQUAKE EARLY WARNING SYSTEM

Glenn Dolphin[1], Shona V.Z. de Jong[1,2], Jason Dropoth[1], Esther Muturi[1]
[1]University of Calgary, [2]Queens University.
E-mail: *glenn.dolphin@ucalgary.ca*

In preparation for the forthcoming Earthquake Early Warning System (EEWS) to be implemented in the western and eastern regions of Canada, our group is researching aspects of the alerting system to better prepare the Canadian public to take appropriate protective actions upon receiving an alert. Specifically, we are investigating two concepts the EEWS uses in its process of developing and sending out alerts to the public, earthquake magnitude and earthquake intensity. In North America, the public often conflates these two ideas, and it is our goal to help the Canadian public develop a robust understanding of both. We are approaching the problem from three directions: historical, linguistic, and socio-cultural. The historical approach focuses on understanding the developmental trajectory of earthquake magnitude and intensity as a result of major earthquakes and developments in technology. The approach will result in a historical case study for teaching these concepts. The linguistic approach focuses on how these concepts are framed in schools, social media, and news media based on the language used when talking about them. This focus will develop linguistic strategies for communicating the concepts to the public. Finally, the socio-cultural focus examines these concepts within the Canadian context, how living in an active or quiescent seismic zone and educational emphases play a role in the public's understanding of magnitude and intensity. Here we will develop strategies for teaching the public that take into consideration the specific contexts of the target populations.

CONTROL OF CRUSTAL DEFORMATION ON OROGENIC Au MINERALIZATION IN HIMALAYA: A CASE STUDY FROM BUZHU

Chaoyi Dong[1,2], Qingfei Wang[1], Daniel Gregory[2]
[1]China University of Geosciences, Beijing, [2]University of Toronto.
E-mail: *dongchaoyi0808@gmail.com*

The Buzhu Au deposit, located on the Kangmar dome margin in the Himalayan orogen, provides an opportunity to investigate the control of crustal deformation on Au mineralization. The deposit contains Au veins controlled by D_3 early subhorizontal shear zones and later extensional faults which formed after thrust-related D_1 and extension-related D_2 deformation. During D_1 and D_2 episodes, a metamorphic quartz-pyrite-muscovite-chlorite ± paragonite assemblage formed along foliations, followed by an Au-related quartz-pyrite-muscovite-chlorite ± arsenopyrite ± base-metal-sulphides assemblages during the formation of a crustal dome in D_3. The estimated temperature range using chlorite geothermometry for mineralization was 292–348°C, higher than regional metamorphism. The relatively higher Fe^{2+}/Fe^{3+} ratio in hydrothermal mica than in metamorphic mica suggests that mineralization occurred under relatively reduced conditions. Pyrites from diagenetic and metamorphic stages contain negligible Au and low As, with significant $\delta^{34}S$ variation. In contrast, hydrothermal arsenian pyrite and arsenopyrite have higher Au and a restricted $\delta^{34}S$ range. The D_3 fault system controlled the vein system that experienced three deformation stages, including hydraulic brecciation during stage I, crack-sealing processes in stage II during the ductile-brittle transition, and crosscutting by veins in newly formed normal faults during stage III. Stages I and II are characterized by a quartz-pyrite-chlorite-muscovite ± arsenopyrite ± base metal sulphides assemblage, while native Au and pyrrhotite formed in stage III. Euhedral quartz in stage I fractures show oscillatory and sector zoning cathodoluminescence patterns. Pyrites in these veins display coupled Au-As variation, high Au contents, and restricted $\delta^{34}S$ values, implying that Au precipitation occurred through fluid-rock reactions. Stage II quartz displays alternating bright and dark cathodoluminescence bands with corresponding high and low Al-Li concentrations, indicating fluid pressure fluctuations. Pyrite from stage II has a negative correlation between Au and $\delta^{34}S$ values (decreasing values from core to rim), consistent with fluid oxidation caused by a fluid pressure drop due to phase separation. Late minor quartz in open spaces transected earlier quartz, implying a drop in the hydrothermal system to near hydrostatic conditions. Partial replacement textures of pyrite and arsenopyrite from stage III with

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slightly varied $\delta^{34}S$ values and the presence of micro-inclusions and visible Au along the contact suggest a fluid-mediated dissolution-reprecipitation process. The data suggest that the Buzhu deposit formed during an extensional setting after crustal compression, and mineralization occurred as the hydrothermal system transitioned from the ductile to brittle domain. The mechanisms responsible for Au precipitation varied from fluid-rock reaction, fluid oxidation, to Au remobilization.

EXTRA-LARGE FLAKE GRAPHITE: A METAMORPHIC-HYDROTHERMAL MODEL

Cameron Drever, Carson Kinney, Chris Yakymchuk
University of Waterloo.
E-mail: *cyakymchuk@uwaterloo.ca*

Graphite is a critical mineral and a crucial raw component of many energy storage devices associated with green energy technology. Larger graphite flakes are particularly valuable for use in battery anodes. Extra-large flake graphite is rare, but one example is found at the Bissett Creek deposit in the Grenville orogen in Ontario. Graphite flakes (1–6 mm in size) are hosted in amphibolite-facies gneisses that record high-temperature metamorphic conditions of > 760°C at crustal depths of ~20–30 km. Graphite has carbon isotope values ($\delta^{13}C_{VPDB}$) that range from –28‰ to –14‰; this range is compatible with a biogenic origin but too wide to be generated exclusively from the graphitization of organic matter. The scarcity of carbonate minerals at Bissett Creek suggests that this range of carbon isotope values is also not the product of calcite-graphite isotope exchange. Intergranular graphite microveinlets suggest graphite precipitation from a carbon-rich fluid or melt during high-temperature metamorphism; carbon mobilization can also explain the variability in carbon isotope values measured at Bissett Creek. We suggest that flake graphite generated by graphitization during metamorphism was coarsened due to the precipitation of additional graphite from carbonic fluids or melts present during metamorphism. This resulted in anomalously large to extra-large graphite flake sizes. A hybrid metamorphic-hydrothermal model may explain the petrogenesis of other large to extra-large flake graphite deposits worldwide and such metamorphic-hydrothermal graphite deposits represent excellent prospects for future development.

CONTROLS ON GOLD THROUGH TIME AND SPACE IN THE ABITIBI GREENSTONE BELT

Benoît Dubé, Patrick Mercier-Langevin
Geological Survey of Canada.
E-mail: *ben_dube@sympatico.ca*

The Abitibi greenstone belt is one of the world's major gold-producing regions with a total endowment, including production (> 200 Moz), reserves, and resources (measured and indicated), of > 300 Moz Au. A significant part of that gold (~13%) is synvolcanic and/or synmagmatic and formed between ca. 2740 and 2695 Ma. However, > 60% of the gold is hosted in orogenic quartz-carbonate vein-style deposits, predominantly along the Larder Lake-Cadillac (LLCF) and Destor-Porcupine (DPF) fault zones. These orogenic deposits were formed during the main phase of crustal shortening, in which the penetrative deformational and metamorphic fabrics were generated, in response to a broad north-south regional shortening event defined as D_3. The quartz-carbonate vein-type deposits are therefore syn- to late-D_3 and formed between ca. 2660 and 2640 ± 10 Ma. D_3 regional shortening followed a period of extension and associated alkaline to sub-alkaline magmatism, and the development of fluvial-alluvial sedimentary basins (< 2679–2669 Ma) referred to as Timiskaming-type in the southern Abitibi. The tectonic inversion from extension to compression is < 2669 Ma, the maximum age of the D_3-deformed Timiskaming rocks. Stockwork-disseminated-replacement-style mineralization is also present with ~16% of the gold in the belt. Such deposits are hosted in and/or associated with ca. 2683–2670 Ma, early- to syn-Timiskaming alkaline to sub-alkaline intrusions along major faults, especially in southern Abitibi and formed late- to post-alkaline to sub-alkaline magmatism, the largest deposits being early- to syn-D_3 (ca. 2670–2660 ± 10 Ma). At belt scale, these illustrate a transition in ore styles during D_3 shortening along the length of the LLCF and DPF. The sequence of events, although similar in most camps, was probably not synchronous at belt scale, but varied/migrated with time and crustal levels both along the main faults and from north to south. The presence of high-level alkaline intrusions spatially associated with Timiskaming conglomerate, large-scale hydrothermal alteration, and numerous gold deposits along the LLCF and DPF indicate that these structures were deeply rooted and tapped auriferous metamorphic-hydrothermal fluids and melts from the upper mantle and/or lower crust, late in the evolution of the belt. Although most magmatic activity along the faults predates gold, magmas have contributed heat, fluids and/or metals to the hydrothermal systems in some cases. This great vertical reach explains why the LLCF and DPF zones are very fertile structures. The exceptional gold endowment along the LLCF and DPF may also suggest that these faults have tapped particularly fertile upper mantle-lower crust gold reservoirs.

STRUCTURAL CONTROL OF THE GEORGIA LAKE LITHIUM-CESIUM-TANTALUM-TYPE PEGMATITE, A FIELD AND LINEAMENT ANALYSIS PERSPECTIVE, QUETICO SUBPROVINCE, ONTARIO

Manuel Duguet, Gaetan Launay
Ontario Geological Survey.
E-mail: *manuel.duguet@ontario.ca*

The Georgia Lake area, east of Nipigon Lake is known to host one of the most remarkable lithium-cesium-tantalum (LCT)-type pegmatite field in Ontario. Geochemistry performed by the Ontario Geological Survey in the mid 2000s established the genetic link by melt fractionation between the parental Glacier Lake batholith and the Georgia Lake pegmatite field and associated fertile granites such as the Barbara Lake stock. This fractionation trend is identical to many others documented elsewhere in LCT-type pegmatite systems. Superimposed on this fractionation trend, it was shown by multiple studies that structural control can play a significant role at collecting and channelizing fractionated melts toward third order structural traps. However, this relationship remained to be demonstrated in the Georgia Lake area. Fieldwork started by the Ontario Geological Survey in 2019 has shown that the emplacement of the Barbara Lake stock into host metaturbidite rocks was assisted by a north-trending fault that crosscut the regional west-trending fabric (composite S_{0-1}). Expression in the field of this fault varies from a N- to NE-trending vertical foliation defined by biotite near the intrusion to cleavage and local upright folds of similar trend away from it. Cordierite, andalusite and sillimanite related to the stock's contact aureole crystalized locally along this foliation and retrogressed the peak metamorphic assemblage (garnet-staurolite-biotite-plagioclase-quartz). Preliminary structural analysis of the lineaments obtained from the treatment of the ASTER images supports the existence of the Barbara Lake stock N-trending fault and highlights the existence of several other N- to NE-trending fault corridors throughout the Georgia Lake area. These corridors form continuous segments over 40–50 km in length and are associated with high lineament densities, especially in the vicinity of the Barbara Lake stock. Based on this lineament analysis, a strong spatial relationship also can be observed between the distribution of the known clusters of LCT-type pegmatite of Georgia Lake and N- to NE-trending faults. All together, these results suggest that the known Li-bearing occurrences hosted in pegmatites were channelized along these N- to NE-trending faults before their emplacement in adjacent subsidiary structures. Statistical analyses are underway to further quantify the spatial relationship and potential links between pegmatites and the different families of structures occurring in the Georgia Lake area. More field work is warranted to document the field expression of these N-trending faults, their regional significance, and their role in the structural control of the Georgia Lake pegmatite field.

WHO WERE YOU? INSIGHTS INTO THE LITHOLOGICAL CHARACTER OF THE GRENVILLE FRONT TECTONIC ZONE NEAR WANUP, ONTARIO

Robert Michael Easton
Ontario Geological Survey.
E-mail: *mike.easton@ontario.ca*

Understanding the original source of any rock package is important for determining its economic potential and/or any potential influences it may have on local hydrology. Multi-deformed and multi-metamorphosed rock packages are no exception, although the identification process is more complicated. This presentation focuses on the character of rocks within the Grenville Front Tectonic Zone (GFTZ) exposed along the Highway 69 corridor west of the Wanapitei River, near Wanup, which was last mapped over 60 years ago. Here, rocks in the GFTZ footwall include metasedimentary rocks of the Huronian Supergroup (HSG), Nipissing gabbro intrusions (ca. 2217 Ma), and felsic intrusions of the Killarney Magmatic Belt (ca. 1740 and 1450 Ma). The GFTZ here is only 8 km wide, and was overthrust by the Nepewassi domain, which includes Killarney plutons, some of which are metamorphosed at granulite facies, and lenticular belts of orthoquartzite of unknown affinity. Within the GFTZ hanging-wall, the lowermost 1 km of rock has been subjected to late-stage cataclasis, which occurs after peak high-grade metamorphism. Above the cataclastic zone south to the boundary with Nepewassi domain, the hanging-wall is characterized by numerous lenticular, anastomosing, compositional varied, moderately dipping (45–65°) belts of highly-strained gneiss. So far, only about 30% of the rocks in the GFTZ have been characterized. Identifiable units in the GFTZ include East Bull Lake suite mafic intrusions (Cu-PGE potential), biotite-garnet-muscovite ± staurolite schists geochemically similar to the McKim Formation, medium-grained felsite bodies geochemically similar to Copper Cliff Formation rhyolite, amphibolite units that may be HSG mafic flows, and Archean tonalite gneisses. Notably absent are the major HSG quartzite units expected to be present. Garnet-rich (20–30%) horizons may represent metamorphosed hydrothermal alteration systems, although it is not known if they are related to volcanogenic massive sulphide alteration (Zn-Cu-Pb potential) or metasomatic iron and alkali-calcic alteration (Au ± Cu ± Fe ± Co potential), with the latter occurring in the GFTZ footwall northeast of the study area. Also present are several thin (30–80 cm wide) impure dolomitic marble and calc-silicate horizons, some containing grossular-fluorvesuvianite-quartz assemblages (XRD confirmed), hosted in orthogneiss. These may be similar in origin to the calcite vein-dykes and pseudocarbonatite rocks in the Boundary Tectonic Zone near Bancroft, rather than being sedimentary in origin. Metamorphosed dismembered Sudbury dykes (ca. 1250 Ma) are common and serve as an important time-marker in the GFTZ. Significantly, rocks not observed in the GFTZ, despite their abundance and proximity to the north and/or south include quartzite, Nipissing gabbro, and Killarney plutons.

CRITICAL MINERAL POTENTIAL OF THE WESTERN, GRENVILLE PROVINCE, ONTARIO: AN OVERVIEW

Robert Michael Easton
Ontario Geological Survey.
E-mail: *mike.easton@ontario.ca*

The western Grenville Province in Ontario has a long history of critical mineral production dating from the 1870s, including commodities such as beryl, copper, fluorspar, graphite, magnesium metal, molybdenum, phosphate, zinc, and uranium. Much of this production came from vein deposits during previous times of global supply concerns, most notably during World Wars I and II. In many instances, these vein deposits were never exhausted, they simply became uneconomic after discovery of larger replacement and/or bedded deposits (e.g. phosphate in Florida, fluorspar in Mexico). The proximity of the western Grenville Province to transportation networks, energy infrastructure, and markets, as well as the availability of numerous detailed studies by the Ontario Geological Survey, necessitates a re-examination of the critical mineral potential of these deposits. The fluorspar deposits in the Madoc are ripe for re-evaluation. These fluorite-calcite-barite veins are located along the NW-trending Moira fault and its splays near the Precambrian–Paleozoic unconformity. The veins formed during the Silurian from low-temperature hydrothermal fluids localized along the fault and likely sourced from the high-fluorine Deloro peralkaline granite. Between 1943 and 1945, 25,000tons of ore was produced with most deposits only mined to shallow depths (20–60 m). The southeastern trace of the Moira fault was never explored, and a modern conductivity survey would delineate additional deposits. In addition, white barite in some of the veins might be a potential by-product. Other high potential deposit types include: graphite from metasedimentary gneiss, including recent past-producers (Kearney mine) and advanced projects (Bissett Creek); magnesium metal from ultra-clean and metal-poor hydrothermally altered dolomite marble from the Cobden area; and aluminum from syenite complexes (> 25% Al_2O_3), especially the U- and Th-poor plutons of the ca. 1080 Ma Kensington-Skootamatta suite as well as from numerous anorthosite intrusions (> 30% Al_2O_3), such as the Whitestone, Arnstein and River Valley anorthosite intrusions. Moderate potential deposit types include: (a) titanium and/or vanadium from a variety of mafic intrusions; (b) beryl, as well as pyrochlore and/or columbite with and without uranium minerals, from the typical NYF-type (Li-poor) pegmatite veins; and (c) "metasomatic deposits" that were historically sources of apatite, mica, molybdenum, and uranium. They are associated with a complex series of host rocks including "calcite vein dykes", coarse-grained pink calcite rocks, diopsidites, apatite veinlets, and mica pyroxenites. They occur with syenite intrusions in crustal-scale deformation zones, and exhibit footwall-related compositional variations, e.g. uranium-rich deposits at Bancroft, aluminium-rich deposits at Craigmont, carbonate-hosted rare earth element mineralization near Brudenell, and abundant fluorite near Cobden.

A RE-WARDING POSSIBILITY: RHENIUM ISOTOPE SIGNATURES IN MOLYBDENITES

Ivan Edgeworth[1], Brian Kendall[1], Jacob Hanley[2]
[1]University of Waterloo, [2]Saint Mary's University.
E-mail: *ipedgewo@uwaterloo.ca*

Rhenium (Re) is a redox-sensitive trace element that readily substitutes for molybdenum (Mo) in the molybdenite (MoS_2) crystal structure. Given that Re concentrations in molybdenite commonly range from single-digit to thousands of ppm, mass-dependent variations in the Re isotope composition of molybdenite hold potential as a tracer of ore-forming processes. Coupled Re and Mo isotope analyses of molybdenite could help interpret the dominant fractionation processes (e.g. Rayleigh distillation, fluid-magma redox conditions, fluid exsolution, fluid boiling, magmatic differentiation) during mineralization and serve as a potential geochemical tracer for mineral exploration. Further, combining the Re–Mo isotope systems with Re–Os molybdenite geochronology may help provide further insights into the temporal evolution of ore-forming systems. Despite recent progress in analyzing the Re isotope composition of various geological materials (seawater, river systems, igneous rocks, meteorites, shales), there has been minimal effort to explore mass-dependent Re isotope variations in molybdenite to date. Using a multi-column chemistry procedure and Re isotope analysis using multi-collector inductively-coupled plasma mass spectrometry, this study presents rhenium isotope data for molybdenite from several deposit types and the Henderson molybdenite standard (NIST RM 8599). In this study, the δ^{187}Re (‰) = ([^{187}Re/^{185}Re$_{sample}$/^{187}Re/^{185}Re$_{NIST\ SRM\ 3143}$]– 1) × 1000) of a rhenium ICP standard and the Henderson molybdenite standard can be measured with an analytical precision of < 0.1‰ (2σ). Molybdenite samples from porphyry, epithermal, porphyry, greisen, and Mo-Bi-W pipe deposits yield Re concentrations between 10 and 650 ppm and δ^{187}Re values that span a range of 0.3‰, signifying that mass-dependent rhenium isotope fractionation occurs during mineralization. Analyses of multiple molybdenite flakes from the same mineral separate, as well as of multiple flakes from a single grain aggregate, show minimal variation in δ^{187}Re. This limited variation in δ^{187}Re at small scales raises the possibility that Re isotopes can serve as a geochemical tracer for processes acting over large scales within ore-forming systems. This work represents the first steps in the development of the Re isotope system as a geochemical tracer for ore deposits.

IN SITU SENSOR-BASED ELECTRODE MEASUREMENTS TO IDENTIFY AND CHARACTERIZE DYNAMIC BIOGEOCHEMICAL PROCESSES

Allison Enright
University of New Brunswick.
E-mail: *aenright@unb.ca*

Many different aspects of landscape restoration, carbon sequestration, and remediation of contaminated environments are accomplished by low-temperature biogeochemical reactions mediated by biology, including microbes, fungi, and plants. Several key reactions, including redox transformations of Fe, Ni, and toxic heavy metals, are exclusively mediated by microbes. Effective remediation and restoration require detailed descriptions of these complex systems. Multiple lines of evidence and interdisciplinary expertise are necessary to characterize the dynamic biological, chemical, and physical processes. Significant research has been done on these environments and processes, characterizing: (i) key environmental variables governing reaction rates and progress (i.e. pH, temperature, reduction-oxidation potential); (ii) nutrients and metabolites for each significant process or pathway; (iii) stoichiometry of individual reactions; and (iv) microbial strains which mediate key reactions. Successful long-term restoration and remediation efforts require ongoing re-assessment of key variables in order to assess shifts in baseline conditions as well as changes in the dynamic processes. One significant challenge in such efforts is the time delay between applying a treatment, and having adequate data to assess its effectiveness, and quantify the impact of specific changes. Electrodes and sensors were used to passively measure parameters such as pH, redox potential, dissolved O_2, and dissolved ions in situ at regular intervals. Recently, signal processing techniques have been applied to these time series data sets and shown to record information about the dominant biogeochemical pathways active in a system of study. In the context of environmental restoration, this information could help to assess the effectiveness of treatments and quantify changes in baseline conditions within hours or a few days. Decision-makers and site managers would benefit significantly from this real-time information. In addition, such analytical techniques may assist in verifying long term ecosystem health, and in predicting tipping points through subtle changes in signal characteristic which may be detectable earlier than change in other measurements or characteristics.

EXOMETASOMATISM PROMPTED BY SPODUMENE-BEARING PEGMATITES AND ITS IMPLICATIONS IN LITHIUM EXPLORATION: THE CASE STUDY FROM ALIJÓ (NORTHERN PORTUGAL)

Jon Errandonea-Martin[1], Encarnación Roda Robles[1], Idoia Garate-Olave[1], Julian F. Menuge[2], Axel Müller[3], Alfonso Pesquera[1], Tania Martins[4], Alexandre Lima[5]
[1]University of the Basque Country, [2]University College Dublin,
[3]University of Oslo, [4]Manitoba Geological Survey, [5]University of Porto.
E-mail: *encar.roda@ehu.es*

Barroso-Alvão is part of the NW of the Iberian Massif in Portugal and is known for significant lithium mineralization associated with granitic pegmatites. Given the number of open pit mines and pegmatite exposures, it constitutes a target for the development of lithium exploration techniques. The spodumene-bearing pegmatite from Alijó is a representative example of Iberian Li-Cs-Ta (LCT) pegmatite that is currently under exploitation. This contribution provides preliminary results of a lithogeochemical study carried out on the host rocks of the aforementioned pegmatite within the framework of the EU H2020 GREENPEG project (N°869274). The Alijó spodumene-bearing pegmatite is a 32 m wide dyke that intrudes discordantly into a psammo-pelitic sequence including mica schists, quartz-feldspathic schists, phyllites, quartz-phyllites, quartzites and metagreywackes. The metasedimentary sequence was affected by Variscan polyphasic deformation and metamorphism and was intruded by widespread late- to post-collisional granitoid rocks. The studied pegmatite body was emplaced at shallow levels of the crust causing a release of fluids that changed the original chemical signature of the host rocks, leading to a metasomatic halo around the pegmatite. Quantification of whole-rock geochemical gains and losses through the isocon method indicates that the pelitic (mica-rich) samples exhibit a markedly higher enrichment in fluid mobile elements than the quartz-rich metasedimentary rocks. In mica-rich samples (SiO_2 < 68 wt.%; Al_2O_3 > 16 wt.%), despite their high Chemical Index of Alteration (CIA > 70) and loss on ignition (LOI > 3 wt.%) values, the Li, Sn, and B could be used as indicators of proximity to a mineralized pegmatite in the area with elevated relative gains of > 2, and showing approximate contents of 200 ppm Li, 15 ppm Sn, and 150 ppm B or higher in mica-rich host rocks. Contents of about 30 ppm Cs and 300 ppm Rb in these regional metasedimentary rocks could act similarly, but they should be treated with caution due to the obtained low relative gains (caused likely by later alteration processes than the generation of the metasomatic halo). These proposed pegmatite proximity contents together with the halo width, with a maximum of 50 m in the studied case, could allow calibration of innovative lithium exploration techniques applicable in similar metasedimentary host rocks worldwide to identify hidden pegmatites by their exposed halos.

CHARACTERIZATION OF MINERALIZING FLUIDS AND MELTS IN ALKALIC PORPHYRY DEPOSITS - MOUNT POLLEY, BRITISH COLUMBIA, CANADA

Maria Paula Estrella, Pilar Lecumberri-Sanchez
University of Alberta.
E-mail: *mestrell@ualberta.ca*

Alkalic porphyries are Cu-Au high grade deposits also known to host important PGE resources. In contrast to calc-alkalic porphyries, the information available on the composition of fluids and mineralizing processes responsible for alkalic porphyry systems is limited. As a consequence, models from calc-alkalic porphyries are applied for exploration of alkalic systems. These models do not accurately represent the paragenetic sequences observed in alkalic porphyry environments, and particularly, the alteration mineral zoning upwards remains poorly known. In this context, this project seeks to contribute to the development of a representative geological model for alkalic porphyries through the study of Mount Polley, in south-central British Columbia. Mount Polley is an alkalic porphyry copper deposit located in the largest alkalic porphyry province known in British Columbia. It is one of the shallowest deposits of this kind, such that the alkalic intrusive complex hosting the mineralization is well exposed on the surface. Mineralization in Mount Polley is Late Triassic age and occurs in a series of discrete Cu-Au (-Ag) ore zones within and around hydrothermal-breccia bodies, as well as minor skarn development in coeval volcanic rocks. The objectives of this research project are (1) to identify the likely source of mineralizing fluids, and (2) characterize the physicochemical properties of these mineralizing fluids and evolution through alkalic systems. In order to achieve these objectives, melt inclusions in the diverse intrusive and volcanic units exposed at surface are being identified towards characterizing how metal budgets evolve and likelihood of water saturation for the different units present. In parallel, this study is looking for fluid inclusions in equilibrium with these melts, as well as through 200 m of vertical exposure towards determining the properties of the fluid and how those properties evolve as the fluid migrates through rock in a well mineralized alkalic porphyry copper deposit.

AERIAL PHOTOGRAPHS TO LiDAR: EVOLUTION OF QUATERNARY GEOLOGICAL MAPPING IN CANADA

Nicholas Eyles[1], Roger Paulen[2], Martin Ross[3], Syed Bukhari[1]
[1]University of Toronto, [2]Geological Survey of Canada, [3]University of Waterloo.
E-mail: *roger.paulen@nrcan-rncan.gc.ca*

The first use of aerial photographs to map glacial landforms in Canada was by F.B. Taylor in 1913, in southern Ontario. After World War I, with the availability of cheap war surplus aircraft and ex- military pilots and especially after the formation of the Royal Canadian Air Force in 1924, Canada initiated a massive aerial photography survey of the entire country, then the largest such undertaking anywhere in the world. Aerial photos and photomosaics were first used by J. Tuzo Wilson in the 1930s to map glacial landforms in the Northwest Territories and ultimately resulted in the first Glacial Map of Canada in 1958; later compilations by Vic Prest and others at the Geological Survey of Canada were used to map the configuration of the Laurentide and Cordilleran ice sheets during the last glacial cycle. Detailed examination of glacial geomorphology portrayed on satellite images allowed observations of ice-moulded landscapes at much larger scales. Various iterations of Landsat imagery allowed recognition of larger ice flow patterns not previously discernable in aerial photographs. Later, Radarsat imagery was also applied to interpret glacial landscape using other parameters, such as surface moisture and reflectivity. This accelerated the development of new terrain mapping techniques based on analysis of genetically related assemblages of glacial landforms and underlying sediments as 'landsystems'. The Shuttle Radar Topography Mission (SRTM) in the early 2000s ushered in a new era by creating the first digital elevation models, with a real resolution of 25 m, but coverage was limited to south of 60 degrees latitude. In 2017, early versions of ArcticDEM were made available, with digital elevation data of the Canadian Arctic with resolution of 2 m or less. The availability of new LiDAR data sets now allows mapping to 1 m resolution in some areas, and higher (5 cm) using drones. In conjunction with machine learning techniques for analysis of large digital data sets this is providing new insights into the origin of glaciated landscapes in Canada, giving a fundamental re-evaluation of the structure and mode of flow of Canadian ice masses, in particular the presence of fast flowing corridors of ice (ice streams), and how glaciers interact with different substrates. The search for critical minerals needed for the emerging green economy is ultimately reliant on further progress in mapping the glacial geological legacy of the last ice sheets and underscores the need for expanded national coverage of high-resolution LiDAR.

KIMBERLITE EMPLACEMENT CONDITIONS AS TOLD BY EXPERIMENTALLY PRODUCED REACTION CORONAE ON ILMENITE MACROCRYSTS

Lydia Fairhurst[1], Yana Fedortchouk[1], Ingrid Chinn[2], Philippe Normandeau[3], Michael Powell[1]
[1]Dalhousie University, [2]De Beers Group, [3]Northwest Territories Geological Survey.
E-mail: *ly593526@dal.ca*

Kimberlites are mantle-derived magmas often emplaced in Archean cratons as pipe-shaped structures consisting of various coherent (CK) and volcaniclastic kimberlite facies, including Kimberley-type pyroclastic kimberlite (KPK), the host of many diamond deposits, where emplacement mechanism is highly debated. Kimberlites transport loads of mantle material including diamonds and oxide minerals such as ilmenite. Ilmenite macrocrysts are not in equilibrium with the kimberlite melt and form reaction coronae (rims of one or more secondary phases). The composition of these coronae varies between different kimberlite facies, most notably forming perovskite in CK facies and titanite in KPK facies. Here we explore the conditions leading to crystallization of titanite in KPK in order to better understand the origin of this complex lithology and differences in the emplacement of different facies within complex kimberlite pipes. Towards this end we perform piston-cylinder experiments using synthetic kimberlite and spheres of natural ilmenite macrocrysts at 600–1200°C and 0.5–2 GPa. Our experiments test the following mechanisms for crystallization of titanite over perovskite: (1) shift from perovskite to titanite crystallization during nearly isobaric cooling of kimberlite; (2) increase in silica activity due to crustal assimilation and formation of titanite; and (3) increase in silica activity triggering crystallization of titanite due to exsolution of volatiles. Our initial experiments produced reaction coronae with Ti-magnetite and perovskite similar to those on natural samples over a range of conditions (1100–1200°C, 0.5–1.8 GPa and –2.1 to 0.1 DNNO) for few compositions with varying SiO_2/CaO ratio. The next set of experiments is testing the effect of assimilation of crustal material, simulated by adding granodiorite to kimberlite mixture, on stability of titanite, and the minimum required amount of assimilation. Understanding the factors leading to titanite crystallization in KPK kimberlite units is a key to understanding the emplacement of these important diamond-bearing kimberlite facies.

EXPLORING FOR URANIUM DEPOSITS USING NOVEL GEOCHEMICAL AND ISOTOPIC TECHNIQUES

Mostafa Fayek
University of Manitoba.
E-mail: *mostafa.fayek@umanitoba.ca*

A critical element is an element that is in high demand with a supply chain at risk of disruption. Critical elements are essential to the global economy and are associated with numerous industries (e.g. batteries). On March 11, 2021, the Government of Canada published its list of critical elements also referred to as critical minerals. Uranium was listed among the list of 31 metals considered integral to the Canadian economy. The list highlights the areas that Canada should focus its future mining and exploration efforts upon. Exploration techniques for uranium deposits can be divided into geophysical or geochemical/mineralogical methods. This presentation will provide a review of the geochemical/mineralogical exploration techniques for uranium deposits and future areas of research for the exploration of this critical element. Mineralogical techniques include, petrography, X-ray methods, normative calculations and short-wave infrared (SWIR or PIMA) clay identification techniques. Changes in clay mineral proportions (e.g. illite > kaolinite, tourmaline and chlorite polytypes) have been linked to uranium mineralization. However, local variations in clay contents and polytypes can limit the utility of these studies, unless they are coupled with other exploration techniques, such as chemical or isotopic methods. Uranium deposits represent natural concentrations of uranium or uranium minerals. The formation of uranium deposits may result in a primary, syngenetic chemical halo that extends up to several kilometres beyond the mineralogical halo. This geochemical pattern may contain specific trace elements related to the formation of the uranium deposit and complementary changes in secondary or alteration mineralogy. In some cases, these broad haloes change in character with increasing distance away from the uranium deposit. In contrast, secondary dispersion typically occurs because of post-depositional fluid (e.g. groundwaters or meteoric fluids) interaction with the uranium ore body. These fluids can mobilize elements from depth to the surface. These elements can concentrate in soils and vegetation, thus creating a surface anomaly over a deeply buried uranium deposit. The utility of using the fractionation of traditional light stable isotopes and Pb as tracers of fluid-solid interactions, geothermometers, and mass transport of uranium is well-established, and radiogenic isotopes (e.g. U–Pb) are useful chronometers of fluid events. Novel analytical techniques and instrumentation have facilitated the use of non-traditional light isotopes such as B and Li, and transition-metal (e.g. Fe) and other heavy-metal isotopes (e.g. U) as tracers of processes associated with uranium deposit formation. Therefore, isotope tracing is among the emerging exploration techniques for uranium deposits.

ACID NEUTRALIZATION AND METAL(LOID) RELEASE IN OIL SANDS FROTH TREATMENT TAILINGS

Stuart Ferry, Matthew Lindsay
University of Saskatchewan.
E-mail: *stu.ferry@gmail.com*

Acid generation and metal(loid) release is an emerging closure consideration for oil sands mines in northern Alberta, Canada. Froth treatment tailings (FTT) generated during bitumen extraction generally exhibit higher sulphide-mineral contents relative to other tailings streams. Recent studies have shown that pyrite oxidation can promote pore-water acidification and metal(loid) release within the unsaturated zone of FTT beach deposits. The corresponding sequence of acid neutralization reactions and their influence on metal(loid) release has not been studied for FTT deposits. We conducted laboratory column experiments to examine acid neutralization reactions and their influence on metal(loid) mobility within FTT beach samples. These samples were collected from non-weathered, partially weathered, and highly weathered areas, which provided an opportunity to examine acid neutralization and metal(loid) release during weathering. Our experiments also considered non-solvent-washed (i.e. as received) and solvent-washed splits of each sample to assess impacts of residual hydrocarbons on these reactions. We continuously pumped 0.05 M H_2SO_4 through each column and collected samples of the input and effluent for geochemical measurements and analyses. Effluent pH decreased from ~7 to 5.5 over the first 5 pore volumes for the non-weathered and partially weathered columns. Gradual decreases in effluent pH to ~4.5 were observed over time, with subsequent rapid pH decreases to < 3 observed after more than 50 pore volumes in these columns. Effluent pH was consistently < 2.0 for the highly weathered columns. We attribute these effluent pH ranges to the dissolution of Ca-bearing carbonate (pH ~6 to 7), Fe-bearing carbonate (pH ~5.5), Al hydroxide (pH ~4.5), and silicate (pH < 3) phases. These interpretations are supported by pH-dependent increases in effluent concentrations of Fe (< 1 to > 500 mg/L), Al (< 0.1 to > 10 mg/L), Si (< 0.1 to > 10 mg/L), and several additional metal(loid)s (e.g. Mn, Ni, Zn, As) associated with the FTT mineral assemblage. Our results offer important new insight into relationships between acid neutralization and metal(loid) release in FTT deposits that can inform FTT management and reclamation.

ANALYSIS OF THE ROLE OF FRACTIONAL CRYSTALLIZATION AND HYDROTHERMAL ALTERATION IN THE EVOLUTION OF UM NAGGAT A-TYPE GRANITES, CENTRAL EASTERN DESERT, EGYPT: IMPLICATIONS FOR RARE METAL MINERALIZATION

Basma Feteha Salem[1], Abdel-Kader Moghazi[1], David Lentz[2]
[1]Alexandria University, [2]University of New Brunswick.
E-mail: *basma_feteha@alexu.edu.eg*

The late Neoproterozoic Um Naggat Granite is a rare metal-bearing post-collision, crustal- to mantle-like high-silica A-type granite. It consists of reduced ferroan, peraluminous (1–1.2), alkalic syenogranite, alkali feldspar granite, and albite granite intruded into a suite of metavolcanic-sedimentary and metagabbro-diorite rocks. The rare metal mineralization is localized within the hypabyssal albite granite, which occurs as a sheet-like cupola, represented by accessory fluorite, allanite, zircon, and Nb-rare earth element (REE) oxides. Field observations, textural evidence, and geochemical attributes suggest a comagmatic origin for the three granite types. The low P, least-evolved syenogranite has high K/Rb (406–878), $(La/Yb)_N$ = 7.2–13.6, $(Gd/Yb)_N$ = 2.4–3.7, and Eu/Eu* = 0.30–0.61. Alkali feldspar granite shows more fractionated K/Rb (51–348), with $(La/Yb)_N$ = 3.5–3.7, $(Gd/Yb)_N$ = 0.9–1.3, and Eu/Eu* = 0.14–0.26. Albite granite (comenditic) is characterized by very low K/Rb (35–17), Zr (433–1226 ppm), high Nb (410–867 ppm), Y (49–260 ppm), Th (50–98 ppm), U (30–70 ppm), and HREEs with flat $(La/Yb)_N$ and $(Gd/Yb)_N$ < 1. The robust Zr/Ti fractionation index covaries very strongly with high field strength elements (HFSE) and high Zr + Nb–Y + Ce in the host albite granite, as well as low Al/Ga are consistent with transitional to mantle A-type signatures formed through extensive fractional crystallization from the alkali feldspar granite, which produced a residual high-silica melt and a late-stage, high-F magmatic volatile phase. Such a highly evolved melt was parental to the mineralized albite granite, forming within the apex to the alkali feldspar granite. These geochemical characteristics along with the continuous variations in most of major and trace elements are consistent with fractional crystallization from a magma derived by partial melting of granulitic lower crustal and mantle sources. There is evidence for fluid fractionation during the evolution of the albite granite. Limited subsolidus replacement of the K-feldspar by albite occurred in the alkali feldspar granite, whereas albite laths and Fe-Ti oxides are well developed in the albite granite. The volatile fluxes in these magmas lowered the crystallization temperature of the accessory minerals, extending the duration of quartz and feldspar crystallization, allowing HFSE elements (including REE, Y, U, Th) to behave incompatibly. Rare-metal enrichment was further promoted by volatile complexing, i.e. hydroxide and fluoride complexes. The rare-metal-bearing accessory minerals locally crystallized in the interstices between the major mineral phases. Extensive magma differentiation led to the exsolution of volatiles enriched in HFSE elements. Intense fluid–rock interaction occurred in the most advanced stages of magmatic–hydrothermal evolution, leading to locally extensive pervasive alteration–mineralization of the albite granite.

INVESTIGATION OF TUNGSTEN RELEASE AND MOBILITY IN SCHEELITE MINE TAILINGS THROUGH COLUMN EXPERIMENTS

Mark Flesch, Hanika Rizo, Richard Amos
Carleton University.
E-mail: *markflesch@cmail.carleton.ca*

Scheelite ($CaWO_4$), a mineral with growing demand, is being mined at increasing rates worldwide. Its valuable component, the heavy metal tungsten (W), has been identified as a potential biological and environmental hazard. Despite this, the transport of W from scheelite tailings sources is poorly constrained. Here, we have analyzed the release of W from scheelite in a laboratory setting, in order to better understand the mechanisms related to its transport through groundwater. Tungsten-rich tailings samples from the Cantung Mine in the Northwest Territories were used to study mineral dissolution rates through column experiments in aerobic and anaerobic conditions. Additionally, a mix of scheelite and quartz, representing a simplified system, was also used to study dissolution rates. Leachate samples taken incrementally along the columns over two months were analyzed to determine the sulphate, ferrous iron, alkalinity, major and trace element concentrations including W. The geochemical modelling software PHREEQC was used to determine important mineral phases. Preliminary results show that there is indeed a release of tungsten with little change in pH in both aerobic and anaerobic environments.

CONTRASTING FEATURES OF ALUMINOUS ROCKS: EVIDENCE OF THE LOW-PRESSURE BELT IN THE CENTRAL GRENVILLE PROVINCE

Arlin Fonseca, Aphrodite Indares
Memorial University of Newfoundland.
E-mail: *abfonsecamar@mun.ca*

The hinterland of the Grenville orogen is characterized by widespread exposure of high-grade metamorphic rocks that were exhumed from different structural levels, providing the basis for a division in belts. In the Central Grenville Province, the High-Pressure and Mid-Pressure belts record metamorphism under eclogite to high-pressure granulite-facies conditions, and mid-pressure granulite-facies conditions, respectively. In addition, a Low-Pressure belt was initially recognized to the south, in the Escoumins Supracrustal Belt, with greenschist to amphibolite facies rocks. However, mineral assemblage and textures in aluminous rocks between the Escoumins Supracrustal Belt and a major shear zone that bounds the well documented portion of the Mid-Pressure belt suggest low-pressure granulite-facies conditions implying a wider extension of the Low-Pressure belt. Aluminous rocks are used in this contribution to compare the Mid-Pressure belt (where they have been well documented and used for P–T determinations) and review the presumed extension of the Low-Pressure belt. The mineral assemblage of the Mid-Pressure belt is dominated by garnet, kyanite/sillimanite, biotite, K-feldspar, plagioclase, and quartz with varied evidence of former melt such as feldspar films in between other minerals, and clusters of biotite as a product of back-reaction during melt crystallization. Garnet commonly contains inclusions with resorbed kyanite/sillimanite, quartz or biotite in a pool of feldspar, indicative of peritectic garnet growth during biotite dehydration melting. Cordierite is locally present but is interstitial and interpreted as a product of melt crystallization at lower pressure than the metamorphic peak. On the other hand, the mineral assemblages of the presumed granulite-facies portion of the Low-Pressure belt includes garnet, sillimanite, biotite, cordierite, K-feldspar, plagioclase, quartz, and orthopyroxene, garnet, biotite, plagioclase, K-feldspar, quartz. Cordierite and orthopyroxene highlight the differences in the metamorphic evolution between the rocks of the two belts. Cordierite appears to be part of the peak assemblage, suggesting lower pressure conditions than in the Mid-Pressure belt, and orthopyroxene only forms at high-temperature stages of the dehydration melting of biotite, at low to mid-pressure conditions. Additionally, former melt inclusions were not recognized in garnet from the Low-Pressure belt, suggesting that it may have formed by a different reaction. The high-temperature character of the granulite portion of the Low-Pressure belt and the presence of large syn-orogenic A-type granitoid plutons in the same area suggest a locally important high geothermal gradient and a more complex tectono-magmatic history of the Grenville orogeny.

THE ARCHEAN HAMMOND REEF DEPOSIT: THE FORMATION OF AN OROGENIC GOLD DEPOSIT IN A CONTRACTIONAL STEP-OVER-ZONE ALONG A MAJOR STRIKE-SLIP FAULT SYSTEM

Gabrielle Fouillard, Bruno Lafrance, Jeffrey Marsh, Mike Hamilton
Laurentian Univeristy.
E-mail: *gfouillard@laurentian.ca*

The Hammond Reef deposit is an orogenic gold system with a measured and indicated resource estimate of 3.3 Moz at an average grade of 0.84 g/t gold. It is located in the south-central region of the Western Wabigoon Subprovince in northwestern Ontario. The Hammond Reef is hosted in the Marmion Shear System (MSS) which is defined by north- to northeast-trending shear zones. The MSS straddles the contact between the ca. 2890.2 ± 1 Ma Diversion stock to the west and Mesoarchean Marmion Batholith to the east. Multiple shear sense indicators, including the deflection of mylonitic foliation in shear zones, drag folds, and shear bands, suggest that the MSS is a major sinistral transcurrent shear system. The bulk of gold mineralization is located in an east-northeast trending bend along the MSS characterized by intense sericite and carbonate alteration, syn-tectonic hydrothermal quartz breccias and shallowly dipping quartz-carbonate veins. This bend represents a contractional step-over-zone between two regional sinistral transcurrent faults. Compression

across the bend resulted in more fracturing that localized the migration of hydrothermal fluids and gold precipitation at ca. 2700 Ma to ca. 2690 Ma.

PREDICTIVE MAPPING FOR BASE AND CRITICAL METAL EXPLORATION USING MULTIVARIATE STATISTICAL ANALYSES IN THE NEW QUÉBEC OROGEN AND WITHIN ITS RETTY ZONE, QUÉBEC, CANADA

Herbert W. Fournier[1], Deanne van Rooyen[2], Stefanie M. Brueckner[3]
[1]Cape Breton University, [2]Acadia University, [3]University of Manitoba.
E-mail: *herbert_fournier@cbu.ca*

Remote predictive mapping is increasingly used to identify and investigate potential exploration targets. This project applies principal component (PC) analyses and K-means clustering algorithms to geochemical data from the New Québec Orogen (NQO) to investigate spatial distribution of possible exploration vectors, and to link those exploration vectors to large-scale crustal structures. Software ioGAS-64™ was used to apply the multivariate techniques to a dataset of geochemical data from 11,260 lake sediment samples obtained from the Système d'information géominière of Québec. The economically significant metals Ag, As, Au, Bi, Co, Cr, Cu, Fe, Mo, Pb, Se, Th, U, V, W, and Zn were selected for analysis. The results show that across the entire NQO four principal components (PC1–PC4) yielded eigenvalues ≥ 1.0 accounting for 58.0% of the variability. PC1 and PC2 comprise the variability between Se, U, Mo and W, and Cu, Ag, Au, Se, Zn and Cr, respectively. PC3 accounts for an enhanced separation between As, Zn, Bi, Pb, Fe, Ag, and Mo. PC4 accounts for positive eigenvectors for Pb and Bi. The association of elements included in PC1 was interpreted as metals transported by sedimentary processes and could potentially be used to highlight areas with hazardous metal elevations (e.g. U, Se). The high scores of PC2 represents metals derived primarily from bedrock units and correlates strongly with bedrock geology. A K-means clustering equal to 6 was obtained using these PCs. The PC2 and K-means results correlated with Ni-Cu-PGE occurrences reported within the Retty and Hurst zones. A refined PC analysis into the Retty Zone (RZPC) over a dataset of 1272 samples using the same metals plus Ni and Li yielded six PCs with eigenvalues ≥ 1.0 accounting for 72.7% of the variability. RZPC1 comprises the variability between Se, Cu, Ag, W, and Au which might correspond with sedimentary and glacial transport. RZPC2, RZPC3 and RZPC4 account for the variability between Cr, V, Ni, Pb and Bi; Co, Ni and Zn; and As, Pb, Ag, Ag and Au, respectively, matching previously reported mineralization occurrences and potentially highlighting new ones. RZPC5 and RZPC6 comprise the variability between Zn and Pb, respectively, and might indicate glacial transport and mineralization. The results of these analyses show that the methods can pinpoint the location of known metal occurrences with excellent spatial accuracy, and in several tested areas accurately outline known geological units. These types of statistical techniques can therefore be used to predict similar occurrences in underexplored areas.

HALOGEN (Cl-Br-I) SYSTEMATICS OF METAMORPHIC FLUIDS THROUGH TIME - A POWERFUL FLUID PROVENANCE TRACER IN OROGENIC GOLD SYSTEMS

Tobias Fusswinkel, Paula Niinikoski-Fusswinkel, Thomas Wagner
RWTH Aachen University.
E-mail: *tobias.fusswinkel@emr.rwth-aachen.de*

The heavy halogens (Cl, Br, I) are exceptional tracers of fluid provenance due to their largely conservative behaviour during fluid-rock interaction processes. While bromine-chlorine ratios have long since been used as provenance tracers, mounting evidence suggests that different geological processes such as evaporation and organic matter interaction result in similar Br/Cl signatures, significantly impacting the utility of Br/Cl ratios as a source tracer in many crustal environments. Iodine, a highly biophilic element, provides an additional proxy that makes it possible to discern between these convergent processes, but it poses significant analytical challenges due to its low concentrations in hydrothermal systems, and until recently could only be analysed using bulk analytical techniques, which cannot resolve complex overprinting fluid signatures commonly observed at the sample scale. However, recent advances in LA-ICP-MS halogen fluid inclusion microanalysis have made it possible to measure Cl-Br-I concentrations in individual fluid inclusions, providing novel opportunities for the study of hydrothermal ore systems with complex protracted fluid histories. We present a comprehensive triple-halogen Cl-Br-I fluid inclusion LA-ICP-MS dataset of Phanerozoic to Archean metamorphic fluids, including ore-forming fluids of the Neoarchean Pampalo orogenic gold deposit (Finland). We show that Phanerozoic metamorphic fluids attain distinct and very systematic halogen signatures within a narrow compositional envelope reflecting variable degrees of organic matter interaction up to very low Br/I ratios relative to seawater, and that these signatures are unaffected by fractionation processes even to high metamorphic grades. The ore-forming fluids of the Pampalo orogenic gold deposit were also derived from organic matter-rich source rocks, but they possess vastly different halogen signatures characterized by high Br/I ratios, which are incompatible with any known halogen fractionating mechanism or fluid source reservoirs like magmatic fluids or bittern brines. We propose that the low iodine contents in these fluids directly reflect the lack of iodine-metabolizing eukaryotic life in Archean oceans, which would have prevented biosequestration of iodine into clastic sediments and limit uptake of iodine into later metamorphic fluids. We show that the halogen signatures of metamorphic fluids reflect the development of Earth's halogen cycles with the proliferation of eukaryotic life, and provide a powerful tool in discerning metamorphic, magmatic and other fluid sources in orogenic gold systems.

PHOSPHATIC, MANGANIFEROUS IRONSTONES OF THE RAPID CREEK FORMATION (NORTHWEST TERRITORIES): A PRELIMINARY STUDY

Michael Gadd, Nikole Bingham-Koslowski, Duane Petts
Geological Survey of Canada.
E-mail: *nikole.bingham-koslowski@nrcan-rncan.gc.ca*

The Rapid Creek Formation contains substantial accumulations of manganiferous ironstones and phosphorites - marine sedimentary rocks deposited on continental margins - that are located in the northern Richardson Mountains of Yukon and Northwest Territories. It was deposited in the northernmost portion of the Western Interior Seaway near the Aptian-Albian boundary (late Early Cretaceous), a significant period in Earth's history associated with oceanic anoxic events. Potentially economically significant iron, phosphorus and manganese resources have been documented in the formation; phosphatic ironstones average approximately 33 wt.% Fe_2O_3, 14 wt.% P_2O_5 and 5 wt.% MnO. The Rapid Creek Formation is perhaps best known for its rare phosphate mineralogy, where it is the source of Yukon's official gemstone (lazulite) as well as the type locality for several phosphate species. These minerals are mostly secondary (i.e. post-depositional), typically filling fractures or forming epitaxially in veins. Otherwise, the Rapid Creek Formation has seen little new work since the early reconnaissance-scale studies in the 1970s. Manganese is a critical mineral, and Mn oxides and sedimentary phosphates have a high affinity for rare earth elements (REE), both of which provide impetus for renewed studies of the Rapid Creek Formation. Preliminary observations from this study suggest syn-depositional to early diagenetic phosphate precipitation, including nodules and hardgrounds. Nodules are present in hematitic sandstone and comprise siderite, apatite, and a Ba-Al-phosphate mineral (gorceixite), with delicate mm-scale blades protruding into the sandstone. Phosphatic hardgrounds contain crypto-crystalline apatite, reworked clasts of nodular phosphates, pyrite, and terrigenous clasts. The pyrite is variably altered to Fe ± Mn oxides. Despite the abundance of phosphates and Mn oxides, bulk REE contents are low (less than or equal to average shale). Moreover, shale-normalized REE patterns show little deviation from average shale - a somewhat surprising outcome given the mineralogy. Preliminary laser ablation-ICP-MS mapping reveals a more nuanced distribution of REE among clasts, oxide minerals, and apatite, where apatite has fairly typical patterns (middle-REE-enriched, negative Ce anomaly) and clasts and oxides are light-REE- and heavy-REE-enriched, respectively. Future work aims to constrain the geochemical and sedimentological controls that resulted in the deposition and preservation of the Rapid Creek Formation, while providing insights on paleoenvironmental conditions conducive to the formation of these ironstones.

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MODERN IMAGERY PLATFORMS IN SUPPORT OF INTEGRATED GLACIER RESEARCH

Henry J.M. Gage, Carolyn H. Eyles
McMaster University.
E-mail: *gageh@mcmaster.ca*

Recent improvements to imagery platforms have expanded the breadth and precision of data for the study of glacial environments. At large spatial scales, remote sensing offers the opportunity to collect spatially continuous data without intensive field sampling. Advances in uncrewed aerial vehicle (UAV) technology now enables low-cost, high-precision imagery collection in challenging field environments. These approaches can be used to produce and evaluate orthomosaics, digital elevation models, and multispectral indices which offer a novel perspective on glacial processes. However, imagery platforms are infrequently used in tandem with paleoclimatic data despite the fact that together they offer a holistic perspective. Here, we describe a multi-method approach which combines remote sensing, UAV, and thermal imagery with paleoclimatic data to examine the effects of climate change on water quality and quantity released by tropical glaciers of the Cordillera Blanca, Peru. This is advantageous because these datasets are complementary and enhance our understanding of both past conditions and modern processes. Imagery data is spatially extensive, with a short but precise temporal extent. Conversely, paleoclimatic data offers a long, but less precise temporal record that is spatially restricted. Paleoclimatic data can also be used to support ground-truthing of remote sensing imagery, while imagery platforms can provide insight into the relationship between geochemical proxies and contemporary glacial processes. In the Cordillera Blanca, data from lacustrine sediment records indicate that recent changes in climatic conditions have raised sediment input and caused iron enrichment in glacial meltwater. Remote sensing and UAV imagery offer additional process-based insight which reveals that these changes are driven by an increase in bedrock weathering resulting from glacial retreat. This integrated approach, utilizing several imagery platforms, can be used to overcome the limitations of individual datasets in remote field environments to offer a more complete understanding of glacial processes.

PROTEROZOIC ZIRCON DATES FROM AURIFEROUS ZONES AT THE ISLAND GOLD DEPOSIT: IMPLICATIONS FOR LATE GOLD REMOBILIZATION IN THE SUPERIOR PROVINCE

Sophie Gagnon, Chris Yakymchuk, Ivan Edgeworth, Shoufa Lin, Brian Kendall
University of Waterloo.
E-mail: *sm2gagno@uwaterloo.ca*

The Island Gold deposit is a high-grade Archean orogenic gold deposit within the Michipicoten greenstone belt of the Superior Province. Hosted within the ~2750 Ma felsic to intermediate Wawa metavolcanic assemblage, gold mineralization has been constrained to between ~2680 and 2672 Ma. However, anomalous Proterozoic ages have been discovered within auriferous alteration zones, suggesting that late hydrothermal activity may have affected the deposit and potentially re-mobilized gold. Mineralization is hosted within quartz (± carbonate) veins, with minimal mineralization within the surrounding altered host rock. To investigate the occurrence and spatial distribution of these anomalous young ages within the deposit, samples along an alteration gradient (weakly to strongly altered) adjacent to auriferous quartz ± carbonate veins, and from differing depths within the ore zone were examined. U–Pb LA-ICP-MS analyses of zircon from strongly altered auriferous zones yielded Archean protolith dates as well as Mesoproterozoic and early Paleozoic to late Mesozoic age groupings. Compared to Archean zircons in the host metavolcanic rocks, the younger zircons have generally higher concentrations of heavy rare earth elements and moderate enrichment in Y, Ta, and Th. We interpret the Mesoproterozoic ages to represent fluid-rock interaction associated with the Grenville orogen or the Mid-Continent Rift, whereas the Paleozoic to Mesozoic grouping may be related to alkalic/kimberlitic activity within the area. It is unclear if these fluids had compositions amenable for large-scale gold mobilization, but they may have played a role in locally distributing gold throughout the Island Gold deposit. An increasing number of reported Proterozoic dates from accessory minerals in Archean gold deposits suggests that post-Archean processes are a potential complication for understanding the distribution of gold and has regional implications for gold exploration in the Superior Province.

CRUSTAL SCALE MODELLING OF GRAVITY DATA USED TO IDENTIFY RIFTING/SEAFLOOR SPREADING IN MODERN AND ANCIENT SEAFLOOR SETTINGS

Christopher Galley[1], Alan Baxter[1], Michael King[2], Erin Bethell[1], Mark Hannington[1], Peter Lelievre[3]
[1]University of Ottawa, [2]Memorial University of Newfoundland, [3]Mount Allison University.
E-mail: *gchrist2@uottawa.ca*

Towards the end of the Archean the Earth's crust had sufficiently cooled to begin a transition period into the formation of tectonic plates. Convective forces from rising mantle plumes or early forms of plate subduction caused these ancient tectonic plates to undergo crustal spreading and/or rifting, where extensional forces created linear zones of crustal growth much like modern seafloor spreading centers. These spreading centers can be identifiable in the ancient rock record by the relic crustal thinning caused by their extension and subsequent mantle upwelling, represented by ridge-like features in the boundary between the crust and the lithospheric mantle, i.e. the Moho. It is at these areas of extension and spreading, on the paleoseafloor, where volcanogenic massive sulphide (VMS) deposits formed. Gravity data collected over such settings can be modelled to produce a 3D density Earth model, from which an elevation map of the Moho can be derived, and from this a crustal thickness map. However, due to the billions of years of deformation Archean crust has undergone, interpreting crustal thickness maps can be challenging. To combat this, we have chosen the Abitibi greenstone belt as our area of study for this project as it contains some of the best-preserved Archean greenstone belts in the world. Yet, however well-preserved the Abitibi is, a control model is still needed, where mapped spreading centers and other crustal structures can be compared against a crustal thickness model. For this, we used the Lau Basin, an actively forming back-arc basin north of New Zealand, as it is at present the best mapped back-arc basin in the world. With the Lau Basin crustal thickness model, we could verify that active and relic rifting and/or seafloor spreading could be seen in the topography of the Moho, allowing us to identify these features in the Abitibi. We propose that knowing the geometry and spatial density of relic spreading centers and/or rifts in Archean greenstone terrains can be used to indicate metal endowment as they can correlate to the occurrence of VMS deposits.

FINAL DRAINAGE OF GLACIAL LAKE AGASSIZ-OJIBWAY: A CLOSER LOOK

Cunhai Gao
Ontario Geological Survey.
E-mail: *george.gao@ontario.ca*

The final, sudden drainage of Lake Agassiz-Ojibway into Hudson Bay is often thought to have freshened the ocean, causing cooling at 8.2 ka as recorded in the Greenland ice core. In the Sandy Lake area in the former Lake Agassiz basin, northwestern Ontario, basal wood samples in surface peat indicated the abandonment of the Ponton beach shortly before 8.1 cal ka. If the time for vegetation colonization is considered, the true age is estimated around 8.15 cal ka. This beach has been suggested to represent the shoreline prior to the final drainage of the lake but has never been directly dated before. The dating result was consistent with the age recently estimated for the drainage event (8.16 cal ka). However, in the Tyrrell Sea/Lake Ojibway basin in the James Bay Lowland, northeastern Ontario, fieldwork at the large open pit of the Victor diamond mine suggested a complicated picture. Logging and sampling along the open pit wall and on the nearby drill cores did not indicate the presence of Lake Ojibway sediments below the Tyrrell Sea deposirts, suggesting that the ice margin at that time was located further to the south. Radiocarbon dating results on basal marine shells at 8.0 and 8.1 ^{14}C ka from the open pit and a nearby drill core were in good agreement with previous dating work across the lowland, suggesting simultaneous marine incursion in this region. Previous calibration of radiocarbon dates on marine fossils is based on marine reservoir effects (ΔR) derived from modern marine samples and, as a result, the calibrated ages tend to be too old

because of larger ^{14}C depletion in the ocean in the glacial period. In the current study, a specific ΔR at 630 ± 76 years derived from paired wood and marine bivalve samples from this site was used in calibration. The calibrated ages on the basal marine shells were at 7.5–7.9 cal ka and 7.5–8.0 cal ka each with a median at 7.7 cal ka, younger than the 8.2 ka cooling event.

REGINAL TILL SAMPLING FOR CRITICAL MINERALS: A CASE STUDY IN ONTARIO'S RING OF FIRE AREA

Cunhai Gao, Dave Crabtree
Ontario Geological Survey.
E-mail: *george.gao@ontario.ca*

Regional till sampling has been undertaken in Ontario for more than 4 decades. Modern alluvium or stream sediment was also sampled in the field concurrently as separated projects. Despite the frequent, irregular sample grids due to the terrain conditions, a thick cover of vegetation and the lack of road access, many of these sampling projects successfully detected the glacial dispersal plumes of the mineral deposits including gold, kimberlites, carbonatite, and chromite. Till and stream sediment were sampled in Ontario's Ring of Fire area on the margin of Hudson Bay Lowlands where multiple till units occur. The results show significantly anomalous detrital chromite grains (2.0–0.125 mm) in an area along the Attawapiskat River about 40 km south of the known mineralization near Esker Camp. Many sand-size chromitite clasts (2.0–0.5 mm) and a pebble-size boulder were also found in the samples. Microprobe analysis indicates that the chromite grains differ geochemically from those derived from the known mineralization. Stratigraphically, these grains came mostly from the middle and lower till units both of which have an ice flow direction to the southwest. Based on the geochemical fingerprints and ice flow directions, these chromite grains likely came from an unknown source located somewhere in the area to the northeast of Highbank Lake.

SURFICIAL SAMPLING IN ONTARIO: PAST, PRESENT, AND FUTURE

Cunhai Gao, Grant Hagedorn, Dave Crabtree, Andrea Marich
Ontario Geological Survey.
E-mail: *george.gao@ontario.ca*

Over the past 40 years, the Ontario Geological Survey has completed many surficial sampling projects to assist mineral exploration efforts. Even with limited access due to terrain condition, thick vegetation cover, and sparse road networks, many of these projects successfully detected the dispersal features of the mineral deposits. Notable examples are till sampling in the Rainy River area for gold, modern alluvium or stream sediment sampling in the James Bay Lowland for kimberlites, till sampling for carbonatite intrusions in the Chapleau area, and till and stream sediment sampling in the Ring of Fire area for chromite deposits. Current till sampling is being undertaken for Ontario's Far North terrain mapping project, e.g. sporadic till sampling in the Pickle Lake and Sandy Lake areas, and for the surficial mapping project along the Highway 17 corridor between Sudbury and Mattawa. Furthermore, in response to the demands for critical minerals, a project to map and sample the area south of Lake Nipigon with known pegmatites, e.g. Georgia Lake Pegmatite Field, has been approved. Additionally, a multi-year project is currently underway to analyze the large number of archived fine fraction (< 0.25 mm) non-magnetic heavy mineral concentrate (HMC) samples for modal mineralogy using SEM energy dispersive X-ray spectroscopy. These legacy samples have good potential for identifying possible critical mineral indicator minerals not previously identified in the coarse fraction (0.25–2 mm) non-magnetic HMC.

PHLOGOPITE DEFORMATION FEATURES IN KIMBERLITES. ARE THEY ALWAYS A RELIABLE INDICATION OF A XENOCRYSTIC ORIGIN FOR PHLOGOPITE AT MANTLE DEPTHS?

Song Gao[1], Roberta L. Flemming[1], Anton R. Chakhmouradian[2]
[1]Western University, [2]University of Manitoba.
E-mail: *sgao289@uwo.ca*

Phlogopite in kimberlites often displays evidence of ductile deformation in the form of kink-banding and undulatory extinction ascribed to strain in the lithospheric mantle. Such deformation textures have been used as convincing evidence for recognizing phlogopite xenocrysts derived from the disaggregation of metasomatized mantle wall rocks. In this work, the degree of plastic deformation in micas from the Drybones Bay and Mud Lake kimberlites was quantified by measurement of streaking along the Debye ring in 2D X-ray diffraction images as sum of full width at half maximum ($\Sigma FWHM_\chi$). Four distinct types of mica were identified based on their textural characteristics, chemical composition, and strain measurements. The first variety (type 1) is observed as discrete crystals and crystal fragments occasionally containing apatite inclusions. These crystals correspond to biotite, enriched in FeO (Fe# = 56 ± 3) and TiO_2 (1.84 ± 0.49 wt.%), but depleted in Cr_2O_3 and BaO (< 0.10 and 0.36 wt.%, respectively). Strain measurements show that they experienced a low to moderate degree of strain-related mosaicity (SRM; $\Sigma FWHM_\chi$ = 5.33 ± 3.91°). Biotite embedded in granitoid nodules (type 2) shows lower concentrations of FeO (Fe# = 49 ± 3) and attenuated SRM ($\Sigma FWHM_\chi$ = 2.52 ± 1.32°), but comparable levels of TiO_2 (1.84 ± 0.26 wt.%), Cr_2O_3 (< 0.10 wt.%) and BaO (< 0.34 wt.%) relative to type 1 biotite. Euhedral-subhedral, unzoned phlogopite macrocrysts and microcrysts (type 3) contain low TiO_2 (0.20–1.24 wt.%), Cr_2O_3 (< 0.62 wt.%) and BaO (< 0.30 wt.%) contents, accompanied by a wide range of Mg# (83–93) and SRM ($\Sigma FWHM_\chi$ = 0.76–25.52°, 6.66 ± 4.31°) measurements. Rounded, partially embayed type 4 phlogopites with hematite lamellae are characterized by somewhat higher TiO_2 (0.14–1.89 wt.%) and Cr_2O_3 (< 0.67 wt.%), but lower SRM ($\Sigma FWHM_\chi$ = 0.98–6.06°, 2.98 ± 1.51°) and similar Mg# (83–94) with respect to the type 3 phlogopites. Notably, most examined mica grains show deformation features, whereas the type 3 phlogopite stands out in showing a multimodal distribution of $\Sigma FWHM_\chi$ values. One feasible explanation is that at least some of the phlogopite microcryst population are cognate phenocrysts and the SRM in these grains is constrained to occur at much shallower depths (i.e. at crustal levels) during kimberlite magma ascent and emplacement. Moreover, the consistently low degree of SRM in type 2 biotite suggests that external stresses caused by the grain tumbling and abrasion during turbulent kimberlite magma flow have a negligible effect on this type of mica. The observed strain features in these minerals, instead, may be inherited from their Archean Defeat plutonic host.

POSTGLACIAL TO INTERGLACIAL MIS 7 SEDIMENTS NEAR GILLAM, MANITOBA, CANADA

Michelle Gauthier[1], Tyler Hodder[1], April Dalton[2], Olav Lian[3], Sarah Finkelstein[4], Minna Väliranta[5], Martin Ross[6], Maria Schaarschmidt[3]
[1]Manitoba Geological Survey, [2]Memorial University of Newfoundland, [3]University of the Fraser Valley, [4]University of Toronto, [5]University of Helsinki, [6]University of Waterloo.
E-mail: *michelle.trommelen@gmail.com*

It has long been thought that Quaternary sediments at the surface belong to the Holocene and the youngest glaciation, and that preservation of older sediments deposited during previous glacial and interglacial periods is rare in north-central Canada. In contrast to this, a gravel pit, at the edge of the western Hudson Bay Lowland near the geographic centre of the North American Ice Sheet Complex, exposes near-surface (< 3 m depth) glacial and non-glacial sediment that predates the last glaciation. At the base of the exposure, glaciofluvial gravel (> 7.5 m thick) is overlain by faulted sands and gravelly sands (~2.0 m thick), with paleocurrents towards Hudson Bay. The sands yielded an optical age of 214 ± 19 ka (1σ error; minimum age model), corresponding to the interglacial Marine Isotope Stage (MIS) 7. A 4.5 m thick unit of laminated silt, deposited within a low-energy floodplain or pond, overlies the sands. Pollen and macrofossil taxa from these silts indicate deposition within a period similar to, or slightly warmer than, present day with slightly higher precipitation. The nonglacial silts are capped by a blocky and dense brown till (3.0 m thick) and glaciolacustrine silt and clay (~1.5 m thick). This site highlights the need to provide absolute ages for Quaternary sediments, given that the uppermost subtill nonglacial sediments in the stratigraphic record were deposited during MIS 7. No depositional record of the MIS 5 interglacial period was found here. Identification of similar 'old' patches preserved in the depositional record, together with till stratigraphy and composition, is essential to unravel large ice-sheet dynamics in response to climatic changes.

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VOLCANIC EVOLUTION AND BASE METAL ENDOWMENT OF THE SWAYZE AREA, ABITIBI GREENSTONE BELT

Thomas Gemmell
Ontario Geological Survey.
E-mail: *thomas.gemmell@gmail.com*

The Swayze area of the western Abitibi greenstone belt contains most of the chronostratigraphic metavolcanic episodes present in the metal-endowed eastern Abitibi greenstone belt; however, few base metal ore deposits have been discovered. New mapping, lithogeochemical, and geochronological data, in conjunction with Metal Earth geophysical surveys, have resulted in a new interpretation of the crustal architecture for the Swayze area. Although the Swayze area contains some of the oldest and youngest Abitibi greenstone belt volcanic episodes, significant differences occur between the two areas such as: (1) the absence of Tisdale episode volcanic rocks (2710–2704 Ma); (2) the abundance of Pacaud (2750–2735 Ma) and Blake River (2704–2695 Ma) volcanic rocks, with the latter lacking volcanic centres containing subvolcanic plutons; (3) the absence of extrusive ultramafic rocks in volcanic episodes except for the Blake River episode; (4) the anomalously thick (up to 200 m) and extensive (up to 20 km) intra-volcanic episode iron formations which contain the known base metal mineralization, and (5) the significant inherited zircons compared to volcanic rocks of the eastern Abitibi greenstone belt. Compared to the eastern Abitibi greenstone belt, these differences suggest that the Swayze area may have a less juvenile crust, a volcanic evolution with fewer mantle plumes, fewer volcanic episodes that lacked the development of localized magmatic/hydrothermal centres, and long volcanic hiatuses during which iron formations containing the known base metal prospects formed (e.g. Shunsby and Jefferson). Such features, collectively, are less favourable for volcanogenic massive sulphide deposit formation.

MISTASSINI-OTISH IMPACT STRUCTURE IV: SIGNIFICANCE OF THE SHOCK METAMORPHISM OBSERVED OVER 450 Km IN DETRITAL SEDIMENTS DEPOSITED PRIOR TO 2.17 Ga IN THE STRUCTURAL TROUGHS DEVELOPED WITHIN THE GRENVILLE FORELAND ZONE

Serge Genest, Francine Robert
Astroblèmes Québec Inc.
E-mail: *astroblemesquebec@gmail.com*

Impact formations have been found in the Mistassini basin, bridging the Chibougamau Formation and the Otish Group for which shock metamorphism features had been previously observed. These impactites are preserved within structural troughs pertaining to a multi-ring impact basin: the Mistassini-Otish impact structure (MOIS). The event is tentatively dated at 2.17 Ga, i.e. the age of the Otish gabbro which is interpreted as a 'mare basalt' which ground-hugged and capped the ejected materials. The transient crater diameter has been estimated to be 508 km and the final crater in the order of 1150 km, thus being the largest impact structure ever reported for the Earth. The shock stages and pressures determined are respectively F-S5 and > 35 GPa for the Chibougamau mining camp, F-S6 and > 60 GPa for the Mistassini basin, and SR-S4 or SE-S4 and > 5.5 GPa for the Otish basin. It is important to note that carbonate rocks are not considered in this classification. Nevertheless, the huge carbonate melt sheet that filled the Mistassini trough is obviously the most striking feature. The targeted terrain was likely a thick carbonate platform in development on a continental margin where stromatolites were flourishing. The timing of the MOIS event nearly coincided with some major changes in the atmosphere and Earth's interior, such as the Great Oxygenation Event ca. 2.3–2.1 Ga, the seemingly coeval Lomagundi Carbon Isotope Excursion, the huge magmatic event observed ca. 2.2 Ga in the Canadian Shield which involved mixing of crustal and mantle rock units, the ore genesis of the Chibougamau mining camp inferred to a major regional event ca. 2.2 Ga, amongst others. The most interesting input is probably the availability of reduced phosphorus to living organisms through the arrival of airborne glassy P-rich spherules. Given the energy developed by the event, the Mistassini spherule layer was deposited worldwide, thus providing reduced phosphorus everywhere on the Earth's surface. Finally, the thickness of the impact magma developed by the MOIS event could have reached > 23 km according to impact modeling, an information that should be taken into account when dealing with the emplacement of anorthosite massifs that occur in the Lac Saint-Jean area.

MISTASSINI-OTISH IMPACT STRUCTURE III: FIRST REPORT OF A HUGE DOLOMITIC MELT SHEET AS THE UPPERMOST UNITS OF THE ALBANEL FORMATION, MISTASSINI GROUP

Serge Genest, Francine Robert
Astroblèmes Québec Inc.
E-mail: *astroblemesquebec@gmail.com*

Regional surveys done in 2015, 2016, and 2017 in the study area revealed the existence of two strongly different dolomite types. The first one, observed in the southern third of the basin, is obviously of sedimentary origin. It displays intense fracturing usually filled with pyrobitumen, anthraxolite, and a very hard carbon allotrope (lonsdaleite?). The second one characterizes the two northern thirds of the basin and is totally different in its habit. It is made of very thick beds of aphanitic dolomite showing vertical jointing and nearly devoid of horizontal ones. Locally, the vertical fracture sets define columnar jointing when the dolomite outcrops in cliffs as can be seen at Lake Cleary. Weathering favoured these fractures sets in the dolomite units, therefore enhancing the vertical fracturing pattern. One observation argues against their tectonic origin, i.e undisturbed black cherty nodules seen bridging over weathered open fractures in thick dolomite bed. The most enigmatic features are probably the scarcity of bedding joints, the exceptional thickness of the beds (up to 6 m), and the banded appearance of some beds which, like some iron formations, exhibit alternating greyish and blackish hues without any textural changes. These observations are not coherent features for a basin involving such a chemical sedimentation. The most significant observation is probably a 465 m thick finely crystallized grey dolomite sequence without any jointing or bedding which has been described in a drill hole. Moreover, the only siliciclastic materials observed within that thick unit are rounded quartz grains averaging 1 mm in size, now recognized as immiscibility globules. As observed from HCl insoluble residues, some globules bear undetermined black inclusions likely incorporated while crystallizing. Given the density differential, their buoyancy could explain the distribution of the siliceous globules which can be scarce but homogeneously distributed in the mass, and evenly closer and nearly stratified at different levels throughout the carbonate sequences. The first case is a characteristic feature of many outcrops seen along the road 167, and for which well developed decimetre-scale hackle marks are commonly observed. It is noticeable that those finely crystallized dolomites bearing immiscible siliceous globules react as porcelain when broken and emit a phonolite-like ringing sound when struck with a hammer.

AUTOMATION OF IDENTIFICATION OF INDICATOR MINERALS USING µ-XRF

Léa Géring, Antoine Nadeau, Georges Beaudoin, Carl Guilmette
Laval University.
E-mail: *leger8@ulaval.ca*

This project aims at developing an automated method for identifying, counting, and characterizing indicator minerals (IMs) of the heavy mineral concentrate (HMC) from overburden sediments based on µ-XRF intensity maps. Polycaprolactone grain mount provides homogeneous composition of non-detectable elements (H, O, and C) and it allows grain top levelling. Grain levelling is necessary to prevent smaller grains being hidden by bigger grains, and because the X-ray source is not orthogonal to the stage. Polycaprolactone has a characteristic X-ray spectrum that yields important bremsstrahlung. The XRF signal at grain edges consists of a mixture between grain fluorescence and mount diffusion. The topography and variable grain size influence the absolute intensity of the characteristic peaks of the X-ray spectra. We develop a data processing workflow using µ-XRF raw count maps as input. First, it identifies grains based on thresholds using the sum of elements counts and the total counts in the bremsstrahlung region. Then, a binary image (grain/mount) is processed using PyImageJ to dissociate grains and determine a region of interest (ROIs) at each grain centre. ROIs data is used in a decision tree that aims at identifying the mineralogy. The first layer of the decision tree classifies into mineral groups such as silicates, sulphides, phosphates, or oxides, based on count thresholds for Si, S, P. The following layers use the threshold for other element counts or count ratios. Once the mineralogy of each grain is determined, composition measurement can be performed using the appropriate calibrated method. Since µ-XRF is semi-quantitative, calibration curves are needed for each mineral. Calibration is achieved using Electron Probe Micro-Analyzer (EPMA) measurements on standard grains. A calibration example shows that chromium and iron are accurately measured, whereas calcium and magnesium are, respectively, under and over-estimated in Cr-diopside. Future calibration work will focus on characteristics that indicate mineralization, such as chromium and calcium to accurately determine pyrope G10 subtype.

VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS: THROUGH METAL EARTH'S EYES

Harold Gibson[1], Taus Jørgensen[1], Keaton Strongman[1], Marina Schofield[1], Thomas Gemmell[2], Bruno Lafrance[1]
[1]Laurentian University, [2]Ontario Geological Survey.
E-mail: *hgibson@laurentian.ca*

The genetic model for volcanogenic massive sulphide (VMS) deposits is one of the best understood ore deposit models. This achievement reflects decades of deposit-scale research on ancient VMS deposits and on modern seafloor massive sulphide analogs. However, several key factors of the larger-scale, metallogenic processes in VMS formation remain enigmatic. For example, the processes responsible for localizing VMS deposits, their metal tenor and gold content, role of metalliferous magmatic fluids, and the absence or differential VMS endowment of seemingly equally permissible volcanic successions remain uncertain. The long-standing question as to why some greenstone belts contain VMS deposits whereas other belts do not is now expanded to what processes control the differential VMS endowment of greenstone belts, and, from an exploration perspective, how to predict VMS endowment. This presentation explores the problems of differential VMS endowment through a new understanding of the crustal architecture and the magmatic/tectonic evolution of Archean greenstone belts and VMS districts from a Metal Earth perspective. We examine the results of Metal Earth's crustal-scale geological, geochemical, isotopic, and geophysical (seismic, magnetotellurics, gravity) surveys. We show how crustal-scale features related to the architecture of greenstone belts (e.g. the presence or absence of Mesoarchean crust) have resulted in differences in the metallogenic processes (e.g. gold tenor) of VMS endowed and lesser endowed belts. Lastly, we discuss the features and processes responsible for differential metal endowment within the world class Rouyn–Noranda district.

EXPLORING SEAFLOOR MASSIVE SULPHIDE DEPOSITS ALONG THE CENTRAL AND SOUTHEASTERN INDIAN RIDGE: THE INDEX PROGRAM

Harold Gibson[1], Thomas Kuhn[2], Sebastian Fuchs[2], Ulrich Schwarz-Schampera[3], Michelle DeWolfe[4], Thomas Gemmell[5], Keaton Strongman[1], Margaret Stewart[4], Marina Schofield[1], Vanessa Freisen[6], Ralf Freitag[2]
[1]Laurentian University,
[2]Federal Institute for Geosciences and Natural Resources (BGR),
[3]International Seabed Authority, [4]Mount Royal University,
[5]Ontario Geological Survey, [6]Luossavaara-Kiirunavaara Aktiebolag.
E-mail: *hgibson@laurentian.ca*

To ensure a constant and stable supply of metals, the Federal Institute for Geosciences and Natural Resources (BGR) recognized the potential of marine mineral resources and was granted two licenses for the exploration of polymetallic manganese nodules in the Central Pacific in 2006, and for the exploration of seafloor massive sulphides (SMS) in 2015 along the mid-ocean ridge system in the Indian Ocean by the International Seabed Authority (ISA). The SMS license consists of 100 blocks, each 10 × 10 km totaling 10,000 km². The blocks are organized in 12 clusters along a 500 km-long segment of the Central (CIR) and 500 km along the Southeastern (SEIR) Indian Mid-Ocean ridge. The BGR developed what is now their ongoing INDEX program to explore for SMS deposits along the CIR and SEIR, with the first expedition in 2011 to support their application to the ISA. INDEX is an integrated geological mapping, chemical (plume) and geophysical exploration program with supporting biological and environment studies. Prior to the INDEX program, only 4 SMS sites (hydrothermal fields) were known on the CIR; JX, Sonne, Kairei, and Edmond. The INDEX program has had substantial success. As of 2022, INDEX has significantly increased the size of the Kairei and Edmond-Gauss-Score hydrothermal fields and discovered 10 new fields (2 on the CIR; 8 on the SEIR). The hydrothermal fields range in size and consist of high-and lower-temperature active and inactive sites; sulphide mounds have several distinct morphologies. The majority occur in tectonically active environments 6–17 km from the ridge axis where the SMS deposits formed on older, faulted, and uplifted Mn-crusted lavas and or talus deposits comprised of pillow and basalt talus. Three examples (Kaimana, JIM, Sooraj) are hosted by exhumed deeper oceanic lithosphere and formed on talus comprising variably serpentinized gabbro and pyroxenite. Penumbra, one of the largest SMS hydrothermal fields discovered to date by INDEX, covers 720,000 m^2, has a "strike length" of 1.7 km, and formed on an off-axial volcanic plateau comprised of older Mn-crusted sheet flows located 14 km from the ridge axis. Off-ridge, tectonically active and volcanically inactive environments are the most favourable for the formation of SMS deposits. To date only two small SMS deposits (Sonne and Pelagia) have been discovered in magmatic environments, both on young pillow volcanoes within 2 km of the ridge. This presentation will discuss these observations and their implications for ancient VMS ore systems.

ANOMALY THRESHOLD IN DETRITAL DISPERSION: FROM STATISTICS TO STOCHASTIC!

Rejean Girard
IOS Services Géoscientifiques Inc.
E-mail: *rejeang@iosgeo.com*

The general practice in exploration geochemistry is to look for samples that are enriched in metals or minerals of interest compared to other samples from the survey. Whatever method is used to select the above threshold, the concept leads to the intrinsic presence of anomalous samples in any survey, which is not necessarily the case. This method is thus spurious and plagued with false anomalies. The abundance of mineral grains such as native gold or pyrope in a sample is a discrete number per unit of mass. Because grains are randomly distributed in the sample, the presence of a grain in an aliquot is independent of the presence of the next grain. Grain abundance hence follows a Poisson distribution, and duplicate samples are not expected to necessarily have the same number of grains. The grain count probability can thus be computed, and elevated counts are possible from any regional signal, although with low probability. Since samples from a survey are deemed independent, their grain abundances are dictated by their own Poisson distribution. A summation of Poisson distributions, such as the grain abundance in a set of samples, follows an Erlang distribution with k degrees of freedom, an indication of the homogeneity of the system. Modelling the results from various surveys confirms that regional populations do follow such distribution, requiring low (2–4) degrees of freedom. The correlation coefficient between measured and predicted abundances is typically in excess of 99%. However, in many surveys, high count samples are discrepant compared to the predicted Erlang distribution, suggestive of the contribution of a small anomalous population with an elevated degree of freedom. Both the regional and anomalous signal can be characterized, and the probability of a contribution from the anomalous population can be computed. Anomaly threshold can then be set to the count where the probability of such count belonging to the anomalous population exceeds probability of belonging to regional population, based on the tolerance of the exploration geologist. Aside from minimizing the false anomalies, the benefit of this threshold determination method is the capability to detect anomalous isolated samples, without the necessity of being contiguous to another one, hence reducing the required sampling density. Dozens of surveys were successfully modelled and examples will be presented.

INTEGRATING WHOLE-ROCK GEOCHEMISTRY, ISOTOPIC MAPPING AND PHASE EQUILIBRIA: IMPLICATIONS FOR ARCHITECTURAL CONTROLS ON MINERAL SYSTEMS IN WAWA

Kristine Glomsaas Nymoen[1], David R. Mole[2], Douglas K. Tinkham[1], Phil C. Thurston[1], Richard A. Stern[3]
[1]Laurentian University, [2]Geoscience Australia, [3]University of Alberta.
E-mail: *knymoen@laurentian.ca*

The Superior Craton hosts numerous world-class ore deposits, particularly in the Abitibi–Wawa terrane, and are often clustered spatially and temporally into 'camps'.

Controls on formation of these clusters, crustal architecture and geodynamic processes leading to mineralization are yet to be fully resolved. Previous studies used combined U–Pb geochronology, radiogenic (Sm–Nd, Lu–Hf) and stable ($^{18}O/^{16}O$, $\delta^{18}O$) isotopes to map spatiotemporal evolution of crustal architecture (e.g. the Yilgarn Craton and Abitibi Subprovince). Our study applies this technique to the less studied eastern Wawa Subprovince, looking to further develop the methodology by integrating whole rock geochemistry to allow mapping of crustal petrogenetic variations. We integrate multiple analytical datasets from tonalite–trondhjemite–granodiorite (TTG) and felsic volcanic rocks with phase equilibrium modelling to understand crustal architecture, including (1) zircon trace element, O- and Hf-isotope compositions to identify involvement of low/high temperature processes and juvenile/ancient crustal input to magmas, (2) whole rock geochemistry, including Sr/Y ratio, to investigate source characteristics and relative source depth, and (3) whole rock Nb content and phase equilibrium modelling of Kapuskasing Structural Zone (KSZ) mafic rocks to establish the depth of source zone melting for Wawa TTG and felsic volcanic rock production. Combining these approaches, we find evidence for a geochemical and isotopic transition around 2695 Ma. Whole rock geochemistry indicates pre-2695 Ma rocks dominated by sodic ($K_2O/Na_2O < 0.7$) magma, and zircon isotopes show mantle-like $\delta^{18}O$ values (4.7–5.9‰) with juvenile εHf values (+2.2 to +5.6). Post-2695 Ma, potassic ($K_2O/Na_2O > 0.7$) rocks are more abundant, showing overall heavier $\delta^{18}O$ isotopes (5.9–7.4‰) and less juvenile εHf values. Whole rock phase equilibrium analysis of Wawa mafic rocks indicates a garnet stability field > 7–8 kbar, suggesting that Wawa TTG source rocks dominated by high Sr/Y were melted predominantly at a crustal depth equivalent to at least ~26–30 km. The felsic volcanic rocks are dominantly sourced from a shallower crustal depth (low Sr/Y) than the TTGs (high Sr/Y). This temporal transition is coupled with a spatial change, with the high Sr/Y crust (deep source) trending N–S at >2695 Ma, compared to E–W at < 2695 Ma. Our results demonstrate spatial and temporal variability in source characteristics, source depth and hence, crustal architecture across the Wawa Subprovince, features likely to have a significant effect on formation and localization of mineral systems. VMS more likely form in a more primitive (sodic, mantle-like $\delta^{18}O$ and εHf) and possibly thinner crustal regime. Less primitive crust (potassic, heavy $\delta^{18}O$ and εHf) may reflect a metasomatized component, potentially important for gold mineralization.

UNDERGROUND HYDROGEN STORAGE - AN ECONOMIC OPTION FOR FUTURE HYDROGEN INFRASTRUCTURE

Nirmal Gnanapragasam[1], Rob Carson[1], Stacey Reinwald[1], Alexi Shkarupin[1], Emily Saurette[1], Daniel Beaton[1], Hui Qun Chen[1], Elizabeth Priebe[1], Frank Brunton[2]
[1]Canadian Nuclear Laboratories, [2]Ontario Geological Survey.
E-mail: *nirmal.gnanapragasam@cnl.ca*

Hydrogen is an energy carrier and therefore has potential to be used as a fuel and as an ingredient in fuels, chemicals, and other industrial products. Hydrogen is identified as a positive means to decarbonize the energy system in Canada through a national strategy. Production and storage of hydrogen are two important and capital-intensive processes that will form a key part of the future hydrogen supply infrastructure in Canada and North America. Hydrogen production from water at medium-scale (8 tonnes/day) is being demonstrated in Canada. Canadian Nuclear Laboratories' hydrogen storage technology assessment demonstrates that low-cost large-scale hydrogen storage is possible with underground hydrogen storage (UHS) in suitable geological rock units. This is especially relevant, when hydrogen is either produced using renewable electricity from wind turbines and solar panels or by using excess electricity from any electrical grid. Hydrogen can be produced in large quantities as the wind blows, as the sun shines, and as the excess capacity in the grid is available. Storing it in underground salt caverns would allow for seasonal storage of hydrogen using low-cost electricity. Collaboration is underway with the Ontario Geological Survey and Geological Survey of Canada (NRCan) to study potentially favourable salt deposits in Ontario and nationally. Storing large quantities of hydrogen made from water at low-cost would enable massive deployment of hydrogen production capacities in Canada. This would bring economy of scale to the hydrogen market price and the commodities made using this hydrogen. Parameters and design constraints for hydrogen storage in various geological rock units are discussed. Canadian capabilities and roles in the UHS research will be highlighted. Challenges and significance of UHS technology components are discussed for further attention from geologists and engineers.

3D MICROSCALE CHARACTERIZATION OF MAGMATIC MAFIC-ULTRAMAFIC ORE DEPOSITS: PAST, PRESENT, AND FUTURE

Belinda Godel, Xiao Chen
CSIRO Mineral Resources ARRC.
E-mail: *belinda.godel@csiro.au*

Critical metals (Ni, Cu, Co, PGE, Cr, Ti, and V) are key to sustain the global energy transition to net zero emissions. These metals are typically mined from deposits associated with magmatic-ultramafic mineral systems. Orebody knowledge and ore characterization in particular are key to understanding the fundamental processes that led to metal accumulation to form an economic deposit, but also to inform downstream processing necessary to extract these critical minerals from the gangue. Over the past decade, non-destructive use of high-resolution X-ray computed tomography combined with 3D image analysis and quantification (referred to as 3D characterization) has become a method of choice to understand the 3D textures of the ores at the sample scale and has provided unprecedented insights into ore genesis, but also how metal can be extracted. More recently, the advent of diffraction contrast tomography (DCT) has allowed the mapping of crystallographic orientations of natural polycrystalline samples in 3D. This presentation will review the application of 3D characterization to magmatic Ni-Cu-Co-PGE and Ti and V deposits with examples from various deposits across the globe and will present its future outlook in a digital world.

GARNET IN S-TYPE GRANITE: Lu–Hf DATING AND TRACE ELEMENT DISTRIBUTION

Antoine Godet[1], Matthijs Smit[2], Carl Guilmette[1], Doug Tinkham[3], François Fournier-Roy[1]
[1]Université Laval, [2]University of British Columbia, [3]Laurentian University.
E-mail: *antoine.godet.1@ulaval.ca*

Late Neoarchean peraluminous granites are recognized as the final magmatic stage of Archean craton assembly worldwide. Constraining the magmatic history and emplacement conditions of these granites and the tectonometamorphic evolution of the host rocks provides critical insights into the thermal structure and tectonic evolution of the crust. The long-lived Decelles batholith (ca. 2670–2620 Ma), exposed in the southeastern Superior craton in Canada, is one of the most voluminous granites in the region. Although it is known that the batholith was sourced from the metasedimentary Pontiac Group at depth, its petrogenesis and relation to magmatism, metamorphism, deformation, and Au-base metal mineralization in the region are yet to be fully understood. In this study, we investigated the isotope and trace-element record of garnet recovered from three muscovite- and garnet-bearing granite samples from the Decelles batholith. Whole-rock and garnet fractions Lu–Hf analysis yielded dates of 2668 ± 4 Ma, 2663 ± 5 Ma, 2656 ± 7 Ma, which overlap with Lu–Hf garnet and U–Pb monazite dates from the amphibolite-facies host rocks of the Pontiac Group. In-situ trace-element mapping of garnet by LA-ICP-MS revealed well-preserved, sharp compositional zoning in all three samples. Garnet grains exhibit a core featuring concentric oscillatory zoning in Li, P, Sc, Ti, Y, Zr, REE, Hf, Th, and U with the concentrations decreasing outward; and an overgrowth marked by relatively high MREE, HREE, and V, and low Li, Ti, P, Sm, Zr, Hf, and U concentrations compared to the cores. The oscillatory zoning in the core is consistent with trace element uptake controlled by varying growth rate and diffusion kinetic at the garnet-matrix interface in a magmatic environment. The trace-element zoning of the overgrowth reflects both a control by similar kinetic processes and limited cation supply by coeval crystallization of muscovite, monazite, apatite, and zircon. Overall, garnet of the Decelles batholith provides new constraints on the timing of the protracted melting of the metasedimentary rocks source at depth, the emplacement of the peraluminous magma at middle-crust level, and the long-lived high thermal conditions during the final assembly of the southeastern Superior craton.

DID YOUR GOLD DEPOSIT FORM BELOW 3 Km? - IT IS NOT MAGMATIC

Richard Goldfarb[1], Iain Pitcairn[2]
[1]China University of Geosciences, [2]Stockholm University.
E-mail: *rjgoldfarb@mac.com*

Orogenic gold deposits are recognized to form from aqueous-carbonic fluids over a wide range of crustal depths, with the majority forming in the seismogenic zone between about 6 and 12 km. They are typically spatially associated with many types of intrusive rocks and may or may not have a temporal overlap with magmatism. Such relationships, allowing for a convenient point source, commonly are argued to suggest a genetic association between orogenic ores and magmatism. However, whereas oxidized intrusions are recognized to form gold-bearing porphyry and epithermal deposits in the upper 3 km of the crust, their ability to form deeper auriferous ores, and thus most orogenic gold deposits, is extremely limited. Rising hydrous granite melts with as much as 6 wt.% H_2O will not exsolve significant fluid volumes capable of forming large ore systems until pressures decline to about 1–2 kbar. In some cases, anomalously superhydrous magmas could become volatile saturated at higher pressures that lead to release of atypically greater fluid volumes at deeper levels than 6 km. Yet fluids released from melt at these depths would ascend up sinuous channels in the mush and not be exsolved out of the sides of crystallizing melts at mesozonal and hypozonal depths. Supralithostatic fluid pressures at the brittle shallow level tops to vertically extensive magmatic systems are required for the forceful expulsion of gold-depositing fluids. The fact that most porphyry deposits with economic gold form at levels no deeper than about 3 km indicates significant gold remains in the melt until very low pressures and even epizonal orogenic gold ores formed between 3 and 6 km are not sourced from melt. These relationships furthermore show that enrichment of gold in the SCLM is not relevant for the orogenic gold model because gold remobilization by melt will not form an orogenic gold deposit, nor will a fluid released from the lithospheric mantle that will be of a carbonic nature as most water at such depths will be trapped in hydrous minerals or dissolved in melt. Although elements such as Te, Bi, W, and Mo are enriched in many magmatic deposits, they can also be mobilized in non-magmatic aqueous-carbonic fluid and are thus not diagnostic of a magmatic-hydrothermal system. The formation of orogenic gold occurrences should be solely viewed as inherent products of moderate- to high-temperature metamorphism in any orogenic belt with fluid focusing into large-scale crustal structures controlling deposit economics.

ADAPTING COMMUNITY EDUCATION AND ENGAGEMENT IN A CHANGING ENVIRONMENT TO COMPLEMENT GROUNDWATER AND WATER MANAGEMENT

Beatriz Gomez Canizo[1], Peter Gray[2], Kyle Davis[3], Daniel Meagher[4]
[1]Waterloo Wellington Children's Groundwater Festival,
[2]MTE Consultants Incorporated, [3]Wellington Source Water Protection,
[4]Region of Waterloo Water Services.
E-mail: *waterfestival@wwcgf.com*

The inclusion of community participation and engagement is key to the success of the management of ongoing water issues. Since 1996 the Waterloo Wellington Children's Groundwater Festival has actively worked to educate members of our community since a young age to spread awareness about water issues and the direct benefits of individual and collective water-based actions. The last three years brought new challenges that forced us to change our engagement approach. Complex problems require different methodologies and approaches; we adapted our programming to offer a hybrid model that aims to inspire a behavioural response that leads to grassroots changes to complement policy-driven conservation.

A CLASSIFICATION STRATEGY FOR IGNEOUS ROCKS IN THE MIDCONTINENT RIFT, CANADA

David Good
Western University.
E-mail: *dgood.sci@gmail.com*

A new classification strategy for Midcontinent Rift (MCR) basalt and associated gabbro and ultramafic rocks is proposed, the main objective being to identify magmatic suites associated with known Ni-Cu-PGE occurrences and their spatial distribution across the rift. The study is based on the idea that units with similar incompatible trace element signatures formed under similar conditions in a similar mantle source region. Thus, a requirement for classification is that discrimination is based on initial melt compositions and excludes effects due to contamination or fractionation. Elements used in this study are REE, Th, Nb, and Zr. The approach taken is to identify point cloud clusters (magmatic suites) on contoured point density plots for REE represented by 'lambda' parameters which emphasize slope and curvature of REE patterns. The resultant groups are checked in Gd/Yb versus Th/Nb and Gd/Yb versus La/Sm diagrams to identify influence by crustal contamination or clinopyroxene fractionation, respectively. Melts produced in a metasomatized mantle source are a special case and are distinguished from contaminated melts in a Zr-Th-La diagram. The data set comprises a total of 1815 samples, 343 of which are basalt, from 70 mafic units. Data are carefully screened for discrepancies and extreme outliers removed. Results indicate a total of eight distinct magmatic suites (Groups 1 to 8). The groups are not listed in stratigraphic order because many units appear simultaneously, and a few are active for most of the MCR event. Highlights of the study with respect to Ni-Cu-PGE mineralized intrusions include: (a) Group 1 includes the Current, Seagull and Thunder intrusions and the Lower Suite basalt of the Osler Volcanic Group; (b) Group 2 is the most voluminous and includes the Duluth, Tamarack, Crystal Lake deposits, the Pigeon, Cloud and Arrow intrusions, and basalt of the Greenstone Flows, Upper Suite at Black Bay (OVG) and Upper Groups A and B at Mamainse Point; (c) The Eagle deposit is intermediate between Groups 2 and 5 but overlaps the field for all flows in Lower Mamainse Point Group A; (d) Groups 3 and 4 are not, as yet, associated with mineralized intrusions and include the Nipigon sills and basalt of the Centre and Upper Suites of the OVG; (e) Group 7 includes the Two Duck Lake (Marathon deposit), Abitibi Dykes and metabasalt unit 3a; and (f) Group 8 includes the Geordie Lake deposit, some dykes of Copper Island and Pukaskwa dyke swarms, and Wolfcamp basalt.

FLUIDAL AND BLOCKY PEPERITES IN THE MCKIM FORMATION OF THE HURONIAN SUPERGROUP: IMPLICATIONS FOR CONTEMPORANEOUS VOLCANISM AND SEDIMENTATION

Caroline Gordon
Ontario Geological Survey.
E-mail: *caroline.gordon@ontario.ca*

Peperites result from the interaction between magma and wet sediment. They are important pieces of evidence that magmatism and sedimentation were broadly contemporaneous. Mapping by the Ontario Geological Survey in the southwestern Sudbury Structure footwall identified peperitic textures along the contacts between synvolcanic sills and/or mafic flows and sedimentary rocks in the Elliot Lake Group of the Huronian Supergroup (HSG). This has implications for the timing and duration of Huronian magmatism during the emplacement of the lowermost HSG. The HSG is a well-preserved package of supracrustal rocks deposited along the southern margin of the Superior Province. The Elliot Lake Group is the lowermost unit of the HSG and consists of, from bottom to top, basal volcanic and sedimentary rocks, sandstone and conglomerate units of the Matinenda Formation, and siltstone and

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mudstone turbidites of the McKim Formation. In the western part of the HSG (Sault Ste Marie–Thessalon area), basal volcanic rocks (Thessalon Formation) are unconformably overlain by the Matinenda and McKim formations. However, in the east (Sudbury study area), there is field and geochemical evidence that the Elliot Lake Group volcanic rocks (Elsie Mountain, Stobie, and Copper Cliff formations) and synvolcanic sills are intercalated with the overlying Matinenda and McKim formations. Multiple occurrences of peperites were identified at the contact of mafic sills (and/or flows) and siltstone-mudstone units of the McKim Formation. These peperites comprise sheet-like occurrences of fluidal and blocky clasts of mafic igneous material (juvenile clasts) within a sedimentary matrix. Diagnostic criteria include: (1) fluidal clast morphology ranging from amoeboid to globular; (2) jigsaw-fit textures in blocky juvenile clasts; (3) sediment infill of fractures in clasts (fluidization of sediment); (4) absence of bedding compared to adjacent laminated mudstones (destruction of sedimentary structures); and (5) contact metamorphism. These relationships and textures suggest that the mafic magma interacted with wet sediments of the McKim Formation pre-consolidation. The presence of the peperites provides field evidence that Huronian magmatism continued (or resumed) during deposition of the upper parts of the Elliot Lake Group.

A NOVEL APPROACH TO MEASURE CRUSTAL EROSION OVER MILLION-YEAR TIMESCALES

John Gosse[1], Alan Hidy[2], Gerald Raab[1], Lauren MacLellan[1], Maya Soukup[3]
[1]Dalhousie University, [2]Lawrence Livermore National Laboratory-CAMS,
[3]New Found Gold Corp.
E-mail: *john.gosse@dal.ca*

Quantifying the variation in topographic relief evolution at hundreds of thousands to million-year timescales remains challenging. Muon paleotopometry is a new approach that may bridge methodological gaps between thermochronology and incision or basin analyses. The cosmic ray muon flux to a deep sample depends on the crustal shielding thickness above the sample and how it changes with time. The spatial pattern of concentrations of multiple muon-induced cosmogenic isotopes measured along a near-horizontal transect under valleys and peaks relates directly to the evolution of that surficial relief history of changes (positive or negative) in crustal thickness. It quantifies a history of paleotopographical variation above a sample datum over an isotope-specific monitoring duration. By sampling at depths of hectametres, long-lived isotopes are not sensitive to minor short-term (< 10^5-yr) changes owing to cut and fill terraces, transgressions, or short-lived ice cover, for instance, but short-lived isotopes may provide constraints on these. The method uses concentration differences among a multi-sample array, so is not significantly impacted by limitations in knowledge of muon flux and interactions at those depths. We report: (i) the proof-of-concept investigation first application of the method using samples in a SUFCO mine adit to measure the history of incision on a tributary to the Colorado River; (ii) a paleotopometry experiment using samples from the Gotthard-Base Tunnel to distinguish between slab break-off and glacial erosion as mechanisms to explain the relief contrast across the Western to Eastern Alps; and (iii) progress on a new experiment planned for the Sudbury region in 2023 to improve muon-production rate systemics at depths to 400 m where we hope to measure the history of Canadian Shield exhumation over the past 10 M.y..

THE ROLE OF PROCESS MINERALOGY IN BENEFICIATION AND GEOMETALLURGY OF CRITICAL MINERALS

Tassos Grammatikopoulos
SGS Canada Ltd.
E-mail: *tassos.grammatikopoulos@sgs.com*

Ore deposits are complex and display a high degree of variability arising from their inherent geological and mineralogical characteristics. Process mineralogy is established as an integral part for both exploration and mineral processing in the mining industry for critical minerals. Process mineralogy provides quantitative data including mineral speciation, grain size, liberation and association to domain the ores for both exploration and mining. Thus, it can link the geological domains to metallurgical response of the ore. Furthermore, process mineralogy is heavily applied in the beneficiation processes to predict grades and recoveries, and explain the response of the minerals during beneficiation (i.e. flotation, gravity). Process mineralogy includes the utilization of automated instruments such as TIMA (Tescan Integrated Mineral Analyser), coupled with mineral chemistry including EPMA, LA-ICP-MS, whole rock chemistry to characterize critical mineral deposits (i.e. REE, Li, Nb). Case studies will be presented to illustrate the complex mineralogical features, and further understand the distribution of metals, minerals, textures, and potential responses during processing and geometallurgical appreciations.

WHAT INCLUSIONS IN DIAMOND TELL US ABOUT THE LITHOSPHERIC MANTLE BENEATH SNAP LAKE KIMBERLITE DYKE (NORTHWEST TERRITORIES, CANADA)

Kelsey Graversen[1,2], Thomas Stachel[2], D. Graham Pearson[2], Ingrid Chinn[1]
[1]De Beers Group, [2]University of Alberta.
E-mail: *kelsey.graversen@debeersgroup.com*

The Snap Lake kimberlite dyke is located on the southern Slave craton, approximately 220 km northeast of Yellowknife, NWT. Previous studies have inferred, through the observation of rare high-Cr majorite garnet inclusions, the presence of an unusually thick lithospheric mantle root (> 200 km), which at depths corresponding to the diamond stability field was mostly harzburgitic. This research characterizes the various diamond substrates which make up the lithospheric mantle beneath Snap Lake, in addition to mantle residence. Based on a set of 87 inclusion-bearing diamonds it is inferred that diamond formation occurred primarily in peridotitic mantle (93%), with a more minor component forming in eclogitic mantle (6%) and a single studied diamond shows rare mixed paragenesis (1%). The peridotitic inclusion suite consists of garnet, olivine, chromite, clino- and orthopyroxene, sulphide minerals and native iron-wüstite, whereas the eclogitic inclusion suite consists of garnet, SiO_2, N-poor sulphide minerals and potassium feldspar. From the single mixed-paragenesis diamond, a peridotitic garnet, an eclogitic coesite and an eclogitic sulphide were recovered, indicating the two sub-populations do not necessarily represent distinct environments beneath Snap Lake. Geothermobarometry results indicate that diamond formation occurred along a cool 36–38 mW/m^2 paleogeotherm at temperatures ranging from 920 to 1230°C, between 120 and at least 210 km in depth. Nitrogen-based mantle residence temperatures agree well with geothermometry results ranging from 1050–1280°C.

AN ASSESSMENT OF THE USE OF FLIPPED CLASSROOMS IN UPPER LEVEL EARTH SCIENCE COURSES

Daniel Gregory[1], Alison Jolley[2]
[1]University of Toronto, [2]University of Waikato.
E-mail: *daniel.gregory@utoronto.ca*

An increase in engagement can be useful to obtain learning objectives in science courses. Active learning has been shown to increase student engagement. Flipped classrooms, where students watch videotaped lectures on their own time and then undertake guided exercises during the scheduled lecture time, is one effective type of active learning. These techniques have been popular for computational STEM courses for some time; however, they have been slow to be implemented in the Earth Sciences. Here we test the efficacy of flipped classroom techniques in upper level non-computational geoscience courses by implementing the technique on a subset of lectures for a fourth year mineral deposits class. Over three years we implemented flipped classrooms, starting with one in 2019 and two in each of 2020 and 2021. These were assessed in 4 different ways. Cognitive engagement was determined by comparing midterm/final exam and lab exam results between material taught as a flipped classroom and traditional lectures. This was supplemented by questionnaires that students filled in to give their impression of how they viewed the flipped lectures ability to help them learn and retain information when compared to traditional lectures. Further, emotional and behavioural engagement was assessed using a combination of questionnaires filled out by the students at the end of the course and interviews conducted 1–3 years after the completion of the course. We found that the flipped classroom lectures only slightly increased the student's ability to learn and retain the information presented. However, the flipped classrooms were enjoyed by most students and appeared to increase their cognitive, behavioural, and emotional engagement. Further, because one of the time-consuming aspects of developing flipped classrooms is production of video taped lectures, and now many of us have video taped lectures because of virtual teaching during the pandemic, use of flipped classrooms is a relatively easy way to increase engagement in Earth Science courses.

THE SOURCE OF STRATABOUND CRITICAL METAL DEPOSITS IN NORTHWEST CANADA: A VIEW FROM V ISOTOPES

Daniel Gregory[1], Danielle McGill[1], Daryll Concepcion[1], Stephan Schuth[2], Ashley N. Martin[2], Merilie A Reynolds[3], Stefanie M Brueckner[4]
[1]University of Toronto, [2]Ruhr University Bochum,
[3]Northwest Territories Geological Survey, [4]University of Manitoba.
E-mail: *daniel.gregory@utoronto.ca*

The Selwyn Basin hosts several stratabound critical metal deposits, including thin, high-grade Ni-Mo deposits and thicker, lower-grade shale-hosted V deposits. It is hypothesized that these deposits are genetically related as they occur near the same stratigraphic position at the sedimentary transition from the Silurian to Devonian. Currently, the favoured deposit model invokes direct precipitation from the ocean during extremely long periods of little to no sedimentation. In this model, the Ni-Mo mineralization is thought to have formed under euxinic (i.e. water column contains H_2S) conditions, and the V-rich deposits are thought to form under anoxic but not sulphidic conditions. To test this hypothesis, we analyze the V-isotope composition of V-rich shales from two different locations - the Rod property in Yukon and the Van property in the Northwest Territories. Each of these locations hosts V mineralization tens of metres thick. Additionally, the Rod property also hosts enrichments of Ni and Mo and maybe a transition between the V-rich and Ni-Mo-rich endmembers of this type of mineralization. ^{51}V isotope signatures are particularly useful for distinguishing between these endmembers as they have distinctive signatures depending on water column conditions during sediment deposition. These include δ^{51}V of –0.15 ± 0.15‰ for hydrothermal sediments, δ^{51}V of –0.9 ± 0.1‰ for oxic sediments, δ^{51}V of –0.5 ± 0.1‰ for anoxic sediments, and δ^{51}V of –0.2 ± 0.1‰ for euxinic sediments. Preliminary results show an average δ^{51}V of –0.09 ± 0.13‰, which we interpret to represent a hydrothermal influence on the stratabound V mineralization, based on the assumption that Silurian/Devonian seawater had a similar δ^{51}V to present. In a subset of these samples, it is possible that euxinic conditions were also present, or were present instead of hydrothermal fluids as there is some overlap between the range of δ^{51}V values expected for hydrothermal sediments and euxinic conditions. However, results for the majority of samples are within the range of values expected exclusively for hydrothermal systems whereas relatively few are within the overlapping range permissive of euxinic conditions. Thus, we propose that hydrothermal fluids are necessary for the significant enrichment of V in metalliferous black shale. Further, because of the proposed genetic relationship with stratabound Ni-Mo mineralization, we suggest that these deposits should also be assessed using V isotope analysis.

IMPROVED UNDERSTANDING OF MINERAL WEATHERING DYNAMICS IN WASTE ROCK THROUGH ADVANCED MINERALOGY

Adriana Guatame-Garcia, Bas Vriens
Queen's University.
E-mail: *adriana.guatamegarcia@queensu.ca*

Mine waste classification schemes to date rely heavily on bulk characterization to assess drainage quality. However, emerging mineralogical tools allow us to quantify mineral compositions, associations, and textures with increasing resolution and throughput. While used extensively in mineral processing, quantitative mineralogy has been deployed surprisingly little in mine waste management. This research aimed to study the mineralogical weathering processes of waste rock using a combination of instrumented kinetic tests, geochemical effluent analyses, and quantitative mineralogy. We used a set of systematic and controlled leaching experiments aimed at simulating the weathering of waste rocks from an iron (sienite) and a gold (skarn) deposit under contrasting storage conditions (i.e. oxic vs. suboxic) for eight months. During this time, we monitored the generated drainage chemistry and mineralogical dynamics by (1) collecting weekly drainage samples and measuring water chemistry (ICP-OES) to assess metal loading and drainage quality deterioration over time, and (2) collecting intra-column grab samples that were mounted and analyzed with mineral liberation analyses (MLA), X-ray diffraction (XRD), and infrared spectroscopy (IR) for microscale vs. bulk mineralogical properties. Our results show that the drainage chemistry of the sienite waste rock was determined by interactions between goethite and magnetite with ankerite and Mn-bearing epidote. In contrast, the drainage of the skarn material was controlled by the dissolution of ankerite and celestine. Under oxic conditions, the drainage from the sienite was circumneutral (pH 7.4 to 7.9), whereas the drainage from the skarn was circumneutral to alkaline (pH 7.5 to 8.3). In the suboxic environment, both skarn and sienite produced alkaline drainage (pH 8.1 to 8.9). The reconciliation between water chemistry (dissolution of Fe, Mn, Sr) and mineralogy permitted us to estimate the specific contribution of carbonate, sulphate, and aluminosilicate phases to the neutralizing potential of the materials. Textural and particle size characterization using automated mineralogy allowed for a quantitative assessment of mineral dissolution and precipitation rates. These results improve the understanding of the mineral dynamics in waste rocks and move beyond standard kinetic tests (e.g. acid-base accounting) to build a better understanding of the material's composition and its role as a source of pollution and can contribute to novel mine waste management strategies.

NEW STRUCTURAL AND GEOCHRONOLOGICAL AGE CONSTRAINTS (U–Pb) ON THE MIGUEL AUZA Ag-Zn (Pb) EPITHERMAL DEPOSIT, MEXICAN SILVER BELT, MEXICO

Jorge Alejandro Guevara Alday[1], Stéphane de Souza[1], Alain Tremblay[1], Morgann Perrot[1], Jorge Ortega[2], Joshua Davies[1]
[1]Université du Québec à Montréal, [2]Excellon Resources Incorporated.
E-mail: *guevara_alday.jorge_alejandro@courrier.uqam.ca*

The Miguel Auza epithermal Ag-Zn (Pb) deposit is located within the Mexican silver belt, in the northern Mesa Central Province, northern Zacatecas. The deposit is hosted by sandstone and siltstone from the Upper Cretaceous Caracol Formation, andesite and monzonite porphyry intrusions, and locally by a rhyolite dome. The Caracol Formation shows shallowly plunging upright open folds that formed during the Laramide orogeny. NW-SE-trending normal faults are common throughout the area and are associated with Basin and Range tectonics. The deposit consists of several mineralized veins, including those of the Calvario and Lechuzas zones, which were mined intermittently until 2009. In addition, other mineralized veins associated with fault and fracture zones have also been identified based on crosscutting relationships, orientation, texture and mineralogy. The emplacement of these mineralized vein systems is poorly constrained. Therefore, we initiated a detailed structural and U–Pb geochronological study to better understand their history, age and role in the context of the Mesa Central Province. The vein field is subdivided into 1) NE-SW- and 2) NW-SE-trending orthogonal vein sets composed of quartz and calcite. The NE-SW-trending veins are steeply-dipping, sulphide-rich (pyrite-sphalerite-galena) fault-fill veins. They contain Ag-sulphosalts and represent the main part of the ore. They are characterized by colloform-crustiform textures, bladed calcite and cockade breccia. The NW-SE-trending veins dip steeply to the NE and SW. They have a low sulphide content and low overall silver concentrations. The kinematic analysis of the mineralized structures indicates that the NE-SW mineralized faults have a normal-oblique slip and are overprinted by the NW-SE-trending normal faults. The andesite and monzonite porphyritic intrusions that host part of the mineralization were dated by U–Pb zircon (LA-ICP-MS) geochronology at ~83 and ~85 Ma, respectively. They contain few inherited zircons between ~170 and 160 Ma. The rhyolite dome, which is cut by both the NW-SE-trending veins and the NE-SW-trending normal faults, was dated at ~43 Ma giving a maximum age to these structures. Our preliminary data is consistent with previous ^{40}Ar–^{39}Ar dating of alteration and vein material between ~46 and ~45 Ma in the Calvario zone. Our work also shows that the silver mineralization is not related to the porphyritic intrusions but may instead be genetically associated with Eocene felsic magmatism in the northern Mesa Central Province.

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TRACE ELEMENT SIGNATURES OF MAGNETITE CRYSTALLIZED FROM MAGMATIC SALTS

Alexandre Guillerez, Zhong-zheng Yuan, Corliss Kin I Sio, Neil Bennett
University of Toronto.
E-mail: *neil.bennett@utoronto.ca*

The trace element composition of magnetite has been used to differentiate between hydrothermal and magmatic origins for a variety of deposit types. Recently, there has been renewed interest in the genesis of iron-oxide apatite (IOA) deposits, in which magnetite is the primary iron oxide. A topic of debate is whether IOA deposits form via predominantly magmatic or hydrothermal processes. Recently published data proposed a new petrogenetic model that invokes country-rock derived carbonate-sulphate melts as the important transporting agent for iron, based on the observation of such compositions in melt-inclusions from several IOA localities. Importantly, the localities they studied were previously considered to have hydrothermal origins. To test this hypothesis, it would be useful to assess if magnetite crystallized from carbonate-sulphate (or similar) melts possesses a unique trace-element signature. To assess the ability of magnetite composition to distinguish the genesis of IOA deposits, we have performed electron-probe microanalysis and laser ablation inductively coupled plasma mass spectrometry on magnetite from 11 localities that were crystallized from silicate magmas, carbonatite magmas, and hydrothermal fluids. Trace element data were treated using principal component analysis (PCA), to identify which elements are most useful in distinguishing magnetite formed in these different settings. Work is ongoing to analyze a greater range of samples by LA-ICP-MS, and high temperature experiments have been started to assess magnetite-salt partitioning and determine the conditions of magnetite saturation in carbonate-sulphate melt compositions.

METASEDIMENTARY SUBPROVINCES OF THE ARCHEAN SUPERIOR CRATON: A SOURCE OF GOLD, OF FLUIDS, AND OF CONFUSION

Carl Guilmette
Université Laval.
E-mail: *carl.guilmette@ggl.ulaval.ca*

The Superior craton of North America, the largest exposure of Archean crust on Earth, is subdivided into subprovinces sharing similar lithological assemblages, metamorphic grades, structural styles, and geophysical signatures. Among the four types of subprovinces, metasedimentary subprovinces are the youngest and likely recorded the final stages of cratonization. They are widely interpreted as accretionary wedges or foreland basins and some have also been identified as important sources for the metamorphic fluids, ligands and gold that were involved in the formation of the numerous orogenic gold deposits of the Superior craton. In this contribution, we review the main characteristics of metasedimentary subprovinces and present preliminary results of the craton-scale Gold Fluid Window research program. Metasedimentary subprovinces are mainly composed of metaturbidite flows of greywacke and mudstone interlayered with volcanic rocks and intruded by late depositional sanukitoids and synmetamorphic S-type granites. Our new results from the Pontiac and Quetico subprovinces indicate that metamorphic sequences relatively close to gold-endowed areas underwent important background gold depletion in the staurolite to sillimanite zones, from 1 to 0.1 ppb. This depletion is not observed in poorly endowed areas. Muscovite-consuming dehydration reactions and the pyrite to pyrrhotite transition may have been responsible for the generation of an important pulse of S-bearing fluids. Phase equilibria modeling and garnet and monazite geochronology constrain such reactions around 2657 Ma for the Pontiac subprovince. S-type granite magmatism broadly overlaps with the duration of prograde and peak metamorphism in the metasedimentary rocks. The main monazite population in the Pontiac subprovince defines a peak at roughly 2645 Ma, corresponding to the main xenotime populations observed in gold-bearing vein assemblages of the Abitibi gold camp. These promising preliminary results support the idea that the metasedimentary subprovinces of the Superior craton may have contributed to its important gold endowment, but do not rule out other sources. This research program also provides an opportunity to revisit the tectonic significance of these giant metasedimentary belts, which are more likely to have initially formed as extensional basins.

MINERAL CHEMISTRY AND Nd ISOTOPE GEOCHEMISTRY OF APATITE IN OROGENIC Au-ASSOCIATED GABBRO, BAIE VERTE, NL

Fatma Gumus, Stephen J. Piercey, John M. Hanchar
Memorial University of Newfoundland.
E-mail: *fatmag@mun.ca*

The textural and chemical variations (major-, minor- and trace-element, and Nd isotope compositions) of fluorapatite were examined to investigate the influence of magmatism and alteration by hydrothermal fluids on the composition of apatite associated with orogenic Au deposits on the Baie Verte Peninsula, Newfoundland. Apatite was obtained from fresh and variably altered gabbroic rocks of the Animal Pond prospect, the Stog'er Tight, and Argyle deposits. Gold mineralization in all three areas is associated with pegmatoidal gabbro bodies that are variably deformed and were metasomatically altered by orogenic Au-related hydrothermal fluids. The original igneous rocks contain primary igneous apatite that was subsequently partially to fully replaced during later metasomatic alteration to produce secondary monazite and xenotime and spatially associated with hydrothermal zircon. Both igneous and hydrothermally altered apatite have similar initial Nd isotope compositions; unaltered rocks ($\varepsilon_{Nd(t)}$ = 2.34–6.60) and altered rocks ($\varepsilon_{Nd(t)}$ = 2.8–6.96). In contrast, the igneous and hydrothermally altered apatite exhibits wide variations in mineral chemistry and textures. Both are subhedral to euhedral and have homogeneous back-scattered electron (BSE) images; however, the apatite in the unaltered rocks displays yellow to yellow-green cathodoluminescence (CL), whereas apatite in the altered rocks has dark green to grey CL. Apatite chemistry, as determined by electron microprobe and laser ablation inductively coupled plasma mass spectrometry, is also distinct. Magmatic apatite is enriched in Mn, Cl, Mg, REEs, U, Th, and depleted in Sr, and has low Sr/Y compared to the hydrothermal apatite. The textures and compositions are consistent with the altered apatite having experienced dissolution-reprecipitation processes and subsequent growth of hydrothermal monazite and to a lesser extent inclusions of xenotime. This study illustrates that igneous apatite can be modified by hydrothermal fluids during fluid-rock interaction and can be used to discriminate igneous vs hydrothermally influenced apatite in orogenic Au, and likely other hydrothermal systems.

MINERAL CHEMISTRY AND Hf ISOTOPE SIGNATURE OF ZIRCON FROM RHYOLITES IN THE IZOK LAKE VMS DEPOSIT, NUNAVUT, CANADA

Lokman Gumus[1], Stephen J. Piercey[1], Corey J. Wall[2,3], Kimberley Bailey[4], Michael P. Stubley[5]
[1]Memorial University of Newfoundland, [2]Boise State University,
[3]University of British Columbia, [4]NorthWest Copper Corporation,
[5]Independent Scholar.
E-mail: *lokmang@mun.ca*

This study integrates the results of U–Pb ages, and major, trace element and Hf isotope compositions of zircon minerals from the Izok Lake volcanogenic massive sulphide (VMS) deposit, Slave Province, Nunavut. The Izok Lake deposit is hosted within a sequence of mostly felsic volcanic rocks with lesser intermediate and mafic metavolcanic rocks. Massive sulphides at Izok are predominantly hosted by felsic volcanic rocks with ~2675 Ma chemical abrasion thermal ionization mass spectrometry (CA-TIMS) U–Pb zircon ages. The temperatures of zircon crystallization deduced from Ti-in-zircon geothermometry on zircon extracted from rhyolites from the Izok Lake deposit are 919°C for footwall (R1-b) rhyolitic rocks and 860°C for hanging wall rhyolitic rocks (R2). The $\varepsilon_{Hf(t)}$ values of footwall and hanging wall zircon grains range from –17.53 to +0.43 (avg = –5.59) and –0.78 to +19.88 (avg = +3.70), respectively, indicating that both depleted mantle and crustal sources contributed to their origin. Footwall zircon depleted mantle model ages (avg T_{DM2} = 2.91 Ga) are older than hanging wall zircon (avg T_{DM2} = 2.77 Ga). Trace element abundances in zircon, as determined by electron microprobe and laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analyses, indicate that footwall rhyolite zircon has higher concentrations of Hf, Ti, U, Th, Y/Dy, and lower Th/U and Zr/Hf ratios, but similar Ce and Eu anomalies and HREE-enrichment in chondrite-normalized zircon REE patterns compared to hanging wall zircons. In addition, in most zircon grains, there is extensive radiation damage, which is interpreted to have been caused by high U concentrations in the zircon. Our study shows that zircon chemistry can effectively be used to monitor igneous processes and their relationships to felsic-hosted VMS deposits.

PILOT PALEOMAGNETIC STUDY OF THE 148 Ma NOTRE DAME BAY MAGMATIC PROVINCE, NEWFOUNDLAND, CANADA AND ITS RELATIONSHIP WITH NORTH ATLANTIC OPENING

Ai Gusti Guna[1], Philip J.A. McCausland[2], Alexander L. Peace[1]
[1]McMaster University, [2]Western University.
E-mail: *Gunaa@mcmaster.ca*

The ca. 147.9 Ma (Late Jurassic, Tithonian) Notre Dame Bay Magmatic Province (NDBMP) in and around Leading Tickles in northern-central Newfoundland, consists of numerous lamprophyre dykes that are radial around the gabbroic Budgell Harbour Stock and are contemporaneous with Mesozoic rifting that led to opening of the North Atlantic and formation of the Newfoundland margin. New paleomagnetic investigation of the NDBMP builds on an earlier study in 1979., with the preliminary results reported here. Measurements of mass-normalized magnetic susceptibility, natural remanent magnetization (NRM), and alternating-field (AF) stepwise demagnetization have been performed sequentially from NDBMP exposures near Leading Tickles. Stepwise demagnetization between 0 to 20 mT removed a northwest and steep downward-directed viscous remanent magnetism (VRM) of Declination = 334.30, Inclination = 68.40, with $\alpha95 = 10.65$, and a precision parameter estimate of k = 28, consistent with the present-day Earth's field (PEF; D=341.9°; I = 68.7°). The VRM typically constitutes between 30 and 90% of the NRM intensity, recognized as an easily removed component of probable recent origin. A remaining stable component is achieved by 40 mT and is interpreted to be the characteristic natural remanent magnetization (ChRM) of NDBMP. The majority of sites carry ChRM directions that have steep downward inclinations in outcrop coordinates. Specimen directions reported in geographic coordinates provide an overall mean ChRM of Declination = 334.60 , Inclination = 59.60, with $\alpha95 = 8.76$, and a precision parameter estimate of k = 21.6 (n = 14 specimens), deemed to reliably represent the locality of the NDBMP. The preliminary paleopole (North polarity) of NDBMP is computed to be $\lambda p = 700$ and $\varphi p = 197.30$, with all sites thus far carrying normal polarity during the formation of NDBMP. Both the original published result and our preliminary data from an expanded investigation suggest that there is no evidence for significant block rotation of the Newfoundland portion of the margin with respect to North America since Late Jurassic – Tithonian time. Further work on other sites seeks to test this result with possible reversed polarity ChRM.

HYDRATION MELTING IN OLIVINE-BEARING ZONE I OF THE STILLWATER COMPLEX, MONTANA, USA

Anya Gupta, Alan Boudreau
Duke University.
E-mail: *anya.gupta@duke.edu*

Olivine-Bearing zone I (OB-1) in the Stillwater Complex, Montana, hosts the highest-grade platinum-group element deposit in the world, the J-M reef. Several lines of evidence, including hydrous melt inclusions in the olivine and chromite, eroded texture of plagioclase in olivine-rich rocks, excess of pegmatoids beneath OB-1, and unusually Cl-rich apatite all have been used to suggest that the reappearance of olivine and PGE-sulphide was from the hydration melting rather than orthomagmatic processes. This study builds upon the hydration melting model using the programs MELTS and PELE using Stillwater bulk rock compositions for the original protolith. Fluid inclusion evidence suggests that real fluids range from a solute-rich mixture of alkalis (Na and K), Ca, Fe, and SiO_2 in solutions ranging from aqueous brines to CO_2-CH_4-rich fluids. The alkalis in particular are strong fluxing agents. Cl-bearing species are not currently well-modeled by MELTS or PELE and in the modelling, simple oxide mixtures (H_2O or a mixture of H_2O+Na_2O) is added to gabbronorite to melanorite at 1000–1050°C at 2 kbar pressure, conditions for which the nominally "dry" protolith is > 95% solid. Incongruent hydration melting produces the most olivine in the melanorite protolith. In contrast, the amount of clinopyroxene is largely unaffected by the degree of partial melting, the clinopyroxene presumably stabilized by Ca liberated by melting of plagioclase. The Mg# of the olivine is a function of the partial melt retained on cooling, and ranges between 66 and 84, overlapping the natural range of olivine compositions observed in the rocks. The amount of partial melting is limited when H_2O alone is the fluxing agent owing to eventual saturation in a fluid. In contrast the addition of the H_2O-Na_2O mixture can lead to assemblages composed almost entirely of olivine + liquid. Finally, Cl-rich fluids can contain substantial PGE and base metals, and fluids with a few percent S can lead to sulphide precipitation during the hydration melting event.

RARE-METAL ENDOWMENT IN THE KEDRON GRANITE, SOUTHWESTERN NB: USE OF PETROGEOCHEMICAL SIGNATURES TO ASSESS CRYSTAL VERSUS FLUID FRACTIONATION

Graham Halcrow[1], David Lentz[1], Kathleen Thorne[2]
[1]University of New Brunswick,
[2]New Brunswick Natural Resources and Energy Development.
E-mail: *graham.halcrow@unb.ca*

The southwestern portion of New Brunswick is host to a series of intrusion-related tin, tungsten, and indium deposits with base-metals and gold related to the Late Devonian to Carboniferous Neoacadian orogeny. The Pomeroy Intrusive Series, a cluster of metaluminous to weakly peraluminous hybrid low-P, reduced I-type granitic intrusions, contains several highly to extremely fractionated hypabyssal F-rich granitic plutons. Most notable of this series is the Mount Pleasant deposits; the earlier W-Mo-Bi Fire Tower Zone formed in the cupola to a highly fractionated topaz microgranite (G1) and the later North Zone Sn-Cu-Zn-In mineralization with endogranitic and exogranitic to the granite porphyry (G2). The Pleasant Ridge Granite, another Pomeroy Intrusive series granite, is a deeper level, extremely fractionated granite intrusion located west of Mount Pleasant, sharing characteristics with surrounding intrusions. Chondrite-normalized REE plots of the Mount Pleasant granites show very distinct bird-wing profiles with extremely negative Eu anomalies. Adjacent to these well-studied evolved granitic systems is the smaller Kedron Granite and spatially related Sn-Cu-Zn-In mineralization. The Kedron Granite is locally aplitic to pegmatitic to porphyritic, and shares geochemical characteristics with local specialized granitic intrusions, including its extent of fractionation, high Li-F, HREE, Y, U, and Ta contents and low Al/Ga, with endo- and exogranitic Sn-W mineralization. It also exhibits a similar bird-wing-shaped, chondrite-normalized REE profile with similar Eu/Eu* ratios. Geochemical analysis of selected drill cores made by Billiton (mid 1980s) and Geodex (early 2010s) reveal the extent of fractionation in various phases of the Kedron Granite. Zr/Hf follows a trend from ~17 to 11.2 and Nb/Ta ranges from 4.3 to as low as 1.9 in the most fractionated section; Rb/Sr range from ~18 to 81, reaching as high as 144. Eu/Eu* ratios fall to as low as 0.01. Zircon saturation temperatures of the most fractionated varieties indicating a crystallization temperature as low as 655°C reflecting fluxing elements. Lithium reached as high as 1600 ppm in certain intervals. Additionally, Sn content in assayed samples reached up to ~0.09 wt.%. Examination of the more fractionated samples shows an abundance of monazite within biotite that explains the REE endowment. Magmatic fluorite has pleochroic halos hosted within biotite, thus we propose that fluorite and associated inclusions crystallizing at the end of emplacement partitioned some high field strength elements into its structure. Preliminary µXRF-EDS analysis of fluorite with biotite phenocrysts shows that elements, such as Ce, Y, and La, are all found in higher concentrations within these fluorites.

CONTROLS ON GOLD MINERALIZATION IN AN AMPHIBOLITE FACIES GOLD DEPOSIT, HIGH LAKE GREENSTONE BELT, NUNAVUT, CANADA

Evan Hall, Ross Sherlock, Bruno Lafrance
Laurentian University.
E-mail: *ehall@laurentian.ca*

The controls on mineralization of gold deposits hosted in amphibolite facies rocks tend to be enigmatic, as textural and structural features present in lower grade metamorphic rocks are commonly obscured if overprinted by high-grade metamorphism and deformation. This may result in difficulties in differentiating orogenic deposits from overprinted and metamorphosed magmatic deposits and provides challenges in determining primary controls on mineralization. The Ulu gold deposit is the

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largest gold deposit within the relatively underexplored High Lake greenstone belt in the Archean Slave craton; located 523 km north-northeast of Yellowknife. The belt runs roughly north-south and consists of mafic volcanic rocks, and lesser felsic volcanic and sedimentary rocks that range in age from 2705–2612 Ma. The deposit is unusual in that it is hosted in amphibolite facies metavolcanic rocks and lacks many of the features common in gold deposits hosted by greenschist facies rocks, such as iron-carbonate alteration. Whole rock geochemistry and outcrop mapping provide a framework for volcanic stratigraphy and structural and chemical controls on gold mineralization within the deposit. The Flood zone, which hosts the bulk of the gold mineralization, occurs at the contact between high and low Fe/Ti basalts. These volcanic rocks are folded into an anticline, and Flood zone mineralization is interpreted to be associated with this folding event. Mineralization occurs as free gold in association with acicular arsenopyrite in a brecciated and intensely silicified northwest trending zone, which is overprinted by younger folds and foliation. This research investigates the structural and stratigraphic setting of the Ulu deposit and aims to provide a chronological framework and interpretation for the emplacement of gold mineralization.

THE MESOPROTEROZOIC–NEOPROTEROZOIC TRANSITION IN NORTHERN CANADA

Galen Halverson[1], Maxwell Lechte[1], J. Wilder Greenman[2], Timothy Gibson[3], Katie Maloney[1], Robert Rainbird[4]
[1]McGill University, [2]Dalhousie University, [3]Yale University, [4]Geological Survey of Canada.
E-mail: *galen.halverson@mcgill.ca*

The Mesoproterozoic–Neoproterozoic transition (ca. 1200–800 Ma) was a critical interval in the diversification and ecological expansion of early eukaryotes. This prelude to the extraordinary geochemical changes and climatic upheaval that define much of the late Proterozoic also spanned the final assembly of the supercontinent Rodinia and its initial demise. Late Mesoproterozoic to early Neoproterozoic stratigraphic successions that capture portions of this time interval are relatively widespread across northern Canada, where they comprise much of what has historically been referred to as "Sequence B". Recent focused stratigraphic investigations on these rocks, coupled with the generation of many new radio-isotopic ages, has both improved broad interbasinal correlations of Sequence B strata and revealed their tectonostratigraphic complexity. For example, it is now evident that the strata in the Bylot basins of northeastern Laurentia were deposited during multiple, discrete episodes between ca. 1.27–1.0 Ga, but that the dominant basin filling stage (ca. 1.1–1.05 Ga) was coeval with the Mid-Continent Rift and a depositional phase in northwestern Laurentia. Here we present an update on the state of knowledge on Sequence B strata with an emphasis on the tectonic and paleobiological implications of the updated ages and revised chronostratigraphic framework. This synthesis highlights the importance of sedimentary successions in northern Canada to understanding the tectonic evolution of Laurentia and global biospheric change across the Mesoproterozoic–Neoproterozoic transition.

WHAT CAN THE CHEMISTRY OF MAGNETITE TELL US ABOUT THE ORIGIN OF MAGNETITE-APATITE DEPOSITS?

John M. Hanchar[1], Fernando Tornos[2]
[1]Memorial University of Newfoundland, [2]Instituto de Geociencias (CSIC-UCM).
E-mail: *jhanchar@mun.ca*

Magnetite (Fe_3O_4) is a near-ubiquitous mineral in igneous rocks of varying compositions (mafic to felsic), cooling histories (plutonic, extrusive), conditions of formation (subduction zones, rifts, hotspots), and crustal settings (oceanic, continental). Magnetite is also a common mineral in metamorphic and metasomatized rocks, and in heavy mineral sands and sedimentary rocks. Many recent studies have examined whether the trace element chemistry of magnetite can be used to: discriminate between magmatic and hydrothermal mineralizing systems; to calculate temperatures; and to develop models for the origin of magnetite-apatite (MtAp) deposits. Magnetite trace element chemistry is a powerful tool for obtaining a better understanding of the geological evolution and history of these systems; however, the indiscriminate and unconstrained use of magnetite trace element geochemistry can potentially lead to geologically unrealistic results. Results will be presented that include a comparison of magnetite compositions from MtAp ore, as well as altered and unaltered host rocks from the El Laco MtAp deposit in northern Chile. For comparison, magnetite trace element data from other localities will be discussed, including a typical unmineralized andesitic country rock from the Punta del Cobre region in Chile, magnetite from the classic Kiruna MtAp deposit in Sweden, from altered and unaltered Icelandic rhyolites, and unaltered granites from the Mojave Desert in California, to assess and evaluate the compositional variations that occur in magnetite from different geological environments. The trace element chemistry of magnetite in both host rock and ore from El Laco are consistently distinct from one another. We further evaluate the use of magnetite trace element chemistry, taking into consideration other geological and geochemical factors including coeval phases, tectonic setting, petrogenetic processes, and metasomatic alteration by hydrothermal fluids involved with elemental availability and partitioning during magnetite crystallization (economic grade or otherwise).

EMERGING THEMES FROM MELT INCLUSION STUDIES IN VMS-MINERALIZED ARCHEAN VOLCANIC ROCKS IN THE ABITIBI SUBPROVINCE, CANADA

Jacob Hanley[1], Priyal Daya[1], Daniel Meagher[1], Kevin Neyedley[1], Zoltan Zajacz[2], Patrick Mercier-Langevin[3], Anne-Sophie Tabaud[4], Stephen Piercey[4]
[1]Saint Mary's University, [2]University of Geneva, [3]Geological Survey of Canada, [4]Memorial University of Newfoundland.
E-mail: *jacob.hanley@smu.ca*

Silicate melt inclusions (SMI) hosted in quartz and zircon in felsic volcanic rocks and related subvolcanic intrusions from variably VMS-endowed volcanic assemblages in the Abitibi subprovince are being investigated through integration of a variety of analytical methods (SEM, confocal Raman spectroscopy, LA-ICP-MS). For zircon-hosted inclusions, comprehensive textural and geochronological characterization of the host (CL, LA-ICP-MS, SHRIMP, CA-ID-TIMS) is in progress, so that melt inclusion data can be linked to incremental magmatic events and inheritance can be avoided. The goals of the research are to better understand the link between metal endowment and magmatic processes, and to present the first melt inclusion data from felsic volcanic rocks of Archean age globally. Four themes have developed from these investigations: (1) Owing to post-entrapment and post-solidus processes (alteration, metamorphism, degassing and crystal accumulation) whole rock data misrepresents the primary magmatic metal endowment. In many assemblages, base and precious metal concentrations are typically at least an order of magnitude lower in the host rocks compared to SMI concentrations, and do not reflect the variable entrapment of metal-rich phases (e.g. sulphide minerals) that were saturated at the time of SMI entrapment; (2) In the Doyon-Bousquet-LaRonde and Kidd Creek districts, the great variability in ore and accessory metal (Cu, Pb, Zn, Co, Ni, As, Sb, Te, Bi) concentrations within the SMI are the result of co-entrapment of sulphide melts, indicating that rhyodacitic liquids were sulphide saturated at depth. The metal enrichment patterns of these sulphide melt phases show marked similarities to specific VMS ores zones (e.g. Au-rich ores at LaRonde), suggesting that degassing or leaching of volcanic rocks prior to, during, or after emplacement may have destabilized these metal rich sulphides contributing metals to hydrothermal ore fluids; (3) Rhyolitic magmas were variably saturated in volatile phases at depth (notably carbonic fluid), and consequently, any consideration of magmatic volatile contributions to VMS ore systems must consider that not all metal sequestering occurred locally and that variable metal loss at depth may actually have been detrimental to the magma metal fertility.

THE GEOSCIENTIFIC FOUNDATION OF NIAGARA WINES: DEVELOPMENT OF AN OPEN ACCESS NIAGARA WINERY GEOTRAIL

Joseph Hansen[1], Keira Hum[1], Katie Maloney[2], Carolyn Eyles[1]
[1]McMaster University, [2]McGill University.
E-mail: *eylesc@mcmaster.ca*

The Niagara region in southern Ontario is famous for its wineries. Wine production in this region thrives because of the unique combination of physiographic, pedolog-

ical, and climatic factors influenced by the local geology. However, there is limited information about these significant environmental factors available in an open-access and accessible format for a public audience. We are creating an informative and educational virtual field trip, known as a GeoTrail to highlight how the geological setting governs the modern climate and the diverse agriculture industry (e.g. specifically vineyards) in the Niagara Region. The GeoTrail will describe the geological and physiographic features of the northern Niagara Peninsula and adjacent escarpment face, the origin of these features, and their importance in affecting pedological and climatic factors critical to successful vine growth in the area. These factors all influence the characteristics of the wines produced by a particular grape in different parts of the region (terroir) and have allowed the identification of specific appellations and sub-appellations. The GeoTrail will include information about the geological and physiographic characteristics of selected wineries from the Lake Iroquois Plain bordering Lake Ontario and the Niagara Escarpment (including several distinct benches and terraces) and the wines characteristic of these particular settings. The GeoTrail will be hosted on the geoscienceinfo.com website and is intended as an informative guide for a driving tour promoting both geoscience communication and local tourism.

STUDIES OF ACCESSORY MINERALS IN THE ATHABASCA BASIN TO EVALUATE THE POSSIBLE SOURCES OF U AND REE IN UNCONFORMITY-RELATED URANIUM DEPOSITS

Goktug Harmanci[1], Guoxiang Chi[1], Yumeng Wang[1], Victoria Tschirhart[2], Jeremy Powell[2], Duane Petts[2]
[1]University of Regina, [2]Geological Survey of Canada.
E-mail: *goktugharmanci3@gmail.com*

Unconformity-related uranium (URU) deposits in the Athabasca Basin are among the largest high-grade uranium deposits in the world and many of them also contain high concentrations of rare earth elements (REE). It remains unclear whether U and REE were derived from the basin, basement, or both. Previous studies indicate the presence of U- and REE-rich diagenetic fluids in the basin, as recorded by fluid inclusions in quartz overgrowths and some diagenetic minerals. However, there are considerable uncertainties regarding where these metals were originally hosted in the sediments (source), how the metals may have been released into the basinal fluids (extraction), how much and in what form the extracted metals may have been retained in the sediments (sink), and how much of the metals remaining in the basinal fluids may have contributed to the formation of the URU deposits. This study aims to characterize the major and trace element compositions and textures of detrital and diagenetic accessory minerals hosting most of the U and REE in the sedimentary rocks (mainly sandstones) of the Athabasca Basin, including zircon, monazite, xenotime, apatite, Fe- and Ti-oxides, aluminum phosphate sulphate (APS) minerals, and clay minerals. A number of samples have been collected from different stratigraphic levels and different locations across the basin and polished thin sections have been prepared from them. Selected samples containing the targeted minerals will be studied with petrographic microscopy, scanning electron microscope-energy dispersive spectroscopy (SEM-EDS), electron probe microanalyser (EPMA), SEM-cathodoluminescence (SEM-CL), Raman spectroscopy and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analysis and mapping. Preliminary results indicate that the potential U- and REE-bearing minerals are unevenly distributed in the sandstones and show various features indicating fluid-mineral reactions. Petrographic features indicating uneven alteration of zircon grains similar to those of metamict zircon that experienced reaction with high-salinity fluids were observed. The results of this study will be combined with the whole-rock analytical results of sedimentary rocks in the Athabasca Basin from the literature to calculate the amounts of U and REE that may have been released from the basin and to assess the potential of U and REE mineralization of the basin as a whole, particularly the contribution of U and REE from the basin to URU mineralization.

EVALUATING REACTIVE MATERIALS FOR PASSIVE WATER TREATMENT IN OIL SAND MINE RECLAMATION LANDFORMS

Sanaz Hasani, Matthew B.J. Lindsay
University of Saskatchewan.
E-mail: *sanaz.hasani@usask.ca*

Mining activities in oil sand mines in northern Alberta, Canada, produce froth treatment tailings (FTT) that are characterized by elevated sulphide-mineral and low carbonate mineral content. Previous studies have shown that oxidative weathering can promote acidification and metal release, with associated FTT porewaters exhibiting pH below 4 and elevated concentrations of several metal(loid)s including Fe, Al, Zn, Ni, Co, Cu, and As. Although neutralization reactions within FTT deposits increase pH and promote metal(loid) attenuation, other mine materials including overburden, tailings, and upgrading by-products could contribute to these mitigation reactions within reclamation landforms. We conducted laboratory batch experiments under anoxic conditions to assess the acid neutralization and metal(loid) attenuation capacity of various mine materials and, for comparison, reactive materials commonly used for water treatment at metal-mining operations. We independently reacted two simulated FTT pore-water solutions (i.e. pH 4.5 and 7.5) with overburden (i.e. peat, glacial till, shale), tailings (i.e. coarse sand tailings, fluid fine tailings), and reactive materials (i.e. zero-valent iron (ZVI), zeolite). In all batches, we observed increases in solution pH and alkalinity coupled with decreasing metal(loid) concentrations. Solution pH increased from 4.5 to ~7 in the acidic batches, while pH values for the circumneutral batches ranged from 7.3 (peat) to ~9 (ZVI). Iron removal ranged from 16 to 96%, with the highest removal observed in the batches containing zeolite. Extensive removal of Co (94–98%), Ni (> 99%), Zn (> 99%), Cu (> 99%), V (> 99%), Se (> 99%), and As (> 99%) was observed for all pH 4.5 and pH 7.5 batches. Our results show that several oil sands mine materials possess substantial capacity for acid neutralization and metal(loid) attenuation, which could be utilized for FTT management and reclamation.

CRITICAL MINERALS IN GOLD DEPOSITS AND THEIR BY-PRODUCT POTENTIAL

Evan Hastie
Ontario Geological Survey.
E-mail: *evan.hastie@ontario.ca*

Gold is one of Ontario's most significant mineral resources, and its gold deposits represent some of the richest in the world. These gold deposits are host to more metals than simply gold, and many of these (e.g. Te, Sb, Mo, Bi, etc.) are listed in global critical mineral strategies. For example, previous studies on the Kirkland Lake gold district have reported some Te concentrations in gold ore but the by-product potential of Te remains unknown due to a lack of data and appropriate certified reference materials. These data suggest Te concentrations in the Kirkland Lake gold district may be comparable to current Te producers (e.g. Boliden Group - Kankberg deposit). By-product potential may also exist for many other elements in other jurisdictions such as Mo-Sb-Te in the Hemlo area and Sb in the Red Lake area, but no comprehensive and quantitative study of all the secondary metals associated gold deposits across Ontario has been undertaken to date. If the concentration of secondary elements in gold deposits and their mineral hosts can be more comprehensively investigated and compiled, then these data would provide a baseline for both researchers and industry across many different disciplines. This presentation explores the close associations of the semi-metals with gold in deposits and gives an overview of the Ontario Geological Survey's critical mineral project looking into the by-product potential of gold deposits across Ontario. The project includes ore from major gold camps, standalone deposits, developing prospects, and will produce the first comprehensive multi-element geochemistry database on gold ore as well as a detailed investigation into the mineral phases and deportment of critical metals. This project will assist gold exploration from the prospector- to major company-level, allow industry to incorporate by-product and critical mineral potential in their resource calculations from the very beginning of exploration, and allow existing operations to re-evaluate their resources. There are more variables than these to consider, such as cost of metallurgical processing and mill design compared to increased profit, but without a basic understanding of the concentrations of metals and their deportment, further action toward by-product production is unlikely.

CRUSTAL ARCHITECTURE AND DEEP BASEMENT STRUCTURES IN THE NORTH RANGE OF THE SUDBURY IMPACT CRATER

Rasmus Haugaard[1], Ademola Adetunji[1], Rajesh Vajavur[1], Saeid Cheraghi[1], Mike Hamilton[2], John Ayer[1], John Spray[3], David Snyder[4], Richard Smith[1], Guido Serafini[5], Kristin Henry[6]
[1]Laurentian University, [2]University of Toronto, [3]University of New Brunswick, [4]Geological Survey of Canada, [5]Glencore Company, [6]Vale Corporation.
E-mail: *rashaugaard@gmail.com*

The 1.85 Ga Sudbury impact structure is one of the largest and best preserved multi-ring craters on Earth. In contrast to many planetary bodies, the Earth has been tectonically active and its surface has undergone intense erosional processes throughout much of its history. Although this has erased most of Earth's original impact structures, the prolonged erosion presents a unique opportunity to access the deeper geological architecture and basement structures of surviving large ancient impact craters. Along a transect across the eastern part of the Sudbury North Range, geophysical surveys (seismic, magnetotelluric (MT) and gravity) were conducted in combination with the geological interpretation of deep (~3 km) drill cores. The crater floor underneath the Sudbury Igneous Complex (SIC) is marked by concave geophysical features that correspond with the top of the basement gneiss (footwall). In this area, the footwall dips to the south beneath the SIC, progressively changing from 45° in the north, to 15–20° further south, beneath the Onaping Formation. At ca. 2.2 km depth, at the base of the SIC, a highly conductive MT-feature correlates with a large Ni-Cu mineralized keel. The syn- to post-impact Penokean orogeny at ca. 1.8 Ga resulted in north-directed thrusting and the formation of a large NW-SE striking anticlinal fold with an amplitude of ca. 1.5 km of both the footwall and the SIC. In addition, a pronounced subvertical crustal fault is evident between the SIC and footwall gneiss close to surface in the north, which can be seismically traced down to a depth of at least 7 km, separating two different seismic domains within gneissic footwall rocks. The origin of this fault is uncertain, but may be related to a potential North Range ring structure exterior to the remaining SIC. The feature could mark the southern boundary of the original uplifted inner ring structure separating a high-grade metamorphic central uplift (inner basin) to the south with a higher crustal level, lower grade metamorphic domain, to the north.

AN EVOLUTIONARY SYSTEM OF MINERALOGY: CLASSIFYING MINERALS BASED ON PROCESS AND TIME

Robert Hazen, Shaunna Morrison
Carnegie Institution for Science.
E-mail: *rhazen@ciw.edu*

The story of Earth is a 4.5-billion-year saga of dramatic transformations, driven by physical, chemical, and ultimately biological processes. The co-evolution of life and rocks unfolds in an irreversible sequence of evolutionary stages. Each stage resculpted our planet's surface, while introducing new planetary processes and phenomena. Sequential changes of terrestrial planets and moons are best preserved in their rich mineral record. "Mineral evolution" attempts to classify minerals based on our planet's diversifying near-surface environment, beginning with a score of different mineral species that formed in the cooling envelopes of exploding stars. Dust and gas from those stars clumped together to form our stellar nebula, the nebula formed the Sun and countless planetesimals, and alteration of planetesimals by water and heat resulted in the 300 minerals found today in meteorites that fall to Earth. Earth's evolution progressed by a sequence of chemical and physical processes, which ultimately led to the origin of life. Once life emerged, mineralogy and biology co-evolved, as changes in the chemistry of oceans, the atmosphere, and the crust dramatically increased Earth's mineral diversity to the more than 5800 species known today. The "evolutionary system of mineralogy" is an effort to place those mineral species approved by the International Mineralogical Association's Commission on New Minerals, Nomenclature, and Classification (IMA-CNMNC; https://rruff.info/ima) into their historical and paragenetic contexts. The initial five parts of the system cataloged almost 300 species that occur as primary and secondary phases in meteorites. Part VI focused on Earth's earliest mineralogy, including 262 species formed via a variety of igneous, hydrothermal, aqueous alteration, and other near-surface processes. Part VII on "The evolution of the igneous minerals" documented 1665 primary species, with special attention to the most common 115 kinds of igneous minerals, while Part VIII examines metamorphic mineral evolution. The final four parts of the system will examine biologically mediated minerals.

ON THE EVOLUTION OF THE IGNEOUS MINERALS: AN INFORMATICS APPROACH TO RARE-ELEMENT MINERALS

Robert Hazen[1], Shaunna Morrison[1], Anirudh Prabhu[1], Michael Walter[1], Jason Williams[2]
[1]Carnegie Institution for Science, [2]United States Geological Survey.
E-mail: *rhazen@ciw.edu*

Igneous rocks display characteristics of an evolving chemical system, with significant increases in their minerals' diversity and chemical complexity over the first two billion years of Earth history. We compiled and analyzed 1635 modes of diverse igneous rocks and applied methods of mineral informatics to explore patterns in igneous mineral evolution. In particular, 115 of the most common primary igneous minerals fall into 4 communities, each with its own set of compositional attributes. Earth's earliest igneous lithologies (> 4.56 Ga), were ultramafic rocks rich in olivine and/or pyroxene - rocks that have been present throughout the planet's history. Basalt, gabbro, and other mafic rocks with significant calcic plagioclase, which were formed from magmas primarily derived by decompression melting of ultramafic rocks, have been present almost as long as ultramafics, probably by 4.56 Ga. Small volumes of quartz-normative igneous rocks formed during the final crystallization stages of some gabbroic intrusions prior to 4.5 Ga, with much greater volumes of granitoid rocks initially formed by partial melting of basalt and/or sediments by 4.4 Ga. Four mineralogically distinctive groups of igneous rocks - complex granite pegmatites, alkaline igneous suites, carbonatites, and layered igneous intrusions, each of which contains diagnostic concentrations of rare elements - significantly postdate the igneous lithologies outlined above. All appear to have first formed close to ~3.0 Ga, possibly because they required the extensive fluid-rock interactions of the crust and upper mantle associated with subduction. Each of these four types of exotic igneous mineralization added to the diversity, as well as the chemical and structural complexity, of Earth's minerals. These more recent varied kinds of igneous rocks hold more than 700 different minerals, 500 of which are unique to these lithologies. Network representations and heatmaps of primary igneous minerals illustrate Bowen's reaction series of igneous mineral evolution, as well as his concepts of mineral associations and antipathies. Furthermore, phase relationships and reaction series associated with the minerals of a dozen major elements (H, Na, K, Mg, Ca, Fe, Al, Si, Ti, C, O, and S), as well as minor elements (notably Li, Be, Sr, Ba, Mn, B, Cr, Y, REE, Ti, Zr, Nb, Ta, P, and F), are embedded in these multi-dimensional visualizations.

DEVELOPMENT OF EDIACARAN ULTRAMAFIC LAMPROPHYRE DYKES IN THE SAGUENAY CITY REGION, QUEBEC

Michael Higgins
Université du Québec à Chicoutimi.
E-mail: *mhiggins@uqac.ca*

The oldest part of Saguenay City Alkali Province (SCAP) comprises two swarms of ultramafic lamprophyre dykes (UML). The Saguenay Fjord swarm (SFD) is exposed along the Saguenay and dips 35° to the north. Some SFD are cumulates of olivine, oxides and baddeleyite (phoscorites). A second, smaller swarm crops out in the Baie de Haha (BDH), just to the south with a vertical NW-strike. The SDF is ca. 580 Ma and the BHD is as yet undated, but probably similar in age. High-temperature mineralogy is only preserved in a few dykes: Mg# Olivine = 84; Pyx = 82; Phlogopite = 81. Compositions of the SFD have a continuous compositional range: e.g. CO_2 =

2–41%; SiO_2 7–48%. One dyke has a mantle-derived xenolith (eclogite?), but the outcrop is now buried. Some dykes have vesicles, now filled with calcite. The BHD have more restricted compositions: CO_2 1–10%; SiO_2 24–42%. The overall compositional range is very similar to other UML fields, such as the well-documented Allik dykes, Labrador. The UML phase was followed by a plutonic phase of carbonatite and syenite intrusions (Sainte Honoré ~570 Ma) that are exploited for niobium. The 10 M.y. difference in age between the hypabyssal and plutonic components of the SCAP rules out a simple model of maturation of a single plumbing system. Instead, it is suggested that the underlying mantle was capable of producing alkali magmas for at least 10 M.y., but that tectonic forces controlled transfer to the upper part of the crust where they are now exposed. Most of the UML dykes appear to have risen quite rapidly from the mantle without much differentiation; however, the phoscorites show that some magma must have been stored at depth and entrained in new magmas. It is likely that some of the ULM magma reached the surface to erupt as maars and ash cones but these have not been preserved. The carbonatite intrusions must represent differentiation during a more prolonged period of storage, perhaps related to significant movements on rift faults. Again, it is likely that the system was open to the surface.

VOLUMINOUS POST-COLLISIONAL, FERROAN, A-TYPE GRANITES AND IMPLICATIONS FOR CRUST FORMATION AND METALLOGENIC TENOR IN THE PALEOPROTEROZOIC

Alana M. Hinchey, Hamish A. Sandeman, Jared P. Butler
Geological Survey of Newfoundland and Labrador.
E-mail: *alanahinchey@gov.nl.ca*

Arc magmatism along convergent plate boundaries has been a major global contributor to continental crustal growth. During the late Paleoproterozoic–Mesoproterozoic assembly of supercontinent Nuna, following arc-backarc-continent collisions, the Makkovik Orogen, along the southern margin of the Archean North Atlantic Craton, experienced major pulses of ca. 1800 Ma continental arc magmatism. Lithogeochemistry indicates compositions typical of ferroan, alkali to alkali calcic, A-type granites formed through fractional crystallization. The magmatic rocks have $\varepsilon_{Nd(t)}$ values varying from –5.3 to +2.0 and $T_{(DM)}$ model ages from 2750 to 1880 Ma, suggesting derivation from variably recycled/assimilated Neoarchean to Paleoproterozoic lithosphere with a noteworthy juvenile component. Oxygen fugacity (fO_2) ratios, estimated by the proxy ratio of $FeO^T/(FeO^T + MgO)$, range from 0.58 to 0.99, indicating the parental magmas formed in both reducing and oxidizing conditions; this, coupled with observed alkali-calcic alteration makes them prospective for a variety of intrusion-related styles of mineralization including iron-oxide-copper-gold (IOCG) and uranium. Based on the petrology, lithogeochemistry, and isotopic compositions, the ca. 1800 Ma magmatic event developed post-collisional following the docking of the Cape Harrison Arc/micro-continent with the North Atlantic Craton (during the assembly of the supercontinent Nuna). This collision was followed by slab roll-back (possible break-off), extensional collapse and mantle upwelling resulting in the generation of the abundant ca. 1800 Ma felsic magmatism. The timing of plutonism in a Makkovik Orogen overlaps with significant felsic plutonism from ca. 1818–1799 Ma in the Julianehåb Igneous Complex and North Atlantic Craton of Ketilidian Orogen of southern Greenland.

UNCONVENTIONAL MAGMATIC SULPHIDE SYSTEMS: IN SEARCH OF THE NEXT Ni-Cu-Co-PGE DISCOVERY

David Holwell
University of Leicester.
E-mail: *dah29@le.ac.uk*

Magmatic Ni-Cu-Co-PGE sulphide deposits are the world's major source of battery grade Ni, PGE, and important contributors to global Cu and Co resources and therefore the discovery and development of these deposits is critical to the energy transition to a net zero carbon future. Magmatic sulphides are hosted by mantle-derived mafic-ultramafic intrusions and throughout the crust. Established models for their genesis, which thus provide direction for exploration models, have focussed on a number of key criteria: (1) a craton margin association for many Ni-rich deposits; (2) an intracratonic setting for most PGE deposits; (3) the importance of plumes and extensional regimes for both; and (4) moderate to high (> 15%) degrees of partial melting of dry, olivine-rich peridotitic source rocks. However, many deposits do not conform to these criteria, and there are a significant number of deposits in orogenic settings formed in more alkaline and hydrous magmas that were sourced from relatively lower degrees of partial melting of a metasomatized, hydrous mantle source. The mineral assemblages in these sources contain phlogopite which can contain Ni concentrations as high as olivine, and thus can be an important source of Ni to magmatic sulphide systems in a wider range of geotectonic settings. A number of examples of more unconventional deposits from Canada and around the globe are explored to illustrate the variable characteristics of magmatic sulphide deposits formed from hydrous and carbonated pyroxenitic, rather than peridotitic mantle sources, emplaced throughout the entire thickness of the continental crust. By identifying greater variability in the components of the Ni-Cu-Co-PGE mineral system, search spaces can be expanded, and the next new discovery could be outside of traditional, established Ni camps.

THE OROGENIC GOLD BELT OF CENTRAL NEWFOUNDLAND AND POSSIBLE CORRELATIONS ALONG STRIKE

Ian W. Honsberger[1], Wouter Bleeker[1], Hamish A.I. Sandeman[2], Aaron L. Bustard[3], Sandra L. Kamo[4]
[1]Geological Survey of Canada,
[2]Geological Survey of Newfoundland and Labrador,
[3]Geological Survey of New Brunswick, [4]University of Toronto.
E-mail: *ian.honsberger@nrcan-rncan.gc.ca*

Paleozoic terranes in the Canadian Appalachians are bound and cut by deep-reaching fault zones that host orogenic gold systems. In Newfoundland, such fault systems extend for more than 400 km northeast-southwest across the Dunnage Zone. The scale of faulting and patterns of structurally controlled gold mineralization in central Newfoundland resemble world-class orogenic gold systems globally. The orogenic gold belt of central Newfoundland is defined by crustal-scale, late Silurian to Devonian fault zones in the eastern Dunnage Zone (Exploits Subzone). These fault zones overprint, crosscut, and reactivate older Silurian structures associated with Salinic accretion. Latest Silurian, post-Salinic, crustal-scale extensional faulting triggered widespread, strongly bimodal magmatism and created the accommodation space for deposition of syn-orogenic clastic rocks (the polymict Rogerson Lake Conglomerate). Latest Silurian extension in central Newfoundland was the key prelude to Devonian thrust reactivation and orogenic gold mineralization. The largest known gold deposits and related prospects are Devonian in age and occur along the Valentine Lake-Victoria Lake shear zone corridor, a narrow structural 'triangle zone' defined by upward-converging, Acadian thrust faults of opposing dip. The model for orogenic gold mineralization along the Valentine Lake-Victoria Lake shear zone corridor in central Newfoundland requires careful testing along strike, both to the southwest and northeast. In northeastern Newfoundland, orogenic gold mineralization is hosted in Ordovician black shale-turbidite sequences and Ordovician and Devonian gabbro bodies along a structural corridor defined by the Dog Bay Line and Appleton Fault Zone. In the southwest, the orogenic gold-mineralized Cape Ray Fault Zone preserves Silurian syn-orogenic sedimentary and igneous rocks similar to the Victoria Lake Shear Zone; however, stratigraphic correlations between these structures depend on systematic structural and geochronological studies. The Cape Ray Fault Zone may continue along strike into northern New Brunswick where latest Silurian to earliest Devonian, extension-related, clastic sedimentary rocks and bimodal igneous rocks occur along the Rocky Brook-Millstream Fault that hosts Devonian orogenic gold mineralization. Present geological, geochronological, and mineralization constraints support a correlation between the Rocky Brook-Millstream Fault and the orogenic gold-mineralized Cape Ray-Valentine Lake-Victoria Lake structural corridor. Future structural studies and syntheses in Newfoundland and New Brunswick will be critical to further test along-strike correlations of orogenic gold-bearing structures.

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THE AMUNDSEN-GANSWINDT BASIN: A PRE-NECTARIAN PEAK-RING BASIN AND VOLATILE COLD TRAP IN PROXIMITY TO THE ARTEMIS III EXPLORATION ZONE

Jack W. Hostrawser, Gordon R. Osinski
Western University.
E-mail: *jhostraw@uwo.ca*

In the region around the lunar south pole being targeted by the Artemis III crewed lunar landing mission is a poorly preserved impact basin, unofficially named "Amundsen-Ganswindt" (81°S, 120°E). This highly eroded basin, with an approximate diameter of 335 km and an age in the range of 4.5 to 3.9 Ga, contains a preserved remnant of an uplifted peak-ring that offers a previously unrecognized confluence of geological targets within the scope of post-Artemis-III missions. This peak-ring remnant has been mostly destroyed by subsequent impacts but its remnants can be identified as a series of disconnected topographic highs that rise above the low-lying basin floor and form an arcuate trend about the centre of Amundsen-Ganswindt. This feature is similarly positioned and of similar shape to the well-preserved peak-ring observed within the nearby Schrödinger basin (75.0°S 132.4°E; 312 km; 3850–3200 Ma). Peak-rings uplift deeply-buried crustal material to the surface, which in this region may mean that the peak-rings of both Amundsen-Ganswindt and Schrödinger have uplifted materials of the outer rim of the South Pole-Aitken basin (SPA)—the oldest and largest basin on the Moon. Dating the SPA via samples will 'anchor' dates for all subsequent lunar impacts and will help to constrain the thermal evolution of the Moon. In the case of the Amundsen-Ganswindt peak-ring remnant, later ejecta from the Schrödinger, Amundsen, and Idel'son L craters have likely draped the structure, making it appear less attractive a target for exploration than the peak-ring of Schrödinger. However, the younger Idel'son L simple crater (84°S, 116°E; 28 km; 3850–3200 Ma) has excavated directly into the Amundsen-Ganswindt peak-ring remnant and thus its ejecta deposits expose 'fresh' material from the peak-ring, delivering it to the traversable, smooth plains below. A remote-sensing study of the region reveals that the ejecta of Idel'son L has spectral signatures suggestive of high weight-percentage plagioclase, which would be expected from uplifted lunar crust. Conveniently, the peak-ring remnant immediately east of Idel'son L casts shadows that contain several kilometre-scale, permanently shadowed regions with detections of water ice by the Lyman-Alpha Mapping Project ultraviolet imager and the Moon Mineralogy Mapper infrared spectrometer. Thus, in a small geographic region, there exists on low-slope terrain the potential to sample SPA material, ejecta from Schrödinger and Amundsen craters, and preserved volatiles.

OVERVIEW OF MAGMATIC Ni-Cu-(PGE) AND CHROMITE DEPOSITS ASSOCIATED WITH MAFIC AND ULTRAMAFIC ORE SYSTEMS IN CANADA

Michel G. Houlé[1], C. Michael Lesher[2]
[1]Geological Survey of Canada, [2]Laurentian University.
E-mail: *michel.houle@nrcan-rncan.gc.ca*

The transition to low-carbon economy that is taking place in Canada and elsewhere around the world is bringing renewed interest in critical minerals, many of which (Ni, Cu, Co, PGE, Cr, Ti, and V) are recovered from various deposit types related to magmatic mafic-ultramafic mineral systems. Canada ranked sixth in Ni production in 2021, representing close to 5% of global Ni production worldwide. Almost all the historic and current Canadian production comes from large mining districts (e.g. Sudbury, Thompson, Voisey's Bay, Raglan, and Lynn Lake), all of which still have significant large brownfield potential. However, several other regions exhibit excellent greenfields potential, as shown by the presence of many historic and recently discovered Ni-Cu-Co-(PGE) deposits. Magmatic Ni-Cu-Co-(PGE) deposits with variable abundances of sulphides/alloys and metal ratios formed throughout geological time (Mesoarchean to Cenozoic) from a wide range of parental magmas (komatiitic to quartz dioritic) in a wide range of tectonic settings (extensional to convergent), so none of these attributes are particularly critical exploration variables. However, they can be subdivided into three target categories based on sulphide abundance: (1) sulphide-rich, (2) sulphide-poor, and (3) sulphide-free deposits. Sulphide-rich deposits typically occur as clusters of high-grade small-tonnage accumulations of massive/net-textured/disseminated/blebby Fe-Ni-Cu sulphides hosted by cumulate-rich units in channelized mafic-ultramafic lava/sill/dyke/feeder complexes (e.g. Raglan-Expo, QC; Thompson, MB; Voisey's Bay, NL). Sulphide-poor deposits typically occur as low-grade large-tonnage accumulations of disseminated Fe-Ni-(Cu) sulphides hosted by cumulate-rich zones in channelized ultramafic lavas/sills or layered ultramafic to mafic intrusions (e.g. Dumont, QC; Crawford, ON; Turnagain, BC). Sulphide-free deposits typically occur as low-grade large-tonnage deposits of disseminated Ni-Fe alloys (e.g. awaruite) hosted by thick ultramafic components of ophiolitic complexes (e.g. Baptiste/Decar, BC). Deposits richer in sulphides are more likely to contain economic abundances of accessory critical minerals (e.g. Te, PGE, Sc). There are two target categories of Cr ± PGE deposits: (1) podiform deposits in ophiolite complexes (e.g. Québec), and (2) stratiform deposits in layered intrusions (e.g. Ring of Fire). There is current no production in Canada, although there was some historic mining during the early part of the 20th century and with the future development of the world-class Ring of Fire chromite deposits, Canada is poised to become a significant chromite producer. Thus, Canada has not only significant potential for discovery of additional Ni-Cu-Co-(PGE) mineralization in traditional and established mining camps, but also has tremendous potential for discovery of new Ni-Cu-Co-(PGE) and Cr-PGE deposits in underexplored regions of Canada.

GEOLOGICAL ATTRIBUTES OF THE Cr-Ni-Cu-PGE AND Fe-Ti-V-P MINERALIZED RING OF FIRE INTRUSIVE SUITE, MCFAULDS LAKE GREENSTONE BELT, SUPERIOR PROVINCE, NORTHERN ONTARIO, CANADA

Michel G. Houlé[1], C. Michael Lesher[2], Anne-Aurélie Sappin[1], Riku T. Metsaranta[3]
[1]Geological Survey of Canada, [2]Laurentian University, [3]Ontario Geological Survey.
E-mail: *michel.houle@nrcan-rncan.gc.ca*

One of the dominant geological features of the arcuate, > 175 km long, Mesoarchean to Neoarchean McFaulds Lake greenstone belt (MLGB) in northern Ontario is the semi-continuous trend of mafic to ultramafic intrusions belonging to the Ring of Fire intrusive suite (RoFIS), which hosts world-class Cr deposits, a major Ni-Cu-(PGE) deposit, and potentially significant Fe-Ti-V-(P) prospects. The RoFIS has been subdivided into two endmembers based on their spatial distribution, lithological associations, geochemical signatures, and mineralization styles: the Ekwan River (ERSS) and Koper Lake (KLSS) subsuites. Although the mafic to ultramafic intrusive bodies of these subsuites have similar emplacement/crystallization ages (KLSS = 2735.5 to 2732.9 Ma vs. ERSS = 2734.1 to 2732.6 Ma), they are significantly different in many respects: (1) the KLSS is spatially much more restricted than the ERSS; (2) the KLSS is composed of dunite, peridotite, chromitite, pyroxenite, and gabbro, whereas the ERSS is composed of abundant gabbro and ferrogabbro with lesser anorthosite and rare pyroxenite and does not contain any olivine-rich ultramafic rocks; (3) the KLSS typically hosts Cr and Ni-Cu-(PGE) mineralization, whereas the ERSS typically hosts Fe-Ti-V-(P) mineralization; and (4) the KLSS (higher values of Ni and Cr) and ERSS (higher values of Ti and V) have clear differences in their geochemical trends indicating a distinct geochemical evolution. Furthermore, ERSS ferrogabbro locally intrudes KLSS units, however, the opposite relationship is also observed at one locality. The magmatic evolution is still being debated, but the above observations suggest temporally overlapping but discrete ultramafic-dominated (KLSS) and mafic-dominated (ERSS) intrusions with complex contact relationships, rather than a single, large, tectonically dismembered layered ultramafic-mafic intrusion, as previously suggested. A newly recognized intrusive body in the area contains olivine-rich ultramafic rocks and chromitite seams, like other members of KLSS, but both are enriched in Fe relative to rocks of the KLSS. Regardless of their origin, the wide diversity of mineral deposit types within the mafic and ultramafic rocks of the Ring of Fire intrusive suite, including Cr, Ni-Cu-(PGE), and Fe-Ti-V-(P) mineralization, make the McFaulds Lake greenstone belt region an excellent exploration target to increase the world's supply of critical minerals.

PROMOTING GEOSCIENCE EDUCATION THROUGH ACCESSIBLE GEOTRAILS IN URBAN SETTINGS

Keira L. Hum[1], Katie M. Maloney[2], Joe Hansen[1], Julia P. Nielsen[1], Carolyn H. Eyles[1], Elli Papangelakis[1], Alexander L. Peace[1]
[1]McMaster University, [2]McGill University.
E-mail: *humk@mcmaster.ca*

It is extremely important to communicate geoscience concepts to the public in an accessible and informative format to encourage appreciation of the importance of geological processes in shaping our urban communities and to raise environmental awareness. At McMaster University, Hamilton, Ontario, our team has created two curated educational virtual field trips, urban GeoTrails, to highlight the geological features of local building stones, and the characteristics of local rocks found in an urban setting. These GeoTrails have been created using ArcGIS StoryMaps, an Esri-developed software, which allows the integration of maps, images, text, and other multi-media content into a user-friendly website. Images collected using non-intrusive technology such as drones, 360-degree cameras, and 3D models utilizing LiDAR technology (collected by the iPad Pro), have been used to illustrate geological features that can be observed along the set trail path. Two virtual urban GeoTrails have been created around the McMaster campus, within the urban Hamilton area, highlighting the importance of the Niagara Escarpment as a local source for building stones as well as the impact this landscape feature has had on the development of surrounding communities: the “McMaster Rock Garden Urban GeoTrail” and the “McMaster Building Stones Urban GeoTrail”. The objective of these GeoTrails is to capture two different aspects of the McMaster campus, aimed toward two different audiences. The McMaster Rock Garden Urban GeoTrail focuses on the usage of notable, unique decorative rocks on the campus grounds and aims to inform students and community members of their geological characteristics and origin. In contrast, the McMaster Building Stones Urban GeoTrail focuses more on the composition and origin of the stones used for the buildings, including their source areas and historical aspects of quarrying in the region. This GeoTrail is primarily aimed towards those interested in introductory geoscience, history, and architecture. In previous years, a scavenger hunt prototype of these tours was used to introduce first-year students to the McMaster campus as well as teach introductory geoscience concepts. The current urban GeoTrails project is being developed in partnership with the Association of Professional Geoscientists of Ontario (APGO) Education Foundation and the GeoTrails are openly accessible to the public on the geoscienceinfo.com website. The creation of these urban GeoTrails is particularly important for exemplifying the impact geology has on our everyday lives and for captivating urban audiences.

UNDERSTANDING THE EFFECTS OF MINERALIZING FLUIDS ON PETROPHYSICAL PROPERTIES: A STUDY OF ELECTRICAL PROPERTIES IN A Cu-Au SYSTEM AT UPPER BEAVER, CANADA

Brandon Hume[1], Christian Dupuis[1], Richard Smith[2]
[1]Laval University, [2]Laurentian University.
E-mail: *brandon.hume.1@ulaval.ca*

The Upper Beaver Deposit (UB) is a Cu-Au hydrothermal system located within the Abitibi subprovince north of the main Larder-Lake Cadillac break. The Upper Beaver Intrusive Complex (UBIC) can be broken down into successive intrusive phases which contain abundant primary and secondary magnetite associated with Cu-Au rich mineralization. The complex structural controls on mineralization often influence the measured geophysical response, resulting in a difference in petrophysical signal for two mineralogically similar host rocks. Using a ratio of a texturally sensitive property (electrical resistivity) we have found that it is possible to differentiate between alteration of geological units based on the geometry of textures (veining, mineralization, and faulting) present. In this work, we show that resistivity is strongly influenced by the geometry of the textures relative to the geometry of the measurement instrument used to acquire borehole data. We show that hydrothermal epidote, sericite, and mineralization have a significant effect on electrical resistivity over centimetre to metre scale and these can be inferred from the results. To better illustrate the scale effects of these features and ultimately the macro texture of the rock mass measured, we have introduced the resistivity ratio N64/N8. At UB, the resistivity of the mineralized rock is expected to increase as textures increase in scale. The veins that are associated with mineralization are dominated by quartz, carbonate and ankerite. The resistivity ratios computed show that different alterations can be split into three broad events: (1) pre-ore, (2) main-ore, and (3) post-ore based on their N64/N8 ratios. Pre-ore alteration occupies a N64/N8 range of 1.5–2.0. Main ore-event alteration can be split between Cu-Au and Au rich. The Cu-Au rich alteration (epidote, K-feldspar) plots between 0.9 and 1.2 while the Au rich alteration (epidote, ankerite) plots between 2.5 and 3.5. The post-ore alteration occupies ratios that range from 0.5 to 0.7. Breccias and faults are associated with carbonate Au rich veins and are shown to have a compounding effect on the N64/N8 ratio. We also found that Cu-Au rich mineralization close to the stock work zone sees an increased resistivity ratio when compared to distal mineralization. Fractures and hole conditions were investigated but did not have a greater effect on resistivity than alteration. We conclude that textures which are often associated with the highest grades of mineralization can be separated from host rock by comparing measurements from different electrode spacings.

IDENTIFYING POTENTIAL SOURCES OF CRITICAL MINERALS IN MINERAL SYSTEMS USING THE CRITICAL MINERALS IN ORES (CMiO) DATABASE

David Huston[1], Evgeniy Bastrakov[1], George Case[2], Garth Graham[2], Al Hofstra[2], Christopher Lawley[3], Vladimir Lisitsin[4], Bronwen Wang[2]
[1]Geoscience Australia, [2]United States Geological Survey,
[3]Geological Survey of Canada, [4]Geological Survey of Queensland.
E-mail: *David.Huston@ga.gov.au*

Although critical minerals (CMs) are currently produced from existing mines, their distributions in many mineral systems are, in many cases, poorly known, raising the possibility that CMs are not fully recovered from some ores. The Critical Minerals in Ores (CMiO) database, compiled by Geoscience Australia, United States Geological Survey, Geological Survey of Canada, and Geological Survey of Queensland as part of the Critical Minerals Mapping Initiative, contains high-quality geochemical data from global ore deposits classified using a common framework, enabling global comparison. Using CMiO and other data, we have undertaken preliminary investigations on distributions of CMs in mineral systems including porphyry Cu (PCu), iron oxide-Cu-Au (IOCG), iron oxide-apatite (IOA), rare earth element (REE), and Zn-dominated systems. The PCu systems are enriched in Re, Pt, Pd, Se, and Te relative to the continental crust. At the Pebble (USA) PCu deposit, Re and Se are enriched in Cu ore zones, whereas Te is enriched immediately outside these zones. Although generally not recovered, alkalic PCu deposits (e.g. Galore Creek, Canada; Cadia, Australia) can be enriched in Pd and Pt. Cobalt and some REEs occur in IOCG systems, with Co enriched in magnetite-dominant IOCG systems (e.g. Ernest Henry, Australia; Kwyjibo, Canada), and REEs enriched in IOA (e.g. Pea Ridge, USA) and hematite-dominant IOCG systems (e.g. Olympic Dam, Australia). The enrichment of individual REEs depends strongly on mineral system type. In magmatic and metasomatic systems, light REEs (Ce to Sm) and Y are enriched in hematite-rich IOCG, IOA and carbonatite (e.g. Saint-Honoré, Canada) deposits, whereas heavy REEs (Eu to Lu) are enriched in deposits associated with peralkaline magmatism (e.g. Strange Lake, Canada). Unconformity-related REE (e.g. Maw, Canada; Wolverine, Australia) and ionic clay (e.g. Koopamurra, Australia) deposits also tend to be heavy REE-rich, whereas shale-hosted (e.g. SBH, Canada) and phosphorite (e.g. Ardmore, Australia) deposits can be enriched in heavy and/or light REEs. Zinc deposits are important sources of Ga, Ge, and In. Assessment of the distribution of these CMs in Zn deposits suggest that Ge is concentrated in deposits formed from low temperature, oxidized fluids (Mississippi Valley-type: Tres Marias, Mexico; sediment-hosted massive sulphides: Red Dog, USA), whereas In is enriched in deposits formed from higher temperature, reduced fluids (volcanic-hosted massive sulphide: Kidd Creek, Canada; skarn: Isabel, Australia). These examples demonstrate the utility of the CMiO and other datasets for characterizing CMs distribution in individual ore deposit and predicting CMs potentials of mineral systems.

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GOLD MINERALIZATION IN THE BLUEBERRY ZONE OF THE SCOTTIE GOLD MINE PROJECT, STIKINE TERRANE, NORTHWEST BRITISH COLUMBIA

Alex Hutchison[1], Margaret Stewart[2], Jacob Hanley[1], Craig Stewart[3]
[1]Saint Mary's University, [2]Mount Royal University, [3]Serac Exploration Ltd.
E-mail: *Alex.Hutchison@smu.ca*

The Scottie Gold Mine Project is located within the Stikine terrane in northwest British Columbia, in an area known as the 'Golden Triangle'. The Scottie Gold Mine Project comprises three main zones across approximately 4 km: the Blueberry zone, the Scottie Gold Mine zone and the Domino zone. The mineralization trend of the Blueberry zone has a N-S orientation and is juxtaposed against the E-W trend of the Scottie Gold Mine and Domino zones. The focus of this study is to determine the timing and origin of gold mineralization in the Blueberry zone, with the larger objective of determining the relationship between the Blueberry mineralization trend and the Scottie Gold Mine-Domino mineralization trend. Mineralization in the Blueberry zone occurs along a strongly and pervasively chlorite-sericite-pyrite-carbonate-altered contact between andesite and siltstone. Mineralized east-northeast striking veins intersect this contact, and the highest gold concentrations are documented along north-plunging ore shoots at the intersection between the contact and the crosscutting veins. Combined results of field mapping, drill core sampling, detailed petrography, and scanning electron microscope (SEM) analyses indicate that gold occurs as electrum and is late in the paragenetic sequence of alteration and sulphide minerals. Gold is spatially associated with pyrite, pyrrhotite, molybdenite, and arsenopyrite. Two phases of arsenopyrite are documented: an Sb-bearing phase and a Co-bearing phase, with gold most closely associated with the Co-bearing phase. Whole-rock geochemistry and SEM analyses indicate a strong correlation between Au, Mo, and Bi along the contact zone. The Au-Mo-Bi association in the Blueberry zone supports an intrusion-related gold model for the development of this zone. The strong structural control on mineralization and the late timing of gold suggest that gold mineralization has been remobilized during deformation and metamorphism. Immediately north of the Blueberry zone is a large intrusion of the Texas Creek Plutonic Suite, which has been interpreted to be the source of mineralization at the Scottie Gold Mine zone and has a U–Pb age of 192.8 Ma. At the Blueberry zone, the timing of gold mineralization is bracketed by an altered and mineralized lamprophyre dyke that cuts the contact and has a U–Pb age of 186 ± 6 Ma and by peak metamorphism and deformation in the area at ca. 110 Ma. This suggests that the Blueberry zone has a distinct source of mineralization, which has significant implications for exploration and targeting in the area.

MINING MATTERS AND CRITICAL MINERALS: THE CRITICAL MINERALS WORKSHOP AND CRITICAL CONNECTIONS POSTER PROJECTS

Lesley Hymers, Samantha Kobak
Mining Matters.
E-mail: *lhymers@miningmatters.ca*

Mining Matters is a charitable organization dedicated to educating young people to develop knowledge and awareness of Earth sciences, the minerals industry and their roles in society. Since 1994, we have reached more than 800,000 students, teachers, and members of the public across Canada. Mining Matters recently developed the Critical Minerals Workshop, aimed toward high school students that introduces them to Canada's critical minerals deemed essential for a clean, sustainable, and digitized future. Through a series of hands-on activities that encourage inquiry-based learning and discussion, students explore and discover the properties and engineering applications of select critical minerals. Students are encouraged to examine and question the criteria that deem a mineral 'critical' through an analysis of its local, national, and global significance. In Module 1: Critical Minerals Lab, students are introduced to critical minerals and some of their applications. Divided into three components, this module allows students to investigate the properties and engineering uses of select critical minerals. In Module 2, Deconstructing Technology, students are introduced to the global interconnectedness of critical minerals. Working in teams, they examine the critical minerals used in a smartphone, trace those materials to their sources, and connect the minerals industry to global markets and the economy. In Module 3, What's Next, students participate in a World Cafe discussion on topics surrounding critical minerals. Using knowledge gained from the first two modules, they consider social and environmental connections in how critical minerals are extracted and used. The workshop is separated into three connecting modules and is available for both in-person and virtual delivery. Mining Matters' Mining Makes It Happen educational poster series explores how minerals, metals, and elements connect with different aspects of daily life. Critical Connections is the sixth poster in the series and features the 31 critical minerals, metals, and elements declared by the Canadian government in 2021. Critical Connections examines the role of critical minerals, metals, and elements in the Canadian aerospace, telecommunications, and automotive industries, and in green energy generation. The poster provides detailed information about where critical minerals are mined and refined in Canada and which provinces and territories host potential deposits. The poster also provides a snapshot of the role that Canada plays in the global production of critical minerals. Future plans include incorporating interactivity into a digital version of the poster.

THE GEOLOGIST IN RESIDENCE - A CANADIAN GEOSCIENCE EDUCATION AND COMMUNICATION PROJECT

Lesley Hymers[1], Victoria Stinson[2], Beth McLarty Halfkenny[3]
[1]Mining Matters, [2]Métis Nation of Ontario,
[3]Canadian Federation of Earth Sciences.
E-mail: *lhymers@miningmatters.ca*

The Geologist in Residence (GIR) was first imagined in 2016, based on the model of the Geological Society of America's GeoCorps program, which was designed to provide short-term geoscience assignments in National Parks. The idea was brought to the Canadian Federation of Earth Sciences (CFES) for consideration and the educational concept was developed by the Canadian Geoscience Education Network (CGEN), the educational arm of CFES. After envisioning the planning and implementation possibilities in a Canadian context, CGEN recommended that the initiative debut as a pilot project, with the GIR serving as volunteer 'geoscience interpreter" within a Canadian National Park. With Parks Canada visitor experience product development officer, Fred Sheppard, as an early champion, meetings were held to introduce the initiative and gauge interest. Parks in Ontario and Newfoundland expressed interest and Pukaskwa National Park was ultimately selected to host the Geologist in Residence Pilot Project. In 2020 CFES entered into partnership with Parks Canada, defining the roles and responsibilities of the GIR volunteer with the goal to increase public awareness and appreciation of the geology in Pukaskwa National Park, and improve the capacity of park interpretive staff to connect visitors with its geological features. This two-week residency would provide a geoscientist the opportunity to gain practical field experience at the park, allowing staff and visitors to engage with and learn from a geoscientist. Scope of work would include communications including social media content and publications. The pilot project launched in August of 2022 with Dr. Victoria Stinson, a geoscientist experienced in the geology of Pukaskwa as the inaugural GIR. During her placement she provided tours highlighting the geological processes that shaped the landscape of the park, hosted oTENTik drop-in sessions for visitors to discuss the geological features they had encountered, and utilized field excursions, hand samples and geological maps to build practical and artistic activities based in experiential learning best-practice. Victoria also assembled a new curated rock collection for the visitors' centre, and created a script for park staff to serve as a geological interpretation resource. The Pukaskwa Park GIR will be offered again in 2023, building on the success of the 2022 project in the hopes of expanding the GIR to other Canadian National Parks in the future. The GIR initiative is delivered by the Canadian Federation of Earth Sciences (CFES) in partnership with Parks Canada with funding from the Association of Professional Geoscientists of Ontario Education Foundation.

SOME COMMENTS ON THE CURRENT AND PAST CORDILLERA HOT BACKARC

Roy D. Hyndman
Geological Survey of Canada.
E-mail: *royhyndman@shaw.ca*

Northwest Canada and Alaska are the continuation of the North American Cordillera through Mexico, western USA and western Canada. Here it is shown that they have similar thermal regimes and thermal control of current tectonics, seismicity, and recent volcanism. A summary of the multiple constraints to crust and upper mantle temperatures are presented followed by some consequences. There are bimodal crust and upper mantle temperatures characteristic of most subduction zones; cool forearc, uniformly hot backarc (Yukon Composite Terrane to Southern Brooks Range, and Mackenzie Mountains), and stable cratonic backstops (Arctic Alaska Terrane and Canadian Shield). The main constraints are: (1) Heat flow measurements; (2) Temperature dependent upper mantle velocities and seismic attenuation; (3) Temperature-dependent topographic elevations; thermal isostasy; (4) Depth and temperature of the seismic lithosphere-asthenosphere boundary (LAB); (5) Origin temperature and depth of craton kimberlite xenoliths; (6) Geochemically inferred source temperature and depth of recent volcanic rocks; (7) Depth to the magnetic Curie temperature; and (8) Depth extent of seismicity. The backarc lithosphere is thin, LAB at 50–85 km and ~1350 ± 25°C. Moho temperatures at 35 km are 850 ± 100°C compared to cool cratonic areas of 400–500°C. The consequences include: (1) Thin and weak backarc lithosphere that accommodates pervasive tectonic deformation indicated by wide-spread seismicity and GPS-defined motions, in contrast to the stable cratonic regions; (2) Widespread sporadic volcanism; and (3) Weak backarc lower crust that flattens the Moho and allows detachment and thrusting of the upper crust over the cold strong Arctic Alaska Terrane and Canadian Shield.

UNDERSTANDING THE GRENVILLE OROGENY THROUGH MODERN ANALOGUES

Roy D. Hyndman
Geological Survey of Canada.
E-mail: *royhyndman@shaw.ca*

Much can be understood of the two main phases of the Grenville orogeny, the ~100 M.y. of tectonic activity with sporadic volcanism, metamorphism and ductile deformation, and the final terminal collisional phase, by comparison with several analogues: (1) the currently tectonically active North American Cordillera; (2) the thick crust high Andes of South America; and (3) the current India-Asia collision. Throughout the Cordillera, Mexico to Alaska, there has been a long history of sporadic volcanism of asthenosphere origin. Most of the Cordillera is in present and recent compression (except Basin and Range) so the volcanism is not associated with extension. A thin hot lithosphere however is required. The Cordillera and most global backarcs 200–1000 km wide have current remarkably uniformly high temperatures in the crust and upper mantle, 800–850°C at the Moho. The first consequence is that the crust is weak enough to have ongoing deformation driven by plate margin forces. The second is a lower crust ductile detachment that allows the upper crust of the backarc hinterland to overthrust the adjacent cold strong craton. The third consequence is that the current crustal temperatures represent Barrovian P–T metamorphic gradients. Regional metamorphism therefore represents exhumation of already hot crust, not deformation-related heating. The high thick crust Andes (Altiplano-Puna) are not a consequence of terrane collision, but rather of an infrequent unusually strong subduction thrust and perhaps underplating. The high Andes are gravitationally unstable, the weak crust collapsing mainly to the east and also laterally N-S to lower elevations, resulting in an upper crust extensional regime in a regionally compressive environment. This upper crust process makes determining the regional paleo-stress regime in the Grenville difficult. The India-Asia collision provides a good analogue to the terminal collision of the Grenville Province. It is important to recognize that one side of the closing ocean in both the Grenville and Asia collisions was a hot and weak backarc margin (Tibet) and the other likely a cold rifted margin (India). Most deformation occurred on the hot backarc side, including thickening of mainly the lower crust. Structurally, the upper crust of the former backarc has thrust a considerable distance on a lower crust ductile detachment over the strong stable India lithosphere. There also has been resulting thrusting on the margin of the distant foreland in both cases.

SOCIAL MEDIA BEST PRACTICES FOR EARTH AND SCIENCE COMMUNICATORS

Melany Hysert
Society of Applied Geoscientists and Engineers, Inc.
E-mail: *melanyhysert@gmail.com*

Science communicators are embracing social media channels like never before with clever memes and engaging videos designed to educate and engage the masses. The 'science' hashtag, #science, currently has 57.5 billion views on TikTok (as measured directly from the TikTok app, January 2023), where the keyword 'science' is an interest selection under the heading of 'Science & Technology' for account preference set-up. The term edutainment best coins this new era of entertaining and informative two-way communication that reaches interested audiences of all ages typically through hand-held devices. There are highly advanced techniques behind engineering popular science content on social media, but finding specific best practice guidelines can be challenging, as this is still a burgeoning field of research. Social media science communication is a complex area of study that crosses many disciplines from digital media to crisis management. It requires a strong understanding of data science, social behaviour, machine learning algorithms, and analytical tools to decipher the simultaneous organic and inorganic nature of social media. This talk focuses on best practices that were compiled from industry professionals and recent peer-reviewed articles for graduate research at Royal Roads University, entitled "Science Museums in Canada: Facebook Trends and Strategies During the Covid-19 Pandemic" by Hysert in 2022. While Facebook was the main focus of this study, best practices for multiple social media channels will be discussed using examples from popular earth science influencers.

THE GRENVILLE PROVINCE: WHAT MAKES IT SPECIAL

Aphrodite Indares
Memorial University of Newfoundland.
E-mail: *aindares@mun.ca*

Understanding the Grenvillian orogeny is key to assessing both changes in orogenic styles through time and late Mesoproterozoic geodynamics. This contribution summarizes some main characteristics of the Grenville Province, with focus on new/additional aspects to consider. (1) It has been generally inferred that the majority of the pre-Grenvillian crust was formed in an active margin setting, and was part of Laurentia before the Ottawan phase (1.09–1.02 Ga) of the Grenvillian orogeny. The youngest feature supporting this is the location of large 1.1 Ga anorthosite suites along older, inherited lithospheric discontinuities of the Laurentian margin. At the broader scale, the connection to Laurentia comes out in the recent reassessments of the Mesoproterozoic Laurentian margin, from eastern Canada to the southwest US. (2) The Grenville Province is classified as a large hot orogen based on widespread, long-lived, Ottawan-age granulite-facies metamorphism and anatexis in the middle to lower crust exposed in the orogenic hinterland. In addition, the NNW margin of the Grenville Province was deformed and metamorphosed later (Rigolet phase, 1.0–0.98 Ga). This overall configuration was attributed to the presence of an Ottawan orogenic plateau in the hinterland, followed by collapse and later propagation of the orogen to the NW during the Rigolet phase. A double crustal thickness under the plateau was inferred by the presence of high-P granulites and eclogites locally exposed at the frontal part of the Ottawan orogen, as for instance in the central Grenville. However, it now emerges that these reflect local crustal thickening, from late-Ottawan to Rigolet, against an Archean ramp. Therefore, there is no indication of double thickened crust at the orogen scale, which is consistent with independent evidence for thin orogenic crust in late Mesoproterozoic. In addition, the relation between the Ottawan and Rigolet phases remains contentious. (3) The hinterland is also characterized by high-T syn- to late-orogenic magmatism, mainly expressed by locally voluminous A-type granitoid rocks and small anorthosite bodies that are concentrated in certain parts of the orogen. In the central Grenville, crystallization ages cover the entire range of the orogeny, with the largest granitoid rocks

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and the small anorthosites being spatially associated with the large 1.1. Ga anorthosite intrusions. The distribution and types of syn-to late-orogenic magmatism outlines lateral variations of the pre-Grenvillian crust and attest to locally enhanced influence of mantle heat over the entire time span of the orogeny, a feature that remains to be reconciled with the continental collision model for the Grenville.

DECODING THE TIMING OF POLYPHASE METAMORPHISM IN THE MAURICIE REGION, CENTRAL GRENVILLE PROVINCE, QUÉBEC

Muhammad Zahoor Iqbal, Renaud Soucy La Roche
Institut national de la recherche scientifique.
E-mail: *muhammad_zahoor.iqbal@inrs.ca*

The Grenville Province in North America is composed of high-grade metamorphic rocks that record evidence of protracted crustal growth, pre-Grenvillian accretionary episodes between ca. 1665 and 1140 Ma, and the final continent-continent Grenvillian collision at ca. 1090–980 Ma that marked the assembly of the supercontinent Rodinia. The Mauricie-Portneuf area exposes several lithotectonic domains metamorphosed and deformed at different structural levels and subsequently juxtaposed tectonically during the Ottawan phase of the Grenvillian orogeny. The variable Ottawan overprint provides the opportunity to better characterize pre-Grenvillian accretionary events. From structurally lowest to highest, the Mékinac–Taureau, Shawinigan, and Portneuf-St. Maurice domains collectively record limited geochronological evidence for metamorphism during the ca. 1390 Ma accretion of the Montauban arc to the southeast Laurentian margin, the ca. 1190–1140 Ma Shawinigan progeny, and the ca. 1090–1020 Ma Ottawan orogeny. However, the spatial extent and metamorphic grade during each of these events is poorly constrained. Understanding the timing and metamorphic conditions of the pre-Grenvillian accretions and the final collision is therefore crucial to decipher the crustal assembly of the central Grenville Province. The peak metamorphic mineral assemblage in paragneiss from the Mékinac–Taureau and Shawinigan domains contains garnet, biotite, prismatic sillimanite, and K-feldspar, indicative of upper amphibolite to granulite facies conditions. Garnet in the Shawinigan domain is characterized by inclusion-rich cores and inclusion-poor rims separated by sharp euhedral to subhedral boundaries, which may indicate polyphase garnet growth during two distinct metamorphic events. In contrast, the mineral assemblage in paragneiss from the Portneuf-St. Maurice domain is characterized by garnet, biotite, muscovite, cordierite, and sillimanite, which indicate lower temperature and pressure conditions. In-situ laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) petrochronology on monazite will be used to constrain the timing of metamorphic events. The textural setting of monazite will be used to determine the timing of growth of metamorphic index minerals; inclusions of monazite in garnet and cordierite are expected to provide a maximum age constraint on porphyroblast crystallization. The trace element contents of monazite will be measured concurrently with isotopic ratios and utilized to establish a relationship between monazite growth and metamorphic reactions that release or sequester Y and REE. The new results on the timing of metamorphic episodes will provide robust constraints on the Mesoproterozoic tectonometamorphic evolution of the Mauricie region in the central Grenville Province, Québec.

JUSTICE-ORIENTED SCIENCE COMMUNICATION FOR INUIT SELF ADVOCACY RELATED TO MINING WATER TREATMENT

Cana Uluak Itchuaqiayq
Virginia Tech.
E-mail: *cana@vt.edu*

Calls for social justice in scientific practices that support empowerment of marginalized scholars and open the sciences to broader communities are on the rise. However, addressing how fields like the geosciences can communicate science back to marginalized communities—especially communities affected by activities like mining—in ways that are equitable and promote that same empowerment and self-advocacy needs similar attention. I am an Inuit technical and scientific scholar from the Arctic who teaches service-learning science communication classes that serve my tribe in NW Alaska—home to Red Dog Mine, the second-largest zinc mine in the world. Creating science communication related to mining that is designed for Inuit rightsholders and land stewards, such as culturally relevant, scientific communication related to mining and water treatment on tribal land, requires reconciling the privilege associated with technical terminology and the effects of long-term and continuing disparities associated with access to STEM education. Because mining affects our water and our subsistence activities, and therefore our cultural integrity and food security, the need for tribal members to understand complex scientific concepts—like acid rock drainage, issues related to melting permafrost and water balance, and environmentally friendly, yet costly, water treatment options—to successfully self-advocate and enact their Indigenous sovereignty is crucial. This talk will discuss the lesson learned from teaching undergraduate and graduate students at Virginia Tech to translate science in culturally relevant and rigorous ways that help Inuit tribal members to better self-advocate with regards to resource development activities on tribal lands related to mining. Audience members will gain an understanding of the opportunities and constraints related to effective and equitable communication with local communities about mining issues. Further, I will discuss the need to recognize and shift western cultural paradigms to meet Inuit realities (e.g. the way a tribally run mine works vs western business models, the utmost importance of subsistence activities in rural Alaska, the ties of Inuit to the land and one another) in order to effectively translate the science in ways that are needed, relevant, and respectful to tribal members.

THE IMPACT-GENERATED HYDROTHERMAL SYSTEM AT THE WEST CLEARWATER LAKE IMPACT STRUCTURE, QUEBEC

Juan P. Jaimes Bermudez, Gordon R. Osinski, Roberta L. Flemming
Western University.
E-mail: *jjaimesb@uwo.ca*

Hypervelocity impacts fracture target rocks and increase the subsurface temperatures of a region mainly via impact melted material. When liquid water or ice is present, transient impact-generated hydrothermal systems may develop. On Earth, impact-generated hydrothermal systems have been reported in 70 out of the 188 terrestrial hypervelocity impact craters and have also been proposed to occur in other planetary bodies. These systems have gained substantial interest as the conditions (fluid source, temperature, pressure, salinity, pH, and fO_2) under which these systems form and develop provide insight into planetary habitability and paleoclimates on other planetary bodies, in particular on Mars. Moreover, the origin of hydrated minerals observed on the surface of Mars is also highly debated and it has been proposed that impact events have a role in leading to the formation of some of these occurrences through solid-state devitrification of hydrous glasses and/or impact-generated hydrothermal alteration. This study presents a case study of impact-generated hydrothermal alteration at the West Clearwater Lake impact structure in Quebec. Specifically, the crater-fill impact melt rocks were investigated through optical microscopy, electron microprobe analysis (EPMA), micro X-ray diffraction (μXRD), and Raman spectroscopy. These analyses indicate that hematite, talc, and quartz are the main alteration minerals. Hematite occurs as replacement of titanomagnetite (Type 1), as pervasive acicular crystals (Type 2), within amygdules (Type 3), and in association with goethite and quartz as colloform bands in veins (Type 4). Quartz occurs within amygdules in association with Type 3 hematite and talc, and as vugs. Talc and a saponite-like clay occur around these quartz vugs as reaction rims and within amygdules. These mineral associations indicate a changing fluid composition and progressive cooling within this system. The results from this study provide insight into the origin of minerals that indicate the presence of water on Mars and how impact structures can record these processes.

INVESTIGATING MULTIPLE METALLOGENIC EPISODES AT THE PROTEROZOIC TOROPARU Au-Cu(-Ag) DEPOSIT SETTING, GUYANA, SOUTH AMERICA

Tramaine James[1], Stéphane Perrouty[1], Daniel Kontak[1], Michael Tedeschi[1], Philip Lypaczewski[1], Robert Creaser[2]
[1]Laurentian University, [2]University of Alberta.
E-mail: *tjames1@laurentian.ca*

The Paleoproterozoic Toroparu Au-Cu(-Ag) system, located within the Mazaruni greenstone belt of the Guiana Shield, Guyana, South America, consists of two main deposits - a magmatic-hydrothermal at Toroparu and orogenic at Sona Hill. The ore is hosted in Rhyacian-age mafic to intermediate volcanic, volcaniclastic and intrusive host rocks metamorphosed to greenschist facies assemblages and lie on a regional NW-trending, sub-vertical high-strained zone with a protracted deformation history. Two stages of Au mineralization are identified. The first, present only at Toroparu, has an assemblage of gold, chalcopyrite, bornite, pyrite II, covellite, molybdenite, and magnetite hosted within NW-trending extensional quartz carbonate ± chlorite (QCBCHL) veins, veinlets and fractures associated with dextral strike-slip movement. Ore-stage molybdenite yielded a Re–Os age of ~2160 Ma which overlaps with a ~2160 Ma U–Pb zircon age for the host intrusion which is a fine- to medium-grained porphyritic tonalite-granodiorite. The second ore stage, dominantly at Sona Hill but also as an overprint at Toroparu, contains pyrite III ± gold within SW-trending and subhorizontal quartz carbonate (QZCB) veins. Hyperspectral imaging in shortwave infrared (SWIR, 1000–2500 nm) indicates that metamorphic chlorite (background) within the project area has absorption bands between 2255 and 2252 nm (Mg# 42–47). In contrast, proximal Au-Cu(-Ag) mineralization zones have chlorite that is Mg rich (Mg# > 90, < 2245 nm); white mica has absorption bands between 2205–2215 nm. Proximal mineralization zones related to the second mineralization event has complete chlorite destruction along vein halos, with absorptions bands between 2195 to 2200 nm for the new white mica. Fluid inclusion studies indicate two different fluid types in QCBCHL and QZCB veins. The former hosts secondary two-phase aqueous types (L_{H_2O}-V_{H_2O}) with Th = 100 to 160°C and moderate- to low-salinities (22.0 to 0 wt.% equiv. NaCl). In contrast, the latter hosts secondary and indeterminate CO_2-rich, low-density, aqueous-carbonic types with XCO_2 = 0.35 to 0.5, $TmCO_2$ = –56.2°C, and Th = 300 to 320°C with low-salinities (2 to 5 wt.% equiv. NaCl). The Toroparu deposit setting has two stages of mineralization. Whereas most of the base metals and Ag are syn-magmatic at ~2160 Ma, Au is both syn-magmatic but possibly as young as ~2080 Ma due to later orogenesis as is noted elsewhere in the Guiana Shield. The Las Cristinas Au-Cu deposit (32 Moz) in Venezuela is hosted in a similar geological setting, which emphasizes the potential for discoveries of magmatic-hydrothermal Au-Cu systems elsewhere in the Guiana Shield.

MINERALOGICAL CONTROLS ON THE MOBILITY OF CRITICAL MINERALS IN MINE WASTE

Heather Jamieson[1], Adriana Taylor[1], Colin Lussier-Purdy[1], Anna Harrison[2], Matthew Leybourne[1], Melissa Turcotte[1], Michael Parsons[3], Brent Kazamel[1], Anežka Borcinova Radková[1], Hendrik Falck[4], Gideon Lambiv Dzemua[4]
[1]Queen's University, [2]University of Bern, [3]Geological Survey of Canada, [4]Government of the Northwest Territories.
E-mail: *jamieson@queensu.ca*

Growing global demand for products that contain critical minerals is expected to lead to an increase in mine waste that contains these elements. Very little is known about the environmental mobility of many critical elements, particularly how they are leached from primary host minerals, mobilized under different conditions of pH and redox, and potentially sequestered in secondary phases. This presentation will focus on field-based studies of the environmental mobility of rare earth elements (REE), cobalt, antimony, and tungsten, based on ore deposits in Canada. REE carbonate ore minerals in pilot plant tailings from the T-zone of the Nechalacho deposit, NWT, are reactive, especially at low pH, and can contribute neutralizing capacity. Secondary REE-bearing fluoride minerals may influence mobility. The release of REE from Basal zone Nechalacho tailings is enhanced by the presence of ligands and colloid-forming iron oxyhydroxide and dissolved organic carbon. The cobalt in silver mine tailings from Cobalt, ON is hosted in primary sulphide, arsenide, and silicate minerals, processing products and secondary minerals. Shake flask tests showed that cobalt is released readily from interaction of mine waste with oxidized water, likely due to the oxidation of fine-grained reduced phases and soluble secondary minerals. Chlorite is a major host of cobalt in these tailings, complicating potential reprocessing of mine waste. The mobility of antimony in mine waste from Beaver Brook mine, NL, is highly dependent on which secondary minerals are stable. Tripuhyite ($FeSbO_4$) is relatively insoluble, whereas brandholzite ($(Mg[Sb(OH)_6]2 \bullet 6(H_2O)$) may be an ephemeral secondary host. Our research at Cantung mine, NWT, has shown that scheelite ($CaWO_4$), the major ore mineral of tungsten, is stable after more than 50 years of exposure to acid drainage. Low concentrations of tungsten are mobile in pH-neutral surface water as dissolved species and adsorbed to colloidal iron oxyhydroxide phases. Our emerging understanding of the geochemical behaviour of critical minerals in the near-surface environment is important for guiding waste management decisions at existing and new mines. However, there are few guidelines for the maximum concentration of these elements in water, soil or sediment - how much is too much? To resolve this, we need toxicological data that are relevant to the mine waste environment to combine with geochemical data and modeling results to help inform the environmentally responsible production of critical minerals.

USING MICRO-XRF TO IMAGE SMALL FEATURES IN LARGE ROCKS FROM THE STILLWATER COMPLEX, MONTANA, USA

M. Christopher Jenkins[1], Stephen J. Barnes[2], Michael L. Zientek[1]
[1]United States Geological Survey, [2]CSIRO.
E-mail: *mcjenkins@usgs.gov*

Cumulates from layered mafic-ultramafic intrusions like the Stillwater Complex may have crystal sizes ranging from millimetres up to tens of centimetres. Petrographic analyses of these potentially very coarse-grained rocks have largely been limited to observations made at the outcrop and hand sample scale or by microscopic investigation of polished thin sections by transmitted light microscopy or microbeam techniques (e.g. SEM-EDS, microprobe, electron backscatter diffraction). The cm-scale size of a standard polished thin section (4.6 cm × 2.7 cm) has limited analysis to fine-scale observations of small portions of these rocks. In some cases, a single poikilitic or pegmatoidal crystal may be larger than the thin section preventing collection of information like chemical zoning in very large crystals. Recent advances in micro-XRF technology such as the Maia Mapper at CSIRO (Australia) have allowed characterization of polished rocks slabs of rock, up to 50 cm × 15 cm in size and up to 10 kg in weight, to show rock fabric and provide qualitative geochemistry at 10s of microns scale. In Stillwater rocks, micro-XRF has been used to document oscillatory zoning in coarse-grained to pegmatoidal rocks and the spatial distribution of Pt-bearing minerals. These previously hidden features can be used to constrain petrogenetic models for the origin of mafic-ultramafic rocks and their ore deposits. In this contribution we show how micro-XRF has been used to image rocks from the B and G chromitites from the Peridotite Zone and the basal contact of the J-M Reef package in the Lower Banded series of the Stillwater Complex.

DEMOGRAPHICS OF CANADIAN ACADEMIC GEOSCIENCE: RESULTS FROM A SURVEY OF THE GREAT WHITE NORTH

Scott Jess[1], Lindsay Schoenbohm[1], Emily Heer[2]
[1]University of Toronto Mississauga, [2]University of Calgary.
E-mail: *scott.jess@utoronto.ca*

Geoscience is currently experiencing a wave of studies aiming to improve our understanding of the demographics represented in the field and barriers that exist for those within. This body of work suggests progress in racial and gender diversity has remained stagnant at all levels of higher education and that the geosciences may have lower racial and ethnic diversity than other physical sciences programs. These works have been important for understanding how the field has evolved and what improvements can be made to create a more inclusive space. Despite this recent influx of studies, publicly available demographic data for academic geosciences do not exist in Canada. Hence, much of our understanding of the demographics of the field and the barriers researchers face is driven by data from the USA, where underlying social issues and demographic makeup are different. This lack of data makes it difficult for departmental EDI committees in Canada to be informed about their workplace and what actions could be taken to improve these spaces regarding inclusion. The purpose of this work is to understand the demographics of academic geoscience in Canada, helping to identify what communities are underrepresented. We disseminated a self-administered online questionnaire to academic geoscience departments between September and December 2022. The survey consisted of 24-questions covering a range of demographic information including age, gender, Indigenous identity, sexual orientation, racial identity, disability, and current research position. We received 482 eligible responses to the survey, accounting for approximately 20% of the research population. Overall, men make up a slight majority

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across all respondents (53%), and the percentage of individuals who identify as white (73%) is greater than the national average (67%). Results also show differences in gender representation between research students (MSc and PhD) and salaried positions (postdoc, research staff and faculty), with women dominant in the former (56%) and men in the latter (67%). Similar contrasts also appear in racial data, where the percentage of individuals who identify solely as white in salaried positions (79%) is above the national average (67%), while the percentage of white research students is similar to the national average (66%). Additional trends outside of these categories are also present in the data set but cannot be summarized in full here. These initial results highlight the disparities in gender and racial representation in Canadian academic geoscience and begin to shed light on priority areas that may improve diversity at all levels of research.

ASSEMBLY OF THE VARISCAN OROGENIC WEDGE: THE P-T-t RECORD OF THE METASEDIMENTARY ROCKS OF ERZGEBIRGE (SAXOTHURINGIAN DOMAIN, BOHEMIAN MASSIF)

Marine Jouvent[1,2], Ondrej Lexa[2], Vít Peřestý[2], Petr Jeřábek[2], Stéphane Scaillet[3,4], Andrew Kylander-Clark[5]
[1]Université Laval, [2]Charles University, [3]Institut des Sciences de la Terre d'Orléans, [4]Université d'Orléans, [5]University of California.
E-mail: *marinejouvent1@gmail.com*

The formation of collisional orogenic wedges involves complex polyphase deformation and metamorphism. This study reveals the tectonic evolution, internal architecture and timing of the Variscan Saxothuringian orogenic wedge evolution through the study of metasedimentary rocks of Erzgebirge (Bohemian Massif). Using field structural geology, petrology, thermodynamic modelling and geochronology, we constrained the P-T conditions and timing of four deformation events (D_1–D_4). Several transects from the low-grade hanging wall phyllites to the footwall medium-grade mica schists were investigated. The first M_1–D_1 event is characterized by HP–LT minerals defining the S_1 foliation with P-T conditions from 13 kbar and 520°C in phyllites to 25 kbar and 560°C in mica schists, suggesting a geothermal gradient of 6–11°C/km, typical for subduction environments. The M_2–D_2 event is the deformation and metamorphic overprint of S_1 fabric during partial decompression. The M_3–D_3 event is mainly developed in mica schists and intensifies towards the footwall. It is accompanied by a subhorizontal S_3 cleavage with MP-MT assemblage and P-T conditions of 5–9 kbar and 595°C, representing a Barrovian-type geothermal gradient of 17–30°C/km. Finally, all metamorphic fabrics were heterogeneously affected by the low-grade M_4–D_4 upright folding. In order to link the ages with individual tectonometamorphic events, in-situ monazite U–Pb geochronology with LASS-ICP-MS, rare-earth-elements geochemistry and mica $^{40}Ar/^{39}Ar$ geochronology were performed. The ages revealed that the phyllites experienced prograde metamorphism around 350 Ma followed by exhumation at 345–340 Ma. The prograde HP–LT evolution in mica schists is at least 339 Ma old and suggests that the mica schists possibly entered the wedge slightly later than the phyllites. A following ductile thinning associated with the M_3–D_3 event was dated at 338–330 Ma. The monazite ages in mica schists and few $^{40}Ar/^{39}Ar$ ages in the deepest phyllites show that the region is then strongly affected by an event at ~330 Ma, interpreted as a lower-grade overprint during final exhumation or possible younger reactivation. This study highlights the tectonic evolution marked by transition from accretion of the subducted continental material to building of the Saxothuringian orogenic wedge from ~360 to ~340 Ma. This process is manifested by thickening and partial exhumation within the wedge accompanied by ductile thinning in upper crustal levels. Finally, the late Variscan intracontinental deformation was responsible for orthogonal shortening, heterogeneous reactivation and final exhumation at 330 Ma. We suggest that the Saxothuringian wedge could be divided into a younger inner part (mica schists and UHP rocks), and an older outer part (phyllites), both showing distinct metamorphic and structural evolution.

BYPRODUCT CRITICAL METALS - HOW CAN WE UNLOCK THE POTENTIAL?

Simon Jowitt
University of Nevada Las Vegas.
E-mail: *simon.jowitt@unlv.edu*

Critical metals and minerals are fundamental for modern society and standards of living, have crucial strategic and defence value, and are vital for climate change mitigation given their fundamentally important roles in low CO_2 energy generations, storage, and transport. All these factors mean that we are currently undergoing a rapid increase in demand for these metals, a significant proportion of which are sourced as byproducts of the production of other base and precious metals. Improving the security of supply of these byproduct critical metals and minerals on both domestic and global basis requires significant improvements in our understanding of the processes that concentrate these elements within different mineralizing systems, the behaviour of these elements and their hosting minerals during mineral processing and metallurgy, and improved policy development to ensure that domestic and 'friendly' supply chains can be both developed and realized. Understanding material flows and where concentrates and other mined material go once they leave the mine gate is also key given the majority of these critical byproduct metals and minerals are extracted at smelters and refineries (providing the smelter or refinery destination can produce the byproduct in question). Increased production of byproduct critical metals and minerals can also provide value for mining companies, including environmental and sustainability value by making the most of existing mineral deposits. This production could also yield economic value given the increasing demand (and price) of some byproduct critical metals and minerals combined with the significant amount of byproduct critical metals and minerals that are already mobilized during active mining but are lost to waste rather than being produced. These commodities also have strategic value for mining companies given recent governmental policymaking that could yield tax breaks and permitting advantages, among other benefits, for mines that can demonstrate they produce critical metals and minerals. This presentation will provide an overview of the byproduct critical metal and mineral potential of key mineralizing systems, examine the critical metal potential of existing mining and metal supply chains, and outline methods to identify high priority deposits for byproduct critical metal and mineral extraction using upstream-down (i.e. mineral deposit focused) and downstream-up (i.e. smelter and refinery focused) approaches. All these data provide key insights into important areas of future research relating to these critical byproducts as well as providing insights into how we can better extract byproduct critical metals and minerals into the future.

THE TIME THAT SIR WILLIAM LOGAN NEVER HAD: A BRIEF HISTORY OF THE JACK SATTERLY GEOCHRONOLOGY LABORATORY

Sandra L. Kamo
University of Toronto.
Email: *skamo@es.utoronoto.ca*

When Sir William Edmund Logan (1798–1875) mapped Precambrian rocks of the "Laurentian System" in Ontario and Quebec in the mid-1800s he did not have the benefit of radio-isotopic dates to help guide his geologic interpretations. It was after his death that Henri Becquerel in 1896 discovered radioactivity, and Marie and Pierre Curie in 1898 described it, sharing the Nobel prize in physics in 1903 for their collective discovery. Rutherford and Soddy (1902) while at McGill University determined that radioactivity resulted from the transmutation of unstable parent isotopes into stable daughter isotopes. With this information they determined the law of radioactivity. From that point onwards it was recognized that long-lived radio-isotopes could be used to quantify geologic time. The ensuing 70 years saw key innovations in dating methods and applications, largely linked to the development of

quantitative mass spectrometry. Details of these advances and discoveries can be found in Davis et al. (2003, Reviews in Mineralogy and Geochemistry). The birth of modern U–Pb geochronology in the 1970s was initiated by a dynamic group at the Carnegie Institution of Washington that included Tom Krogh, Gordon Davis, Jim Mattinson, George Wetherill, and Tom Aldrich among others. Shortly after Krogh's (1973, Geochimica et Cosmochimica Acta) seminal 'zircon hydrothermal decomposition' method, which simplified procedures and allowed a thousand-fold reduction in sample size, Tom was invited to his native Canada in 1975 to build a state-of-the-art U–Pb geochronology laboratory at the Royal Ontario Museum (ROM). Here, unsurpassed technical advances were achieved, advancing research into Archean greenstone belt construction, the formation of deep crustal gneisses, and meteorite impacts. After a successful 26-years, the ROM lab was rebuilt at the University of Toronto in 2003, where several in the original group as well as younger researchers continue to make important discoveries today. U–Pb geochronology on zircon is one of the few methods by which it is possible to probe deep into Earth's history to obtain robust, absolute knowledge about the development of the crust and mantle, as well as the pace and timing of biological evolution. A key driver in our lab is the quest for improved age results with the knowledge that the more precisely and accurately we can determine the ages of rocks, the closer it brings us to fundamental discovery. Better precision and accuracy have been achieved through reduced Pb background levels, improved spikes, and more efficient Pb ionization. The advent of Jim Mattinson's (2005, Chemical Geology) chemical abrasion pretreatment of zircon, which removes internally disturbed portions of zircon grains, is perhaps the single greatest analytical improvement since Krogh's air abrasion procedure 23 years earlier. These advances have proven to be effective in refining our data and have led to on-going development of precise methods applied to ever smaller sub-microgram sample sizes. U–Pb geochronology integrated with geology, geochemistry, and geophysics has played a pivotal role in understanding Earth history. U–Pb isotope dilution dates on chemically abraded zircon have helped us correlate major extinction events with the formation of large igneous provinces and meteorite impacts and informed us on how life adapted to severe environmental crises. Current work documenting short timescales, such as within a single magmatic system, has allowed us to challenge conventional theories of igneous processes. High precision dates used in paleo-continental reconstructions can help us locate prospective mineral deposit targets on formerly adjacent cratons. U–Pb isotopes can now be more rapidly analyzed using a number of microbeam methods, applied to more accessory minerals, and integrated with trace element and other isotopic information. The wealth of data that have resulted and the expansion of knowledge about the Earth would have astounded Logan but would not have been possible without fundamental programs of field mapping that Logan initiated.

INFLUENCE OF PRE-EXISTING STRUCTURES AND MAGMATISM IN RIFTING AND BREAKUP: A CASE STUDY FROM THE NOTRE DAME BAY MAGMATIC PROVINCE, NEWFOUNDLAND, CANADA

Emma Keefe, Alexander L. Peace
McMaster University.
E-mail: *keefeej@mcmaster.ca*

Pre-existing lithospheric structures play a significant role in continental rifting and subsequent breakup. However, the mechanisms in which these structures may reactivate and influence rift-related processes, such as faulting and magmatism, are poorly understood. This research focuses on the relationship between pre-existing structures and rift-related magmatism and the role this interaction played in the Mesozoic rifting and subsequent breakup on the magma-poor Newfoundland margin. The Newfoundland margin formed following rifting between Newfoundland and Ireland, plus Iberia, in two main phases. The first phase occurred in the Late Triassic–Early Jurassic, extension was distributed over a wide area, and crustal thinning was relatively small. After a period of thermal subsidence, a second phase of extension in the Late Jurassic through Early Cretaceous resulted in the breakup of Newfoundland from Iberia. Despite being classified as magma-poor, Mesozoic igneous rocks contemporaneous with rifting have been documented on and offshore of Newfoundland. However, the relationship between rift-related magmatism and faulting on the Newfoundland margin is also poorly understood. To address this, the relationship between magmatism and faulting on the Newfoundland margin was analyzed by focusing on the interactions between pre-rift structures, faults and lamprophyre dykes, exposed near Leading Tickles in Notre Dame Bay in northern-central Newfoundland. The lamprophyre dykes are part of the previously reported Mesozoic Notre Dame Bay Magmatic Province which also includes several gabbroic intrusions, including the Budgell Harbour Stock and Dildo Pond Intrusion. The dataset includes ~180 field-based structural measurements of dykes, and host rock structures along either side of a fault zone, petrographic analysis of dyke thin sections, and a 3-D model of the measured outcrops. These data were plotted and analyzed using MOVETM, a structural geology modelling software. Structural analysis indicates that emplacement of the dykes was likely controlled by pre-existing geological structures and that the dykes show evidence of being deformed post-intrusion, potentially via the reactivation of pre-rift faults. Overall, this work contributes towards a growing body of work showing that even on magma-poor margins, the role of magmatism should not be dismissed as an important factor in the development of continental rifting and breakup.

THE GIANTS OF GEORGIAN BAY: GEOHERITAGE OF AN ASPIRING UNESCO GEOPARK

Kirsten Kennedy, Nicholas Eyles
University of Toronto Scarborough.
E-mail: *kirsten.kennedy@mail.utoronto.ca*

Lying astride the Great Unconformity with ice-scoured metamorphosed Canadian Shield rocks to the north, and shallowly dipping Paleozoic sedimentary strata to the south, the contrasting coasts of Georgian Bay have helped shaped Canadian geoscience for 180 years and are the part of the rich geoheritage celebrated by the newly founded Georgian Bay aspiring UNESCO Geopark. The oldest rocks on the bay are strata of the 2.4 billion year old Huronian Supergroup. They were first described in the pioneering Geological Survey of Canada reports of Alexander Murray and William Logan, who used them to subdivide the "Azoic" (Precambrian). Later recognition of climatic cycles and glacial events within the Huronian Supergroup cemented its significance as the most important Paleoproterozoic succession in the world. Work in Killarney and the 30,000 Islands by WH Collins and others, tracing the progressive deformation and disappearance of the Huronian in favour of Grenvillian gneiss and migmatite, established the importance of crustal mobility and transformation of preexisting rocks during metamorphism. As plate-tectonic theory gained acceptance through the 1960s and 1970s, the Grenville orogeny was understood to result from continental collisions at the end of a Wilson Cycle, so named for J. Tuzo Wilson who had a cottage on the bay and was much influenced by the complex geological mosaic exposed on its shores. Seminal advances by academics working out of institutions like the University of Toronto, Memorial University, and Dalhousie University in the fields of radiometric dating, deep crustal geophysics, and petrology helped to establish the Grenville orogeny as an ancient analog to the Himalayas. With thousands of glacially polished and wave-washed islands, there can be no better place to walk over the deep roots of a mountain belt. In stark contrast, the Niagara Escarpment of tough Silurian dolostone stands proud on the southern shore of Georgian Bay. The swelling of the Escarpment out of the Main Channel of Georgian Bay, to reach a maximum elevation towards the Algonquin Arch. is a reflection of the crustal dynamics of the Michigan Basin. The study of the unusually diverse biotic communities that arose along thinly mantled limestone plains, ending at sheer cliffs above lush sediment-filled valleys, has served as an excellent example of the value of interdisciplinary geo-biological research that underpins ongoing conservation efforts. This rich geological legacy, spanning diverse fields and eras, is globally significant and is foundational to the creation of the new Georgian Bay Geopark.

CRITICAL MINERALS IN CANADA: CONCEPTS, CHALLENGES AND CONTRADICTIONS

Andrew Kerr
Memorial University of Newfoundland.
E-mail: *akerr@mun.ca*

The quest for "Critical Minerals" is now a persistent theme for the resource industries and in related government policies. This review delves into the developing debate surrounding this topic to explain important concepts, but also to explore some of the challenges and contradictions involved in future exploration and devel-

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opment. The critical minerals concept first developed following World War II, but gained new relevance from recent supply disruptions, and wider recognition of the role of mineral resources in the much-vaunted energy transition, seen as vital to combat climate change. Canada's Critical Minerals list differs from those issued by other jurisdictions because it includes some major commodities and also uranium, which carry little or no supply risk. Many other entries are commodities specifically linked to the energy transition. These include cobalt, lithium, manganese, nickel, graphite and vanadium (used in EV batteries and energy storage), rare earth elements (REE; for magnets in motors and turbines) and rarer elements (e.g. germanium, gallium, indium and tellurium) used in solar energy production. Some critical minerals can be primary products (e.g. lithium, graphite, and REE) but many more represent byproducts from extraction of major commodities, notably iron, aluminum, nickel, copper and zinc. There are specific challenges related to critical mineral resources. The end-use technology evolves on a timescale of years, but exploration and development now takes decades. Economic forecasts concede that exact predictions are difficult but suggest that supplies for some commodities need to increase by up to 500%. These relative forecasts are impressive and obviously influential, but for many commodities absolute global production will remain small, which may limit potential for new discoveries. Simple measures of grade and tonnage may not guarantee viability, because some commodities (e.g. the REE) form mineralogically complex deposits. Important byproduct commodities may effectively be lost whenever concentrates are exported for processing. Associated emissions and impacts will require auditing if critical mineral development is to be explicitly linked to climate goals, which may present challenges in the North. Most draft land-use plans in northern regions emphasize large-scale land conservation, which could limit exploration access before potential is fully assessed, and global biodiversity initiatives set even more ambitious targets for land protection. Given strong division of opinion about resource development, especially in Canada's North, controversy and polarized debate should be anticipated. More than anything else, there is a need for systematic geoscience data to aid in this difficult yet vitally important quest.

CRITICAL MINERAL RESOURCES IN NEWFOUNDLAND AND LABRADOR: FROM ESTABLISHED COMMODITIES TO NEW EXPLORATION TARGETS

Andrew Kerr[1], John Hinchey[2], James Conliffe[2], Zsuzsanna Magyarosi[2], Hamish Sandeman[2], Greg Sparkes[2], Greg Stapleton[2]
[1]Memorial University of Newfoundland,
[2]Geological Survey of Newfoundland and Labrador.
E-mail: *akerr@mun.ca*

The earliest extraction of mineral resources in present-day Canada occurred in northern Labrador about 6000 years ago, and Newfoundland witnessed some of the earliest exploration and mining ventures by Europeans on this continent. The famous Ramah Chert from the Torngat Mountains was probably a "Critical Mineral" in ancient North America. Newfoundland and Labrador (including Nunatsiavut) is now poised to become an important supplier of critical minerals in the 21st century. This review presentation outlines this rich resource inventory and discusses future mineral potential in these regions. Current exploration in the province largely focuses on gold (Au), notably in Newfoundland, but activity related to critical minerals is likely to grow in future years. Iron ore from Labrador continues to represent the largest share of the Provincial mining industry, but nickel and copper (Ni, Cu; mostly from the Voisey's Bay mine in Nunatsiavut) are increasingly important. In the context of critical minerals, there is previous and/or intermittent production of fluorspar (from St. Lawrence, Newfoundland), antimony (Sb, from Beaver Brook, Newfoundland) and manganese (Mn; ore extracted from discrete zones in some Labrador iron-ore deposits). Zinc was first produced in Newfoundland in the mid-19th century and several undeveloped deposits remain. Some of these are known to be enriched in cadmium (Cd), but few data are available to assess associated gallium (Ga), germanium (Ge), indium (In) or tellurium (Te). The processing of Ni-Cu ores from Voisey's Bay provides the important byproduct cobalt (Co). Magmatic sulphide mineralization elsewhere in Labrador shows Co enrichment, but is presently subeconomic with respect to Ni and Cu. The "Central Mineral Belt" of Labrador (largely Nunatsiavut) holds the largest inventory of uranium outside Saskatchewan, including two large undeveloped deposits. Other important critical mineral resources in this region include much of the world-class Strange Lake rare earth element (REE) deposit, located on the Québec-Nunatsiavut border, and similar deposits in central and southeastern Labrador. Some of these REE deposits also contain niobium (Nb), zirconium (Zr) and locally beryllium (Be). Plutonic rocks across Labrador contain vanadium-enriched oxide mineralization and layered mafic intrusions are under-explored as potential targets for platinum-group elements (PGE). Metasedimentary rocks of western Labrador contain known graphite deposits, and similar potential may reside in other unexplored Precambrian metamorphic terranes. On the island of Newfoundland, Mo and W deposits (some with defined resources) are associated with specialized Devonian granites, and Li-bearing pegmatites were recently discovered in associated metasedimentary terranes.

APATITE FROM MAFIC LAYERED INTRUSIONS: FROM THE RECORDING OF MAGMATIC PROCESSES TO THEIR USE FOR EXPLORATION OF Fe-Ti-P MINERALIZATION

Marie Kieffer[1], Sarah Dare[1], Olivier Namur[2]
[1]Université du Québec à Chicoutimi, [2]KU Leuven. E-mail: *sdare@uqac.ca*

Apatite is a weathering-resistant mineral that can be found in most igneous, sedimentary, metamorphic and hydrothermal rocks. Its chemistry is commonly used to trace magmatic processes, but also as a provenance indicator for sedimentary studies. As its chemical composition varies according to deposit type, apatite also has the potential to be used as an indicator mineral for exploration. However, apatite from mafic layered intrusions, which are host to Fe-Ti-V-P resources, is not yet taken into account by existing discrimination diagrams. Our study uses a petrogenetic approach aiming to better understand chemical variations of apatite within mafic layered intrusions and develop the use of apatite as a provenance indicator and as an indicator mineral for exploration. The Sept-Iles Intrusive Suite (Quebec, Canada) is one of the world's most voluminous mafic layered intrusions. It represents a natural laboratory to study the differentiation of a ferrobasaltic melt that led to a felsic magma by extreme fractional crystallization. Immiscibility played an important role in the formation of the Fe-Ti-P mineralization at the top of the mafic sequence (Critical Zone). Detailed chemical composition of apatite from the mafic Layered Series and from the felsic Upper Series was determined by electron microprobe analyses and LA-ICP-MS (31 trace elements). Results show that cumulus apatite records the compositional variations of the ferrobasaltic magma during its fractionation from the mafic towards the felsic rocks (enrichment in rare earth elements, Th, U, K, Pb, and depletion in Sr, Ba, V and Mg, in apatite). Chemical differences between apatite from the Fe-Ti-P-rich and -poor layers of the Critical Zone are attributed to the partition of trace elements between two immiscible silicate melts, as well as to the different cotectic proportions of apatite that crystallize from these melts (calculated at 5 to 8% and 1%, respectively). The abundance of apatite (7 to 36 vol.%) in Fe-Ti-P-rich layers is explained by sorting and crystal settling. A better understanding of Sept-Iles apatite chemical composition allows us to propose new discrimination diagrams (mafic vs. felsic, cumulus vs. intercumulus), which prove the potential of apatite as an indicator mineral for exploration of Fe-Ti-P mineralization associated with mafic layered intrusions.

A TOUR OF THE LARGE SCALE STRUCTURE AND CONTROLS ON MINERALIZATION OF THE SUDBURY AREA FROM REGIONAL 3-D INVERSIONS AND INTEGRATED MODELING

Alan King
Geoscience North Ltd., Laurentian University.
E-mail: *ak@geosciencenorth.ca*

With the wider availability of commercial 3-D inversion software for magnetic and gravity data it is now possible to routinely make 3-D density and magnetic models of large areas (up to 500 km by 500 km by 20 km) from public-domain data. Regional inversions have been used by the author on exploration projects throughout the Sudbury area from the enigmatic Wanapitei/Temagami anomaly in the east, through the Sudbury Igneous Structure (SIC), to the East Bull Lake in the west and south into the Grenville for commodities including Ni, Cu, PGEs, Au, U, Tungsten, etc. So far, most of the inversion models have been unconstrained, but when these are integrated with regional geological maps and sections the large-scale 3-D geological structure are often apparent. We also know that large orebodies and ore systems generally require large volumes of source rocks and large-scale structures, so regional geology and structure are critical in targeting areas for more detailed exploration and evaluating individual prospects. Inversions translate geophysical anomalies into approximate 3-D source volumes. The geophysical data signatures can be complex for magnetic data and even gravity data is sharpened up enormously when the inversions migrate the anomalies back to their sources. The simplest use of these products is to compare them to the mapped regional geology. It is perhaps not unexpected that about 10–20% of the mapped surface geology is not consistent with the large-scale geophysical models. This can be due to low-resolution mapping or to the near-surface outcropping rocks not being representative of the bulk of the underlying material. This mismatch can be used to extend known greenstone belts or indicate new greenstone belts under possibly shallow cover which could consist of mushroom-shaped granitoids or gneisses, Huronian sedimentary rocks, etc. Several examples will be shown to illustrate the value of this process including: the world famous Wanapetei structure; the SIC, Cobalt embayment; Bull Lake mafic body; Grenville; Southern Province. Integrating the geophysical models with all available earth science data in free 3-D exploration software can help us understand some of the large-scale controls on geology and mineral deposits, but it also shows new features, raises new questions and may help target new exploration programs. It is recommended that this process be routinely integrated into geological mapping and modelling by provincial and national geological surveys as a high value/low-cost value-added process.

THE FORGOTTEN FRONTENAC: (U)HT METAMORPHISM RECORDED IN THE SOUTHERN GRENVILLE PROVINCE

Carson Kinney, Chris Yakymchuk
University of Waterloo.
E-mail: *ckinney@uwaterloo.ca*

Ultra-high temperatures (UHT; > 900°C) are a metamorphic extreme within Earth's crust and can produce remarkable mineral assemblages potentially containing garnet, cordierite, orthopyroxene, sapphirine, perthite, or spinel. The recognition of UHT terranes has sky-rocketed in recent decades, implying that they reflect a common — but previously underappreciated — extreme thermal regime active during the orogenic cycle. However, the processes needed to not only reach these extreme temperatures, but also to preserve the diagnostic minerals in the geologic record, are unresolved. The Frontenac Terrane is a subdivision within the Frontenac-Adirondack Belt which is the south-easternmost lithotectonic block of the Grenville orogen and has undergone relatively little study since the 1980s. The Frontenac Terrane consists of quartzite, quartzofeldspathic schist, aluminous schist, marble, and mafic schist grading into one another, indicating they form a quasi-conformable supracrustal sequence. This supracrustal package was intruded by voluminous monzonite-syenite-granite (MSG) magmas with minor amounts of gabbro, diorite, and anorthosite coeval (ca. 1166–1157 Ma) with metamorphism. Past attempts at calculating peak metamorphic conditions returned estimates of 650–810°C and 4–8 kbar; these mostly used conventional thermobarometry that is susceptible to diffusional resetting during retrogression. However, we report the first observations of sapphirine-quartz, sillimanite-orthopyroxene, and spinel-quartz metamorphic assemblages in aluminous schists, which are each indicative of UHT conditions. Further, perthite thermometry, alongside thermodynamic modelling, provides additional lines of evidence for UHT metamorphism in the Frontenac Terrane. Although other UHT metamorphic assemblages have been observed in the Adirondack Highlands, UHT metamorphism in the Frontenac Terrane likely occurred ~100 M.y. earlier. These new findings provide an exciting new development in the early history of the Grenville orogeny, and allow for the interrogation of a newly discovered UHT terrane to better understand the processes that cause these extreme metamorphic conditions and how they are preserved in the rock record.

STOCKWORK VEIN SEQUENCE AND HIGH PRECISION GEOCHRONOLOGY: NEW INSIGHT INTO THE TIMING AND DURATION OF MINERALIZATION AT BINGHAM CANYON, UTAH

Simon Kocher[1], Simon J.E. Large[2], Thomas Monecke[1], Jamie J. Wilkinson[3,4], Robert A. Creaser[5]
[1]Colorado School of Mines, [2]CRU Group, London,
[3]The Natural History Museum, London, [4]Imperial College London,
[5]University of Alberta.
E-mail: *skocher@mines.edu*

Porphyry deposits are the primary source of copper for the global economy and are critical to support green energy infrastructure in the 21st century and beyond. These deposits are typically associated with volatile-rich intermediate to felsic subvolcanic intrusions located in magmatic arc settings. Hypogene mineralization in porphyry deposits comprises stockwork-hosted and disseminated sulphides that form large volumes of low-grade ore. Understanding the mineralizing processes, their geometry, and timescales is critical in developing models for successful mineral exploration. In this study we combine detailed petrographic observations and hyperspectral imaging with high-precision Re–Os molybdenite ages and compare them to literature data to reconstruct the hydrothermal evolution of the giant Cu-Mo-Au deposit at Bingham Canyon, Utah. Petrographic evidence suggests the presence of A, B, C, and D veins, each with characteristic textures, mineral, and alteration assemblages. Veins frequently show signs of reopening. Potassic alteration is observed in association with A and B veins, resulting in secondary K-feldspar, and shreddy biotite. C veins are accompanied by chlorite alteration, primarily affecting earlier biotite. Sericite alteration is most strongly developed in halos surrounding D veins. The occurrence of molybdenite is limited to reopened A veins, as well as B veins where it forms crystals intergrown with quartz along the vein margins or coarser-grained aggregates. Chalcopyrite is hosted in C and reopened A and B veins, as well as in disseminations associated with vein halos. Pyrite is primarily associated with D veins, forming discrete sulphide-filled fractures and disseminations. Ten analyzed molybdenite samples yield highly precise dates that indicate molybdenite deposition at ~38.2–37.6 Ma. A weighted average for these ten analyses yields an age of 37.9 ± 0.7 Ma. This suggests that molybdenum mineralization formed during a period between the emplacement of the two youngest porphyry phases.

RETROGRADE TERRANE EXHUMATION AND RELATED COMPLEX HYDROTHERMAL EVOLUTION, NALUNAQ GOLD DEPOSIT, SOUTH GREENLAND

Jochen Kolb[1], Robin-Marie Bell[2], Torsten Vennemann[3], Laure Martin[4], Marco Fiorentini[4], Tod Waight[5]
[1]Karlsruhe Institute of Technology,
[2]Geological Survey of Denmark and Greenland (GEUS), [3]University of Lausanne,
[4]University of Western Australia, [5]University of Copenhagen.
E-mail: *jochen.kolb@kit.edu*

The Nalunaq gold deposit is an orogenic gold deposit that is situated in the Paleoproterozoic Ketilidian Orogen, south Greenland. Orogenic gold deposits often represent one of many hydrothermal stages in a complex orogenic evolution. This setting allows detailed investigation of hydrothermal fluids extant during orogeny. We present stable-isotope data from four hydrothermal stages and wall rocks of the Nalunaq gold deposit. Nalunaq (ca. 11 t Au produced) is hosted by amphibolite in the NW-vergent Nanortalik Nappe. The nappe is intruded by ca. 1745 Ma monzogranite. The auriferous quartz veins are hosted in a reverse, NW-vergent shear zone. They are cut by faults, pegmatite and ca. 1762 Ma aplite. Four hydrothermal alteration stages are distinguished: (1) the 1783 ± 9 Ma clinopyroxene-plagioclase-garnet stage; (2) the auriferous biotite-arsenopyrite stage; (3) the 1766 ± 9 Ma calcite-titan-

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ite stage; and (4) the 1745 ± 5 Ma epidote-calcite-zoisite stage. The host rock, the pre-gold, the auriferous and the post-gold alteration assemblages are in equilibrium with hydrothermal water with a $\delta^{18}O$ of ~10‰, in the range of orogenic gold deposits ($\delta^{18}O$ = 4–15‰) and of metamorphic fluids. This indicates early pervasive hydrothermal alteration. The following stages are explained by continuous evolution or by total equilibration with the host rock. In contrast, plagioclase from the ca. 1765 Ma aplite dyke is in equilibrium with typical values for primary magmatic waters that are too low to be in equilibrium with the hydrothermal assemblages, indicating only minor or no magmatic influence on the regional hydrothermal evolution. The δD (biotite) of the auriferous fluid is 33.2‰ (orogenic gold –80 to –5‰). Also, $\delta^{34}S$ (pyrrhotite) overlaps with the range for orogenic gold deposits (–3 to 9‰). Sulphur isotopes lack evidence for mass-independent fractionation. The stable-isotope systematics of the auriferous stage indicate a metamorphic fluid that formed during metamorphism of the Paleoproterozoic terrane or total equilibration with previously altered host rocks. Stable-isotope systematics of the ca. 1745 Ma stage yield $\delta^{18}O$ of ~0‰ and $\delta^{13}C$ of –6.7‰. Although this stage is contemporaneous with monzogranite emplacement, these values are outside the field of primary magmatic water. They are consistent with the composition of meteoric water and atmospheric CO_2. This indicates exhumation of the auriferous terrane to shallow crustal levels by ca. 1745 Ma and a complete change of the hydrothermal system from metamorphic to meteoric fluids.

TECTONIC CONTROLS ON THE PATTERNS OF THE MESOZOIC INTRAPLATE MAGMATISM IN CENTRAL CANADA: INSIGHTS FROM PLATE KINEMATIC MODELING

Egor Koptev, Alexander Peace
McMaster University.
E-mail: *kopteve@mcmaster.ca*

Mesozoic intraplate magmatic activity in Canada occurs as kimberlite fields and ultramafic lamprophyres (UML) across Nunavut, Ontario, and Quebec, including the Monteregian Hills alkaline province in Quebec. Based on the isotope ages obtained for some of these intrusions, several petrogenetic models explaining their corridor-like spatial distribution have been developed, variously attributing their emplacement to the passage of one or several mantle plumes, effects of edge-driven convection along the Superior craton margin, or influence of Farallon slab subduction. This study aims to test the feasibility of these proposed models using existing plate-tectonic reconstructions based on previously published data. A dataset consisting of 50 isotopic-age determinations and precise locations for kimberlites and UMLs in the Rankin Inlet, Attawapiskat, Kirkland Lake and Lake Timiscaming regions, and some individual kimberlite occurrences, as well as for Monteregian Hills intrusions and New England seamounts, was compiled from the literature. The GPlates 2.3 software package was used to calculate the North American hotspot tracks of the Azores, Madeira, Canary Islands, Cabo Verde, and Great Meteor plumes according to three widely used plate-movement reconstructions. The positions of intraplate magmatism occurrences relative to the Superior craton boundary. and s-wave velocity anomalies at the depth of 200 km, were also considered. Stress-field orientations in the Monteregian and Timiscaming regions were inferred from plate kinematics at the time of formation of the respective magmatic provinces. Multiple major differences between the hotspot tracks reconstructed from geochronological data, and those reconstructed from existing plate movement models, were discovered even in the best-fit combinations, e.g. the oldest of the Timiscaming Structural Zone kimberlites were emplaced ~30 M.y. after the last plume passage through the area, and the Monteregian intrusions are ~25 M.y. 'late'; the Timiscaming field is also distant (~700 km) from craton margins or mantle shear-wave velocity anomalies. The results suggest either that significant inaccuracies exist in some of the datasets used for the modeling, or that mantle phenomena alone are not sufficient to explain the spatio-temporal distribution of intraplate intrusions in Canada, and that structural controls imposed by the crust play a significant role. We suggest that the Mesozoic reactivation of faults in the Ottawa-Bonnechere graben system triggered the emplacement of some of the intraplate intrusions, although the previous passage of the plumes could have primed the subcontinental lithospheric mantle for ultra-alkaline melt generation.

REVISITING THE PALEOELEVATION HISTORY OF THE CENTRAL ALTIPLANO USING STABLE ISOTOPES IN HYDRATED VOLCANIC GLASS FROM THE CORQUE SYNCLINE, WESTERN BOLIVIA

Helen Kopystecki, Samuel Martin, Joel E. Saylor
University of British Columbia.
E-mail: *hkopys01@student.ubc.ca*

The paleoelevation history of the Altiplano, a major intermontane basin within the central Andes of Peru and Bolivia, has been studied using a variety of paleoaltimetry techniques, including $\delta^{18}O$ in carbonate rocks. A major Late Miocene decrease in $\delta^{18}O$ values has been interpreted to indicate high-magnitude, rapid surface uplift of the central Altiplano. However, carbonates are subject to several complications including temperature-dependent fractionation of O isotopes during carbonate precipitation, diagenetic resetting of O isotopic compositions, and climatic influences on surface water composition. Climate models show that regional temperatures and the isotopic composition of precipitation are subject to threshold responses to surface uplift. Temperature changes would maximize the signal of threshold-related isotopic shifts preserved in carbonate, potentially obscuring the timing of surface uplift. Volcanic glass has become widely used in paleoaltimetry because it incorporates several weight percent of environmental water within 10 ka after eruption. The δD signature of this water in hydrated volcanic glass can be retained over geologic timescales due to development of an impermeable layer of amorphous silica following removal of mobile cations. Fractionation of D into volcanic glass is temperature-independent, and thus may present a possibly simpler proxy for paleoelevation. Nevertheless, it is subject to the same elevation-threshold isotopic effects discussed above, so results must be interpreted in the context of uplift-related and global climate change. We analyzed the D composition of 11 volcanic glass samples from the Callapa region where previous paleoelevation research documented an abrupt, significant decrease in $\delta^{18}O$ values between 10 and 6 Ma. In contrast to the previous research, our preliminary data shows consistently low δD values over this interval, with a steady decrease from ~–135‰ to –162‰ between 10.8 and 4.8 Ma. We propose two possible explanations for the discrepancy between the datasets. First, it is possible that either or both of the isotopic systems have been reset. If this is the case, additional research is needed to determine if either dataset can provide paleoelevation constraints. Alternatively, the volcanic glass may record primary changes in isotopic composition of precipitation and environmental water. In this second scenario the carbonates may record a convoluted signal of gradual isotopic change and threshold temperature changes at ~6 Ma, rather than directly recording rapid uplift. If the volcanic glass is pristine and tracking precipitation isotopic compositions, this suggests that the central Altiplano has been at near-modern elevations since at least 10 Ma.

EFFECT OF SALINITY ON ARSENIC MOBILIZATION FROM DESULPHURIZED AND FILTERED MINE TAILINGS

Rocky K. Kubuya, Lucie Coudert, Isabelle Demers, Jean-Francois Boulanger
Université du Québec en Abitibi-Témiscamingue.
E-mail: *lucie.coudert@uqat.ca*

Tailings management is one of the most important challenges that the mining industry is facing due to potential geotechnical and/or geochemical instabilities. Filtration of mine tailings has been successfully applied on several mine sites, reducing the risks of geotechnical failure. However, the effect of pore water quality (i.e. high salinity) on the geochemical stability of sulphide minerals is poorly documented. Oxidation of As-bearing sulphide minerals, when exposed to air and water, has led to the production of As-contaminated mine drainage. Many factors, such as redox potential and pH conditions as well as water quality (i.e. salinity), play a crucial role in the (im)mobilization of As from mine tailings. Many studies have evaluated the mobility of As from mine tailings or pure minerals under several conditions, but little information is available on the geochemical behaviour of As from desulphurized and filtered mine tailings (DFT). The main objective of the present study was to evaluate the effect of water chemistry on the mobilization of As from DFT. To do so, an exhaustive physico-chemical (e.g. particle size distribution, chemical composition, granulochemical distribution) and mineralogical (e.g. identification of As-bearing minerals and degree of liberation) characterization of a DFT was performed. Four weathering cell tests were performed on washed and unwashed DFT with different water quality (demineralized vs. saline water) to evaluate the effect of salinity on As mobility. DFT, which is mainly composed of fine particles (d_{80} = 75.5 µm), initially contained 0.1% of As, essentially concentrated in the fine fraction (89.9% of As found in the < 32 µm fraction, which accounted for 55% of the total mass of DFT). Speciation of As revealed that 11% of As was associated with the leachable fraction, while 81% was associated with the residual fraction. Löllingite and arsenopyrite were identified as the main As-bearing minerals. Weathering cells results showed that there is no clear effect of salinity on As mobility from DFT, under the conditions tested ([Cl^-] = 1.9-2.5 g/L, [SO_4^{2-}] = 3.3–3.5 g/L). Indeed, the proportion of As leached after 130 days (2.09–3.59%) and As leaching rates (0.011–0.017 mg/d) were quite similar for all weathering cells.

SPATIAL AND GENETIC RELATIONSHIPS OF CO-ASSOCIATED Cr AND Ni-Cu-(PGE) MINERALIZATION IN THE ESKER INTRUSIVE COMPLEX, MCFAULDS LAKE GREENSTONE BELT, SUPERIOR PROVINCE, CANADA

Klaus Kuster[1], Michael Lesher[1], Michel Houlé[2]
[1]Laurentian University, [2]Natural Resources Canada.
E-mail: *kkuster@laurentian.ca*

The Esker Intrusive Complex (EIC) is a semi-continuous ~16 km-long ultramafic-dominated sill of komatiitic affinity in the ultramafic-mafic Ring of Fire (RoF) intrusive suite within the Meso- to Neoarchean McFaulds Lake greenstone belt. It hosts world-class Cr and economic Ni-Cu-(PGE) mineralization and consists of multiple intrusions of variable morphologies, including blade-shaped dykes (e.g. Eagle's Nest), sills/chonoliths (e.g. Black Thor, Double Eagle), and keel/trough-shaped intrusions/feeder dykes (e.g. Blue Jay; AT-12) composed of interlayered sequences of dunite, lherzolite, harzburgite, chromitite, olivine websterite, websterite, and gabbroic rocks. After initial emplacement, the cogenetic Late Websterite Intrusion (LWI) reactivated the feeder conduits, intruding the semi-consolidated basal successions of the Black Thor intrusion and Eagle's Nest dyke. Emplacement of the LWI produced zones of hybrid matrix, and interfingering and/or brecciation of earlier BTI, generating anteliths/antecrysts with amoeboidal to subangular shapes, sharp to diffuse margins, and variable compositions (dunite, lherzolite, chromitite). High-grade Ni-Cu-(PGE) sulphide mineralization in the EIC is restricted to the Eagle's Nest dyke; however, many small occurrences occur preferentially at the bases of keel-shaped bodies (e.g. Blue Jay), along basal contacts (e.g. Blue Jay Extension), and in breccia zones associated with emplacement of LWI, whereas Cr mineralization (e.g. Black Label, Black Thor) is restricted to the Middle and Upper Ultramafic zones of the EIC. Ni-Cu-(PGE) mineralization appears to preferentially form at the base of the intrusive succession, where magmas interact with S-rich upper crustal rocks (e.g. sulphidic argillite rocks) to produce sulphide xenomelts that are upgraded by the komatiitic magma. Cr mineralization is often located above sulphide mineralization, at a point in the ultramafic sequence where the komatiitic magma reaches chromite saturation. However, the ≤ 100 m-thick chromite zones in the Black Thor deposit cannot have formed by crystallization from a Cr-saturated komatiitic magma. Such thick chromite zones appear to require a model involving partial melting of oxide-facies iron formation and dynamic upgrading of xenocrystic oxides, analogous to the model for sulphide mineralization. Thus far, the association between Cr and Ni-Cu-(PGE) mineralization appears to simply represent a confluence of favourable geological conditions/processes rather than a genetic relationship. Formation of Ni-Cu-(PGE) mineralization generally produces only subeconomic amounts of Cr, and formation of Cr mineralization generally produces only subeconomic amounts of Ni-Cu, but under some circumstances (still being debated), some ultramafic to mafic systems could produce both economic Cr and Ni-Cu-(PGE) mineralization, as in the EIC.

CONTINENTAL LARGE IGNEOUS PROVINCES AND GLOBAL PLATE TECTONICS LINKS TO OROGENIC GOLD

Brett Kuzmicz[1], Richard E. Ernst[1], Hafida El Bilali[1], Simon Jowitt[2], Alexander Ovas[1]
[1]Carleton University, [2]University of Nevada at Las Vegas.
E-mail: *brettkuzmicz@cmail.carleton.ca*

Orogenic gold deposits represent a significant proportion of global gold production and resources, yet the wider-scale drivers of some orogenic gold metallogenic events remain somewhat unclear. This study investigates the relationship between orogenic gold and continental Large Igneous Provinces (LIPs) by means of analyzing mantle plumes, as proxied by LIPs, and their influence in changes of global tectonics. This is achieved by first finding which orogenic gold deposits are temporally correlated to major continental LIP emplacement events between 2.2 Ga and 500 Ma. The results show a temporal link between orogenic gold and distal continental LIPs in the following three events: the breakup of Rodinia which occurred at 820 Ma with gold deposits in the Yenisei ridge ranging from 820 Ma to 640 Ma; the amalgamation of Nuna (Columbia) which occurred around 1730 Ma with coeval orogenic gold deposits found in Laurentia; and the breakup of an Archean supercontinent from 2120–2060 Ma with orogenic gold deposits in the West African, Amazonian, and São Francisco cratons. For these three examples, a global tectonic reconstruction is produced with the locations of the gold deposits and LIPs with mantle plume centres and plate boundaries such as subduction zones and rift margins, to interpret the tectonic stresses occurring during the mineralization of gold. Multiple models describing the influence of mantle plumes on tectonic regimes are used to explain the stresses occurring at the orogenic gold deposits due to the emplacement of continental LIPs. The results show that there are links between orogenic gold deposits and continental LIPs, both temporally and spatially. The deposits in West Africa, Amazonia, and São Francisco are hypothesized to be affected by mantle plume uplift, tilting, and plume-push of the supercontinent. Similarly, the deposits in Laurentia are found to be influenced by mantle plumes, proxied by LIPs, also pushing the lithospheric keel of Nuna toward a convergent boundary. The deposits of the Yenisei Ridge are linked to various voluminous LIPs punctuating initiation and changes in mineralization during rifting and breakup events. Finally, continental LIPs proximal to the deposits at the Yenisei Ridge occurring at 720 Ma are found to have affected the thermal conditions for reactivation of tectonic, metasomatic, and hydrothermal processes for gold mineralization. The orientation and timing of gold bearing and large-scale structures of the deposits will be investigated and compared to the tectonic stresses during mineralization. to form an additional spatial link.

WHAT LICHEN CAN TELL US ABOUT THE SUDBURY SMELTER EMISSIONS – A STORY OF REDUCTIONS WITH A NEW FOCUS ON CRITICAL MINERALS

Max Lakanen[1], Julia Anderson[1,2], Brad Halvorson[2], Marissa Brown[2], Mark Charbonneau[2], Francois Caron[3], Peter Beckett[1], Graeme Spiers[1]
[1]Laurentian University, [2]Testmark Laboratories Ltd.,
[3]Royal Military College of Canada.
E-mail: *mr_lakanen@laurentian.ca*

This new 2022–23 study in the Sudbury region, known for historic landscape devastation and recovery and re-greening programs, compares elemental data gathered from a variety of sampled media, including Broom Moss (*Dicranum scoparium*), terricolous lichens, Caribou Lichen (*Cladonia rangiferina*) and Foam Lichen (*Stereocaulon spp.),* an epiphytic lichen, Boreal Oakmoss lichen (*Evernia mesomorpha*), surface soil material, and snowpack, along a 130 km NW transect from the Sudbury smelting operations. The chemical elements discussed include both those highlighted as Contaminants of Concern by the Sudbury Area Risk Assessment and with a new focus on Canadian Critical Minerals. The study examines the relationship between emissions loading to the studied environmental media and distance (130 km) from one

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of the major industrial areas of Sudbury. Our results show a substantial decrease in contaminant levels compared to historical data, probably a direct outcome of the pollution control measures in the Sudbury Region smelting operations. An abrupt drop off of ~90% for many key elements is observed with distance. Results from the study support the use of lichens as sensitive bioindicators and monitoring tools, based on the congruence between sample categories and tight sample variability. The elemental composition of particulate matter from snow is compared with concentrations of elements quantified in lichens and supported by observations using FTIR spectra and SEM-EDS. These results provide a new updated regional distribution compared to historical data, illustrating the fact that environmental recovery is taking place.

FORMATION OF PGE-Cu-Ni DEPOSITS IN THE DEEP-SEATED PARTS OF GIANT ULTRABASIC CONDUIT SYSTEMS DURING THE EDIACARAN CIMP EVENT: OBSERVATIONS FROM THE SEILAND IGNEOUS PROVINCE, NORWAY

Rune B. Larsen, Bjørn E. Sørensen
Norwegian University of Science and Technology.
E-mail: *rune.larsen@ntnu.no*

The Central Iapetus Magmatic Province (CIMP, 610–560 Ma) is a prominent worldwide Large Igneous Province (LIP), well known from Greenland, Labrador, elsewhere in North America, and the Baltic shield. The Seiland Igneous Province (SIP) formed at 570–560 Ma, in northern Norway, comprises the most deep-seated parts of the CIMP event (ca. 1 GPa). The SIP hosts five giant ultrabasic conduit systems conveying thousands of km^3 of melts from the asthenosphere to the continental lithosphere. In the SIP, we have located several metres-wide sub-horizontal Cu-Ni-PGE occurrences in one of these conduits. Four exploratory drill holes (170–400 m) confirmed the presence of several decoupled Cu-Ni and PGE horizons in dunitic cumulates. Shallow horizons 40–100 metres below the surface assayed 1.2–1.6 wt.% total sulphides. As an example, one drill hole yielded 5 metres of dunite with 0.4 wt.% sulphide-bound Ni, 0.14 wt.% Cu, and 70 ppb PGE + Au. Twenty-five metres below, another horizon showing 5 metres with 0.23 wt.% Ni and 715 ppb PGE + Au was identified. Here, most of the PGE + Au is confined to a 1 m dunite section with 1635 ppb PGE + Au including 750 ppb Pd, 430 ppb Pt, 220 ppb Au and, 235 ppb IPGE with an Os-peak at 200 ppb. The Ni peak occurs 7 m higher up, hence the PGE-reef is clearly decoupled from the Ni-reef, which is decoupled from the Cu-reef. This strong decoupling between PGE-reef and Cu- and Ni-reefs occurs in all four drill holes but most of the mineralized horizons are associated with narrow Cr-rich intervals interpreted as stratigraphic markers, suggesting recharge events. The studied PGE-Cu-Ni mineralization occurs in a swelling structure forming a side chamber along the main magmatic conduit. Accordingly, the identification of such side chambers in other much larger conduit systems within SIP may serve as an exploration target. There are high contents of carbonate minerals and hydrous phases throughout all cumulate types, as well as within mineralization, but also within early and late dykes. Therefore, it may be concluded that the ultrabasic parental melts were strongly enriched in dissolved volatile constituents. The significance of the volatile-rich phases for asthenosphere-lithosphere transfer of fertile ultrabasic melts is still debated. However, we propose that dissolved and immiscible volatile constituents greatly lower the density of these nominally dense melts and aid in mantle-to-crust emplacement as well as the formation and later disruption/remobilization of the Cu-Ni-PGE mineralization.

IMPORTANCE OF LOWER CRUSTAL MAGMATISM AT MAGMA-RICH CONTINENTAL MARGINS FOR THE FORMATION OF LIP AND Cu-Ni-PGE DEPOSITS

Rune B. Larsen[1], Bjørn E. Sørensen[1], Christian Tegner[2], Sara Callegaro[3], Sverre Planke[3]
[1]Norwegian University of Science and Technology, [2]Århus University, [3]University of Oslo.
E-mail: *rune.larsen@ntnu.no*

The lower continental crust is one of the most intangible frontiers in geosciences. At the few localities where the deep crust is exposed, primary features are obliterated by high-grade metamorphism and deformation. At magma-rich volcanic margins ca. 80 vol.% of mafic/ultramafic bodies, also known as Lower Crustal Bodies (LCBs), comprise the lower crust. The Seiland Igneous Province (SIP) in northern Norway appears to represent an easily accessible epitome of such an LCB. The 5000 km^2 SIP matches the description of the lower continental crust at magma-rich passive volcanic margins, in featuring ca. 80% mafic/ultramafic plutons emplaced into gneissic basement rocks at depths of 1 GPa. The SIP formed at 570–560 Ma and is associated with an LIP known as the Central Iapetus Magmatic Province. Our preliminary studies show that the emplacement of dense juvenile melts in SIP were facilitated by unexpectedly high volatile contents, which were partially buffered by co-existing hydrous-carbonated alkaline silicate melts. The SIP comprises > 20,000 km^3 of mafic and ultramafic intrusions with minor alkaline-carbonatitic complexes and felsic rocks. Four large peridotite complexes are regarded as the main conduit systems for the intercrustal emplacement of thousands of km^3 of basic and ultrabasic melts. Gravimetric studies suggest four major ultramafic conduits extending > 9 km downwards. These ultramafic conduits are well exposed in a right-way-up position in steep-sided 20–200 km^2 plugs. From edge to core, they comprise a marginal fusion zone towards the country rock, followed by olivine-clinopyroxenite cumulates, then wehrlitic and, at the centre, dunitic cumulates. Parental melt modelling implies ultramafic parent melts with 16–22 wt.% MgO, Cr of 1594 ppm, and Ni of 611 ppm. They were emplaced at 1400–1500°C and mostly formed at 1630ºC and 7 GPa by partial melting of carbonated asthenospheric peridotite. Abundant hornblendites, carbonatites, and lamprophyres throughout the SIP confirm the volatile-rich nature of the mantle source region and are further corroborated by high average contents of magmatic sulphides (0.5–1%), as well as carbonated and hydrous phases (1–5%). Volatile-rich phases are particularly common at PGE-Cu-Ni occurrences where they co-exist with the ore-forming sulphide-rich assemblages, and we hypothesize that immiscible volatile-rich alkaline melts aided in both deposition and later disruption of ore-deposits. Volatile phases will also lower melt densities and viscosities and may be important for rapid fluxing from the mantle through the deep crust to the more shallow crustal realm of these nominally dense basic-ultrabasic melts.

THE NORTHERNMOST CANADIAN SHIELD: LATE NEOARCHEAN AND PALEOPROTEROZOIC ROCKS OF DEVON AND ELLESMERE ISLANDS

Joshua Laughton[1], Gordon Osinski[1], Chris Yakymchuk[2]
[1]Western University, [2]University of Waterloo.
E-mail: *jlaught2@uwo.ca*

Crystalline basement rocks of the Canadian Shield outcrop from southern Ontario to the Canadian Arctic Archipelago. The northernmost exposures of the Canadian Shield are on Devon and Ellesmere islands, where granulite facies rocks of the Churchill Province outcrop along the coasts of an ice-dominated terrain. Our zircon and monazite chronology results demonstrate that the shield rocks of these islands differ from typical ≥ 2.6 Ga Rae cratonic crust to the south, as the oldest rocks are represented by a late Neoarchean (ca. 2.55–2.47 Ga) terrane on Devon Island. This late Neoarchean terrane is bordered to the north by middle Paleoproterozoic metasedimentary sequence(s) and plutonic rocks, on northern Devon and Ellesmere islands. We also carried out phase-equilibrium modelling of high-temperature to ultrahigh-temperature metamorphic assemblages on Devon and Ellesmere islands that indicate conditions associated with ca. 1.9 Ga metamorphism reached ≥ 850°C. Earlier, poorly constrained metamorphic events are recorded at ca. 2.54, 2.47 and 2.30 Ga, possibly associated with pulses of the ca. 2.5–2.3 Ga Arrowsmith orogen. The late Neoarchean Devon Island terrane has likely continuations on the Boothia Peninsula and in northwestern Greenland, while the middle Paleoproterozoic rocks of northern Devon and Ellesmere islands represent a northern extension of the ca. 2.0–1.9 Ga Thelon tectonic zone.

CANADIAN Sn-W RESOURCE POTENTIAL – A REVIEW OF THE METALLOGENY AND EXPLORATION METHODS

Gaetan Launay
Ontario Geological Survey.
E-mail: *gaetan.launay@ontario.ca*

Tin (Sn) and tungsten (W) are considered critical metals because of their high supply risk and their importance for current and still-in-development technologies.

Although Canada represents only 8% and < 1 % of the global W and Sn reserve, the varied geology of Canada offers lots of potential for further resource discoveries. Most of the primary Sn-W deposits are spatially associated with highly fractionated felsic intrusions that have been emplaced in orogenic belts and continental arc settings. These intrusions occur usually at moderate to high crustal levels in an environment that permits brittle fracturing and migration of the metal-bearing fluids expelled from the intrusions at the magmatic-hydrothermal transition. Most of the Canadian intrusion-related Sn-W deposits are widely distributed in the Cordilleran (Yukon and Northwest Territories) and Appalachian (New Brunswick and Nova Scotia) orogenic belts. The Sn-W mineralization occurs in a wide range of deposit types including mostly quartz veins, greisen, skarn, and less commonly porphyry-type occurrences and pegmatitic rocks. Vein-style deposits consist of simple to complex fracture fillings that occur in and around felsic intrusions. The Sn-W-bearing quartz veins commonly coexist with disseminated low-grade greisen deposits that occur mainly in the highly altered apical portions of granite intrusions. The Mount Pleasant (New Brunswick) and East Kemptville (Nova Scotia) deposits are typical Canadian examples of vein-and-greisen deposits. Skarn deposits are formed by contact metamorphism of carbonate-dominated country rocks that undergo a variety of metasomatic processes involving fluids of magmatic, metamorphic, and meteoric origin. Mineralization consists of scheelite associated with calc-silicate assemblages such as pyroxene and garnets. In the west, the Cordilleran belt hosts among the world's largest known W deposits; namely the Cantung and MacTung deposits. They are the most representative Canadian examples of skarn deposits. Archean greenstone belts composing the Slave and Superior provinces also constitute interesting targets for further exploration. W mineralization can be locally found in lode gold deposits, as in the Porcupine gold camp (Timmins, Ontario), where substantial amounts of scheelite were recovered from altered porphyry bodies during World War II. Furthermore, Sn and Sn-bearing minerals can be prominent in deformed and metamorphosed (amphibolite-granulite facies) base-metal volcanogenic massive sulphide deposits, as in the Geco and Kidd Creek (Ontario) deposits. This presentation aims to provide an overview of the principal characteristics of Sn-W deposits that can be discovered in Canada and the methods applied in the exploration of these deposits.

INTERNATIONAL COLLABORATION FOR CONTINENT-SCALE PROSPECTIVITY MODELLING OF CRITICAL RAW MATERIALS

Christopher Lawley[1], Anne McCafferty[2], Garth Graham[2], David Huston[3], Karen Kelley[2], Karol Czarnota[3], Suzanne Paradis[1], Jan Peter[1], Nathan Hayward[1], Mike Barlow[3], Poul Emsbo[2], Joshua Coyan[2], Carma San Juan[2], Michael Gadd[1]

[1]Natural Resources Canada, [2]U.S. Geological Survey, [3]Geoscience Australia.
E-mail: *christopher.lawley@nrcan-rncan.gc.ca*

Mapping each component of a mineral system is essential for reducing the search space for critical raw materials and is the major focus of prospectivity modelling. However, defining mappable criteria for the drivers, sources, and deepest pathways of mineral systems has proven difficult in practice, despite the potential for these components to significantly improve exploration targeting and prospectivity modelling results in brownfield and greenfield areas. Recent progress on converting raw data to mappable criteria via feature engineering, three-dimensional geophysical imaging of the crust and uppermost mantle, models for the evolution of the lithosphere in deep time, and the increased availability of geoscience data compilations (e.g. magnetotelluric, geochronology, isotope geochemistry, lithogeochemistry, and lithostratigraphy) provide new mappable proxies for entire mineral systems to address that knowledge gap. Here we present prospectivity modelling results across Canada, the U.S., and Australia to highlight how improved knowledge exchange and data-sharing between geological survey organizations can also contribute to the modelling and understanding of these mineral systems across political boundaries. For example, we demonstrate the importance of global paleo-tectonic reconstructions for predicting the location of brine-generating source regions based on the paleolatitude of the sedimentary host rocks for clastic-dominated (previously termed SEDEX) and Mississippi Valley-type zinc-lead deposits. These types of non-traditional geoscience datasets are particularly effective for assessing mineral potential in greenfield areas that may lack the high-resolution surveys that are needed for district- to deposit-scale prospectivity models. We further demonstrate how geoscience language models can be applied to text-based lithostratigraphic and geochronologic data compilations for predicting the locations of alkalic and pegmatitic source rocks, which represent important sources for rare earth elements and lithium. Securing the global supply chains for these and other critical minerals will depend on international cooperation, as recently described in Canada's critical mineral strategy.

THE TIME AND PLACE FOR OROGENIC GOLD DEPOSITS

Christopher J.M. Lawley[1], Patrick Mercier-Langevin[1], Benoît Dubé[1], Jean-Luc Pilote[1], Sébastien Castonguay[1], Ian W. Honsberger[1], Simon E. Jackson[1], Duane C. Petts[1], Zhaoping Yang[1], Sally J. Pehrsson[1], Riccardo Graziani[1], William J. Davis[1], David Selby[2], Robert A. Creaser[3], Renelle Dubosq[4], David Schneider[5]

[1]Geological Survey of Canada, [2]Durham University, [3]University of Alberta, [4]Max-Planck-Institut für Eisenforschung, [5]University of Ottawa.
E-mail: *christopher.lawley@nrcan-rncan.gc.ca*

Recent petrochronological research demonstrates that some orogenic gold deposits are the end-products of overprinting hydrothermal, deformational, and metamorphic stages spanning 10s to 100s of M.y. rather than a single metallogenic event. Gold is coarsened, remobilized, and upgraded into high-grade ore shoots as part of this complex geological history. However, direct Re–Os dating of sulphide minerals provides evidence that gold is introduced at multiple orogenic stages, in addition to the remobilization of pre-existing gold. The multistage history of some orogenic gold deposits contrasts with the broad 'syn'-metamorphic timing identified through relative timing relationships, and challenges the standard metamorphic devolatilization model because: (1) thermal conduction is generally too slow to explain the earliest auriferous veins that occur prior to peak metamorphism; (2) the youngest auriferous veins post-date peak metamorphism by 10s to 100s of M.y.; (3) auriferous veins and gold-rich minerals are preserved despite being metamorphosed to amphibolite-facies conditions; and (4) mass-balance calculations for sulphur and gold are incompatible with mineral-systems models that suggest gold is sourced and/or remobilized from the local host rocks. Instead, new petrochronological results suggest that multistage orogenic gold deposits are associated with favourable temperature windows that allow gold transport as sulphide complexes before, after, and, in some cases during regional metamorphism. Exhumation is the most likely driver for post-orogenic ore-forming fluids, rather than simply conductive heat transfer and devolatilization during regional metamorphism. In nearly all cases, fault reactivation is important for creating pathways to transport gold to the same chemically reactive host rocks and structural traps through time. Favourable lithospheric architecture is thus critical for controlling all subsequent deformation stages and is an important mineral exploration criterion. Field- and laboratory-based thematic research, conducted in collaboration with the mineral exploration industry, is essential to recognize and place these ore-forming processes into a mineral systems framework.

BALANCING CRITICAL MINERAL EXPLORATION WITH BIODIVERSITY AND CONSERVATION VALUES IN CANADA'S ARCTIC

Christopher Lawley[1], Matthew Mitchell[2], Diana Stralberg[1], Richard Schuster[3], Eliot McIntire[1], Joseph Bennett[4]

[1]Natural Resources Canada, [2]University of British Columbia, [3]Nature Conservancy of Canada, [4]Carleton University.
E-mail: *christopher.lawley@nrcan-rncan.gc.ca*

Canada's critical mineral strategy highlights the need to discover new mineral deposits to secure the supply chains of the green economy. However, any increased exploration and development for critical minerals will likely accelerate pressures on natural ecosystems and will require partnerships with Indigenous peoples and other impacted communities. This is particularly true for the Arctic, which is home to multiple species at risk and is experiencing rapid warming that threatens locally adapted terrestrial and freshwater ecosystems. New data-driven natural resources management strategies are needed to balance critical-mineral development with biodiversity and conservation values. Herein we address that knowledge gap using machine learning-based prospectivity models for Canada's major source of battery minerals (i.e. magmatic nickel, copper, and cobalt deposits) with five ecosystem services (i.e.

freshwater resources, carbon, nature-based recreation, species at risk, climate-change refugia) and gaps in the current protected-area network. We demonstrate that many of Canada's northern ecoregions have less than half of the protected areas required to meet the post-2020 Global Biodiversity Framework conservation target of protecting 30% of Canada's land and seas by 2030. Prospective and poorly protected ecoregions with one or more of the five ecosystem services are interpreted as hotspots with the potential for conflicting land-use priorities in the future. Multiple land-use priorities are also identified in southern Canada, where important ecosystem services and relatively large numbers of species at risk are protected by small and poorly connected conservation areas. Balancing critical mineral development goals with area-based conservation targets will require spatial analysis at multiple scales, which, for the Canadian Arctic, is limited by the availability of geoscience and environmental datasets. New geoscience research funded as part of Canada's critical mineral strategy will addresses some of these knowledge gaps, contributing to improved data-driven natural resources management strategies for the Arctic.

THE VALENTINE GOLD PROJECT: PALEOZOIC OROGENIC GOLD DEPOSITION IN THE CENTRAL NEWFOUNDLAND GOLD BELT

Graham D. Layne[1], Monica Barrington[2], Charles Samson[1], Nicholas J.M. Capps[3]
[1]Memorial University of Newfoundland, [2]Core Assets Corporation, [3]Marathon Gold Corporation.
E-mail: *gdlayne@mun.ca*

The gold deposits of the Valentine gold project (VGP) lie within the Exploits Subzone of the Dunnage Zone terrane in central Newfoundland. Gold mineralization is localized proximal to a "break" where the Valentine Lake Intrusive Complex (VLIC) abuts the Silurian Rogerson Lake conglomerate (RLC) along the Valentine Lake Shear Zone (VLSZ), part of a larger regionally extensive structure initiated during the Salinic orogeny. The Rogerson Lake conglomerate was deposited in a marine basin during a period of transient post-Salinic Extension ca. 425–418 Ma. Gold mineralization is specifically localized in quartz-tourmaline-pyrite (QTP) veins, which occupy fracture-controlled sets, largely within the granitoid components of the VLIC — an older quartz monzonite (QM) group (U–Pb zircon age 573 ± 2 Ma), and a trondhjemite-tonalite-granodiorite (TTG) group (U–Pb zircon age 566.2 ± 2.2 Ma). Suites of mafic dykes associated with both episodes of VLIC plutonism may also have benefitted gold mineralization by promoting brittle failure that enhanced and focused fluid flow. Alteration related to gold mineralization is far less obvious, or extensive, than in orogenic deposits hosted in more mafic lithologies. The main alteration style contemporaneous with Au deposition is a "whitening" of the surrounding wallrock over a short distance (cm scale). This whitening is a consequence of the alteration of host rock plagioclase to a more Na-rich (and un-twinned) composition. There is little evidence of wallrock sulphidation as a mechanism for gold precipitation, even where QTP veins traverse more mafic members of the VLIC. Instead, the main mechanism of ore localization appears to have been a phase change ('boiling') of hydrothermal fluids that abruptly reduced Au solubility. Secondary ion mass spectrometry (SIMS) microanalyses of boron isotopes in tourmaline in QTP veins from throughout the VGP range from –16.6‰ to –0.4‰ $\delta^{11}B$ (mean of –7.6 ± 2.8‰ (1σ)). This range overlaps with those reported for Archean orogenic districts (e.g. Val d'Or, James Bay, Yilgarn), and matches that expected for boron derived from granitic intrusions and/or clastic metasedimentary rocks. Recent data from U–Pb dating of monazite from auriferous QTP veins within the VGP indicates that the main QTP gold mineralization occurred ca. 377 Ma, during the Neoacadian orogeny, rather than at > 400 Ma, during the preceding Acadian orogeny, as implied by U–Pb dating of rutile.

EFFECT OF OXYGEN BARRIER COVERS ON MICROBIAL COMMUNITIES WITHIN HIGHLY OXIDIZED MINE TAILINGS: IMPLICATIONS FOR SECONDARY MINERALOGY AND METAL MOBILITY

Mignon Le Roux[1], Gary Schudel[2], Benoît Plante[2], Bruno Bussière[2], Joyce McBeth[3]
[1]University of Saskatchewan, [2]Université du Québec en Abitibi-Témiscamingue, [3]University of Regina.
E-mail: *joyce.mcbeth@uregina.ca*

Microbial communities can influence the biogeochemical cycling of metals and other constituents of concern within sulphidic tailings. Although considerable research has focused on microbial populations and secondary mineralization within acid mine drainage (AMD) environments, relatively few studies have focused on the response of microbial communities in tailings to the construction of oxygen barrier cover systems. The abandoned Manitou mine site (Val d'Or, Québec) represents an ideal location to examine the response of AMD microbial communities to an oxygen barrier cover system; a portion of the site's highly acid-generating tailings was reclaimed in 2009 with a monolayer cover and elevated water table (EWT), while another portion of the site remains unreclaimed. Lab and field experiments were performed to achieve the following objectives: (1) compare and contrast microbial communities, mineralogy, and geochemistry of reclaimed and unreclaimed areas; (2) evaluate the influence of microbial communities on the stability of secondary minerals and metal mobility; and (3) enrich and characterize iron- and sulphur-cycling microbes from the Manitou Mine site to better understand microbial community function. The chemical and mineralogical compositions of the tailings were evaluated using synchrotron techniques, conventional mineralogical analyses and geochemical analyses; these included X-ray absorption spectroscopy (XAS), micro-XRF mapping, powder X-ray diffraction, and sequential extractions. Microbial diversity, function, and abundance will be evaluated using high throughput 16S rRNA gene sequencing and enrichment cultures. This study will yield an improved understanding of the influence of microbes on metal mobility within acidic tailings environments and identify opportunities to optimize the management of oxidized sulphidic tailings.

USING OOLITIC IRONSTONE ROCKS TO TRACK CONTINENTAL WEATHERING AND NUTRIENT CYCLING IN THE PROTEROZOIC

Maxwell Lechte[1], Galen Halverson[1], Malcolm Wallace[2], Chang-Le Wang[3], Leslie Robbins[4], Suzannah Porter[5], Malcolm Hodgskiss[6], Ashleigh Hood[2], Margaret Whelan[1]
[1]McGill University, [2]University of Melbourne, [3]China University of Geosciences Beijing, [4]University of Regina, [5]University of California Santa Barbara, [6]Geological Survey of Norway.
E-mail: *maxwell.lechte@mail.mcgill.ca*

The rare earth element (REE) composition of chemical sedimentary rocks can act as a proxy for the chemistry of the fluid from which they formed, and the REE contents of ancient iron formations have long been used as proxies for palaeo-seawater chemistry. Less commonly studied are oolitic ironstone rocks, which are largely restricted to the Phanerozoic, yet examples can be found throughout the Proterozoic stratigraphic record. These deposits are generally interpreted to have been deposited in coastal environments, and therefore their chemical composition may be influenced by the local chemical conditions of continental runoff and shallow seawater. Component-selective, laser-ablation REE analyses of the authigenic iron oxides and iron silicates of ironstones suggest a hydrogenetic origin (as indicated by negative Y anomalies), and that their genesis involved redox cycling (positive Ce anomalies) and the influence of acidic fluids (middle REE enrichment). Stratigraphic relationships show that ironstone rocks are generally deposited at the beginning of a transgression following a regressive trend. We propose a model wherein lateritic weathering and drainage of locally exposed continental rocks supplied abundant metal cations to coastal environments in acidic solution, which would have been oxidized upon mixing with the higher-pH seawater. The resultant flux of Fe (oxyhydr)oxides to the seafloor drove dissimilatory iron reduction, leading to iron phyllosilicate authigenesis (reverse weathering), and phosphorus remineralization and phosphogenesis (sink switching). With this model in mind, we re-evaluate the temporal distribution of ironstone rocks, and propose that the onset of oxidative chemical weathering during the Great Oxidation Event was a prerequisite for ironstone deposition. The evolution of the Earth's atmospheric composition, climate and tectonic configuration may help to explain their abundance and distribution following this time. Proterozoic ironstone rocks therefore represent an important deep-time archive of biogeochemical cycling at the interface between the continental and marine realms.

DECIPHERING THE ORIGIN OF ELEMENT SIGNATURES IN STREAM WATERS DRAINING ENDMEMBER SILICATE BEDROCK TYPES IN NEWFOUNDLAND

Gabrielle Ledesma[1], Michael Babechuk[1], Wei Wang[2], Huy Dang[2]
[1]Memorial University of Newfoundland, [2]Trent University.
E-mail: *gmledesma@mun.ca*

Bedrock geology exerts an important first-order control on the element composition of stream waters, including low-level trace element signatures. Studies from small hydrological catchments, with a singular or restricted range of bedrock type(s), present an ideal scenario to understand the details of geological controls and how they compete with other physico-chemical and environmental factors. Understanding these relationships is important from a local scale, such as identifying areas for potential toxic element inputs, and a regional scale, such as deciphering how major rivers that transport dissolved elements to the oceans may inherit their signatures. Here, we present elemental data, including the rare earth elements and yttrium, from streams in two study sites within the same climate zone that drain silicate end-member bedrock compositions: (1) in the Bay of Islands in western Newfoundland draining an ophiolite sequence of mafic/ultramafic bedrock, and (2) in the Burin Peninsula, Newfoundland draining a large Devonian–Carboniferous granite pluton (St. Lawrence granite) that hosts fluorite mineralization. Low-contamination water sampling in July 2022 was followed by ICP-MS elemental analysis at Trent University. Hypothesized variations in stream-water chemistry between the catchments of highly contrasting bedrock geology were confirmed with both major (Ca, Na, Mg, K) and trace-element data. Rock-type diversity in the sampled subbasins was calculated using open access DEM data and revealed correlations to Mg-Ca-Na-K variations, such as elevated Mg relative to other major cations in drainage basins with ultramafic > mafic rocks. The most diagnostic trace element fingerprints of bedrock type are relative enrichments of Cs-Rb-U vs. Ni-Cr, which also deviated significantly in the smaller streams from world river averages and major rivers from Newfoundland. Normalized REE + Y patterns also discriminate stream waters from endmember catchments with distinctive negative Eu and positive Y anomalies inherited by streams draining granite. However, bedrock-inherited signatures in the dissolved element budgets do show evidence of being modified by effects related to incongruent mineral weathering, and local environmental factors such as enhanced element release following rainfall events. The resulting dataset from this study characterizes a wide suite of dissolved elements, including low-level trace elements, some of which are the first to be determined for stream waters in Newfoundland and Labrador. This dataset can be used as an environmental baseline for the studied areas, while also illustrating how dissolved element signatures can vary with diverse geology.

ASSESSING CRITICAL METAL INCORPORATION IN Ca-CARBONATE MINERALS USING CYANOBACTERIA: APPLICATION TO MINE SITE ENVIRONMENTS

Benjamin Lei, Jenine McCutcheon
University of Waterloo.
E-mail: *b6lei@uwaterloo.ca*

Biomineralization has applications to bioremediation, including carbon sequestration in carbonate minerals in mafic and intermediate mining environments. Cyanobacteria produce extracellular polymeric substances (EPS) containing negatively charged functional groups, which act as sites for both biosorption of cations from solution and nucleation sites for mineral precipitation. Previous studies have demonstrated the ability of cyanobacteria to 1) precipitate carbonate minerals and 2) sorb critical metals from solution; however, the process by which critical metals are incorporated into biogenic Ca-carbonate mineral precipitates is not well understood. The presented study examines cyanobacteria EPS production in response to varying metal and nutrient concentrations and assesses the ability of cyanobacteria to immobilize transition metals in Ca-carbonate minerals. *Synechococcus leopoliensis* was selected for its capability to produce EPS and sorb metals including cobalt, nickel, and chromium. In the first experiment, media will be inoculated with *S. Ieopoliensis* in the presence of varying Co^{2+}(aq), Ni^{2+}(aq), and Cr^{6+}(aq) concentrations under nutrient (NO_3^-(aq) and PO_4^{3-}(aq)) enriched and deficient conditions. The second experiment will assess cobalt, nickel, and chromium incorporation into calcium carbonate precipitates by simulating mine site geochemical conditions. Time-resolved EPS production, critical-metal sorption, and mineral precipitation will be monitored using transmission electron microscopy (TEM) and scanning electron microscopy (SEM), selected area electron diffraction (SAED), Raman spectroscopy, and inductively coupled plasma mass spectrometry (ICP-MS). This study will provide insight into the role of cyanobacteria in storing critical metals in carbonate minerals such as calcite ($CaCO_3$) and aragonite ($CaCO_3$). The results will have applications to critical-metal recovery from waste waters and metal immobilization through biogenic mineral precipitation in mafic and intermediate mine-waste materials.

CHARACTERIZING THE PRECIOUS METAL-BEARING BASE METAL MINERALIZATION AT THE HOMER LAKE PROSPECT, YELLOWKNIFE GREENSTONE BELT, NORTHWEST TERRITORIES

Tara Lemke[1], Stefanie Brueckner[1], Jana David[2], Bernadette Knox[3], Merilie Reynolds[3], Ryan Bachynski[4]
[1]University of Manitoba, [2]University of Mainz,
[3]Northwest Territories Geological Survey, [4]Gold Terra Resources.
E-mail: *lemket@myumanitoba.ca*

The Homer Lake prospect, located 25 km north of Yellowknife, is hosted within the ~2.7 Ga Yellowknife greenstone belt (YGB) in the southern Slave Craton, Northwest Territories. The YGB is known for its gold enrichment that occurs primarily within mineralized quartz veins that have been previously mined (two examples being the Con and Giant deposits). Base-metal mineralization (Zn, Pb ± Cu) has also been observed in the belt and is especially abundant at the Homer Lake prospect (2.77 g/t Au, 58 g/t Ag, 3.09% Pb, and 7.46% Zn over 5.27 m in drill hole TNB-14-004). Hence, the prospect was selected to investigate the genetic model for base-metal mineralization within the YGB. The origin of base-metal mineralization within the belt has long been debated between a volcanogenic massive sulphide source or a structurally dominated, shear-hosted origin. Preliminary results from core logging, whole rock multielement analysis, and micro-X-ray fluorescence element mapping will be presented to address this knowledge gap. The Homer Lake prospect is dominated by massive tholeiitic and some transitional basalt flows, succeeded by less abundant calc-alkaline rhyolite and rhyodacite, and minor trachyte. Gabbroic sills are also common in downhole stratigraphy. Cross -cutting quartz and calcite veins are present in all lithologies and locally associated with mineralization. Patchy and pervasive carbonate and chlorite alteration is observed throughout all

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cores logged, though it is not continuous throughout the holes. The tholeiitic basalt flows and rhyolite/rhyodacite show several mineralization textures including (i) thin sphalerite stringers typically occurring with well-developed shear foliation fabric, (ii) disseminated euhedral pyrite cubes within a sphalerite host, typically seen in stringers, and (iii) (semi-) massive sulphides, commonly consisting of arsenopyrite, pyrite, and sphalerite, with local zones containing trace galena. Micro X-ray fluorescence indicates that there are strong associations of Zn and Pb with mineralization, due to the occurrence of sphalerite (Zn) and minor galena (Pb). Although mineralization shows similarities to both volcanogenic massive sulphide mineralization (e.g. massive sulphides dominated in Zn-Pb) and structurally controlled mineralization (e.g. association with strong foliation and quartz veining), the origin of the precious metal-bearing base-metal mineralization is currently unknown.

DIAGNOSING CHALCOPYRITE DISEASE: IS SPHALERITE REALLY SICK OR JUST A DISORDER?

David R. Lentz
University of New Brunswick.
E-mail: *dlentz@unb.ca*

The honour of receiving the Martin Alfred Peacock Award dictates that I present a short review of his amazing accomplishments and service to his field, students, and our society. Much of his academic legacy relates to his and his students' research on sulphides, so I decided to follow that research theme as the Mineralogical Association of Canada's (MAC) journal, now evolving to "Canadian Journal of Mineralogy and Petrology" this year, was always a home to amazing sulphide research since the journal's inception, inspired by Professor Peacock and carried forward by editors like Leonard G. Berry, John Jambor, and Louis Cabri; all sulphide experts. I dedicate this to their inspirational efforts. This publishing tradition has continued under the watchful eyes of Bob Martin and Lee Groat, of course, and now Stephen Prevec and Andy McDonald. Therefore, examining key sulphides and their enigmatic texture(s) together with crystal-chemistry and kinetic implications examined is quite fitting at this time. Diagnosing this fascinating disease was mostly inspired by the prodigious Steve Scott. It is fitting to review the signs and symptoms in sphalerite (the innocent host) and chalcopyrite (the valuable infection), the nature of this host-infection relationship, and the various diagnoses from exsolution to inoculation, to finally understand the disorder.

BUILDING ROBUST MODELS FOR EXTREME FRACTIONATION IN RARE-METAL GRANITES AND PEGMATITES: A CASE FOR ESTIMATING BULK D USING THE RAYLEIGH FRACTIONATION-DISTILLATION LAW FROM LOW-T MAGMA SERIES

David R. Lentz
University of New Brunswick.
E-mail: *dlentz@unb.ca*

There has been growing interest in understanding how incompatible elements are enriched in highly evolved felsic magmatic systems. In the granite literature, there has also been a growing interest in the mechanisms responsible for extreme enrichment. In the pegmatite literature, there are similar challenges, but for different reasons. Surprisingly, the two sets of literature seem to have evolved quite separately but using many of the same techniques and the mineralogical scale, although pegmatites have been challenged with bulk lithogeochemical techniques. The key is that there have been quite convincing arguments in the pegmatite literature that the role of volatiles is within the melts, acting as fluxes to lower liquidi-solidi, but rarely responsible for any of the mineralization, which is generally presented as magmatic. However, in the granite literature, there has been growing speculation that fluid fractionation is responsible for extreme fractionation, based on evidence from elemental abundance and ratio gaps, like Zr/Hf and Nb/Ta; regardless, Ti/Zr is one of the most consistent indices for fractionation in any of these evolved systems. However, we know from detailed mineral-chemical analyses in LCT and NYF pegmatites that a continuum in Zr/Hf and Nb/Ta to extremely low values is obviously igneous. Even though the models for some pegmatitic systems are evolving from the fractional crystallization models from evolved granites to combinations of selective partial melting, then extensive crystal fractionation, but still no exsolved volatiles are invoked for the rare-metal mineralization process; rather, fluxes with water in these melts are considered the culprits for extreme fractionation to low temperatures during ascent; volatiles are no doubt exsolved, but rarely the ephemeral evidence is preserved, albeit there are exceptions. In granite-related systems, hydrothermal mineralization is readily evident, which is compelling evidence for fluids having a major role; this is unequivocal. Therefore, the role of fluids at volatile saturation in the suprasolidus setting (fluid fractionation) is erroneously compelling for some highly enriched granites and their extrusive equivalents, like the Macusani tuff and the Brockman tuff (Nb tuff); however, neither could be enriched by exsolved volatiles, as gas and glass behave separately upon fragmentation during eruption. Rather, developing more robust Kd and bulk D models experimentally and empirically for these unique melts at low temperatures is needed, to utilize in both fractional partial melting and fractional crystallization models; a Rayleigh fractionation-distillation law interpolation can estimate bulk D for rock series that is more realistic for these low-temperature magmatic systems.

GENESIS OF Ni-Cu-PGE MINERALIZATION IN THE SUDBURY IGNEOUS COMPLEX

C. Michael Lesher, Edward F. Pattison
Laurentian University.
E-mail: *mlesher@laurentian.ca*

The world's largest accumulation of Ni-Cu-PGE ores occurs in embayments at the base of the crystallized impact melt (Main Mass) and in associated radial/concentric dykes of the Sudbury Igneous Complex. There are currently two models for the genesis and localization of the mineralization, both involving incorporation of Fe ± Ni ± Cu sulphide-bearing target rocks: 1) Dissolution of sulphides in the superheated impact melt followed by cooling, exsolution of sulphide droplets, settling to the basal contact, and flowage into footwall embayments/funnels/troughs. 2) Volatilization of significant amounts of S-Hg-Tl-Cd-Se-Sn-Te-Zn-Pb-Bi and lesser Sb-Ag-Cu-Au-As during impact, followed by melting of post-impact debris produced during rebound and collapse of the central peak, assimilation of silicate components, generation of sulphide xenomelts, and upgrading by reaction with the impact melt. In the exsolution model, most processes are much slower: Fe-Ni-Cu sulphide droplets must nucleate and exsolve from the impact melt, obtain metals via diffusion, settle through the 3–5 km-thick melt sheet, coalesce, and migrate along the base of the complex before being injected into the offset dykes. In the xenomelt model most processes are much faster: sulphide xenomelts are generated more-or-less in place and start with variable Fe ± Ni ± Cu contents that are upgraded/downgraded through interaction with the impact melt before and during injection into offset dykes. Timing constraints are provided by the sulphide-poor margins of the offset dykes, which range continuously down to < 50 ppm S (i.e. up to 30 x less than the S content at sulphide saturation), so must have been emplaced prior to the sulphide-bearing cores. The marginal phase is rarely baked by the core phase, the core phase is rarely chilled against the marginal phase, and there are abundant inclusions of the marginal phase in the core phase but rarely the reverse, and thermal modelling suggests rapid sequential emplacement within 1–5 days. The exsolution model is too slow to accommodate such close timing. The Main Mass norites exhibit progressive upward depletion in PGE > Cu > Ni, but the sulphides in the lowermost norites and in the Sublayer norites have Ni-Cu-PGE contents similar to average Sudbury ores, so the decreasing upwards trends of the metals were produced by fractional crystallization and accumulation of Opx-Chr-Sul in norites after ore formation, not by wholesale stripping of metals during sulphide exsolution. The xenomelt model is also much more consistent with the wider variations in Pb–S isotopes in the ores than in the Main Mass.

TOTBLOCKS: A NEW WAY TO TEACH MINERALOGY USING 3-D-PRINTED MODULAR BUILDING BLOCKS

Derek D.V. Leung[1,2], Paige E. DePolo[2]
[1]Laurentian University, [2]University of Edinburgh.
E-mail: *dleung@laurentian.ca*

Spatial thinking and understanding of complex 3-D structures mark fundamental challenges in geology education. At the atomic scale, minerals have complex 3-D structures that are difficult to conceptualize. However, many common rock-forming silicate minerals have shared chemical building blocks. These minerals arise from combinations of vertex-sharing silica tetrahedra (T) and edge-sharing metal-oxygen octahedra (O) modules. Using the concepts of T and O modules, a better understanding of the similarities and differences between these structures can be developed. The TotBlocks project aims to communicate the crystal structures of modular rock-forming chain and sheet silicate minerals (pyroxenes, amphiboles, micas, and clay minerals) through 3-D printed building blocks. TotBlocks are free and open source and represent a cost-effective, accessible way to visualize these structures. TotBlocks can be used to construct modular minerals within the biopyribole (biotite-pyroxene-amphibole) and palysepiole (palygorskite-sepiolite) series, and other layered minerals (brucite, kaolinite-serpentine, and chlorite groups). TotBlocks hold the potential to be widely applied in both classroom and outreach settings. For example, these manipulatives could be used to extend student learning in courses where crystal structures are relevant ([optical] mineralogy, petrology, soil science). Students can use TotBlocks to elucidate the relationships between crystal structures and the properties of minerals. For example, the wider chains in the amphiboles leads to their developing 125°/55° cleavages, versus the 85°/95° cleavages observed in pyroxenes, and these can be seen in hand samples and thin sections. They can similarly be used to illustrate mineral habits and extinction angles. Additionally, TotBlocks could be incorporated into the dynamic displays of museums and science centres, or brought into primary and secondary school classrooms to encourage students to think about the building blocks of the Earth. For example, a display on spodumene (a lithium ore) in a critical-metals exhibit could incorporate the crystal structure of a pyroxene to show that lithium resides within the O modules of the crystal structure. TotBlocks provide a versatile way to visualize mineral structures in a variety of educational settings.

PROTOLITH AND ALTERATION CONTROLS ON THE MINERAL CHEMISTRY OF Cr- AND V-BEARING PHYLLOSILICATES AT THE KERR-ADDISON GOLD DEPOSIT, VIRGINIATOWN, ON: IMPLICATIONS ON THE MOBILITY OF Cr VERSUS V AND MINERAL EXPLORATION

Derek D.V. Leung, Andrew M. McDonald
Laurentian University.
E-mail: *dleung@laurentian.ca*

The empirical association of Cr- and V-bearing muscovite in lode gold deposits is well known, but the genetic relationship between the two has not been fully investigated. This relationship can be divided into paragenetic, geochemical, and spatial domains. Along these domains, this study considers the paragenesis of Cr- and V-bearing phyllosilicate minerals (i.e. muscovite and chlorite), as well as determining whether protolith geochemistry and degree of alteration influence the mineral chemistry of these minerals, using the Kerr-Addison gold deposit (Virginiatown, ON) as a case study. Muscovite and chlorite from drill-core samples of the two principal protoliths (ultramafic and mafic volcanic rocks of the Larder Lake group), collected proximal and distal to ore zones, were analyzed for major-, minor-, and trace-element chemistry using energy- and wavelength-dispersive spectroscopy (EDS/WDS) in conjunction with laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). Results show that muscovite and chlorite are the major secondary mineralogical hosts for Cr and V in the altered rocks, with muscovite replacing chlorite in the ultramafic suite (diffuse rims of pitted muscovite enveloping chlorite islands with similar Cr contents). A dichotomy exists with respect to protolith type: Cr-bearing phyllosilicate minerals are found in ultramafic protoliths, whereas V-bearing phyllosilicate minerals are found in mafic protoliths. In the ultramafic protoliths, muscovite and chlorite contain variable, but consistent Cr contents, whereas in mafic protoliths, the V contents in chlorite show an apparent increase in proximal samples. In terms of alteration trends in the ultramafic suite, there are no significant systematic changes in mineral chemistry of muscovite as a function of proximal-to-distal alteration or gold grade, except for decreases in trace-element contents of V in muscovite towards proximal alteration zones. Implications of this study include: (1) the protolith chemistry exerts a primary control on the chemistry of phyllosilicate minerals, implying that the hydrothermal fluid-rock reactions were wall-rock buffered; (2) Cr is immobile and must be locally sourced, whereas V may be mobile in these alteration systems, highlighting the contrast in geochemical behaviour between the two elements; and (3) the V contents in chlorite and muscovite may be a useful vector for gold mineralization.

MULTISCALE STRUCTURAL SIGNATURES OF THE GRENVILLIAN OROGENY

Changcheng Li[1], Dazhi Jiang[2]
[1]University of Waterloo, [2]Western University.
E-mail: *c293li@uwaterloo.ca*

The Grenvillian Orogeny comprises the Ottawan (ca. 1090–1020 Ma) and the Rigolet (ca. 1000–980 Ma) orogenic phases. Our field work in the Grenville Front Tectonic Zone (GFTZ) in Ontario shows that multiscale deformation structures, corresponding to both orogenic phases, are well developed in the GFTZ. We established three generations of deformation (D1, D2, and D3) in the Grenvillian rocks northwest of the Allochthon Boundary Thrust (ABT). D1 deformation structures consist of the regional transposition foliation (ST1) and isoclinal, intra-foliation F1 folds. D2 deformation structures are boudinage structures and large-scale transverse F2 folds, with fold axes nearly orthogonal to the GFTZ. D3 deformation folded the ST1 transposition foliation into F3 folds and created mylonite zones at the Grenville Front (GF). The axial planes of F3 folds are parallel to the mylonite zones and the GFTZ. Microstructures of the mylonite suggest top-to-the-NW thrusting. F2 transverse folds in the GFTZ were not reported in previous work because they are not clearly visible in satellite images due to the overprinting of D3 deformation. In addition, because F2 and F3 folds occur at different scales, outcrop overprinting relationships between F2 and F3 are not observable. Nevertheless, the overprinting relation between F2 and F3 is clearly on the regional scale and the overprinting of D2 boudinage structures by F3 is clear in many outcrops. F2 folds have axial planes nearly perpendicular to the GF. The F2 folds cannot be explained by the kinematic transtensional folding model. They can be readily explained by orogen-orthogonal extension if large deflection effect of buckling is considered, and the along-strike continuity assumption is relaxed. The geometries and kinematics of the deformation structures in the GFTZ provide constraints on the tectonic boundary conditions of the Grenvillian Orogeny. D1 deformation structures are signatures of middle/lower crustal deformation and metamorphism in the crust-thickening process of the Ottawan orogenic phase. D2 deformation structures record orogen-orthogonal extension and may be related to the final stage of the Midcontinent rifting. D3 structures may reflect a new phase of convergence (the Rigolet orogenic phase) in the Grenvillian Orogeny.

VARIABILITY IN SEDIMENTARY PYRITE $\delta^{34}S$ RECORDS CAUSED BY MULTIPLE FACTORS: A CASE STUDY OF SLOPE SHALES OF THE GREEN POINT FORMATION IN WESTERN NEWFOUNDLAND, CANADA

Jie Li[1], Karem Azmy[1], Peir K. Pufahl[2]
[1]Memorial University of Newfoundland, [2]Queen's University.
E-mail: *jli19@mun.ca*

The Green Point Formation in western Newfoundland, global boundary stratotype and point (GSSP) of the Cambrian–Ordovician boundary, is dominated by slope rhythmites (alternating interbeds of lime mudstone and shale). It is believed to have been deposited in a semi-restricted basin with variable connectivity to the open ocean. In this study, we investigate the morphology and bulk $\delta^{34}S_{py}$ signals of pyrite in the shales, together with previously published geochemical data of the same interval, to better understand factors influencing the bulk $\delta^{34}S_{py}$ variations. Petrographic examinations reveal two main forms of pyrite: (1) framboidal pyrite and (2) ^{34}S-enriched primary subhedral to euhedral pyrite. The former was probably formed near the sediment-water interface, and the latter within sedimentary porewaters during late early diagenesis. The pyrite $\delta^{34}S$ signals span widely from −17.6 to +22.4‰ (VCDT) and exhibit a pronounced positive excursion of ~25‰ near the Cambrian–Ordovician boundary. Poor correlations between the $\delta^{34}S_{py}$ values and the K/Ca, TOC, and pyrite contents argue against significant post-depositional diagenetic alteration of the $\delta^{34}S_{py}$ signatures. Abundances of the primary subhedral to euhedral pyrite generally mimic changes in the $\delta^{34}S_{py}$, suggesting that the $\delta^{34}S_{py}$ variability could be partly attributed to varying contents of the ^{34}S-enriched primary subhedral

to euhedral pyrite. In addition, there are significant negative correlations between the $\delta^{34}S_{py}$ and the Al, Th, and ∑REE values, indicating that terrestrial sulphate inputs might have also influenced the $\delta^{34}S_{py}$ variability by modulating the basinal sulphate reservoir size and the biological sulphur-isotopic fractionation. Therefore, rather than being evidence of oceanic redox changes, the positive $\delta^{34}S_{py}$ excursion of ~25‰ in this interval was probably caused by a combination of the decline in sulphate concentration of the local basin water and changes in abundance of the ^{34}S-enriched primary subhedral to euhedral pyrite. This finding suggests that variations of the bulk sedimentary $\delta^{34}S_{py}$ signatures can likely be linked to fluctuations of the local sulphur cycle, and positions of pyrite formation, rather than global mechanisms.

PALEOPROTEROZOIC TECTONIC EVOLUTION FROM SUBDUCTION TO COLLISION OF THE KHONDALITE BELT IN NORTH CHINA: EVIDENCE FROM MULTIPLE MAGMATISM IN THE QIANLISHAN COMPLEX

Wenxuan Li[1], Shoufa Lin[1], Changqing Yin[2], Jian Zhang[3], Jiahui Qian[2]
[1]University of Waterloo, [2]Sun Yat-Sen University, [3]The University of Hong Kong.
E-mail: *w54li@uwaterloo.ca*

The Khondalite Belt formed from continental-continental collision between the Yinshan and Ordos blocks and amalgamated into the Western Block of the North China Craton at ~1.95 Ga. The major lithologies of this belt are dominated by graphite-bearing Al-rich gneiss/granulite, garnet-bearing quartzite, felsic paragneiss, calcsilicate rock and marble, collectively termed khondalites. Previous studies on the Khondalite Belt focused on the sedimentary protoliths of these khondalites, it has now become increasingly clear that the sedimentary protoliths of the khondalites are mainly derived from a ca. 2.0 Ga provenance. This suggests a significant Paleoproterozoic crustal accretion in north China. However, the detailed accretion history is unclear because of the lack of systematic studies of synchronous magmatic rocks. This study presents detailed petrology, major- and trace-element, Sr–Nd isotope, and in-situ zircon U–Pb dating and Hf–O isotopes of granites from the Qianlishan Complex of the Khondalite Belt. Zircon SIMS U–Pb data determine three episodes of Paleoproterozoic magmatism in the Qianlishan Complex at 2.06 Ga, 1.95 Ga and 1.92 Ga, respectively. Of those, the 2.06 Ga granites display typical features of A-type granite, represented by metaluminous affinity, high FeO(T)/MgO ratios (3.29–5.63), and Ga/Al, Zr + Nb + Ce + Y values with high zircon saturation temperatures (916–1000°C). Moreover, they have positive zircon εHf values of 0.29–5.01 and homogenous $\delta^{18}O$ values of 5.11–5.87‰, probably derived from the partial melting of calc-alkaline granitoids without addition of supracrustal rocks. The 1.95 Ga granites contain peraluminous minerals of garnet and muscovite and have high ASI indices (> 1.1) and $\delta^{18}O$ values (7.14–9.18 ‰), belonging to S-type granite. Their negative whole-rock εNd(t) values (–2.87 ~ –2.81) and zircon εHf(t) values (–4.06 ~ 1.29) suggest a source nature of ancient supracrustal rocks. On the other hand, the 1.92 Ga granites present metaluminous and magnesian signatures of I-type granite, including low A/CNK and FeO(T)/MgO ratios, as well as high Y contents and low U/Yb ratios. Their negative εHf(t) values (–5.00 ~ –1.64) and homogenous $\delta^{18}O$ values (5.20–6.00) reveal that the original magma was derived primarily from the enriched lower crust. The results, combined with regional geology and previous studies, established a prolonged magmatic evolution of the Khondalite Belt from subduction to collision, involving 2.3–2.0 Ga subduction-related arc magmatism, 1.95 Ga syn-collisional high-pressure high-temperature crustal anatexis, and 1.92 Ga post-collisional magmatism and synchronous ultrahigh temperature metamorphism due to slab break-off. This constrains subduction-related accretion and amalgamation history and establishes a new tectonic model of the western block of the North China Craton.

HOW DOES WEATHERING INFLUENCE GEOCHEMICAL PROXIES IN PALEOPROTEROZOIC BANDED IRON FORMATIONS? A CASE STUDY FROM OUTCROP SAMPLES OF THE 2.46 Ga BANDED IRON FORMATION, HAMERSLEY BASIN

Zhiquan Li[1,2], Yongzhang Zhou[2], Erin Adlakha[3], Cody Lazowski[1], Ernesto Pecoits[4], Natalie Aubet[4], Pilar Lecumberri-Sanchez[1], Daniel Alessi[1], Kurt Konhauser[1], Leslie Robbins[5]
[1]University of Alberta, [2]Sun Yat-sen University, [3]Saint Mary's Unviersity, [4]Universidad Tecnológica del Uruguay, [5]University of Regina.
E-mail: *zhiquan1@ualberta.ca*

Banded iron formation (BIF) rocks are critical archives of ancient Earth's evolution. Trace-metal and rare earth element (REE) studies of BIF reveal their origins and the chemical composition of the contemporaneous coupled ocean-atmosphere system. In part, this stems from the stability of solid phases in BIF, including resistance to secondary alteration processes (e.g. metamorphism, fluid exchange, and weathering). Recent studies, however, have raised concerns about whether outcrop samples of BIF are suitable ancient Earth proxies, particularly concerning the redox-sensitive elements, as their exposure to surface and modern weathering regimes may have altered their concentrations, distributions, or redox states in BIF. A detailed assessment of the scale of weathering on BIF outcrop samples is required. Here, we present a case study examining outcrop from the 2.46 Ga Boolgeeda Iron Formation and Turee Creek Group of the Hammersley Basin, Western Australia, to investigate micro-scale differences in composition between BIF and its surficial weathered surface (crust). Elemental mapping and bulk rock-geochemical analyses revealed that most elements are enriched in the weathered crust relative to the BIF, except for Si which is significantly depleted. After normalization by TiO_2 from the parent rock, there is a significant loss of the redox-sensitive elements (e.g. U, V and Cr) compared to immobile elements (e.g. Al and Th) in weathered crust, suggesting that the surfaces of outcrop samples have been affected by higher degrees of chemical leaching relative to physical erosion. REE concentrations are similarly modified in the weathered crust, where characteristic low Y/Ho ratios, negative Y anomalies, and varied Ce anomalies are observed. These signatures that characterize the weathered crust are distinct from the remainder of the sample. Importantly, all weathering-related geochemical signatures are restricted to millimetre-scale thin crusts, while the interiors of the outcrop samples have geochemical characteristics that are similar to previously reported drill core samples for the Boolgeeda Iron Formation. This means that with sufficient screening of samples for obvious signs of alteration, the chemistry of BIF outcrop samples can indeed be used as proxies for the evolution of Earth's coupled ocean-atmosphere system. Importantly, this dramatically increases useable Precambrian sample material, rather than solely relying on costly drilling programs.

PROMONTORY/SMALL CONTINENT COLLISION, COLLISIONAL OROGENS AND EARLY PALEOZOIC WUYI-YUNKAI OROGENY IN EASTERN SOUTH CHINA

Shoufa Lin[1], Lijun Wang[1,2]
[1]University of Waterloo, [2]Chinese Academy of Sciences.
E-mail: *shoufa@uwaterloo.ca*

Continental margins commonly exhibit promontories and re-entrants. Where this is the case, collision between two continents is expected to start at a promontory or between two promontories, leading to potentially deep subduction and burial of the continental crust on the lower plate. A similar scenario is the collision of a small continent (e.g. India) on the lower plate with another continent, and we suggest that

archetypal collisional orogens like the Himalayas and the Qinling-Dabie orogen formed through such collisions. We propose that the early Paleozoic Wuyi-Yunkai orogeny in eastern south China resulted from a promontory or small-continent collision. In the model, the West Cathaysia terrane of south China was (part of) a promontory or small continent on the lower plate and collided with another continent in Cambrian–Ordovician, at the late stage of Gondwana assembly, and the Late Ordovician–Silurian Wuyi-Yunkai orogeny, characterized by amphibolite-granulite facies metamorphism and extensive anataxis, was a continuation of the Cambrian–Ordovician collisional orogeny. The model explains the unique features of West Cathaysia in the context of Gondwana assembly. It offers a solution to the biggest puzzle concerning south China in the early Paleozoic; that is, a major tectono-thermal event in south China, with characteristics of a collisional orogeny, took place tens of millions of years after the Gondwana supercontinent had been assembled and collision appeared to have been over. We believe that such a big lag in time, between onset of collision and peak metamorphism/anatexis in the subducting continental crust, is an inherent feature of promontory/small continent collision.

AN OVERVIEW OF THE FORMATION OF LITHIUM PEGMATITES

Robert Linnen
Western University, KoBold Metals.
E-mail: *rlinnen@uwo.ca*

Pegmatites are magmatic rocks that contain highly variable grain sizes, including exceptionally large crystals. These and other textures are generally accepted to reflect rapid crystal growth at supersaturated conditions. There are several key components that contribute to the generation of economic quantities of Li in pegmatites. Lithium pegmatites form in orogenic tectonic settings, typically at the waning stages of the orogeny. There is also a strong structural control of pegmatite emplacement. The source of the granitic melts is from crustal rocks, with potential contributions from both meta-sedimentary and meta-igneous rocks. The melting of muscovite- and biotite-bearing rocks produces peraluminous melts and the crystallization of these melts yields characteristic peraluminous minerals such as muscovite, garnet and tourmaline. Lithium pegmatites are typically associated with high temperature/low pressure metamorphic gradients. Melting takes place at temperatures in excess of ~600°C, but Li pegmatites are emplaced at much lower temperatures at brittle or brittle-ductile conditions, i.e. greenschist to lower amphibolite metamorphic grade. Other types of pegmatites can be emplaced at other P-T conditions, but these do not form economic Li mineralization. Crustal rocks rarely contain greater than 100 ppm Li and the highest concentrations of Li are in pelitic rocks. Lithium is concentrated in micas in these rocks and the crystal-melt partition coefficients of Li for biotite and muscovite are 1.65 and 0.80–1.67, respectively, i.e. Li is moderately compatible in micas. As a result, low degrees of partial melting of a typical pelite produce melts with only hundreds of ppm Li. There are two dominant models in pegmatite genesis: anatexis and fractional crystallization. In the former, Li pegmatites are derived directly from crustal melts and are not related to granites, whereas in the latter, granites are first produced from melting of the crust but subsequently undergo fractional crystallization to enrich the melts in Li. Spodumene and petalite solubilities in granitic melts are temperature-dependent, and as noted above likely crystallize at supersaturated conditions. Nevertheless, solubility studies indicate that approximately 5000–10,000 ppm Li in the melt is required for the temperatures at which pegmatites crystallize. Consequently, it is unlikely that Li pegmatites can be produced by anatexis alone, and that fractional crystallization is required, even at locations where Li pegmatites cannot be related to a source intrusion. However, the most effective mechanism of concentrating Li is through multiple episodes of melting. followed by fractional crystallization.

THE LITHIUM CYCLE AND CONSTRAINTS ON THE GENERATION OF LITHIUM PEGMATITES

Robert Linnen
Western University, KoBold Metals.
E-mail: *rlinnen@uwo.ca*

The Li content of the mantle is approximately 1.4 ppm, but a typical mineralized pegmatite contains ~6000 ppm Li, which is similar to the Li concentration required to saturate a granitic melt in spodumene. Understanding the global Li cycle is fundamental to evaluating the processes needed to enrich Li by more than three orders of magnitude. Key characteristics of Li are that it has a +1 valence, and that its ionic radius is similar to Mg^{2+}. Thus, Li can substitute for Mg in silicate minerals, but because of the charge difference, Li is a moderately incompatible element. High concentrations of Li in ferro-magnesian minerals will only occur in minerals where coupled substitutions can occur, e.g. $^{VI}Al^{3+} + ^{VI}\square \leftrightarrow ^{VI}Mg^{2+} + ^{VI}Li^{+}$, where VI refers to an octahedral site and □ is a vacancy. The Li cycle can be divided into mantle and crustal components. Lithium is only moderately enriched in mantle melts and MORB contains on the order of 6 ppm. Seawater contains ~0.1–0.2 ppm Li and the Mg enrichment that accompanies seafloor alteration results in up to ~50 ppm Li in altered basalt. Pelagic sediments also contain ~50 ppm. Thus, during subduction the down-going slab is enriched in Li and dehydration of the slab can metasomatize the overlying mantle in Li. If the metasomatized mantle is melted and these melts fractionate, alkaline granites with up to 3400 ppm Li can be produced, but this is below the level needed to form Li mineralization. Therefore, mantle processes do not control the generation of Li deposits. In the crust, pelitic and metagreywacke rocks typically contain on the order of 50–70 ppm Li. Biotite hosts the highest concentrations of Li (up to thousands of ppm), and muscovite can host tens to hundreds of ppm Li. The Li contents of anatectic melts are largely controlled by muscovite and biotite melting reactions, although locally other Fe-Mg minerals such as staurolite may also play a role. Lithium is moderately compatible in biotite, therefore melting aluminous sedimentary rocks can produce granitic melts with hundreds of ppm Li. This value is far below the Li contents required for spodumene or petalite saturation. There is currently a debate as to whether Li pegmatites are the result of anatexis or extreme fractional crystallization of granitic melts. Although anatexis is important for initial Li enrichment in melts, fractional crystallization is needed to attain sufficient Li concentrations needed for spodumene saturation.

MODELING THE IMPACT PROCESS AND CRYSTALLIZATION SEQUENCE OF THE SUDBURY IGNEOUS COMPLEX: IMPLICATIONS FOR HADEAN CRUST FORMATION

Nicolas Litza[1], Miki Nakajima[1], J. Brian Balta[2,3], Dustin Trail[1], Steven B. Shirey[4], Ian Szumila[1], Rasmus Haugaard[5], Taus R.C. Jørgensen[5], Michael Ackerson[6], Scott Hull[1]
[1]University of Rochester, [2]Cornell University, [3]Lunar and Planetary Institute, [4]Carnegie Institution for Science, [5]Laurentian University, [6]Smithsonian Institution.
E-mail: *nlitza@ur.rochester.edu*

The 1.85 Ga Sudbury Basin is among the Earth's three largest known impact structures and contains the largest preserved impact-induced melt sheet on Earth, the Sudbury Igneous Complex (SIC). Thus, Sudbury might represent one of the best sites to test if some of Earth's Hadean crust formed by impact-related processes. The SIC has well-defined geological units including norite, quartz-gabbro, and granophyre, which are believed to have formed via fractional crystallization of impact-induced melt. The impact process and subsequent crystallization of the SIC are not well understood. Previous impact simulations, for instance, have failed to model the impact process, and have been unable to reach the observed crater size. Here, impact simulations using the iSALE (impact simplified arbitrary lagrangian eulerian) code are used to identify impact conditions that match the observed crater size, recorded pressure, and melt sheet volume. The subsequent cooling, fractional crystallization, and differentiation process of the SIC are modelled using the rhyolite-MELTS algorithm of alphaMELTS, a thermodynamic modeling software package. Finally, the predictions of alphaMELTS are compared with experimental data obtained from a laboratory-created sample, which was synthesized with the estimated initial bulk composition of the SIC. A piston cylinder was used to investigate crystallization as a function of temperature. Using these two computational suites and the laboratory experiments, the aim is to analyze the Sudbury Basin from both a physical and geological perspective. Based on preliminary results, a rocky bolide with a diameter between 18 and 21 km and an impact velocity of 15 km/s can reproduce the original crater size. The possibility of an icy comet being responsible for the impact is unlikely, as it would require a significant increase in either diameter or velocity to attain the energy needed for the estimated volume of the melt sheet. Whether the most primitive known unit in the SIC, the Offset Dykes, could represent a parental composition to the observed rocks was tested using experiments and alphaMELTS calcula-

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tions. Initial calculations suggest that the known dykes are too evolved to produce the most olivine-rich unit found in the sequence. Experiments at 1 GPa show generally similar phases to those found in calculations, although they differ in that iron sulphide and quartz phases crystallize first. After building a complete model for Sudbury, it will be used to test the hypothesis that the crystallization of an impact melt sheet can generate the Hadean crust.

ACCELERATING CARBONATION OF BRUCITE-BEARING MINE TAILINGS USING WASTE ORGANICS

Justin A. Lockhart, Ian M. Power, Kwon Rausis, Carlos Paulo, Lance Dostie
Trent University.
E-mail: *justinlockhart@trentu.ca*

Enhanced weathering and mineralization of ultramafic tailings permanently stores carbon dioxide (CO_2) within stable carbonate minerals, thereby reducing the carbon emissions of mining. Brucite [$Mg(OH)_2$], a minor phase (up to ~13 wt.%) of ultramafic tailings, is found in nickel-bearing serpentinite rocks, including at the Dumont (Canada) and Mount Keith (Australia) nickel mines. Although brucite offers substantial CO_2 sequestration potential, its carbonation is limited by CO_2 supply. Here, we propose coupling inorganic-organic carbon cycling to accelerate brucite carbonation by amending ultramafic tailings with waste organics, such as what may occur during tailings remediation. This study aimed to understand the influence of tailings grain size and organics content on brucite carbonation. The CO_2 gas concentrations, total inorganic carbon (TIC), and stable carbon isotopes were measured. Column experiments (~20 cm height, 6.7 cm diameter; 10 weeks long) involved layering waste organics and brucite-bearing tailings (2 wt.%) of different grain sizes (< 63, 63–125, and 125–250 µm). These columns were compared to controls of organics and tailings only. Average carbonation rates for amended columns (102 kg CO_2/t tailings/yr) supplied with respired CO_2 (0.1–1.4% CO_2) were ~8 × faster than tailings controls (13 kg CO_2/t tailings/yr) that were only exposed to laboratory CO_2 (0.04% CO_2). Brucite consumption ranged from 40–68% (ΔTIC = +0.09–0.19%), mainly occurring within the first 3 weeks and was not significantly influenced by tailings grain size. These values are comparable to those produced in cylindrical tests that used compacted tailings exposed to CO_2-generating organics (64–84% brucite consumption), which resulted in unconfined compressive strengths of 0.4–6.9 MPa, a co-benefit of brucite carbonation. Furthermore, incomplete brucite carbonation may have occurred due to surface passivation relating to low water availability. Carbonation rates depend on the CO_2 concentration, which relates to the ratio of organics to tailings and their respiration rate. Reacted tailings had ^{13}C compositions (−2.8‰ > $\delta^{13}C$ > −11.6‰ VPDB) that were depleted relative to the initial tailings, suggesting incorporation of respired CO_2. Our study demonstrates that using waste organics significantly accelerates brucite carbonation, which has implications for tailings remediation. While this approach results in CO_2 avoidance rather than atmospheric CO_2 removal, it is a passive system that does not require expensive direct air capture units to provide concentrated CO_2 streams.

ENVIRONMENTAL, SOCIAL, AND GOVERNANCE COMPLEXITY OF CRITICAL MINERALS IN THE ARCTIC

Julia Loginova
University of Queensland.
E-mail: *j.loginova@uq.edu.au*

This presentation will address the environmental, social, and governance dimensions of mineral mining in the Arctic, highlighting their increasing complexity. Drawing upon a recently published online resource on "The Changing Arctic and Just Energy Transitions", it will provide an overview of critical-mineral projects across the Arctic. The projects will be discussed within the context of the global transition to a low-carbon economy, the 'rush' to extract minerals, geopolitical shifts, and demands for enhanced social and environmental performance. An important theme in global debates about responsible mining is the importance of community consultation and consent, to act as a safeguard for Indigenous and local communities affected by mining projects. The presentation will provide a quick overview of the requirements for meaningful community consultation and free, prior and informed consent. Selected case studies across the Arctic will highlight community engagement experiences at various mining stages. Considering patterns of community consultation and consent in an environment as complex as the Arctic raises critical questions about the governance of natural resources and the differential vulnerability of diverse segments of society. In the criticality assessment of minerals and metals, what is the role of societal complexity?

MINERAL EXPLORATION FOOTPRINTS OF CRUSTAL-SCALE DEFORMATION ZONES IN NEOARCHEAN GREENSTONE BELTS, CANADA: FIELDWORK RESUME AND FIRST HYPERSPECTRAL AND GEOCHEMISTRY RESULTS FOR THE VAL-D'OR AREA

Théo Lombard[1], Stéphane Perrouty[1], Robert Linnen[2], Philip Lypaczewski[3]
[1]Laurentian University, [2]Western University.
[3]College of the North Atlantic.
E-mail: *tlombard@laurentian.ca*

Orogenic gold deposits are one of the major sources of gold in the world, in particular along deformation zones in Precambrian greenstone belts. It is well-known that faults play the role of fluid pathways during orogenic gold deposit formation. The fluid can modify and alter the host rock during its transport, leaving evidence of its passing. This study aims to determine the footprint of the fluid pathway along major deformation zones in Archean greenstone belts by comparing two regions with similar structure but contrasting amounts of gold enrichment. This study focuses on the Val-d'Or area, an example of high gold enrichment, where deposits are primarily distributed north of the crustal-scale Larder Lake-Cadillac Deformation Zone (LLCDZ). The deformation and alteration intensity across the LLCDZ were determined through fieldwork. The LLCDZ marks the tectonic boundary between the metavolcanic rocks (2714–2702 Ma) of the Abitibi subprovince to the north, and the metaturbidite sequences (2691–2686 Ma) of the Pontiac subprovince to the south. The metavolcanic package includes ultramafic-mafic rocks, massive flows, locally with pillows, at greenschist metamorphic facies. Southward, the metasedimentary rocks show an increase of the metamorphic grade, from biotite to garnet to staurolite facies. The area is bounded in the north and south by intermediate to felsic intrusions and is crosscut by diorite/quartz-diorite NW-SE trending dykes. The main foliation post-dates these dykes and is subvertical and oriented E-W. Deformation intensity decreases rapidly with distance from the LLCDZ and secondary high strain zones. Carbonate alteration (calcite and ankerite) occurs mainly in mafic metavolcanic rocks, locally with epidote alteration, and is minor in the metasedimentary rocks and in the dykes. Pyrite occurs in all rock units. Albitization is common within the dykes. Most veins are subparallel to the foliation, laminated, spatially associated with high-strain zones and intrusive bodies. They are composed of more proximal quartz-tourmaline-carbonate and more distal and widely dispersed quartz-carbonate, and can bear sulphide minerals such as pyrite, arsenopyrite, pyrrhotite, and chalcopyrite (rare). One hundred and thirty-nine samples were analyzed by hyperspectral imaging (short, mid and long-wave infrared imaging) and 44 samples by whole rock geochemistry analysis, which both outline mineralogical changes such as carbonate, white mica and chlorite and elemental gains and losses related to fluid-rock interaction within the metasomatic halo of the LLCDZ.

COUPLING EDS AND EBSD (SEM) TO IDENTIFY LCT-PEGMATITE MINERALS IN TILLS

Hugues Longuépée, Jonathan Tremblay
IOS Services Géoscientifiques.
E-mail: *hlonguepee@iosgeo.com*

The increasing demand for lithium has prospectors considering Li-Cs-Ta (LCT) pegmatites, previously viewed as oddities, as prime exploration targets. Because of this, known pegmatites are being revisited. However, most of these known pegmatites were found through conventional prospecting, well before the lithium rush. Discovery of non-outcropping pegmatites is hindered by their dimmed geophysical response or geochemical signature that may offer little contrast to other granitic terrain. Chemical and mineralogical vectoring can only be used when outcrops are numerous. When eroded, the geochemical signature of LCT pegmatites is quickly diluted and may be difficult to discriminate. However, their mineralogy is more contrasting and the presence of a few grains of the exotic mineral in sediment can be

meaningful. The use of indicator minerals for the search of such pegmatite is hampered by their low density, lack of distinctive visual features or scarcity. Furthermore, SEM-based automated mineral identification procedures are considered to be ineffective, since lithium is too light to be detected by conventional EDS spectrometers. In recent years, automated indicator-mineral studies, such as ARTMin (automated recognition technology for minerals) which enable chemical analysis of every grain, have become commonly used. Since lithium is not detectable by conventional EDS spectrometers, most common lithium silicate minerals (spodumene, petalite, lepidolite, eucryptite, etc.) are chemically seen as aluminosilicates or clays. Tests indicate that they can be discriminated, based on their silica to alumina ratios and trace-element content. The only exception is spodumene, which can be mistaken for pyrophyllite. Determination of the exact nature of these minerals can be achieved by simultaneous electron back scattered diffraction (EBSD) characterization which enables validation of the crystal structure and EDS chemical analyses. The technology can identify other LCT pegmatite-related minerals like Ta-rich columbite or tantalite, and Cs-bearing minerals. Since a semi-quantitative chemical analysis is available for each mineral, their identification is robust, and each grain can be re-analyzed to a fully quantitative level for chemical fingerprinting. With a combination of SEM-EDS and EBSD, abundance of LCT pegmatites minerals can be measured efficiently in tills or alluvial samples and used as a dependable exploration method at a regional scale.

NO TIME TO REST: GARNET AND ZIRCON PETROCHRONOLOGY IN HIGH-PRESSURE GRANULITE HIGHLIGHT A TECTONOMETAMORPHIC CONTINUUM BETWEEN THE OTTAWAN AND RIGOLET PHASES OF THE GRENVILLE OROGENY

Caroline Lotout[1,2], Aphrodite Indares[1], Etienne Deloule[2], Jeffrey Vervoort[3]
[1]Memorial University of Newfoundland, [2]Université de Lorraine,
[3]Washington State University.
E-mail: *caroline.lotout@univ-lorraine.fr*

Petrochronological investigation of the rock-forming mineral garnet and accessory minerals like zircon, within the framework of P-T pseudosections, is one of the most reliable approaches to decipher the timescale and style of orogenic processes. In the Grenville Province, high-P rocks that are discontinuously exposed along the margin of the allochthonous belt are an essential puzzle piece to Mesoproterozoic geodynamics, by preserving the record of deep crustal processes. The Manicouagan Imbricate zone (MIZ) in the central Grenville Province represents part of the Laurentian lower crust metamorphosed under high-P conditions during the Laurentia-Amazonia collision in Mesoproterozoic times. It is located between the Parautochthonous Belt to the north and the orogenic hinterland to the south, which were metamorphosed during the 1005–980 Ma Rigolet and the 1080–1020 Ma Ottawan orogenic phases, respectively. In the western MIZ, the Lelukuau Terrane (LT) mostly consists of Labradorian-age (~1650 Ma) mafic suites with a fringe of aluminous rocks at its southern edge. Two metamafic samples from the western and eastern parts of the LT are investigated for P-T estimates, in-situ U–Pb zircon dating, and Lu–Hf and Sm–Nd garnet dating. Both samples display a peak assemblage of garnet, clinopyroxene, plagioclase, rare pargasite or edenite, and quartz ± biotite, rutile, kyanite, apatite and zircon. Pseudosection modelling suggests high-P granulite peak conditions at ca. 14 to 16 kbar and 800–900°C, with the scarcity of hydrous phases and quartz explaining the observed lack of partial melting. Zircon cores from the western LT sample show a maximum magmatic age of ca 1.6 Ga, and distinct metamorphic rims elusively record first order pre-Grenvillian geodynamic evolution between 1.4 and 1.2 Ga. The Lu–Hf and Sm–Nd dating on garnet from this sample yields ages of 1020 ± 7 Ma and 1005 ± 13 Ma, overlapping within error and inferred to represent peak metamorphic conditions followed by fast cooling. In the eastern LT sample, garnet Lu–Hf dating yields two ages that are consistent with a petrographically preserved two-stage growth, at 1033 ± 6 Ma and 1013 ± 6 Ma, while the Sm–Nd age indicates cooling at 1003 ± 8 Ma. High-P granulite facies conditions were recorded diachronously between the eastern and western part of the LT, highlighting a late Ottawan to Rigolet-age crustal thickening at the margin of the hinterland during the propagation of the orogen to the NW. In addition, these new results demonstrate that there was no tectonic hiatus between the two orogenic phases, as previously thought.

BUSHVELD IGNEOUS COMPLEX AS AN ANALOGUE FOR MINERALIZATION ON 4 VESTA AND THE V-TYPE ASTEROIDS

Lukas Louwerse, Philip J.A. McCausland, Roberta L. Flemming
Western University.
E-mail: *llouwers@uwo.ca*

4 Vesta is the second largest of the Main Belt asteroids and is a likely source of the Howardite-Eucrite-Diogenite (HED) achondrite meteorite clan and the V-type asteroids. Following primary differentiation the asteroid likely experienced plutonic activity, and the compositions of the diogenite meteorites show that there are indeed different plutonic rock types present on the asteroid that resemble rocks found in terrestrial plutonic bodies like the Bushveld Igneous Complex (BIC). HED meteorites also include ore minerals such as chromite, raising questions of how chromite might be represented on 4 Vesta and in the V-type asteroids and how asteroidal chromite deposits could be detected by spacecraft using geophysical methods. In this study, samples from the BIC were used as analogues for plutonic material from 4 Vesta and other small, differentiated bodies in the solar system. Induced polarization (IP), electrical resistivity, and acoustic P-wave measurements were carried out on a selection of terrestrial samples under conditions analogous to those found throughout the solar system: dry, water saturated, and frozen. In addition, magnetic susceptibility and grain-density measurements, micro-X-ray fluorescence mapping, and micro-computed tomography imaging were carried out where possible. Preliminary results showed that in most cases resistivity was slightly lower in frozen samples than in dry samples, though of the same order of magnitude. For chromite-poor samples, resistivity values were typically one order of magnitude lower when wet compared to when dry. For chromite-rich samples, resistivity values were typically one order of magnitude higher when wet than when dry. The IP measurements showed that chargeability was similar across the three trials, but typically declined slightly from dry to wet samples and declined slightly further when the samples were frozen. P-wave velocity measurements showed that, compared to dry samples, water-saturated samples had higher P-wave velocities, and frozen samples had even higher P-wave velocities. In samples with higher (> 4 g/cm^3) densities, wet and frozen P-wave velocities were very close, but in lower density samples these values differed by 100s of m/s. Based on these preliminary bulk sample results, a spacecraft conducting a survey of a V-type asteroid would be able to use resistivity in conjunction with induced polarization to discern what rock types lie beneath the surface and potentially whether or not the rock is saturated with liquid or frozen water. This information could then inform deployed seismic methods to produce a more accurate model of the interior and contents of the asteroid.

THE USE OF HYPERSPECTRAL IMAGING TECHNIQUES TO EXPAND MINERAL FOOTPRINTS: REVIEW OF DATA FROM THE NSERC-CMIC FOOTPRINTS PROGRAM, AND NEW INITIATIVES

Philip Lypaczewski
College of the North Atlantic, Laurentian University.
E-mail: *philip.lypaczewski@cna.nl.ca*

Hyperspectral imaging is a spectroscopic technique that allows the rapid identification of mineralogy without the need for sample preparation. Data can be acquired directly on a variety of surfaces, including on entire drill core boxes, hand samples, or loose material (e.g. till) in a matter of seconds, making this technology ideally suited for large-scale data acquisition projects. The NSERC-CMIC - Mineral Exploration Footprints Program (2013–2018) saw the first large-scale use of hyperspectral imaging data in geological research in Canada. In this collaborative research project, high-resolution (0.2–1 mm/pixel) hyperspectral data were acquired on all project participants' samples, amounting to over 3000 metres of drill core and over 1200 hand samples from the Canadian Malartic gold deposit in Quebec and the Highland Valley Copper porphyry-Cu deposit in British Columbia. At Canadian Malartic, changes in white mica and biotite chemistry both at deposit and regional scale were identified as potential vectors to mineralization. White-mica chemistry was additionally identified as an indicator of regional metamorphic grades. At Highland Valley Copper, mineralogical zonations outboard of the deposit were identified as a potential regional vectoring tool, and included a large distal prehnite alteration halo that

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was not previously recognized. Within the deposit, the presence of kaolinite/dickite, tourmaline, and changes in white mica chemistry and/or grain size were identified as potential indicators of mineralization.

HYPERSPECTRAL IMAGING AS A RESEARCH AND MINERAL EXPLORATION TECHNIQUE IN A NEWFOUNDLAND AND LABRADOR DRILL CORE DIGITIZATION INITIATIVE - FIRST DATA RELEASE IN SUPPORT OF NEW GEOSCIENCE

Philip Lypaczewski[1,2], Halina Kondrasovas[1], Gary Thompson[1], Derek Wilton[1], Glen Penney[3]
[1]College of the North Atlantic, [2]Laurentian University,
[3]Newfoundland and Labrador Department of Industry, Energy and Technology.
E-mail: *philip.lypaczewski@cna.nl.ca*

Hyperspectral imaging is a spectroscopic technique that allows rapid mineral identification in a variety of samples (e.g. drill core, rock slabs, thin-section offcuts, drill cuttings) without the need for sample preparation, and high-resolution (<1 mm/pixel) data can be acquired directly on entire drillcore boxes in a matter of seconds. An ongoing public geoscience initiative at the College of the North Atlantic is acquiring hyperspectral imaging data for over 200,000 m of drill core stored in Newfoundland and Labrador's Department of Industry, Energy and Technology core storage libraries, using a full range of hyperspectral instruments, ranging the visible-near infrared (VNIR, 400–1000 nm), shortwave infrared (SWIR, 1000–2800 nm), midwave infrared (2800–5400 nm) to the longwave infrared (LWIR, 7500–13000 nm). Interpreted high-resolution mineralogical data are to be released in an online public geoscience database, which will facilitate geoscience research and mineral exploration in the province. The first data release covers over 25,000 m of drill core from 248 drill holes stored in the Pasadena core-storage library. The instrumental setup, data examples, and highlights of key drillhole intervals in a variety of deposit types will be presented, and potential applications in both research and mineral exploration will be reviewed.

POTENTIAL NEW MINERALS AND PARAGENESIS OF THE GUN BARIUM SILICATE LOCALITY, YUKON, CANADA

Mary Macquistan[1], Lee Groat[1], Ron Peterson[2], Brian Joy[2], Brian Patrick[1], Jacob Kabel[1]
[1]University of British Columbia, [2]Queen's University.
E-mail: *mary.macquistan@gmail.com*

The Gun occurrence is an unusual barium silicate (Ba-Si) mineral locality near Itsi Mountain, Yukon, Canada. The initial Ba-Si mineral assemblage formed through contact metasomatism of the host rock during the intrusion of the Gun pluton in the Cretaceous. The assemblage has undergone multiple phases of alteration since its original crystallization. Thin section petrography, automated mineralogy maps, backscatter electron imaging, and electron probe microanalysis (EPMA) were used to describe a preliminary paragenetic sequence for this occurrence. Paragenesis and mineral chemistry were then used to constrain the possible composition of the metasomatic fluid responsible for Ba-Si crystallization. The Gun occurrence represents a rare opportunity to explore variations in the texture and chemistry of one of the most diverse Ba-Si mineral assemblages on Earth. In addition to the more than 17 Ba-Si minerals previously documented at this occurrence, this project identified bazirite and kampfite, raising the number of Ba-Si species occurring at the Gun to at least 19. Three potential new barium minerals were also identified and have been analyzed using EPMA. Unknown 1 is a Ba-W-oxide occurring with fine-grained cerchiaraite and witherite. Electron microprobe analyses normalized to 4 oxygens per formula unit (pfu) yielded a proposed formula of $Ba_{0.978–1.016}W_{0.974–1.006}O_4$. Single crystal X-ray diffraction yielded a space group of I41/a and unit cell dimensions a = 5.63 and c = 12.74 Å, indicating that this mineral is likely the barium analogue of scheelite. Unknown 2 is a Ba-Ca-Cl-silicate very similar to walstromite [$BaCa_2(Si_3O_9)$]. It occurs with walstromite, pellyite, and itsiite with inclusions of pyroxene and anhedral sphalerite. Electron microprobe analyses normalized to 9 oxygens pfu yield a proposed chemical formula of approximately $Ba_{0.85–0.88}Ca_{2.87–2.9}Si_{2.6}Cl_{0.8}$. Preliminary qualitative Raman analyses identify a strong peak at ~1085 cm^{-1} which is not present in reference spectrum R070634 for walstromite. At this stage, it is hypothesized that unknown 2 is a hydrated and chlorine-rich version of walstromite. Unknown 3 is another Ba-Ca-Cl-silicate. Detailed chemical analysis is in progress. It is poikiloblastic and found with meierite in massive sanbornite. It has the same optical properties as muirite [$Ba_{10}Ca_2Mn^{2+}Ti[HSi_2O_7]_5(OH,Cl,F)_5$] but no Mn or Ti has been identified in the analyses. Collection of the remaining data necessary for submission of these unknowns to the IMA for recognition as new mineral species is in progress.

RARE EARTH ELEMENT MINERALIZATION ASSOCIATED WITH THE PERALKALINE FOX HARBOUR VOLCANIC BELT

Zsuzsanna Magyarosi[1], Nicole Rayner[2]
[1]Geological Survey of Newfoundland and Labrador,
[2]Geological Survey of Canada.
E-mail: *zsuzsannamagyarosi@gov.nl.ca*

The Fox Harbour Volcanic Belt (FHVB) is host to one of the most advanced rare earth element (REE) projects in Atlantic Canada. It is located in the Grenville Province in southeastern Labrador and is one of several REE-mineralized Mesoproterozoic peralkaline complexes across Labrador including the Strange Lake and Flowers River complexes, and the Red Wine Intrusive Suite. The FHVB is ~64 km long, ranging in thickness from 50 m in the east to 3 km in the west, and contains three parallel mineralized belts composed of mainly peralkaline and non-peralkaline rhyolite, trachyte and basalt. All rocks are strongly deformed and metamorphosed due to Grenville orogenesis. The felsic rocks are A-type (mostly A2-type), peralkaline to metaluminous, and plot in the within-plate granite field. Modal mineralogy changes from east to west with relatively reduced quartz and more ferromagnesian minerals and albite in the west. Rare earth element mineralization is hosted in the most evolved rocks, composed of pantellerite, comendite, and pantelleritic and comenditic trachyte, which are characterized by the highest REE, Zr, Nb, U, Th and FeO contents. The Zr content is ≤ 26,361 ppm, and the light REE and heavy REE enrichments are ≤ 20,000 times and ≤ 1000 times the chondrite concentrations, respectively. The concentrations of light REE are higher in the east, but the heavy REE/light REE ratio is higher in the west. The main REE minerals are allanite, fergusonite, locally REE-titanite, rare britholite, chevkinite, bastnaesite, synchysite and monazite. Late magmatic fluids mobilized Na and K, resulting in Na loss and K metasomatism in parts of the FHVB. Typical hydrothermal REE minerals (e.g. REE-fluorocarbonate phases) are rare, but some of the allanite is hydrothermal. Uranium–Pb geochronology in zircon yielded igneous crystallization ages of 1314 ± 12 Ma in comendite and 1269 ± 9.5 Ma in non-peralkaline rhyolite, indicating that the non-peralkaline rhyolite is younger than the more evolved comendite. In non-peralkaline rhyolite, the igneous crystallization age is overprinted by Grenvillian metamorphism at 1031 ± 15 Ma. Pantellerite returned only a metamorphic age of 1065.9 ± 8.2 Ma, except one core that returned an age of ~1238 Ma, suggesting that it is younger than both comendite and non-peralkaline rhyolite, consistent with crosscutting relationships. This study highlights the complex evolution (magmatic, hydrothermal and metamorphic) of the rocks and challenges several aspects of the current models for these types of deposits, such as the lack of significant REE mineralization in peralkaline extrusive rocks and increase in degree of fractionation over time.

THE STATE OF THE ART IN MAGMATIC ORE DEPOSITS: THE CONTRIBUTIONS OF PROFESSOR SARAH-JANE BARNES

Wolfgang Maier
Cardiff University.
E-mail: *maierw@cardiff.ac.uk*

The origin of magmatic Ni-Cu-PGE ore deposits remains debated, despite more than a century of research, and some overly optimistic views in the 1980s that magmatic Ni-Cu-PGE ore deposits are amongst the best understood of ore deposits. However, significant progress has been made in the last decades, notably for mineralization hosted in magma conduits. These are now widely accepted to have formed via a sequence of processes including (i) contamination of relatively unevolved mantle derived magma with sulphidic crust triggering formation of an immiscible sulphide melt, (ii) entrainment of the sulphide melt in the ascending magma to facilitate equilibration of sulphide with large volumes of fertile silicate melt, and enrichment of sulphide in chalcophile metals, (iii) deposition of the metal-rich sulphides in flow dynamic traps, and (iv) fractional crystallization of the sulphide melt during which Cu-rich residual melt may be separated from crystallizing Ni-rich monosulphide solid solution (mss). Remaining challenges include a better understanding of the distance across which sulphide transport and mobilization can occur, and development of proxies that could distinguish between barren and fertile magma conduits. There is less consensus on the origin of PGE-(Ni-Cu) reef-style deposits (and indeed Cr- and V-Ti-rich oxide layers) within layered intrusions. Debate continues on the emplacement mechanism of the intrusions, the size of the magma chambers, the origin of the layering and the role of reactive flow of late stage melts and volatiles in concentrating and redistributing metals. Professor emerita Sarah-Jane Barnes has been at the forefront of research into mafic–ultramafic-hosted magmatic ore deposits for more than three decades, including landmark studies at Bushveld, Noril'sk, Sudbury, Stillwater, Pechenga, Kabanga, Lac des Iles, Raglan and Muskox. In this talk, a review of her career and some of the most important contributions she made together with her students and co-workers will be addressed such as the use of Cu/Pd ratios in distinguishing prospective from barren intrusions, the first application of X-ray computed tomography in magmatic ore deposits, the first analogue tank experiments applied to the formation of igneous layering, and the application of trace elements in oxides as exploration tools.

PIONERSKAYA PIPE: RECLASSIFICATION FROM ORANGEITE TO CONTAMINATED KIMBERLITE

Amy Mailey[1], Maya G. Kopylova[1], Anna Nosova[2]
[1]University of British Columbia, [2]Russian Academy of Sciences.
E-mail: *amailey@eoas.ubc.ca*

The Pionerskaya pipe belongs to the Late Devonian Arkhangelsk Diamond Province (NW Russia) and occurs 6 km south of the Lomonosov diamond deposit. Pionerskaya contains both hypabyssal kimberlite (HK) and pyroclastic kimberlite (PK) facies. This study focuses on phlogopite and clinopyroxene-rich samples from the HK facies which occurs intermittently from depths below 900 m. Pionerskaya has historically been classified as an orangeite (or Group II kimberlite) which is mineralogically distinct from kimberlite. Orangeite bodies may contain clinopyroxene and they have a larger proportion of phlogopite than kimberlite. Kimberlite bodies contain monticellite, which is absent in orangeite. This study proposes that the Pionerskaya phlogopite and clinopyroxene are hybrid minerals resulting from alteration by reactions with felsic crustal xenoliths. There are granitoid, amphibolite–biotite schist and diorite xenoliths that commonly possess reaction rims with distinct sequences of minerals. Bulk rock XRF analysis indicates that the reacted felsic xenoliths have an intermediate composition between that of the HK groundmass and the fresh, unreacted country rocks from the study area. The relative proximity of the felsic crustal xenoliths in the HK impacts the size, shape, inclusion content, and composition of the phlogopite. Phlogopite shows an overall decrease in FeO and increase in Al_2O_3 and TiO_2 as proximity to felsic xenoliths increases. Similar trends are also observed in clinopyroxene with CaO increasing and FeO decreasing in proximity to felsic xenoliths. There is evidence of very late stage development of clinopyroxene which is demonstrated by microcrystalline clinopyroxene replacing hydrogarnet, which is itself an alteration mineral. The phlogopite also contains monticellite inclusions. The petrological, mineralogical, and geochemical evidence from this study supports the conclusion that there are hybrid minerals formed as the reaction products of felsic crustal xenoliths and kimberlite melt in the Pionerskaya pipe. This interpretation is also supported by a good match between the observed mineralogy and the theoretically predicted mineralogy modelled by Perple_X. The results of this study indicate that the Pionerskaya pipe should be reclassified as a Group I kimberlite, which favourably impacts its diamond potential.

GEOTRAILS: MAKING GEOSCIENCE ACCESSIBLE TO THE PUBLIC

Katie Maloney[1], Joe Hansen[1], Keira Hum[1], Julia Nielsen[1], Kate Pearson[1], Shania Ramharrack-Maharaj[1], Deana Schwarz[2], Carolyn Eyles[1], Elli Papangelakis[1], Alexander Peace[1]
[1]McMaster University, [2]APGO Education Foundation.
E-mail: *katie.maloney@mail.mcgill.ca*

As geoscientists we must prioritize improving our ability to communicate science to the public. Effective geoscience communication enables communities to understand how geological processes have shaped our planet and make informed decisions about Earth's future. Research outputs have traditionally been published in peer-reviewed journals and presented at conferences. Consequently, essential information about the local geology is rarely available to the community in accessible, open access, and engaging formats. Here we propose curated educational virtual field trips, or Geotrails as a possible solution to address the disconnect between geoscience research and public knowledge by improving our communication to the public. Geotrails are created in partnership with the APGO Education Foundation and provide interesting and accessible information about the local geology through ArcGIS StoryMaps. This initiative is undergraduate student-driven, with students selecting points of geoscientific interest along the trails and collecting field data (e.g. digital photography, 360° images, 3D models, drone photography) to illustrate the features they identify. These virtual field data are integrated with concise text descriptions derived and synthesized from longer peer-reviewed journal articles and Ontario Geological Survey Reports written for geoscientists. Geotrails are living documents that also allow us to showcase active research and update text as we learn more about the local geology. The goal of the project is to communicate how rocks created in the distant past influence our culture and environment today and to provide information about the potential impact of changing climate on our landscapes and communities.

SYSTEMATIC PALEONTOLOGY OF MACROALGAL FOSSILS FROM THE TONIAN MACKENZIE MOUNTAINS SUPERGROUP

Katie Maloney[1], Dakota Maverick[2], James Schiffbauer[2], Galen Halverson[1], Shuhai Xiao[3], Marc Laflamme[4]
[1]McGill University, [2]University of Missouri, [3]Virginia Tech, [4]University of Toronto.
E-mail: *katie.maloney@mail.mcgill.ca*

Proterozoic eukaryotic macrofossils are rarely preserved with enough morphological detail to inform their phylogeny. Previous reports of exceptionally preserved Tonian (ca. 950 Ma) fossils from the Dolores Creek Formation of northwestern Canada noted two size classes of filaments, of which the larger class is interpreted as green macroalgae. Here, we describe these two size classes of filamentous fossils and discuss the implications of their complex morphology on ecosystem and eukaryotic diversity during the early Neoproterozoic. The larger size class specimens are described as green macroalgae consisting of an unbranching, uniseriate thallus (with uniform width throughout; n = 304, width = 0.20–0.85 mm) and possessing an elliptical to globose anchoring holdfast. Fossils from the smaller size class (n = 90, width = 0.03–0.06 mm) retain too little morphological information to define properly. However, a third form is also documented, consisting of a ribbon-shaped thallus with a consistent width (n = 19, width = 1.0–1.7 mm). The order-of-magnitude size range of these different, likely photoautotrophic, organisms support the hypothesis of an increasing morphological complexity and overall diversification of macroalgae during the Tonian, leading to dramatic changes to benthic marine ecosystems prior to the evolution of animals.

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NEOARCHEAN CRUSTAL ARCHITECTURE OF THE NORTHERN PONTIAC SUBPROVINCE (SUPERIOR CRATON, CANADA): NEW INSIGHTS FROM PHASE EQUILIBRIA MODELLING AND MULTI-METHOD PETROCHRONOLOGY

Isaac S. Malta[1], Carl Guilmette[1], Antoine Godet[1], Douglas Tinkham[2], Bruna Coldebella[1], Matthijs Smit[3], Jeffrey Marsh[2], Georges Beaudoin[1], Crystal LaFlamme[1]
[1]Université Laval, [2]Laurentian University, [3]University of British Columbia.
E-mail: *isaac.siles-malta.1@ulaval.ca*

Metamorphic rocks can record transient first-order parameters (P, T, and thermal gradients) that are critical to identifying changes in the architecture and thermal state of orogenic belts through time. The Neoarchean era is of particular interest as multiple studies suggest it is the time of initiation of modern-day plate tectonics. The Pontiac subprovince (PS) in the southeastern Superior craton (Canada) is a Neoarchean metasedimentary belt with a complex history and tectonic evolution that is highly debated. In its northern part, prograde metamorphism is recorded in turbidite sequences by the southward succession of index minerals, biotite, garnet, staurolite, kyanite, and sillimanite, defining an apparent Barrovian-like sequence. New mapping of metamorphic zones, petrographic analysis, phase equilibria modelling, and Lu–Hf garnet and U–Pb monazite/zircon geochronology from multiple zones are integrated to decipher the tectonothermal evolution of the northern PS. Our analysis indicates that rocks from the garnet zone experienced a clockwise path with peak P–T conditions at 8.1 kbar/585°C along low thermal gradients of 20°C/km. In contrast, rocks from the staurolite and sillimanite/melt zones followed isobaric heating and isothermal decompression paths with peak P–T conditions of 5.8 kbar/600°C and 5.9 kbar/710°C, respectively, along moderate thermal gradients of ~31–34°C/km. Subsolidus monazite and garnet growth at 2667 ± 1.4 Ma and 2657 ± 4.2 Ma record the timing of prograde metamorphism. Suprasolidus zircon overgrowths in the sillimanite/melt zone at 2647 ± 3.5 Ma record the timing of high-T cooling. These results indicate a short-lived residence (~10 M.y.) for these rocks at mid-crustal conditions and the coeval development of diverse P–T–t paths (isobaric heating, isothermal decompression, and clockwise paths) along two contrasting thermal gradients. Our data cannot be interpreted in the framework of tectonic models previously proposed for the PS, which include exotic terrane, accretionary prism, and plume-related rift basin models. Our data is more compatible with a sagduction process, where previous numerical modelling indicates high heat influx into the shallow crust caused by pooling voluminous magmas producing a crustal overturn, allowing the development of diverse P–T–t paths, fast burial and exhumation rates and contrasting thermal gradients. Our study provides insights into the Neoarchean evolution of the southeastern Superior craton and highlights the need to apply an integrated quantitative approach to decipher the architecture and thermal state of ancient orogens.

CONCEPTUAL AND EMPIRICAL PREDICTIVE MODELS FOR GOLD EXPLORATION: AN EXAMPLE FROM THE MCINTYRE BROOK GOLD PROPERTY, NEW BRUNSWICK, CANADA

Farzaneh Mami Khalifani[1], Mohammad Parsa[2], David Lentz[1], James Walker[3]
[1]University of New Brunswick, [2]Geological Survey of Canada,
[3]New Brunswick Department of Natural Resources and Energy Development.
E-mail: *farzaneh.mamikhalifani@unb.ca*

The Tobique-Chaleur Zone in northern New Brunswick and the adjacent Gaspé Peninsula hosts numerous orogenic and epithermal gold occurrences/deposits that are spatially related to large-scale crustal structures or their subsidiary splays (e.g. the Rocky Brook-Millstream Fault system or RBMF). Mineralization is dominated by quartz-carbonate veins associated with fractures and shear zones. The McIntyre Brook gold property, located approximately 50 km east of Saint-Quentin, lies along the McIntyre Brook fault, a splay of the RBMF. The area is underlain by Early Devonian bimodal volcanic and sedimentary rocks of the Wapske Formation (Tobique Group), that are in fault contact with red clastic sedimentary rocks of the Greys Gulch Formation (Tobique Group) to the south. Gold mineralization in hematite- and sulphide-bearing quartz-carbonate veins, within potassically altered feldspar-phyric rhyolite, is oriented along an east-northeast striking shear zone. This study intends to narrow the search space for gold exploration by successively integrating geochemical, geophysical, and geological signatures that are directly or indirectly associated with gold mineralization. In this study, we use historical aeromagnetic data acquired in 1986 and 1997 with a line spacing of 300 m. Various filters, including the analytic signal of the Reduced to Pole, first vertical derivative, the total horizontal derivative of upward (THD) continued filter, and tilt derivative (TDR), were applied to process and interpret the geophysical data. These filters helped to identify geophysical signatures that might represent gold mineralization in this area. The geochemistry of 2612 samples, collected over the entire McIntyre Brook property, was analyzed via a 36-element package that used an aqua regia partial digestion. Composition-based multivariate techniques were applied to the multi-element datasets to investigate the correlation of multi-elements in this region. Compositional biplots derived from the data show that Au, Sb, Ag, W, Sn and Pb are closely associated. Additionally, till geochemical data were utilized to gain a better understanding of the anomalous behaviour of gold and its pathfinders in the study area. The vectors derived from geochemical and geophysical data, coupled with those derived from geological maps, were used to develop conceptual and empirical predictive models. The latter procedure was conducted by different machine- and deep-learning procedures. In addition to the common statistical procedures used for verification of geological prospectivity models, we employed mineralogical studies to verify and interpret the results of our models. It is concluded herein that the models successfully reduced the search space for exploration, thereby helping de-risk the exploration surveys conducted in the property.

DRUMLINS, DE GEERS, AND DELTAS: LIDAR AND LANDFORM INTERPRETATIONS WITHIN THE LAKE NIPISSING BASIN, NORTHEASTERN ONTARIO

Andrea S. Marich
Ontario Geological Survey.
E-mail: *andrea.marich@ontario.ca*

A multi-year mapping program was initiated in the Lake Nipissing basin of northeastern Ontario to improve understanding of glacial history and the characteristics of regional surficial sediments and landforms. The recent release of high-resolution lidar DEMs has led to the identification of previously unidentified glacial landforms including streamlined bedforms, crag-and-tails, De Geer moraines, deltas and other raised shoreline features that constrain regional deglaciation. Streamlined landforms including drumlins, and crag-and-tails, occur throughout the region and represent a period of advancing ice. These landforms reflect ice flow to the southwest in the western and eastern portions of the study area, and ice flow due south in the central part of the study area. They vary in length from < 100 m to > 3 km, in height from about 2 to 8 m, and have large elongation ratios. These streamlined forms are easily discernable on lidar data and collectively mark the bed of paleo-ice streams. Several previously unidentified ice streams can now be mapped in the study area. De Geer moraines have been identified in multiple large clusters within the study area. These generally till-cored features form at the ice front, along the grounding line within a proglacial waterbody. De Geer moraines in the study area are 1 to 2 m high, several tens to hundreds of metres long and are evenly spaced within the clusters. Existing studies of De Geer moraines suggest these small ridges mark pauses in ice retreat, and in some cases may be used as yearly markers of retreat, allowing for calculations of rate of recession of the ice margin. This project will attempt to determine if these moraines indicate yearly retreat or if they simply mark short still-stands of retreating ice. Raised shorelines are observed between 200 and 370 m asl in the area, and deltas developed at locations where sediment supply rates were high during a period of stable water levels. At several locations, these sand-dominant features were subsequently altered by shoreline process when proglacial lake levels dropped, forming beach bluffs that mark successive lower lake levels. Streamlined landforms indicate ice streaming was occurring during ice advance, De Geer moraines may mark yearly retreat, and raised shorelines can provide insight into post-retreat conditions. Future work includes ongoing landform interpretations from the lidar DEM, field mapping of the Quaternary geology of the area, sample collection and evaluation of past radiocarbon data to further constrain timing of glacial events.

PREDICTION OF CONTAMINATED NEUTRAL DRAINAGE: CASE STUDY OF DESULPHURIZED LAC TIO TAILINGS

Vincent Marmier[1], Benoît Plante[1], Isabelle Demers[1], Youssef Toubri[1], Mathieu Fillion[2]
[1]Université du Québec en Abitibi-Témiscamingue, [2]Rio Tinto, Fer et Titane Inc.
E-mail: *marv29@uqat.ca*

Lac Tio is the biggest massive hemo-ilmenite deposit in the world. The mine site has been active since 1950 and its mine waste has been extensively studied. To reduce the SO_2 emissions generated by ore roasting, Rio Tinto Iron and Titanium experimented with the separation of the magnetic ore from the non-magnetic rock to remove sulphide phases from the ore. The Lac Tio waste rocks are known to leach Ni-contaminated neutral mine drainage Because the new tailings are different in terms of grain size distribution, chemistry and mineralogy, assessing the potential for Ni leaching was necessary. To do so, a combination of chemical analyses, batch sorption tests and kinetic leaching with an EDTA solution has been implemented. Kinetic leaching suggests that the material could generate up to 30 mg/L of Ni without any immobilization mechanisms (sorption and precipitation). Sorption tests suggest the material can sorb up to 1060 mg Ni/kg. Since the material contained 166 mg Ni/kg, a ratio of sorption to generation of 6.4 can be calculated. Further work is required to define whether this ratio can be considered "safe" in terms of potential Ni leaching upon saturation of sorption sites.

INFLUENCE OF TAILINGS WEATHERING HISTORY ON THE HYDROGEOCHEMICAL EVOLUTION OF OIL SANDS FROTH TREATMENT TAILINGS UNDER A RECLAMATION SOIL COVER

J. Eduardo Marquez[1], Jordan G. Hamilton[2], Matthew B.J. Lindsay[1]
[1]University of Saskatchewan, [2]Syncrude Canada Ltd.
E-mail: *e.marquez@usask.ca*

Bitumen extraction at oil sands mining operations in northern Alberta, Canada, produces several types of tailings that will be incorporated into the closure landscape. One tailings stream known as froth treatment tailings (FTT) has been found to concentrate sulphide minerals during extraction relative to the ore body. Froth treatment tailings have been characterized as potentially acid-generating material given that the acid generation potential exceeds the acid neutralization potential. A component of life-of-mine closure plans for oil sands operations is the construction of clay-rich till and peat covers (i.e. soil covers) to support revegetation. For sulphide mineral-bearing tailings, such as FTT, weathering prior to reclamation may affect the physical, geochemical, and mineralogical characteristics of these tailings. There is currently uncertainty as to how FTT at different stages of oxidative weathering will (bio)geochemically respond to the placement of a reclamation soil cover. Six large-scale (3 m x 3 m) field lysimeters were constructed at an oil sands mine in Fort McMurray, Alberta, to better understand the hydrogeochemical implications of reclamation soil covers on non-weathered (i.e. freshly deposited), partially weathered, and heavily weathered FTT. The experiments are instrumented for remote in situ monitoring of various parameters (i.e. T, EC, θ, O_2) and designed to allow periodic collection of tailings and leachate samples for chemical analysis. While all FTT samples collected for these experiments were classified as potentially acid-generating due to elevated sulphide mineral content and limited dolomite/calcite content, concentrations of sulphide and inorganic carbon differed among the tailings types. Weathered FTT samples were characterized by lower total sulphide content (0.84 to 2.1% as S) and negligible inorganic carbon content (0.04 to 0.10%), compared to unweathered FTT which had higher sulphide content (2.3 to 3.6% as S) and higher inorganic carbon content (0.44% to 0.55%). Furthermore, initial pH of leachates from the heavily weathered tailings were lower (pH 3.1 to 5.8), compared to the partially weathered and unweathered tailings (pH 5.9 to 6.5). Particle size analysis and soil water characteristic curves indicate that weathered FTT contain a higher proportion of fines (1 to 100 μm particle size) compared to the unweathered and partially weathered FTT, and slightly higher water retention capacity within the 0 to 5 bar suction range. Results to date indicate that FTT weathering history can influence the hydrogeochemical performance of reclaimed tailings.

CRITICAL MINERALS GEOSCIENCE AND DATA

Geneviève Marquis
Geological Survey of Canada.
E-mail: *genevieve.marquis@nrcan-rncan.gc.ca*

The Geological Survey of Canada (GSC) is launching a new initiative that is one part the Canadian Government's strategy to strengthen supply chains of critical minerals. Although it is paramount for countries around the world to establish and maintain resilient critical mineral value chains, ensuring producers adhere to high environmental, social and governance standards is equally important. The GSC's new initiative will focus on 14 critical minerals on Canada's critical minerals list that are the building blocks for a green and digital economy and energy transition. These minerals are vital to a range of industries including technology, energy, defence and infrastructure, and are essential to produce a wide range of products, including batteries, electronics, and infrastructure materials. In addition to supporting the responsible development of Canada's critical mineral resources, government research programs play a key role in providing reliable and up-to-date information on the location, quality and mineral potential of these resources through cutting edge research, data collection and analysis. This overview presentation will outline the geoscience research agenda for critical minerals in Canada and how geological surveys can provide geoscience data to guide responsible resource development and investment while supporting the growth of industries that rely on these critical mineral resources.

CHANGING CLIMATE AND POTASH DEPOSITION IN THE DEVONIAN PRAIRIE EVAPORITE FORMATION: INSIGHTS FROM THE SEDIMENTOLOGY AND 7 Å CLAY MINERAL AUTHIGENESIS

Edward J. Matheson[1], Branimir Šegvić[2], Tanner Soroka[3], Peir K. Pufahl[4]
[1]Cape Breton University, [2]Texas Tech University, [3]Nutrien Ltd, [4]Queen's University.
E-mail: *ted_matheson@cbu.ca*

The Prairie Evaporite Formation of central Canada is one of a small number of Phanerozoic basin-scale potash giants, having accumulated across a quarter million square kilometres in the tropical, epicontinental Middle Devonian Elk Point Basin. It is mined at conventional and unconventional operations across Saskatchewan and is responsible for approximately one third of global potash production. Despite its economic importance, there remain unanswered questions regarding depositional and diagenetic controls on its accumulation and modern day composition. The potash, primarily sylvite, halite, and lesser carnallite, contains a poorly understood subordinate "insoluble" component. Here we present a novel sedimentologic, stratigraphic, petrographic, and mineralogic characterization of the insoluble minerals that allows refined reconstruction of the paleoclimatic and oceanographic evolution of the Elk Point Basin. The insoluble minerals include dolomite, quartz, anhydrite and clay minerals. They are found either as disseminated interstitial material between salt crystals or in elevated abundances mixed with salts in regionally correlatable decimetre-scale beds, both of which increase in abundance upwards in the succession. The clay mineral assemblage in the oldest potash members is almost exclusively illite and chlorite whereas the youngest potash contains ubiquitous illite, chlorite, and an odinite-like phase. Odinite is a 7 Å Mg–Fe-rich clay mineral formed through authigenic precipitation from terrigenous Fe substrates in modern shallow, tropical marine settings. It typically undergoes transformation to chlorite during burial and is recognized in the Prairie Evaporite for the first time in this study. This marks a rare example of Paleozoic odinite that has not been affected by chlorite interstratification and is one of the oldest known occurrences of odinite in the geologic record. Critical examination of odinite's stratigraphic distribution, both within the Prairie Evaporite and in the overlying stratigraphic units, suggests a secular trend in basin chemistry and clay authigenesis through deposition. We propose that this change reflects a climate evolving from arid to more humid through potash accumulation. The increasingly wet climate is interpreted to have intensified weathering in the surrounding desert, which led to episodic interruptions in potash deposition, and caused odinite authigenesis. These changes resulted in the temporal trends in insoluble composition and abundance and eventually contributed to the cessation of potash deposition altogether, providing new insight into the life of the potash basin.

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When expanded to the overlying Devonian strata, this interpretation also provides a new regional, and perhaps global, framework for tropical climate cyclicity coupled with eustatic sea level fluctuations through the Middle and Late Devonian.

DEVELOPING AN ALBITE SHOCK CALIBRATION CURVE TO QUANTIFY SHOCK IN TYPE 3.6–6 ORDINARY CHONDRITES AND IMPACTS INTO FELSIC TERRESTRIAL TARGETS

Trevor Matterson[1], Roberta Flemming[1], Steven Jaret[2], Jeffrey Johnson[3]
[1]Western University, [2]American Museum of Natural History,
[3]Johns Hopkins University.
E-mail: *tmatter@uwo.ca*

Albite is prevalent on Earth in felsic rocks but could also have significant applications for meteorite analysis. In ordinary chondrites of petrologic type 3.6, primary anorthite begins to alter to albite, increasing in rate with increasing petrologic grade from 3.6–5. Also, mesostasis glass recrystallizes to form albite above petrologic grade 3.6. As a result, albite can be used as a pressure indicator in type 3.6–6 ordinary chondrites. Impact metamorphism, also referred to as shock metamorphism, is the effect of the shock wave generated by a hypervelocity collision of a bolide with a planetary surface. Terrestrial albite samples, which had been artificially shocked to peak shock pressures ranging from 0 GPa (unshocked) to 55.8 GPa, were used for this study. Micro X-ray diffraction (µXRD) data were collected on a Bruker D8, with Co*Ka* radiation and a 300 µm beam diameter, using an XYZ stage and camera-laser targeting system. These data were used to quantitatively measure strain-related mosaicity (SRM) exhibited by shocked albite crystals as a result of non-uniform strain causing subdomain misorientation. This appears as streaking along the Debye ring or chi (χ) direction in the 2D image, while diffracted rays from unstrained crystals appear as single spots. Plots of intensity versus χ angle produced one or more peaks for which peak full width at half maximum (FWHMχ) was measured in degrees χ. These were summed to produce Σ(FWHMχ) values, which were plotted against the peak shock pressure of the sample. The measured SRM had a strong positive linear correlation with peak shock pressure, where Σ(FWHMχ) values increased with increasing peak shock pressure until complete amorphization occurred between 50 GPa and 55.8 GPa. Σ(FWHMχ) values varied from 3.04° at 0 GPa to 15.10° at 50 GPa. Using this calibration curve, the Σ(FWHMχ) of albite grains in naturally shocked ordinary chondrites of petrologic type 4–6 or felsic impact targets on Earth can be used to estimate peak shock pressures. This can be used to classify meteorites based on the shock classification scheme and to determine the impact history of planetary materials.

GEOLOGY OF THE SOUTH ZONES, GOLDEX MINE: A PRE-MAIN DEFORMATION GOLD DEPOSIT IN THE VAL D'OR MINING CAMP

Liam Maw[1], Patrick Mercier-Langevin[2], David Yergeau[3], Pierre-Simon Ross[1]
[1]Institut national de la recherche scientifique, [2]Geological Survey of Canada,
[3]Agnico Eagle Mines Ltd.
E-mail: *liam.maw@inrs.ca*

For the past 13 years, Agnico Eagle Mines Limited has been exploiting the low-grade, high-tonnage Goldex deposit (resources, reserves and past-production of 97.9 Mt at 1.51 g/t Au, for a total of 148 tonnes Au, or 4.76 Moz Au, as of December 2021). The deposit consists of a network of subvertical and shallowly dipping quartz-tourmaline-carbonate-pyrite ± scheelite-gypsum vein stockwork and breccia forming a large, steeply north-dipping ore-body hosted within the 2687.0 ± 1.2 Ma (post-volcanic, pre-Timiskaming) calc-alkaline Goldex diorite. The latter is emplaced within a major WNW–ESE shear zone of the Marbenite–Norbenite structural corridor; the mineralization is compatible with syn-D3 emplacement (< 2660 Ma). Since 2019, a portion of gold production has come from the South Zones, which form a network of higher grade zones (resources, reserves and past-production of 6.1 Mt at 3.24 g/t Au, for a total of 19.7 tonnes Au, or 0.635 Moz Au) within basalt of the Jacola Formation, in the immediate structural footwall of the Goldex diorite. The South Zones occur within moderately (~45 to 65°) north-dipping high strain zones and a series of subvertical corridors. Gold-rich intervals within the moderate dip zones form decimetre- to metre-scale zones of "silica flooding" and grey quartz veins with variable amounts of disseminated chalcopyrite-pyrrhotite ± sphalerite-native gold, bordered by an assemblage of pervasive pyrrhotite-biotite-amphibole-silica ± epidote alteration. Subvertical zones host gold within discontinuous grey quartz veinlets and disseminated pyrrhotite-chalcopyrite-pyrite aggregates transposed along the regional foliation (S3), subparallel to S0. Several lines of evidence, including the spatial distribution of ore zones, the styles of veining, ore and alteration mineral assemblages, metal associations, and gold concentrations distinguish the South Zones from the syn-D3 mineralization in the Goldex diorite. The South Zones are cut by a series of calc-alkaline post-volcanic, pre-Timiskaming dykes of similar age and composition as the Goldex diorite, indicating pre-D3 emplacement. Other supporting evidence includes deformation of veins during D3, native Au within amphibole porphyroblasts, amphibole porphyroblasts within sulphide aggregates, high temperature dynamic quartz recrystallization, and replacement of pyrite by pyrrhotite. This study indicates that, despite the juxtaposition of the ore-bodies, the South Zones and Goldex deposit are a rare example of two geologically and temporally distinct, structurally controlled lode Au deposits. The South Zones, markedly different from other pre-D3 "quartz-carbonate" deposits in the Val d'Or camp, offer new insights into early deformation and mineralization in the Southern Abitibi, and attest to the importance and protracted history of the Marbenite–Norbenite structural corridor as a gold metallotect.

A NEW, UNUSUAL IIE IRON METEORITE FROM AN UNUSUAL IRON PARENT BODY

Philip McCausland[1,2], Veronica Di Cecco[1], Kim Tait[1], Chris Herd[3], Roberta Flemming[2], Brian Joy[4]
[1]Royal Ontario Museum, [2]Western University, [3]University of Alberta, [4]Queen's University.
E-mail: *pmccausl@uwo.ca*

Iron and metal-dominated meteorites represent a minor fraction of meteorites arriving on Earth, but appear to represent the differentiated cores of over 50 chemically distinct parent bodies in the early solar system. Some iron meteorites contain silicate inclusions, which permit comparison with silicate meteorite types to assess possible parent body relationships. M58921 is a silicated iron meteorite in the David Gregory collection, investigated and described at the Royal Ontario Museum as M58921, a 26 g Northwest Africa desert meteorite with ~20 vol.% silicate-sulphide inclusions. Near inclusions, metal is featureless, but 300 µm away from inclusions kamacite and taenite form a fine to very fine octahedrite (Off), with geometrically corrected kamacite lamellae bandwidths 141 ± 28 µm (n = 16). Bulk iron metal subsample analysis by ICP-MS gives trace element abundances including Ni = 7.12 wt.%, Ga = 13 ppm, Ge = 45 ppm, Ir = 2.63 ppm. On both Ni wt.% versus Ge and Ir plots, M58921 plots near the IIE, IIIAB and IIIE iron meteorite chemical groups, with IIE being the only silicated iron group of those three; M58921 potentially extends the IIE group to slightly lower Ni and Ge values. EPMA data for the silicate phases match H chondrite compositions, with olivine $Fa_{18.37 \pm 0.35}$, Fe/Mn = 35.8 (n = 30); Ca-poor pyroxene $Fs_{16.18 \pm 0.22}$, $Wo_{1.76 \pm 0.25}$, Fe/Mn = 21.5 (n = 24); Ca-rich pyroxene $Fs_{7.10 \pm 0.09}$, $Wo_{43.13 \pm 0.42}$ (n = 6). Olivine and pyroxene compositional variation is minor, consistent with textural observations in reflected light and BSE images that show the silicate inclusions to be highly recrystallized. Amazingly for an iron meteorite, relict porphyritic olivine chondrules are present within the inclusions, indicating that they are chondritic. In situ X-ray diffraction of olivine and pyroxene indicates low-to-moderate shock in the inclusions. IIE irons are linked with H chondrites or more reduced HH chondrites; the 30+ members of this group range from having no inclusions to having silicate inclusions of gabbroic, silicate melt or chondritic types. M58921 seems texturally similar to the Netschaëvo IIE iron, which has angular silicate-sulphide inclusions containing relict chondrules. IIE irons are recently posited to have come from a partially differentiated parent body which hosted a dynamo, but they do not show a magmatic trend of chemical evolution and may represent impact mixing of metal and reduced chondritic material. M58921 appears to be a rare example of direct mixing between iron and chondritic components on a parent body and is a possible analogue for upcoming spacecraft observations of the M-type asteroid 16 Psyche.

CONSTRAINING THE NATURE AND AGE OF THE HOLLEFORD IMPACT CRATER

Emer McConnell-Radford, Christopher J. Spencer
Queen's University.
E-mail: *emermr08@gmail.com*

Impact cratering is a ubiquitous geological process affecting all planetary bodies with a solid surface. However, unlike most other planetary bodies, Earth's surface undergoes a much faster resurfacing due to erosion and active tectonics that actively removes impact structures from the geologic record. Small craters tend to be removed quicker by erosive forces due to the limited depth to which they can be recognized and small volume of shocked material. In particular, the Holleford crater, just north of Kingston, Ontario, being roughly 2.35 km in diameter, is part of an enigma of small but old impact craters in the geologic record. The characterization of this impact crater is limited to the identification of a circular depression in the 1950s from aerial photographs, and a single study in the 1960s which discovered coesite, as confirmed with X-ray powder diffraction. Previous studies have estimated an age of around 550 Ma for this crater, based on the deposition time of the undisturbed Potsdam Formation which fills the crater. Detailed logging of the Holleford crater core and modern analytical techniques are used to identify shocked minerals from the Holleford crater, providing a more robust characterization of an impact feature and the possibility of determining an accurate age through dating neoblastic accessory minerals.

REPROCESSING TAILINGS FOR METAL RECOVERY AND CARBON DIOXIDE REMOVAL: CHALLENGES AND OPPORTUNITIES

Jenine McCutcheon[1], Jessica Hamilton[2], Thomas Ray Jones[3], Wing Lam Savina Tam[1], Decla McParland[1], Connor Turvey[4], Jordan Poitras[3], Siobhan A. Wilson[4], Ian M. Power[5], Gordon Southam[3]
[1]University of Waterloo, [2]Australian Synchrotron, [3]The University of Queensland, [4]University of Alberta, [5]Trent University.
E-mail: *jenine.mccutcheon@uwaterloo.ca*

The global demand for metals has increased in recent years in step with the transition away from fossil-based energy sources. With the variety of historic, active, and reserve mineral extraction sites found in Canada, the Canadian mining sector is well positioned to help meet these demands. Concurrently, the sector will be expected to abide by greenhouse gas emission policies that will become more stringent over time. There is an opportunity to align these goals by reprocessing and reusing mine tailings from historic and active sites to 1) extract residual metals present in low concentrations and 2) store atmospheric carbon in secondary carbonate minerals as a strategy for onsite carbon dioxide removal (CDR). Mine tailings present a challenging starting material for both metal recovery and mineral carbonation due to their mineralogical and geochemical heterogeneity, which is complicated by presiding microbial processes and tailing storage conditions. The presented results highlight how advanced microscopy techniques can reveal the spatial complexity of tailings, which must be considered when assessing the suitability of historic tailings for reprocessing or CDR. Mafic and ultramafic tailings, such as those generated by chrysotile, diamond and nickel mines, contain high concentrations of magnesium and calcium, making them well suited to CDR via mineral carbonation. Precipitation of secondary Mg- and Ca-carbonate minerals in mine tailings occurs naturally and can be accelerated through biotic and abiotic processes. Cyanobacteria and other microbes mediate the precipitation of carbonate minerals through alkalinity generation and nucleation site production. Trials of mine site implementation of this CDR strategy identified that mineral carbonation was limited by water and carbon availability, thereby demonstrating the need to integrate mineral carbonation in mine site design for successful deployment. Rates of CDR via mineral carbonation can be increased through enhanced weathering of tailing minerals, however, this presents a risk of potential mobilization of co-located transition metals. Mitigating metal release into the environment may involve either 1) immobilizing the metals in secondary carbonate minerals if they are not present in economically valuable concentrations, or 2) first recovering the transition metals and subsequently precipitating carbonate minerals from the remaining solution. These findings highlight the challenges of working with mine tailings and the need for a 'toolbox' of biogeochemical strategies for reusing tailings in order to maximize site-specific metal recovery and CDR as the mining sector shifts towards a more sustainable, carbon-neutral future.

FIELD-DEPLOYABLE DRAINAGE COLUMNS FOR MONITORING CO_2 SEQUESTRATION VIA ENHANCED WEATHERING AND MINERALIZATION OF KIMBERLITE MINE WASTES, OLIVINE, AND WOLLASTONITE

Duncan McDonald[1], Ian Power[1], Carlos Paulo[1], Nina Zeyen[2], Baolin Wang[2], Sasha Wilson[2]
[1]Trent University, [2]University of Alberta.
E-mail: *duncanmcdonald@trentu.ca*

Alkaline mineral feedstocks, including ultramafic mine wastes, can be used for enhanced rock weathering (ERW), offering the ability to sequester CO_2 as a dissolved phase (e.g. HCO_3^-) or as a solid carbonate. However, the rate at which this occurs can vary greatly, requiring prediction of CO_2 sequestration rates coupled with high-resolution monitoring to accurately verify carbon additions to a system. As part of De Beers' CarbonVault, experiments were conducted using kimberlite residues from the Gahcho Kué, Venetia, and Voorspoed diamond mines along with other common ERW feedstocks included for comparison. The release of easily extractable Ca and Mg from non-carbonate sources was determined via batch leaches. Using these data, the CO_2 sequestration potentials of the kimberlite residues were determined to be 3–12 kg CO_2/t. Following this initial assessment, a year-long drainage column study that included Gahcho Kué kimberlite, wollastonite skarn, and olivine sand, was conducted. Carbon additions were tracked over one year using total inorganic carbon (TIC), dissolved inorganic carbon (DIC) and CO_2 flux measurements. The kimberlite residues sequestered 0.03 kg CO_2/t as DIC and 0.6 kg CO_2/t as TIC. Wollastonite skarn was dominated by mineral trapping of CO_2, with secondary carbonate minerals providing 99.5% of the 6.31 kg CO_2/t that the columns sequestered. Finally, the olivine sand yielded 0.5 kg CO_2/t through solubility trapping alone, the highest rate observed. While direct measurements of CO_2 fluxes provided indications of drawdown in wollastonite skarn, the discontinuous monitoring resulted in rates less than what was measured through TIC. Moreover, the comparatively low reactivity of the kimberlite and olivine sand inhibited their rate determination through CO_2 flux measurements. The results of our study indicate that leaching columns are a valuable carbon verification tool that can be used to monitor large, spatially variable environments. Although much less reactive than wollastonite, CO_2 removal rates of kimberlite residues were comparable to olivine, one of the reactive mafic minerals that is also of interest for ERW. The two experiments outlined in this study represent critical aspects of the pursuing carbon sequestration in mine wastes or ERW settings. Batch leaches provide the ability to predict the sequestration potential based on what is easily released, and field-deployable drainage columns offer high-resolution monitoring to verify carbon offsets.

GEOLOGY AND GEOCHEMISTRY OF THE SHALE-HOSTED VANADIUM MINERALIZATION AT THE VAN PROPERTY, NORTHWEST TERRITORIES

Danielle McGill[1], Daniel Gregory[1], Merilie Reynolds[2], Daryll Concepcion[1], Stefanie M. Brueckner[3]
[1]University of Toronto, [2]Northwest Territories Geological Survey, [3]University of Manitoba.
E-mail: *danielle.mcgill@mail.utoronto.ca*

Vanadium (V) is an increasingly important critical element, in part due to its use in vanadium redox flow batteries, a technology that will support the transition towards a green economy. To provide for this need, the discovery and development of new deposits is essential. The Van property, located in western Northwest Territories, contains several showings of shale-hosted V in the Lower Ordovician to Devonian Duo Lake Formation of the Road River Group. The dominant structure of the area is a large-scale NW-trending, upright fold, and mirrored stratigraphy can be seen on either side of the valley floor. The genesis of this style of V mineralization is poorly understood and the mineralization at the Van property has not been characterized in detail. We present geological observations from a field visit in summer 2022, which provide important context for understanding of the sedimentary environment and structural setting of the shale which hosts V mineralization. Approximately 100 samples were collected systematically from two sections of host strata at the Janice and Jim Creek showings. An additional 28 samples were collected from around the property, including older rocks of the Road River Group and younger rocks of the Earn Group. Full fusion whole rock lithogeochemistry on samples from the mineralized horizon found V concentration ranging from 400 ppm to 6390 ppm and Zn from 136 ppm to 14,600 ppm. Ni and Mo were also elevated, reaching up to 159 and 77 ppm, respectively. Outside of the mineralized horizon, in the younger Prevost Formation, anomalous values of barium (BaO) of up to 8.59 wt.% were also found. Initial optical and scanning electron microscopy was used to identify potential V-bearing minerals in the deposit and any alteration associated with V mineralization. Metamorphic temperatures of the Van property were determined using peak decomposition of Raman spectra carbonaceous matter and found to be between 310 to 340°C. Results will be used to develop a model for deposit formation, which will support future exploration efforts. This work will also have important implications for how V can be effectively and efficiently extracted during mining.

ARSENIC IN YELLOWKNIFE GARDEN SOILS

Sean McHale[1], Heather E. Jamieson[1], Michael J. Palmer[2], Anežka Borčinová Radková[1]
[1]Queen's University, [2]Aurora Research Institute.
E-mail: *19stm3@queensu.ca*

In Yellowknife, Northwest Territories, gold-mining operations at Giant and Con mines aerially dispersed over 20,000 tonnes of arsenic-rich emissions during operations (1938–1999). An environmental legacy of elevated arsenic in soils persists in the region, with mine-derived arsenic detected in undisturbed soils as far as 30 km from historical point sources. In this study, we investigate arsenic concentration and host phases in Yellowknife garden soils. Garden soil samples (n = 116) were collected from 106 Yellowknife gardens at the end of the growing season in 2020 and 2021. Residents either provided their sample or had a composite sample collected by the research team. Composite samples comprised grab samples of soils nearby to vegetable growth within a garden. Samples were collected with a trowel, which was cleaned prior to each sampling event, or by nitrile-gloved hand. Soil samples were bagged and stored frozen after collection and prior to analysis. The sampling campaign was advertised by radio and social media and through local gardening groups. Questionnaires on soil origin, water source, and fertilizer used were completed by garden owners. Garden soil arsenic concentrations measured by ICP–MS ranged from 0.7 to 60 mg/kg, with a median of 14 mg/kg and a mean of 16 ± 11 mg/kg. Sixty-eight of 116 garden soil samples had arsenic concentrations above 12 mg/kg, which is the Canadian soil quality guideline for arsenic for the protection of environmental and human health. Solid phase arsenic distribution was determined with SEM-based automated mineralogy at Queen's University for 10 garden soil samples. Arsenopyrite is the dominant arsenic host in the samples, present in 7 of 10 samples and hosting more than 70 wt.% arsenic in 6 samples. Arsenopyrite may be geogenic or anthropogenic, such as from repurposed waste rock for road building. Arsenic trioxide is present in seven samples; it is considered anthropogenic due to legacy aerial emissions. Arsenic-bearing iron oxides are present in 11 samples; their source nature may be anthropogenic or geogenic, however, synchrotron-based micro-X-ray diffraction determined 15 target grains across two samples were maghemite or hematite, both roaster-generated iron oxide phases. These results show roaster-generated phases are present in recent day garden soil at Yellowknife; however, the dominant arsenic host, arsenopyrite, is not prevalent in regional Yellowknife soils where arsenic trioxide from aerial emissions has been shown to dominate, being detected in 82% of a sample set.

CANADIAN GEOSCIENCE EDUCATION NETWORK (CGEN): CHARTING A COURSE FOR THE FUTURE

Beth McLarty Halfkenny
Canadian Geoscience Education Network (CGEN).
E-mail: *beth.mclartyhalfkenny@carleton.ca*

The Canadian Geoscience Education Network (CGEN) was founded in 1996 to increase public awareness of Earth Science and acts as the education assembly of the Canadian Federation of Earth Sciences (CFES). Directed by a national network of volunteers, CGEN aims to improve Earth Science literacy across Canada. CGEN promotes and supports Earth Science education and fosters Earth scientists in education and outreach activities that increase public appreciation of the study of our planet. CGEN welcomes members from all areas of geoscience, who share a common vision and who are interested in working within a coordinated network, creating a forum for information exchange, sharing ideas and challenges. Our most successful and impactful program, the EdGEO Canadian Earth Science Teacher Workshop Program is a principal activity of CGEN. EdGEO supports teacher professional development workshops, providing funding and teaching resources for locally organized, curriculum-specific teacher training. Since 1976, EdGEO funding has enabled teachers to gain knowledge, resources, and confidence to teach Earth science components of the curriculum. EdGEO grants are awarded annually to support workshops and field trips designed for teachers in their respective region, and annually in conjunction with the GAC-MAC conference. The Geoscientists in Residence program (GIR) is a new CFES/CGEN initiative in partnership with Parks Canada. Although many of Canada's National Parks were selected and inscribed due to their exceptional geological heritage, geology is not always recognized and communicated to the public. The first pilot project took place at Pukaskwa National Park in Ontario during the Summer 2022. During her two-week residency, Dr. Victoria Stinson assisted the Park's staff in identifying and interpreting its geological assets and provided programming to familiarize visitors to the geology that underpins the magnificent landscapes. Following the success of this pilot project, a second GIR opportunity will take place at Pukaskwa in August 2023, once again supported by a grant from the Association of Professional Geologists of Ontario (APGO) Education Foundation. At a time when geoscience faces a public perception crisis, geoscientists are needed more than ever to support Canada's response to global challenges. CGEN members are working with other stakeholders on initiatives aimed at recruiting youth into geoscience post-secondary programs, including a rebuild of the earthsciencecanada.ca Careers Website. Following an engaging brainstorming session at GAC MAC 2022 in Halifax, CGEN received great feedback, which we will share in the hopes it can inform our way forward and keep the discussion going.

CELEBRATING UNESCO INTERNATIONAL GEODIVERSITY DAY; PLUGGING INTO THIS NEW OPPORTUNITY FOR EARTH SCIENCE EDUCATION

Beth McLarty Halfkenny
Carleton University.
E-mail: *beth.mclartyhalfkenny@carleton.ca*

In November of 2021, UNESCO's General Assembly, proclaimed October 6th *International Geodiversity Day*, to promote a better understanding of Earth processes and recognize the deep interconnection between the solid Earth and the ecosystems and environments that rely upon it. Geodiversity refers to what Western science calls the abiotic or non-living parts of nature: rocks, sediments, minerals, fossils, soils, landscapes and water systems. It has been called the "silent partner" of biodiversity, understanding that biologically diverse ecosystems rely on a diversity of underlying geological materials from which to source nutrients and other services. Humans too depend on geological materials to support our societies, for food production, clean potable water, building materials and resources necessary to create clean energy technologies. On the evening of October 6, 2022, Carleton University Earth Sciences and the Faculty of Science in partnership with Ingenium's Curiosity on Stage presented "Celebrating Geodiversity; the critical foundation for diverse ecosystems on a changing planet." This symposium, held at the Canada Science and Technology Museum (CSTM), featured a keynote address by Dr. Claudia Schröder-Adams, entitled "Remarkable Earth and Ecosystem Changes in the Canadian Arctic Through Deep Time", followed by a panel discussion exploring the concept of Geodiversity. Panelists with expertise in biodiversity, local ecosystems and our water and mineral resources provided insight into the connections between Canada's remarkable and varied landscapes, ecosystems and human societies. Funded jointly by Carleton's Faculty of Science and Ingenium and supported by a grant from the Canadian Geological Foundation, the event drew 65 in-person and 90 virtual attendees and was recorded for the CSTM Curiosity on Stage YouTube Channel. Dr. Schröder-Adams talk was a highlight, showcasing stunning images of Canada's North, and the panel discussion was a lively, interdisciplinary conversation, guided by thoughtful questions from the very engaged hybrid audience. Future plans include creating an annual day-long Geodiversity Day program at Carleton campus allowing Earth Science students, the wider university community and the public to explore geodiversity and society. Among other program elements being considered, a short video highlighting the geodiversity of Canada's Arctic is in development, which we hope to use to launch an evening public talk. This talk will provide details of our event, discuss ideas for celebrating UNESCO's annual International Geodiversity Day, and encourage you to plug in to this newly named day as a geoscience communication opportunity to highlight the importance of geoscience in solving major challenges facing humanity.

THE CANADIAN FEDERATION OF EARTH SCIENCES: PROMOTING THE GEOSCIENCES THROUGH NEW EDUCATION AND OUTREACH INITIATIVES

Beth McLarty Halfkenny, Janice Zinck
Canadian Federation of Earth Sciences (CFES).
E-mail: *beth.mclartyhalfkenny@carleton.ca*

CFES is the Canadian Federation of Earth Sciences. We are an umbrella organization that represents a federation of approximately 10,000 geoscientists working in Earth science societies and associations across Canada, including the Geological Association of Canada and the Mineralogical Association of Canada. Established in 2006 as the successor to the Canadian Geoscience Council, CFES brings together 13 organizations of Earth scientists in industry, government, and academia. We cooperate with observer organizations and other relevant Canadian non-member organizations on issues of public education and professional registration. Nationally, we advocate on behalf of the Canadian Earth Science community with government and the Canadian public through our memberships in the Partnership Group for Science and Engineering (PAGSE), and the Science Media Centre of Canada (SMCC). Internationally, we advocate through our membership in the International Union of Geosciences (IUGS) and UNESCO. Our mission is to be the coordinated voice of Canada's Earth Science community, ensuring that decision makers and the public understand the contributions of Earth Science to Canadian society and the economy. CFES strategic priorities come from our member organizations, guiding our activities in support of those mutual goals. We coordinate overlapping efforts among member organizations to maximize efficiency and impact. CFES strategic objectives are determined by the Council of Member Organizations. These objectives are: (1) to coordinate and provide a common voice for member organizations and the Earth Science community in Canada; (2) to coordinate public policy advocacy on Earth science in Canada; (3) to facilitate public awareness of Earth science and support Earth science literacy; (4) to represent and promote Canadian Earth Science internationally; (5) to provide service to member organizations and the Earth science community; and (6) to coordinate support for professional and academic organizations in Canada. The Canadian Geoscience Education Network (CGEN) is the education arm of CFES, working to increase public awareness of Earth science. Founded in 1996, CGEN is a national network of volunteers supporting Earth Science literacy at all levels of education through various initiatives. EdGEO Canadian Earth Science Teacher Workshop Program is one of CGEN's primary activities, providing financial support, volunteers, and resources for locally run teacher professional development programs. The CFES invites you to visit us during the poster session to learn about the Careers Website rebuild and other initiatives to encourage youth to consider a career in Earth Sciences. Come find out how you can be involved.

PYRITE–GOLD ASSOCIATION IN WITWATERSRAND-STYLE MODIFIED PALEOPLACER GOLD DEPOSIT, PARDO TOWNSHIP, ONTARIO

Thomas R. McLoughlin-Coleman[1,2], Robert H. Rainbird[1,2], James E. Mungall[1], Duane Petts[2], Christopher J.M. Lawley[2], Wesley Whymark[3]
[1]Carleton University, [2]Geological Survey of Canada,
[3]Inventus Mining Corporation.
E-mail: *thomasmcloughlincole@cmail.carleton.ca*

The Huronian (ca. 2.4–2.2 Ga) Mississagi Formation is host to a modified paleoplacer gold deposit located 60 km northeast of Sudbury, Ontario in Pardo Township, where gold grains are distributed within basal cobble to boulder conglomerate in association with abundant detrital and epigenetic pyrite. Gold occurs mainly as irregular, angular clusters scattered throughout a matrix of chlorite and quartz. Less commonly, Au can occur as inclusions in, or along the boundaries of, epigenetic pyrite. Rare, rounded, possibly detrital, gold is preserved in quartz cement and gold transported in quartz vein pebbles is locally observed, suggesting a point source for at least some of the gold. A north to south reduction of silver content in the gold following inferred paleocurrents supports a placer model of fluvial gold transport. Mineralogical associations for gold include uraninite and pyrobitumen, pyrrhotite, and euhedral epigenetic and detrital pyrite. Similar to gold reefs of the Witwatersrand basin in South Africa, there is a particularly strong association between uraninite and gold, including having uraninite grains with gold and pyrobitumen coatings. This U-Au correlation is thought to have developed in two stages. First, heavy minerals were originally concentrated in a fluvial setting. Then, hydrocarbon-bearing diagenetic fluids were trapped in the pore space surrounding the uraninite grains through radiolytic polymerization. As a result, carbon coatings formed around grains then acted as a reductant to later gold-rich metamorphic fluids, leading to gold deposition. New LA-ICP-MS trace element mapping results suggest that much of the detrital pyrite is enriched in gold as lattice-bound Au (1.5–4 ppm) or as rare micro-inclusions of < 10 μm. Some detrital pyrite grains in the basal conglomerate texturally resemble pyrite nodules from organic-rich black shale in Archean basement rocks, including Fe-formation, exposed ~15 km to the north, near a past-producing gold mine. Hydrothermal dissolution fronts around the margins of some detrital pyrite highlight areas where much material has been dissolved. In contrast, euhedral, epigenetic pyrite tends to be gold-poor (below detection limit of 0.13 ppm). Previously published sulphur isotope results demonstrate that this type of secondary, gold-poor, pyrite yields overlapping isotope signatures with the gold-bearing detrital pyrite, possibly indicating a similar source. Younger pyrite overgrowths may have developed during greenschist-facies metamorphism of the Huronian basin during the Penokean orogeny between 1.85 and 1.5 Ga. Gold at Pardo appears to have been detrital and modified mainly by local hydrothermal dissolution and reprecipitation.

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BIOLOGICALLY INDUCED CARBONATE PRECIPITATION: IMPLICATIONS FOR ENGINEERED WETLANDS AT MINE SITES FOR CARBON DIOXIDE REMOVAL

Decla McParland[1], Ian M. Power[2], Carol J. Ptacek[1], Siobhan A. Wilson[3], Jenine McCutcheon[1]
[1]University of Waterloo, [2]Trent University, [3]University of Alberta.
E-mail: *dsmcparl@uwaterloo.ca*

Biologically induced mineralization of stable Mg-carbonate minerals in ultramafic tailings can lead to carbon-neutral mines. Microbial communities facilitate carbonate formation by acting as templates for nucleation such as on extracellular polymeric substances (EPS) and generating alkalinity through metabolic activity. For instance, the reduction of sulphate ions and the consumption of organic acids by sulphate-reducing bacteria (SRB) induces both an increase in alkalinity and pH. However, the limitations of this biomineralization process must be better understood to apply it to mining environments. In this study, phototrophic microbial mats and underlying SRB-rich sediments were collected from an alkaline wetland within a hydromagnesite [$Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$)]–magnesite ($MgCO_3$) playa near Atlin, British Columbia, Canada, for the purpose of studying Mg-carbonate mineral precipitation. Previous studies of this site have demonstrated Mg-carbonate formation by microbes that have adjusted to high magnesium concentrations. Water sampling, metagenomic information, and climate conditions collected from the site were used to inform the geochemistry and environmental conditions of this experiment. In this study of temporal and spatial impacts on carbonate formation, a ~38 L, open top aquarium was used to mimic the conditions of the wetland and included layering the 5 cm-thick microbial mats on top of 6 cm of SRB-inoculated silica sand, using SRB enrichment cultures from the wetland sediment. Sampling ports allowed for diurnal water sampling at each mat layer. Water chemistry from 'day' and 'night' periods were analyzed, placing a focus on carbon cycling. The solution maintained a pH ~9 with alkalinity increasing over the course of the experiment (270 mg/L $CaCO_3$ initially to 1950–2200 mg/L $CaCO_3$ by week 12). The balance of individual metabolisms in the mat community maintained the overall pH and generated dissolved inorganic carbon (DIC) in the mat pore water, thereby impacting the precipitation of carbonate minerals. Tracking the flow of carbon and metabolic by-products through a laminated microbial mat provides an insight into the overall community metabolisms' impact on organomineralization of carbonate minerals. Ca-carbonate and Mg-carbonate mineral precipitation by mat layer was monitored using scanning electron microscopy, X-ray diffraction, total inorganic carbon (TIC) and total organic carbon (TOC). TIC and TOC measurements identified new carbonate mineral precipitation in the experiment, compared to mats collected from the field. Findings from this study will improve the current understanding of the biogeochemistry of natural alkaline wetland sites, which has implications in the development of CO_2 sequestration strategies at mines with ultramafic tailings.

THE EFFECTS OF METAL ADDITIONS ON MICROBIAL COMMUNITIES IN SIMULATED PERMEABLE REACTIVE BARRIER SYSTEMS

Kagan Meier[1], Collin Burelle[1], Joyce McBeth[2]
[1]University of Saskatchewan, [2]University of Regina.
E-mail: *joyce.mcbeth@uregina.ca*

Permeable reactive barriers (PRBs) are a passive treatment approach for removing or transforming metals, organic materials, and/or other constituents of concern from water. The objective of this study is to better understand the effects of metals on microbial community changes within PRBs and associated implications for the biogeochemistry of these systems. Specifically, we are interested in changes that may impact metal retention or removal, including changes in microbial community diversity and functionality, pH, redox conditions, and conductivity. We prepared batch experiments to simulate metal-containing microenvironments within PRBs; the experiments contained a mixture of leaf mulch, zero-valent iron, sand, water containing salts, and an environmentally relevant culture that included sulphate-reducing bacteria, methanogens, and nitrogen-cycling microbes. We prepared experimental treatments in triplicate including samples with nickel or cobalt added, and controls with no added nickel or cobalt. We added aqueous nickel or cobalt to the experiments at 4 week intervals. Samples of the solids and water from each experiment were taken monthly over 6 months. DNA was extracted from the solids and the V4 region of the 16S rRNA gene was sequenced with high throughput amplicon sequencing (Illumina MiSeq) to monitor microbial community changes throughout the sampling period. We also examined temporal patterns in the relative abundances of bacteria likely to have important functional contributions to the system. Metal concentrations in solution were monitored, and the fate of the Co and Ni was investigated with sequential extractions, including extraction steps for water-soluble metals, sorption, incorporation into iron oxides, and metals incorporated into sulphides or associated with organic phases. This information should help us better understand the influence of metal fluctuations in PRB systems on microbial communities, and the impact of these changes on long term PRB metal retention and biogeochemical conditions.

FORMATION OF OXIDIZED SULPHUR-RICH MAGMAS IN NEOARCHEAN SUBDUCTION ZONES

Xuyang Meng[1], Adam Simon[2], Jackie Kleinsasser[2], David Mole[3], Daniel Kontak[4], Pedro Jugo[4], Jingwen Mao[1], Jeremy Richards[1]
[1]China University of Geosciences (Beijing), [2]University of Michigan (Ann Arbor), [3]Australian National University, [4]Laurentian University.
E-mail: *xmeng1@cugb.edu.cn*

Oxidized, sulphur-rich arc magmas are ubiquitous in modern subduction-zone environments. These magmas are thought to form when the fluids released during prograde metamorphism of subducting oceanic crust and overlying sedimentary rocks oxidize and hydrate the asthenospheric mantle. In contrast, Archean arc-type magmas are thought to be relatively reduced and sulphur-poor, owing to the lower concentrations of marine sulphate and limited oxidative seafloor alteration in the anoxic ocean before the Great Oxidation Event some 2.4 billion years ago (Ga). Here we measure the total sulphur concentration and relative abundances of S^{6+}, S^{4+} and S^{2-} in zircon-hosted apatite grains from sodic and potassic intrusive rocks from the ~2.7 Ga southeastern Superior Province, Canada. We find that, rather than being reduced and sulphur-poor, the sulphur budget of the Neoarchean magma bodies was dominated by S^{6+} and abruptly increased to concentrations comparable to Phanerozoic arc magma bodies following the interpreted onset of subduction at approximately 2.7 Ga, coincident with the first global pulse of crust generation. These findings indicate that oxidized, sulphur-rich magma bodies formed in subduction zones independent of ocean redox state and could have influenced oceanic–atmospheric and metallogenic evolution in the Neoarchean.

STREAM SEDIMENT ANALYSIS FOR SPODUMENE PEGMATITE EXPLORATION IN IRELAND AND AUSTRIA

Julian Menuge[1], Lawrence Carter[2], Teimoor Nazari-Dehkordi[1], Ben Williamson[2], Gavin Rollinson[2]
[1]University College Dublin, [2]Camborne School of Mines.
E-mail: *j.f.menuge@ucd.ie*

Stream sediment geochemistry has long been used in exploration for gold and other chemically resistant minerals, typically at district or larger scales. Spodumene pegmatite bodies contain a variety of distinctive heavy minerals and common minerals with distinctive chemistry and/or texture, many of them resistant to weathering. As part of the GREENPEG project, which is developing toolkits for buried pegmatite exploration, we have applied this technique on the prospect scale (25–50 km^2) in two areas of known spodumene pegmatite subcrop beneath thin (< 1 m) soil: the Moylisha prospect, southeast Ireland and the Wolfsberg prospect on the Carinthia–Styria border, Austria. In Moylisha, ~400 Ma spodumene pegmatite was emplaced along the contact between ~410 Ma granite intruding Ordovician mica schist; in Wolfsberg, ~270 Ma spodumene pegmatite was emplaced into Variscan mica schist and amphibolite, and later metamorphosed to eclogite facies at around 90 Ma. Samples were collected mainly from first and second order streams, washed, and sieved on-site into three size fractions. Heavy mineral fractions were separated by shaking table from the 125/150 to 500 µm sieved samples. An aliquot of each heavy fraction was resin-mounted, polished and analyzed by QEMSCAN automated mineralogy. In both Moylisha (Ireland) and Wolfsberg (Austria) we demonstrate relatively high abundances of spodumene, beryl and kaolinite (among other minerals) in streams draining known subcropping spodumene pegmatite intrusions. Abundance correlations are also demonstrated by principal component analysis. Abundances of these minerals are markedly lower in samples draining other lithologies. Further, we show that certain normalized mineral associations (calculated by QEMSCAN as a percentage of what touches what in the sample), such as spodumene with beryl and spodumene with quartz, are highest in streams draining pegmatite intrusions. These findings highlight the potential of QEMSCAN of stream sediments as a vectoring tool at the district to prospect scale at early stages of spodumene pegmatite exploration campaigns.

NEW FIELD OBSERVATIONS FROM BRAZILIAN PEGMATITE: STRUCTURAL CONTROL AND RELATED MINERALOGY

Andrew Miles, Sofia Chinaglia
Univeristy of Leicester.
E-mail: *sc889@leicester.ac.uk*

Brazil provides an ideal opportunity to improve exploration targeting via studying lithium-bearing pegmatite bodies and the impacts of metasomatism on lithium mobilization, as there is excellent access to a large variety of pegmatite intrusions. The general area of Araçuaí (Minas Gerais) is the focus of the sampling for this study. Metasomatism has been observed to have altered pegmatite on a large scale; for example, metasomatic zones overprinting 100% of the host rock and extending for tens to hundreds of metres have been observed. Recent field work in Brazil also reported metasomatic alteration of spodumene crystals such that Li concentrations have been reduced from expected concentrations of around 3% to background levels (< 500 ppm). Another example of observed metasomatism was reported by producing spodumene mines, which have found that lamellae within spodumene crystals have been partially replaced by feldspar, thus reducing Li content to 1% or less in some more extreme cases. Also, in the field area in Brazil there is evidence of multiphase injection that has caused brecciation, but these observations are not well reported in the literature. Pegmatite bodies in Brazil were observed to be structurally controlled, with each orientation hosting distinct types of Li mineralization. For example, pegmatite bodies striking at 340° are unzoned and characterized by Li-bearing minerals (e.g. spodumene), but also show evidence of metasomatism over 100 m. A second group striking 310° contain spodumene and amblygonite and is frequently found in en echelon formation. A third group which trends 280° contain gems (e.g. tourmaline) and lepidolite, but rarely spodumene. A fourth group striking 060° is usually zoned and contains spodumene, petalite, amblygonite, and lepidolite. Finally, pegmatite trending at 010°, which is the primary regional trend, is frequently brecciated. These relationships between structure and mineralogy have not previously been reported in the literature. A field guide to aid geologists in rapidly assessing the economic potential of Li-bearing pegmatite bodies is in preparation. This work builds on the literature and on field observations to establish approximately eight groups of pegmatite with characteristic mineralogy, which will allow field geologists to rapidly evaluate the potential of Li occurrence and thus determine if further work is appropriate. This technique has been field-tested in Brazil, where it is possible to visit several large pegmatite outcrops each day, and where it has been found to be reliable.

PRELIMINARY PETRO-GEOCHEMICAL INVESTIGATION OF THE Ni–Cu OCCURRENCE OF W1 ULTRAMAFIC INTRUSION (WAPATIK) WITHIN THE LOWER EASTMAIN GREENSTONE BELT OF THE SUPERIOR PROVINCE, EEYOU–ISTCHEE BAIE-JAMES, NORTHERN QUEBEC, CANADA

Killian Milier[1], Michel G. Houlé[2], Benoit M. Saumur[1], Brigitte Dejou[3], Jean-Marc Lulin[3]
[1]Université du Québec à Montréal,
[2]Comission géologique du Canada – Direction du Québec,
[3]Azimut Exploration Incorporated.
E-mail: *milier.killian@courrier.uqam.ca*

The Superior Province and its greenstone belts are favourable environments for the emplacement of mafic–ultramafic intrusions prospective for Ni-Cu-(PGE) mineralization. However, remote areas of the Superior Province, such as the Eeyou–Istchee Baie-James region of northern Quebec, remain underexplored. In 2021, Ni-Cu sulphide mineralization was discovered in a previously unrecognized kilometre-scale ultramafic intrusion, referred to as "W1", within the Lower Eastmain greenstone belt (LEGB) of the La Grande subprovince. W1 is a folded, undifferentiated ultramafic sill, located on the southern flank of a regional E–W trending anticline, emplaced within the ca. 2752 Ma Kauputauch Formation. This formation corresponds to the first volcanic cycle of the LEGB and consists of a succession of volcanic and volcano-sedimentary rocks that have reached greenschist to amphibolite facies. The W1 intrusion is emplaced within sulphide-rich supracrustal rocks of the Kauputauch Formation and subsequently intruded by late felsic plutons and gabbroic dykes. It is composed mainly of peridotite, with subordinate olivine pyroxenite and pyroxenite. Small enclaves of pyroxenite are occasionally recognized within peridotite. Diffuse crosscutting contacts between peridotite and pyroxenite units suggest that they were emplaced synchronously. Several styles of Ni-Cu mineralization occur within W1: (1) disseminated sulphide within the ultramafic rocks, (2) semi-massive to massive sulphide at or near the contact with footwall rocks or internally within the intrusion, and (3) semi-massive sulphide veinlets within the metasedimentary rocks stratigraphically below the intrusion. The semi-massive to massive sulphide is the most common mineralization style and can be found at two locations, albeit with very different characteristics. A first occurrence occurs within the hinge zone of the deposit-scale fold and consists of a few horizons (0.1 to 1.15 m) of semi-massive sulphide containing ultramafic and wall rock clasts. Sulphide occurrences are an assemblage of pyrrhotite, pentlandite and chalcopyrite that grade up to 2.68% Ni, 1.30% Cu, and 0.09% Co over 3.30 m. The second occurrence occurs on the limb of the fold and exhibits a classic magmatic ore profile showing, from bottom up, massive, semi-massive, net-textured, and disseminated sulphide. It occurs in the middle of the ultramafic body, presumably at a contact between two subunits. The sulphide assemblage is dominated by pyrrhotite and is relatively depleted in chalcophile elements compared to the first occurrence. Future work will consist of petrography and whole rock geochemistry of the mineralization and ultramafic rocks of the intrusion and will provide further insight on the mineral potential of Archean ultramafic intrusions of Eeyou–Istchee Baie-James.

PERFORMANCE OF A PERMEABLE REACTIVE BARRIER 26 YEARS AFTER INSTALLATION

Austin Miller[1], Jeff Bain[1], Eva Pakostova[1,2], Carol Ptacek[1], David Blowes[1]
[1]University of Waterloo, [2]Coventry University.
E-mail: *a46mille@uwaterloo.ca*

Permeable reactive barriers (PRBs) designed to promote dissimilatory sulphate reduction (DSR) catalyzed by sulphate-reducing bacteria (SRB) are an established passive remediation technique to mitigate the environmental impacts of mine-impacted waters. At present, little is known about the long-term treatment performance, long-term contaminant immobilization mechanisms, and contaminant stability which limits design calculations for future installations. The investigated PRB, installed in 1995 at an abandoned Ni-Cu mine in northern Ontario, is the first field-scale PRB to treat mine-impacted groundwater. Geochemical, microbiological, and mineralogical analyses were conducted to investigate the performance of this PRB 26 years after installation. Within the PRB, porewater concentrations of Fe decreased by 402 mg L^{-1} (77% of mean influent) and Ni concentrations decrease from concentrations up to 255 mg L^{-1} (97 mg L^{-1} mean) to < 25 mg L^{-1}. The decrease in Fe together with an increase in alkalinity, resulted in a transition from net acid-producing porewater in the upgradient aquifer to neutral or net acid-consuming porewater downgradient of the PRB. The decrease in porewater SO_4 by 1243 mg L^{-1} (70% of mean influent), concomitant with an increase in the porewater SO_4 $\delta^{34}S$, indicate ongoing DSR and Fe sulphide precipitation. The 16S rRNA gene amplicon sequencing used to investigate the microbial community composition in the PRB system revealed the presence of cellulose degraders and fermenters, which are commonly found in lignocellulose-based sulphidogenic bioreactors. Differences in the SRB community structures were observed across the study site; *Desulphobacteraceae* were the dominant SRB in the PRB and the abundance of *Desulphobacca* was greater in the aquifer material. In addition, S- and/or Fe-oxidizing prokaryotes were detected in low abundances in the PRB material, likely contributing to S and Fe biogeochemical cycling. Geochemical extractions suggest acid volatile sulphide phases are abundant throughout the PRB and in aquifer material where organic matter is pres-

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ent. Mineralogical investigations revealed Fe sulphide and framboidal pyrite accumulated within and around organic material cellular structures. Occasional Fe (III) oxides were observed primarily in the downgradient aquifer material. The findings of this study indicate that previous treatment system lifespan assessments greatly underestimated the longevity of the treatment capacity of the PRB. The PRB appears to still be operating as designed, with complex organic compounds supporting DSR leading to efficient Fe sulphide precipitation and contaminant immobilization.

OXIDE–APATITE MINERALIZATION ASSOCIATED WITH PROTEROZOIC MASSIF-TYPE ANORTHOSITE IN THE CENTRAL GRENVILLE PROVINCE, QUEBEC: INSIGHTS FROM TRACE ELEMENT GEOCHEMISTRY OF THE LAC MIREPOIX Fe–Ti–P MINERALIZATION

Pedro Miloski[1], Sarah Dare[1], Caroline-Emanuelle Morisset[2], Joshua Davies[3], Morgann Perrot[3]
[1]Université du Québec à Chicoutimi, [2]Agence spatiale canadienne, [3]Université du Québec à Montréal.
E-mail: *miloski.geo@gmail.com*

Magmatic oxide–apatite mineralization is associated with Proterozoic massif-type anorthosite bodies, providing important resources of TiO_2 (hemo-ilmenite) and P (apatite). However, the origin of the mineralization and its genetic relationship with the anorthosite host are still highly debated. We have studied several Fe-Ti-P mineralized bodies in the central part of the Grenville Province in Quebec, with focus on two sites: the Lac à l'Orignal and the Lac Mirepoix Fe-Ti-P mineralization. Here we present a detailed chemostratigraphic study of oxide-apatite-rich cumulates across the Lac Mirepoix mineralization, located ~100 km northeast of Chicoutimi (Quebec), hosted within the eastern margin of the Vanel anorthosite (previously dated at 1080 ± 2Ma). The mineralization is (hemo-)ilmenite-dominated, accompanied by magnetite and apatite. It is subdivided into three different zones due to the appearance of different cumulate phases: zone I comprises mainly massive oxide (> 70% hemo-ilmenite ± magnetite) layers hosted in anorthosite. Towards the centre of the mineralization (zone II), massive oxide layers are less common whereas apatite-bearing cumulates appear, forming massive nelsonite (50–70% magnetite ± ilmenite and 25–30% apatite) and oxide apatite norite (OAN, 15–25% hemo-ilmenite ± magnetite and 8–20% apatite). Finally, zone III is marked by the alternation of OAN layers (10–25m), richer in magnetite, in addition to (hemo-)ilmenite and apatite, and an absence of massive oxide and nelsonite. In situ trace element analysis of plagioclase, apatite and oxides by laser ablation-ICP-MS reveals cryptic variations related to magma differentiation and multiple injections of ferrodiorite parental magmas of similar composition. In situ U–Pb dating of zircon from the OAN mineralization itself indicates two different crystallization ages between zone III (1050 ± 8 Ma) and zone I (964 ± 10 Ma), favouring a model of multi-stage injections, which is supported by trace element geochemistry. The Lac Mirepoix mineralization records the following fractional crystallization sequence of a high-Ti-P magma, residual after the anorthosite formation: first, massive oxides of hemo-ilmenite crystallized (high Ti/Fe) with primitive compositions. Oxide-apatite mineralization (OAN/nelsonite) crystallized from the residual liquid (lower Ti/Fe, evolved compositions) in which magnetite was more abundant. The observed decrease in Ti content of the evolving melt is supported by the liquid line of descent of several ferrodiorite dykes present in the area. The Lac Mirepoix Fe-Ti-P mineralization thus constitutes an important opportunity to study the timescales of formation and the different types of cumulates related to the magma differentiation from a high-Ti/Fe system (similar to the world-class Lac Tio deposit) to a low-Ti/Fe system (similar to the Lac à l'Orignal Fe-Ti-P mineralization).

THE KODAL Fe-Ti-P DEPOSIT IN THE PERMO–CARBONIFEROUS LARVIK PLUTONIC COMPLEX, OSLO RIFT, NORWAY: USING THE DISTRIBUTION OF TRACE ELEMENTS IN APATITE AND Fe-OXIDES TO CONSTRAIN ORE-FORMING PROCESSES

Ana Carolina Miranda[1], Nolwenn Coint[1], Sarah Dare[2], Eduardo Mansur[1]
[1]Geological Survey of Norway, [2]Université du Québec à Chicoutimi.
E-mail: *acrmiranda1@gmail.com*

Iron-Ti-P-rich rocks are commonly associated with mafic intrusive complexes such as anorthosite-mangerite-charnockite-granite (AMCG) and layered intrusions or related to iron oxide-apatite (IOA) hydrothermal systems. In magmatic systems, the origin of these non-cotectic rocks has been widely debated and petrogenetic models such as liquid immiscibility, fractional crystallization, mineral accumulation, and residual liquids concentrated by filter pressing have been proposed as alternatives to explain the origin of Fe-Ti-P-rich rocks and nelsonite intrusions. The Kodal deposit, located in Oslo Rift at the southern part of Norway, is the largest occurrence of Fe-Ti-P mineralization in the Larvik Plutonic Complex (LPC), with a total indicated resource of 14.6 Mt at 5.18% P_2O_5 and 24.12% Fe. Different from known occurrences hosted within AMCG suites and mafic layered intrusions, the Fe-Ti-P mineralization at Kodal is hosted within slightly to undersaturated, alkaline coarse-grained monzonite (regionally referred to as larvikite), formed during Permian rifting. The Fe-Ti-P mineralization comprises an approximately 2 km long and approximately 100 m thick, tabular, E-W trending, sub-vertical orebody, dipping towards the south. It consists of variable amounts of magnetite, apatite, augite, and ilmenite, and minor amphibole and biotite, which occur both disseminated in the monzonite and as massive nelsonite ores. The latter vary from a few centimetre intervals to zones of approximately 2 m in thickness, normally surrounded by disseminated Fe-Ti-P-rich intervals. The contact between the disseminated and massive ores may be abrupt or gradational. In the latter, oriented rhomboidal feldspars crystals immersed in a Fe-Ti-P rich matrix suggest magmatic flow structures. Round pockets of massive ore commonly occur immersed within the disseminated ore and less frequently in direct contact with the host monzonite. Due to the geometry and association with monzonitic rocks, three processes may account for the formation of Fe-Ti-P mineralization at Kodal: (i) silicate–liquid immiscibility leading to the separation of an Fe-rich melt, (ii) fractional crystallization and physical accumulation of apatite and Fe-Ti-oxides from a monzonitic magma, and (iii) apatite and Fe-Ti oxide crystallization at depth followed by upward transport, accompanied by mineral sorting, to shallow crustal levels. We have systematically sampled four representative drill cores across the Kodal deposit and have investigated the concentration of trace elements in magnetite and apatite in the host rock, disseminated and massive ores by LA-ICP-MS. This will allow us to provide constraints on the processes that led to the formation of Fe-Ti-P mineralization in the LPC.

MOLYBDENITE MINERALIZATION IN THE BURNTHILL BROOK AREA, NEW BRUNSWICK, CANADA: AN IMPLICATION OF MULTI-PULSED MAGMATISM DURING THE NEOACADIAN OROGENY

Nadia Mohammadi[1], David Lentz[2], Jim Walker[3], Kathleen Thorne[3], Neil Rogers[1], Brian Cousens[4], Christopher McFarlane[2]
[1]Geological Survey of Canada, [2]University of New Brunswick, [3]New Brunswick Geological Survey, [4]Carleton University.
E-mail: *nadia.mohammadi@nrcan-rncan.gc.ca*

The Burnthill Brook area of central New Brunswick contains six Late Devonian intrusions (Burnthill, Buttermilk Brook, Dungarvon, Sisters Brook, Trout Lake, and Rocky Brook plutons) emplaced into greenschist-facies Cambro–Ordovician graphite-bearing metasedimentary rocks of the Miramichi Group and/or Middle Ordovician bimodal metavolcanic rocks of Tetagouche Group. To help resolve the complex nature of molybdenite mineralization and its relationship with the magmatic evolution of the Burnthill Brook area, this study combines whole rock geochemistry (major and trace elements, and Sr–Nd–Hf–Pb isotopes) with U–Pb zircon and Re–Os molybdenite analysis of samples collected from the Falls Creek Mo prospect (FC) and the Burnthill Sn-W-Mo deposit. New Burnthill Brook area geochronological data, in combination with previous Ar–Ar and U–Pb data, define a protracted (25 M.y.) period of plutonism from 396 to 371 Ma. These data indicate that two distinct peaks of mineralization at ca. 380 and 378 Ma correlate with two particular pulses of magmatism occurring at ca. 381 Ma and ca. 377 to 378 Ma, respectively. The younger mineralization corresponds with the final magmatic pulse in the area and is likely genetically related to aplitic dykes present within the FC (the most fractionated phase in the system). The plutons of the Burnthill Brook area are highly evolved, high-silica peraluminous A-type granite bodies that have undergone extensive fractionation, leading to elevated concentrations of incompatible elements (e.g. Rb, Y, Nb, Cs, Th and U) and fluorine (mean = 0.08 ± 0.05 wt.%), as well as economically important elements, such as Sn, Ta, W, Mo, Zn, and Pb. The enrichment of these elements is primarily associated with fractional crystallization, a process that was amplified by repeated magmatic pulses over a protracted period, resulting in molybdenite saturation. The evolution of granite-related mineral deposits in the Burnthill Brook area is attributed to a regional-scale metallogenic epoch associated with the Neoacadian orogeny. This same metallogenic epoch is likely responsible for the formation of numerous granite-related mineral deposits across New Brunswick, and further reinforces the conclusion that pulsed magmatism during the Neoacadian orogeny (390–350 Ma) played an integral role in the formation of these deposits.

PERMIAN KLONDIKE MAGMATISM IN THE YUKON–TANANA TERRANE, NORTHERN CORDILLERA

Nadia Mohammadi[1], Alex Zagorevski[1], Bill Davis[1], Tom Pestaj[1], Richard Stern[2]
[1]Geological Survey of Canada, [2]University of Alberta.
E-mail: *nadia.mohammadi@nrcan-rncan.gc.ca*

The Yukon–Tanana terrane (YTT) of the Northern Cordillera is an allochthonous terrane comprising volcanic arcs that were constructed on Laurentian continental basement during the Late Devonian to Permian. The youngest Paleozoic magmatic episode, the Permian Klondike arc, is largely represented by the Sulphur Creek plutonic suite and the Klondike assemblage volcanic rocks in west-central Yukon. In this study, we re-investigate the Sulphur Creek (SC) suite to determine if this magmatism is related to the continental arc setting as previously suggested. Geochronology of the SC suite is relatively well constrained and zircon separates are readily available. Separates from four syenogranitic to monzogranitic samples recovered from the Mount Adami Pluton were examined: two samples, 262.7 ± 2 Ma and 262.6 ± 2.1 Ma, one sample near Patton Hill, northwest of Canadian Creek (260.8 ± 2.6 Ma), and one sample in the Stevenson Ridge area (261 ± 2 Ma). Zircon separates were repicked and imaged using backscattered electron analysis (BSE) and broadband cathodoluminescence (CL) and analyzed for oxygen isotopes using a Cameca multicollector ion microprobe. Imaging and oxygen isotope analyses were followed with sensitive high resolution ion microprobe (SHRIMP) measurements on each individual grain to verify the U–Pb ages. Analyzed zircon grains generally range from 50–300 μm in diameter, exhibit euhedral to subhedral and stubby to prismatic morphologies, and oscillatory and sector zonings, consistent with igneous crystallization. The $\delta^{18}O$ weighted mean values are (1) +8.65 ± 0.11‰ (MSWD = 2.6; n = 10), (2) +7.74 ± 0.86‰ (MSWD = 0.86; n = 13), (3) +10.35 ± 0.12‰ (MSWD = 2.3, n = 8), and (4) +8.76 ± 0.08‰ (MSWD = 1.6, n = 11). Most of the SHRIMP analyses yielded ages similar or close to crystallization ages of each sample, indicating that the $\delta^{18}O$ values characterize zircon SC suite magmatism, rather than being inherited. Sulphur Creek suite $\delta^{18}O$ values are higher than typical arc system (5.3 ± 0.3‰) or continental arcs (+5 to +8‰) and more characteristic of partial melting or assimilation of supracrustal rocks weathered or altered at low temperatures. The results are consistent with the generally potassic, alkali feldspar granite to monzogranite composition of the SC suite. Emplacement of the voluminous SC suite was broadly coeval with exhumation of orogenic peridotite and OIB-related cumulates in western Yukon. Overall, this argues against a continental arc setting but rather suggests that Permian magmatism was related to lithospheric extension and concomitant mafic underplating and crustal melting. Eclogite-facies metamorphism along the eastern edge of the YTT suggests that the terrane may have occupied a similar setting to the present-day Papuan Peninsula, where the Woodlark basin extension has propagated into the Australian continental margin.

MULTIPLE SULPHUR ISOTOPES ANALYSIS IDENTIFIES AN ARCHEAN SULPHUR INPUT TO AURIFEROUS FLUIDS AT THE PALEOPROTEROZOIC MELIADINE GOLD DISTRICT, NUNAVUT, CANADA

Philippe Mongeau[1], Crystal Laflamme[1], Patrick Mercier-Langevin[2], Guillaume Barré[1], Olivier Côté-Mantha[3], Pierre Cartigny[4], Laure Martin[5]
[1]Université Laval, [2]Geological Survey of Canada, [3]Agnico Eagle Mines Ltd., [4]Institut de Physique du Globe de Paris, [5]University of Western Australia.
E-mail: *philippe.mongeau.1@ulaval.ca*

Orogenic gold deposits are the main source of gold in Canada, but the source of the auriferous hydrothermal fluids in such deposits remains equivocal. Further, fluid–rock reactions play an important role in gold precipitation at these deposits and influence the chemical composition of sulphide phases. This project aims to document the multiple sulphur isotope signatures ($\delta^{34}S$, $\Delta^{33}S$ and $\Delta^{36}S$) of gold-associated sulphide phases in orogenic gold veins, in order to track the source and evolution of auriferous fluids and to better understand near-mine controls on gold precipitation. The Meliadine gold district, located in the western Churchill Province in Nunavut, hosts close to 10 Moz of gold, occurring as a series of deposits hosted in Archean host rocks of the Rankin Inlet greenstone belt (Tiriginaq, Wesmeg, Normeg and Pump). These deposits, thought to have been emplaced during the Paleoproterozoic Trans-Hudson orogeny, are spatially associated with the Pyke fault, forming sub-parallel quartz–carbonate vein corridors through iron formation, clastic metasedimentary (e.g. iron-rich turbidites) and metavolcanic rocks, where replacement-style mineralization occurs in iron-rich lithologies as gold associated with sulphide. Two generations of sulphide are recognized based on textural and chemical evidence and relationship to gold. Generation 1 corresponds to early, barren, pyrrhotite ± (pyrite-chalcopyrite), while generation 2 consists of gold-associated arsenopyrite–pyrrhotite ± (pyrite-galena-chalcopyrite), subdivided into 2a and 2b, with 2b associated with late-stage sulphide deformation and free gold-related arsenic-rich recrystallization haloes of 2a sulphide minerals. Multiple sulphur isotope analyses were completed in bulk (SF6+-line IRMS) and in situ (SIMS), allowing to test the efficiency of the vectoring and to better understand the role host rocks have in controlling fluid redox. Results show that the $\delta^{34}S$ sees little variation at the sample, drillhole and deposit scale with an average of $\delta^{34}S$ = 3.1‰ ± 2.8 (2 s.d.; n = 238) and indicates no correlation to gold grade. Sulphur mass-independent fractionation (S-MIF) is present in all samples, yielding average values of $\Delta^{33}S$ = 0.3‰ ± 0.2 (2 s.d.; n = 129) and $\Delta^{36}S$ = –0.7‰ ± 0.6 (2 s.d.; n = 58), which indicates an Archean metasedimentary input of sulphur to the auriferous fluids responsible for the formation of a Paleoproterozoic deposit. In situ analyses show that the $\delta^{34}S$ and $\Delta^{33}S$ remain homogeneous within sulphide grains. This new dataset shows that, here, the source of these auriferous fluids is clearly associated with fluid-rock interactions with the host rock, and that the devolatilization of deep-seated metasedimentary and metavolcanic units during prograde metamorphism may play an important role in sourcing sulphur, key to the transportation of gold at the crustal scale.

STRUCTURAL GEOLOGY, TIMING OF DEFORMATION AND BOUNDARY RELATIONSHIPS OF THE MARTYN LAKE FORMATION OF THE WAUGH LAKE GROUP, SOUTHERN TALTSON OROGEN

Nicholas Montenegro, Kathryn Bethune, Jordan Deane, Ken Ashton
University of Regina.
E-mail: *nicmontenegro13@gmail.com*

Supracrustal rocks provide important windows of insight into superposed orogenesis, but the roles played by several Paleoproterozoic sequences in the evolution of the western Rae craton remain enigmatic. One of these, the 2.02–1.97 Ga Waugh Lake group (WLg), is preserved within a greenschist-facies synformal outlier in extreme NE Alberta, bordering Saskatchewan, and was hypothesized to be an intra-

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arc/back-arc basin to the 1.99–1.96 Ga Taltson arc. As originally mapped, the WLg consists of a package of turbidites, the Martyn Lake Formation (MLfm), unconformably overlain by conglomeratic and local mafic and intermediate–felsic volcanic rocks (Doze, Sederholm, and Johnson Lake formations), in turn overlain by a thick mafic volcanic unit (Niggli Lake Formation). This study focuses on the age, deformational history, and boundary relationships of the postulated basal unit, the MLfm. Structural study indicates that the rhythmically bedded turbidites of this unit contain abundant younging reversals, indicating the presence of an earlier set of isoclinal (F1) folds. Early folding of bedding led to the development of a sub-vertical, broadly SW-striking composite S0/S1 foliation with locally preserved rootless F1 isoclines. The composite (S0/S1) foliation was later refolded about NNE-trending axes resulting in type 3 'hook-style' fold interference patterns. The MLfm structural data confirm co-axial refolding by the near coincidence of hinge lines of F1 and F2 folds. Progressive D1-2 deformation was accompanied by the emplacement of a metadiorite unit that cuts F1 folds but carries the S2 foliation and whose age, in conjunction with detrital zircon geochronology, may provide an upper limit for deposition/early deformation. However, while the MLfm bedded turbidites record two phases of folding, the unconformably overlying rocks of the upper WLg appear to record only one, i.e. the secondary phase. This hints at the possibility that the MLfm may be significantly older than the rest of the group, which may force re-evaluation of stratigraphic relationships and the back-arc model. Although it is known to be locally intruded by 1.97 Ga granitoid plutons, the fuller contact relationships of the WLg (i.e. autochthonous or allochthonous) also remain unclear. Investigation of the eastern margin of the belt indicates that MLfm turbidites are in sheared/faulted contact with a mylonitic, pink and grey gneiss whose oldest (tonalitic) component could represent basement or a strongly deformed marginal, i.e. Taltson arc pluton. Future work will be directed at U–Pb dating of key units, including the metadiorite and tonalite, to more fully elucidate the timing of deposition and deformation of the MLfm.

BASE, CRITICAL, AND PRECIOUS METALS MINERALIZATION IN THE METASOMATIC IRON AND ALKALI–CALCIC SYSTEMS OF THE SOUTHERN PROVINCE IN THE SUDBURY AND TEMAGAMI AREAS

Jean-François Montreuil[1,2], Mallory Hamilton[2], Louise Corriveau[3], Shirley Peloquin[4], Erin Adlakha[5]
[1]Red Pine Exploration Inc., [2]MacDonald Mines Exploration Inc., [3]Geological Survey of Canada, [4]Ontario Geological Survey, [5]Saint Mary's University.
E-mail: *montreuil.jean.francois@gmail.com*

In the Sudbury district (Ontario, Canada), many occurrences of precious and critical metal mineralization such as the Long Lake Au, Norstar Cu-Au and Scadding Au mines are hosted in zones of intense albitization where albitite replaced the Paleoproterozoic sedimentary rocks of the Southern Province. Regional corridors of intense sodic alteration such as those extending from at least Bruce Mine to the west, across the Sudbury district and into the Temagami area (e.g. Copperfield polymetallic copper and Golden Rose gold mines) are typical of the onset of metasomatic iron and alkali-calcic mineral (MIAC) systems. MIAC systems extend over tens of kilometres along metallogenic belts of up to 1500 km long. Individual systems form distinct deposit types as they evolve through a series of alteration facies. Beyond iron oxide-copper-gold (IOCG) deposits, the diversified suite of critical and precious metal deposits in MIAC systems can have Ag, Au, Bi, Co, Cu, Fe, Mo, Ni, P, Pb, REE, U, W and Zn as primary commodities. The Wanapitei area of the Sudbury district and the Golden Rose Mine area west of Lake Temagami, were examined as part of the Targeted Geoscience Initiative Program of the Geological Survey of Canada with complementary site visits in the Wanapitei area by the Ontario Geological Survey. All diagnostic alteration facies of MIAC systems have been recognized and linked to a range of metasomatic critical and precious metals mineralization, i.e. Ag, Au, Co, Cu, Ni and LREE. The study of alteration facies in the Wanapitei and Temagami areas also illustrates the ability of MIAC systems to form alteration and mineralization zones with a broad range of iron enrichment and iron-rich minerals. In the Belfast–Copper targets of the Temagami area and the Limestone prospects of the Wanapitei area, high temperature iron metasomatism formed mineral assemblages rich in silicate phases with variable iron sulphides or oxides. In the Scadding–Glade targets of the Wanapitei area, low temperature iron metasomatism formed mineral assemblages rich in silicates with variable iron oxide and sulphides that transition to quartz-rich assemblages. The showings and prospects of the Wanapitei area also illustrate some of the iron-poor mineralization styles that are possible in MIAC systems and provide analogues to recontextualize comparable mineralization styles in the other MIAC systems of Canada. In iron-poor mineralization zones, iron oxides occur in low abundance or are absent, and mineralization is associated with the development of alkali–calcic alteration facies with variable amounts of quartz and carbonates.

VALIDATION OF MAGMATIC, VOLCANOGENIC, AND OROGENIC MINERAL SYSTEM MODELS WITH NOVEL GEOLOGICALLY REPRESENTATIVE FEATURE MAPS

Rebecca M. Montsion[1,2], Stéphane Perrouty[1], Mark D. Lindsay[2,3], Mark W. Jessell[2], Ross Sherlock[1]
[1]Laurentian University, [2]University of Western Australia, [3]Commonwealth Scientific and Industrial Research Organization.
E-mail: *rmontsion@laurentian.ca*

Methodological advances in machine learning frequently focus on improved model prediction with limited consideration for the representativeness of geological features/processes in layers defining target characteristics. Commonly applied inputs for machine learning are sometimes oversimplifications derived from variably subjective constraints or are purely empirical data containing convoluted signals. To build on existing techniques, hybridized approaches that integrate expert knowledge with multi-disciplinary data using a variety of statistical methods are used to develop enhanced feature engineering techniques. This integrated approach has been applied to the Timmins region of the southern Abitibi subprovince in Ontario and has produced feature maps representing pre- to syn-deformation non-Euclidean distances for fluid transport, semi-discrete interpolation of geochemistry, discrete gridding of rock properties, as well as rheological and chemical contrast/gradients maps. Additionally, assemblage, mobile element gain/loss, structural complexity, and airborne magnetic intensity maps are used to comprehensively capture components controlling fertility in magmatic, volcanogenic, and orogenic mineral systems. Comparisons between conceptual mineral system models to ranked feature importance from random forests confirm that the combination of enhanced feature maps are generally representative of naturally complex local geology and may provide new geological insight about mineral systems.

DETERMINING THE ORIGIN AND MODE OF EMPLACEMENT OF AN ENIGMATIC FRAGMENTAL UNIT AT THE WINDFALL GOLD DEPOSIT

Alexander Moses[1], Jean-Luc Pilote[2], Pierre-Simon Ross[1], Sébastien Castonguay[2], Patrick Mercier-Langevin[2], Brandon Choquette[3], Édouard Côté-Lavoie[3]
[1]Institut national de la recherche scientifique , [2]Geological Survey of Canada, [3]Osisko Mining Inc.
E-mail: *alexander_sirapop.moses@inrs.ca*

The Urban–Barry greenstone belt, located in the eastern section of the Abitibi subprovince, hosts several prospective gold projects, notably the 7.4 Moz Windfall gold deposit (WGD) with a combined measured and indicated resource of 11.1 Mt at 11.4 g/t Au and an inferred resource of 12.3 Mt at 8.4 g/t Au. Windfall is hosted in a deformed and metamorphosed bimodal tholeiitic volcanic assemblage of the ca. 2718 Ma Macho Formation with stratigraphic contacts striking N to ENE and dipping 35°–80° to the ESE. Folded sequences in the northeast portion form an apparent NE-plunging synform with the SE limb sheared and truncated by the SE-dipping Masères fault. The bulk of the mineralization is located in the footwall of this structure. The stratigraphy is cut by a suite of ca. 2700–2695 calc-alkaline felsic intrusive rocks collectively called the Windfall intrusive complex (WIC), which are interpreted to pre- and post-date the main Au mineralization. The intrusions are quartz-feldspar-phyric, variably altered, and form < 1–10 m dykes and stocks. Gold is associated with sericite-pyrite stringers ± silica alteration zones and quartz-carbonate-pyrite ± tourmaline veins with mineralization occurring at or near intrusive contacts. The earliest phase of the WIC is a felsic polylithic unit that occupies the core of the synform. This ~300 m thick unit is in sharp contact with the underlying felsic tholeiitic volcanic rocks and is intruded by felsic and gabbroic dykes and hosts some of the mineralization. It is composed of sub-rounded to angular, millimetre- to centimetre-scale fragments of tourmaline, quartz–pyrite-altered igneous fragments, felsic volcanic fragments and aphyric to quartz-feldspar-phyric fragments. The matrix is mostly fine-grained but also contains rounded mm-sized quartz grains. Owing to the equivocal textures, lithofacies, and nature of contacts with surrounding units, the age and origin of this fragmental unit are poorly understood. Multiple hypotheses are considered (e.g. volcanic, sub-volcanic, or intrusive) and this study aims to resolve this question through detailed drill core logging and underground mapping, coupled with U–Pb geochronology, whole rock and mineral (EPMA) geochemistry and systematic pXRF analyses on drill core sections. Preliminary work shows fragment size variations and sharp to gradational transitions from matrix- to fragment-supported facies across multiple drill holes. Given the complexity in some of the field relationships on which metallogenic reconstructions depend, constraining the nature of emplacement of this unit is critical for defining a robust genetic model for the WGD and exploration strategies beyond the deposit footprint.

CANADA'S MARITIME FRONTIER: MAPPING CANADA'S CONTINENTAL MARGIN FOR THE UNITED NATIONS CONVENTION ON THE LAW OF THE SEA

David Mosher, Mary-Lynn Dickson, John Shimeld, Kai Boggild
Geological Survey of Canada.
E-mail: *Dcmosher@clcshelf.com*

Canada ratified the United Nations Convention on the Law of the Sea (UNCLOS) in 2003 which provided entitlement to delineate its maritime limits, or extended continental shelf (ECS), beyond 200 nautical miles (the exclusive economic zone) if certain conditions are present. These conditions pertain to the shape and geology of the continental margin. Canada subsequently spent 13 years compiling and acquiring data to provide the scientific evidence to support this delineation. As such, Canada's proposed maritime limits provide Canada with 2.4 million km^2 of additional submarine landmass in the Atlantic and the Arctic oceans over which Canada may exercise sovereign rights for the purpose of exploring and exploiting its natural resources. The tectonic framework of the continental margin, the geomorphology and geology of the margin, the geological nature of adjoined ridges, rises, and plateaus, and sediment thickness within adjacent basins are examples of fundamental pieces of geoscientific information needed to substantiate Canada's outermost maritime limits. This presentation highlights a number of segments of Canada's continental margins in the Atlantic and the Arctic to showcase this scientific evidence, how it is applied in the UNCLOS context and how it has advanced scientific knowledge of our submarine landmass. The massive data compilation in the Atlantic has led to a new conceptual understanding of the development of continental margins. For example, in a source to sink scenario, it has been shown that there is an equilibrium base level that is comparable to the dynamic equilibrium known for stream bed systems. Departures from this shape relate to the interplay of sedimentary processes. A significant part of the Atlantic margin is shown to be heavily influenced by along-slope geostrophic currents that generated massive contourite drift deposits. In the Arctic, there was less than 5000 km of seismic reflection data prior to 2006 and most bathymetric data were spot soundings. Significant technological developments and massive data acquisition in these ice-covered seas led to many discoveries, including a newly recognized seamount. Perhaps foremost amongst this new knowledge is demonstration that the Canada Basin is indeed a fully developed ocean basin. Additionally, once thought to be relatively stagnant, sedimentary processes such as found in many ocean basins were discovered in the Arctic Ocean. Evidence of geostrophic currents, sediment mass failures and deep sea turbidity current channels were found to be ubiquitous, even in the deepest parts of the Arctic's basins.

THE GREENPEG HORIZON 2020 PROJECT: EXPLORATION FOR PEGMATITE MINERALS TO FEED THE ENERGY TRANSITION

Axel Müller[1], Wolfgang Reimer[2], Frances Wall[3], Ben Williamson[3], Julian Menuge[4], Marco Brönner[5], Claudia Haase[5], Kerstin Saalmann[5], Klaus Brauch[6], Claudia Pohl[6], Alexandre Lima[7], Ana Teodoro[7], Joana Cardoso-Fernandes[7], Encarnación Roda-Robles[8], Idoia Garate-Olave[8], Jon Errandonea-Martin[8], Douglas Santos[7], Haoyang Zhou[1], William Keyser[1], John Harrop[9], Kate Smith[3], Dietrich Wanke[10], Thomas Unterweissacher[11], Ralf Steiner[11], Lawrence Carter[3], Mario Hopfner[12], Brendan Clifford[13], Paulo Moutela[13], Luigi Ranza[14], Stephan Kroner[14], Carla Lloret[1]
[1]University of Oslo, [2]Geokompetenzzentrum Freiberg e.V.,
[3]Camborne School of Mines, University of Exeter, [4]University College Dublin,
[5]Geological Survey of Norway, [6]terratec Geophysical Services,
[7]University of Porto, [8]Universidad del País Vasco-UPV/EHU,
[9]Blackstairs Lithium Ltd., [10]ECM Lithium AT GmbH,
[11]Geo-Unterweissacher GmbH,
[12]IFU GmbH Privates Institut für Umweltanalysen,
[13]Felmica – Minerais Industriais, S.A., [14]Ciaotech–PNO Group.
E-mail: *a.b.muller@nhm.uio.no*

The EU-funded GREENPEG project aims to develop multi-method exploration toolsets for the identification of buried, small-scale (< 5 million m^3) rare metal-mineralized pegmatite deposits with focus on lithium and high purity quartz resources. Silicon produced from quartz and lithium are two of the most sought-after green technology metals as they are essential for photovoltaics and Li-ion batteries in electric vehicles, respectively. The project has come into its 3rd year. Exploration method testing at province, district, and prospect scale at the GREENPEG test sites, Wolfsberg, Austria, Leinster, Ireland, and Tysfjord, Norway, are complete. These sites present a wide spectrum of challenges in exploration for European pegmatite deposits, such as variable wall rocks (Leinster), dense vegetation and long winter snow cover (Norway), extreme (alpine) topography (Wolfsberg), thick soil cover (Leinster), tills and glacial sediments hampering conventional soil geochemistry-based exploration (Norway), features which will ensure that the delivered toolsets are robust and flexible enough to be applicable in manifold environments. The toolset development is based on a new genetic model for pegmatite deposits and utilizes the lithogeochemical halo in wall rocks of pegmatite ore bodies. Verification of individual tools in the test sites showed that airborne high-resolution radiometry and magnetometry, district-scale geochemical trace element-in-quartz mapping, ground-based electrical resistivity measurements are, among others, the most successful exploration methods to detect buried pegmatite bodies of specific mineralogical types. In the next step of the toolset development, the best combinations of these methods will be established to make the toolset comprehensively applicable to different geological, topographic and climatic settings to increase exploration success and decrease environmental and societal impacts. With the delivered toolsets GREENPEG will contribute to change the focus of exploration strategies from large volume towards small volume, high quality ores and overcome the lack of exploration technologies for pegmatite ore deposits.

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THE YOUNGER DRYAS IN CENTRAL ONTARIO: UNRAVELING THE LINKS BETWEEN GLACIAL GREAT LAKES AND THE CHAMPLAIN SEA

Riley Mulligan
Ontario Geological Survey.
E-mail: *riley.mulligan@ontario.ca*

The Younger Dryas chronozone (~12,800–11,600 years before present) remains a poorly defined interval in eastern and central Ontario's glacial record due to poor road access across rugged shield highlands, lowlands blanketed by thick postglacial muds, and sparse, poorly constrained geochronology data. High-resolution lidar terrain models covering > 50,000 km^2 of the region, combined with recent field work, permit improved landform mapping and a basis for establishing geomorphological correlations of landforms and evaluating the context of past geochronology data across the region. Collectively, data indicate the presence of fast-flowing and highly topographically controlled ice during the Younger Dryas, based on locally high elongation ratios of sediment-cored bedforms and the strong correlation between moraine ridge orientations with respect to local bed topography, respectively. Ice was warm-based and subglacial meltwater was abundant, resulting in the deposition of numerous large subaquatic fans and ice-contact deltas along prominent moraine systems across multiple proglacial water bodies within the region. Many large moraines are rimmed by a series of strandplains, deltas, or raised shorelines along the margins of subaquatic fans that range up to 391 m asl in the eastern Lake Huron basin and 186 m asl in the Champlain Sea basin. Clusters of small (< 6 m high) moraine ridges may assist in constraining ice margin retreat rates and link to other geochronological data sets if they have an annual origin. Remote mapping of the highest shorelines throughout both the Champlain Sea and the Lake Huron glacial Lake Algonquin basins assists in evaluating existing waterplane reconstructions. Well-developed ice-marginal systems appear to block parts of previously proposed eastward drainage routes into the Champlain Sea, suggesting a need for revision of previous lake reconstructions. Shorelines have locally been reworked into large parabolic dunes that straddle the former shorelines and may be suitable for optically stimulated luminescence age determination. Parabolic dunes along the highest local shorelines were formed by easterly paleowinds, likely indicating a genesis from katabatic winds originating from the ice sheet. The combination of new field and terrain data and re-evaluation of past radiocarbon ages permits a new appraisal of the nature and timing of major drainage events from glacial Great Lakes into the Champlain Sea and Atlantic Ocean.

REFINING HYDROTHERMAL ALTERATION FOOTPRINTS USING HYPERSPECTRAL IMAGING AT THE HAMMOND REEF GOLD DEPOSIT IN ONTARIO, CANADA

Sean Mundreon[1,2], Stéphane Perrouty[1], Philip Lypaczewski[1,3], Olivier Côté-Mantha[2]
[1]Laurentian University, [2]Agnico Eagle Mines Ltd., [3]College of North Atlantic.
E-mail: *smundreon@laurentian.ca*

Hammond Reef is a disseminated, high tonnage, low grade Archean gold deposit located in the western Wabigoon subprovince of northwestern Ontario. Current reserves are 3.3 Moz Au at 0.84 g/t Au, with additional measured and indicated resources of 2.3 Moz Au at 0.54 g/t Au. The deposit is hosted within the tonalitic to gneissic Marmion 'batholith' and is primarily controlled by high-strain zones that relate to the regional scale Marmion deformation zone. The presence of mafic dykes, which provide local competency and chemical contrasts with the host tonalite may also partially control mineralization. Large, disseminated gold deposits are commonly characterized by extensive alteration footprints that can extend for kilometres beyond mineralization, although these alteration footprints are not always visible at a core logging scale. Automated high-resolution hyperspectral imaging of 12,000 m of drill core has been combined with regional sampling in order to investigate the variability of white mica, biotite, chlorite, and carbonate chemistries. Key absorption features for each mineral (e.g. 2200 nm, 2250 nm) are considered in conjunction with conventional analytical methods (petrography, multi-element whole rock geochemistry, X-ray diffraction and electron probe microanalysis) to provide site-specific metrics for the Hammond Reef hydrothermal footprint that can improve 3D geological domaining and vector toward mineralization in similar exploration settings. The hyperspectral imaging results suggest that the distal alteration footprint of the deposit is muscovitic (Al^{VI} ~1.9 apfu) with Fe-rich chlorite (Mg# ~50) and calcite. The proximal alteration is characterized by phengitic white micas (Al^{VI} ~1.6 apfu), Mg-rich chlorite (Mg# ~70) and Mg-rich carbonate minerals. Chlorite abundance can also be used as a vector since the gold mineralization at Hammond Reef appears to be a chlorite-destructive event.

CJES AT 60: CELEBRATING CANADIAN GEOSCIENCE AND GEOSCIENTISTS

Brendan Murphy[1], Sally Pehrsson[2]
[1]St. Francis Xavier University, [2]Geological Survey of Canada.
E-mail: *sally.pehrsson@nrcan-rncan.gc.ca*

Canadian Journal of Earth Sciences turned 60 years old in January 2023 and to mark this anniversary we are celebrating advances in Canadian geosciences that have provided seminal contributions to many sub-disciplines, including the development of the plate tectonic paradigm in ancient and modern orogens, the genesis of different types of mineral deposits, precise geochronology (which enables us to measure the pulse of the Earth), the evolution and extinction of various life-forms (from dinosaurs to dinoflagellates), oxygenation of the atmosphere over time, geophysics of the Earth's interior and the forces that create and destroy mountains. CJES was established in 1963 as a monthly peer-reviewed journal that presents all aspects of the Earth Sciences, from geomatics and geophysics to bedrock and 'soft rock' geology. Since 1964 when H.C. Gunning was the first editor-in-chief, CJES has had a dozen EICs, and has been fortunate to have been shaped by many dedicated Canadian geoscientists including John Ambrose, Ward Neale, David Piper and John Clague, with a common thread of many having been involved in science outreach and communication, and also active in the Geological Association of Canada and the Geological Survey of Canada. Over this time the journal has grown and established an international presence, publishing many important special issues on topics from paleontology to crustal architecture. This reach is exemplified by the range of contributions in this session, from fundamental advances in host magmatism of major mineral deposit types, to the development of U–Pb geochronology over the past 60 years, and major new advances in understanding of glacial dynamics and surficial geology.

APPINITE COMPLEXES, GRANITOID BATHOLITHS AND CRUSTAL GROWTH: A CONCEPTUAL MODEL

J. Brendan Murphy[1], William J. Collins[2], Donnelly B. Archibald[1]
[1]St. Francis Xavier University, [2]Curtin University.
E-mail: *bmurphy@stfx.ca*

Appinite complexes are a suite of plutonic rocks, ranging from ultramafic to felsic in composition, that are characterized by idiomorphic hornblende as the dominant mafic mineral in all lithologies and by spectacularly diverse textures, including planar and linear magmatic fabrics, mafic pegmatite intrusions and widespread evidence of mingling between mafic and felsic compositions. These features suggest crystallization from anomalously water-rich magma which, according to limited isotopic studies, has both mantle and meteoric components. Appinite typically occurs as small (~2 km diameter) complexes emplaced along the periphery of granitoid plutons and commonly adjacent to major deep crustal faults, which they preferentially exploit during their ascent. Several studies emphasize the relationship between intrusion of appinite, granitoid plutonism and termination of subduction. However, recent geochronological data suggest a more long-lived genetic relationship between appinite and granitoid magma generation and subduction. Appinite complexes may represent aliquots of hydrous basaltic magma derived from variably fractionated mafic underplates that were originally emplaced during protracted subduction adjacent to the Moho, triggering generation of voluminous granitoid magma by partial melting in the overlying MASH zone. The hydrous mafic magma from this underplate may have ascended, accumulated and differentiated at mid-to-upper crustal levels (ca. 3–6 kbar, 15 km depth) and crystallized under water-saturated conditions. The granitoid magma bodies were emplaced in pulses when transient stresses activated favourably oriented structures which became conduits for magma transport. The ascent of late mafic magma, however, is impeded by the rheological barriers created by the structurally overlying granitoid magma bodies. Magma that formed appinite complexes evaded those rheological barriers because they preferentially exploited the deep crustal faults that bounded the plutonic system. In this scenario, appinite complexes may be a direct connection to the mafic underplate and so its most mafic components may provide insights into processes that generate granitoid batholiths and, more generally, into crustal growth in arc systems.

BIOLEACHING OF MINE WASTES: SCALING UP 'NEW' TOOLS FOR CRITICAL MINERAL RECOVERY

Nadia Mykytczuk
MIRARCO Mining Innovation.
E-mail: *nx_mykytczuk@laurentian.ca*

Mine waste management has proven to be one of the greatest costs of mining, imposing an immense industry-wide challenge, as companies seek safe and permanent treatment options for stored waste. Canada's 200 active mines and approximately 15,000 abandoned mines (nearly 5700 in Ontario alone) present the single largest source of wastes produced by any natural resource industry with > 250 M tonnes deposited yearly. And yet, as we look at the incredible demand for critical minerals and the significant gap in supply, we are re-assessing these vast low-grade wastes as a viable source of elements. One of the many challenges with re-processing tailings is how to economically extract the < 1% metals of interest while also addressing the environmental liability associated with the material. Bioleaching applications for a variety of mineral wastes have existed for over 50 years, but have remained a niche application, often limited to refractory minerals. Bioleaching employs microbial communities as catalysts for mineral breakdown and release of desired elements either through oxidative or reductive breakdown allowing for recovery. Genomics tools have helped us understand many of the microbial communities (such as Fe and/or S oxidizers or reducers) which has opened the "black box" of bioleaching, and with it the potential to demonstrate it as a robust technology. We will provide some recent examples of successful bioleaching applications from tailings materials using native microbial consortia, and the recovery of precious (Au from arsenopyrite) and battery metals (Ni and Co from pyrrhotite). Efforts to accelerate the scale-up, de-risking, and commercialization of these technologies is also underway with the development of a new Centre for Mine Waste Biotechnology to be built in Sudbury, Ontario. The centre, along with a collaborative network of researchers and industry are working to bring these (not so) 'new' technologies to the toolbox as we reconsider how we manage, valorize, and repurpose mine wastes in an environmentally sustainable way.

THE PETROGENESIS OF NEOPROTEROZOIC MAGMATISM AND ASSOCIATED FENITIZATION IN SOUTHEASTERN YUKON TERRITORY

Tiera Venesse Naber, Lee Allan Groat
University of British Columbia.
E-mail: *tnaber@eoas.ubc.ca*

Alkaline silicate complexes located in SE Yukon have received minimal academic study due to their remote locations. The Pool Creek syenite is a Neoproterozoic syenite complex composed of nepheline syenite, pyroxene syenite, amphibole–pyroxene syenite and amphibole syenite. In this study we present geophysical, geochemical, mineralogical and geochronological data collected from fenite and syenite associated with the Pool Creek syenite complex. Fieldwork covered the southwestern area of the complex. Rock types analyzed in this study include nepheline syenite, arfvedsonite–aegirine syenite, arfvedsonite syenite, actinolite syenite, layered fenite, fenite breccia and argillite. Hand-held gamma ray spectrometry survey results show that outcrops of fenite and syenite bearing amphiboles and pyroxenes are elevated in K, U, and Th in comparison to the sedimentary country rock and U and Th in comparison to nepheline syenite. Whole rock geochemistry data show that syenite and fenite are elevated in F, Na, K, Fe, Ti, Y, La, Ce, Pr, Sm, Nd, Nb, Ta, Zr, Pb, Th and U with respect to the country rock. Mineral phases bearing rare earth elements Nb and Ta in nepheline syenite include bastnäsite-(Ce) and fluorapatite, and phases in non-nepheline syenite and fenite include fluorapatite, niobian rutile, niobian titanite, allanite-(Ce) and -(La), fluorocalciopyrochlore, and columbite-(Mn) and -(Fe). The textures of the non-nepheline syenite and fenite strongly vary with changes in the degree of alteration, whereas the textures in nepheline syenite, argillite, and quartzite do not. Mineralogical and geochemical evidence show that syenite and fenite have experienced varying degrees of sodic metasomatism. Uranium–Pb in situ zircon geochronology shows that the age of emplacement of the syenite likely occurred between 680 and 630 Ma and the alteration between 630 and 590 Ma. Zircon in non-nepheline syenite and fenite shows visible alteration and are elevated in LREE in comparison to unaltered zircon in nepheline syenite. The findings of this study reveal the diverse and complex geology described in less than a quarter of the area of the Pool Creek syenite complex and its fenite aureole, highlighting the need for in-depth mapping and sampling to be conducted across the syenite and fenite units to understand the system. These findings show that alkaline complexes in the Canadian Cordillera extend into the Yukon Territory and will aid in creating exploration models for similar rare earth and high field strength element occurrences in the Canadian Cordillera.

CRITICAL METALS AT PORPHYRY Cu DEPOSITS

Olivier Nadeau
IOS Services Géoscientifiques.
E-mail: *nadeau.oli@gmail.com*

Porphyry Cu deposits are primary providers of Cu-Au-Mo, but have also recently become the most important sources of Se-Te-Re. Although Au and Se are not considered critical by Canada, Cu and Mo are, as Cu is one of the most important metals for electrical devices, and Mo is an essential constituent of alloys used for example in power generation turbines. Similarly, Te and Re are also deemed critical, as Te is used in photovoltaic solar cells, and Re is used in advanced materials such as superalloys. Selenium is considered critical in many other countries as it is also a photoreceptor. Given the wider distribution of hydrothermal alteration over mineralization, most techniques used to find porphyry deposits are derived from the geophysical, geochemical or mineralogical signatures of alteration haloes. Pioneering work defined zones of potassic alteration centred on intrusions, with zones of phyllic-, argillic-, and propylitic alterations located gradually more distally in the periphery. The model was refined over time, with zones of sodic–calcic alteration, zones of chlorite-sericite and sericitic alteration overlying the potassic alteration, and different zones of argillic alteration overlying the sericitic alteration. More recently, scientific advances in clay mineralogy allow further characterization of high-temperature advanced argillic-, intermediate argillic- and argillic zones of alterations. Traditional porphyry Cu-type mineralization consists mostly of chalcopyrite, with subsidiary amounts of other Cu sulphides, Cu arsenosulphides, and molybdenite. Trace amounts of Au might also occur in sulphides. This mineralization is commonly hosted in potassic-chlorite-sericite- and sericitic alteration, and epithermal-type Cu-Au-Ag mineralization might also be present in the argillic alteration. By contrast, Se generally replaces S in sulphides, reaching up to a few hundred ppm, but rarely forms selenides, Te is commonly present as tellurides but might also occur in sulphides, and Re generally replaces Mo in molybdenite. Porphyry Mo hosts more Re than porphyry Cu but the latter hosts molybdenite with higher Re. The geochemical behaviours of Se-Te-Re differ from those of Cu-Mo-Au, so that the critical metals should in principle reach maximum concentrations in different zones than Cu-Mo-Au sulphides. Although Se-bearing sulphides, tellurides, and Re-bearing molybdenite are recovered from Cu-Mo-Au ores from phyllic and argillic-type alterations, a lot remains to be discovered about the distribution and ore potential of Se-Te-Re. Characterizing clay minerals and quantifying Se-Te-Re in rocks and minerals from different alteration zones, using advanced techniques, will increase Canada's potential for critical metals, clean energies, and strategic resources.

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VECTORING TOWARDS VMS-TYPE MINERALIZATION IN THE SELBAIE MINING CAMP (ABITIBI, QUÉBEC) USING PYRITE CHEMISTRY FROM SEMI-CONCORDANT MATTABI-TYPE CARBONATE ALTERATION

Rémi Naulot[1], Dominique Genna[1], Sarah Dare[1], Jean-Daniel Fortin-Rhéaume[2]
[1]Université du Québec à Chicoutimi, [2]Soquem Inc.
E-mail: *remi.naulot1@uqac.ca*

Volcanogenic massive sulphide (VMS) deposits are a significant source of base metals (Cu, Zn) classified as critical and strategic by the Government of Canada, and one of the main types of deposits in Canada's greenstone belts. These deposits are known for their large alteration haloes, which are commonly used for exploration. VMS deposits can be classified based on their alteration minerals: 1) Noranda-type, with a chlorite–sericite alteration, and 2) Mattabi-type, with wide semi-concordant carbonate alteration superimposed over the chlorite–sericite assemblage. This carbonate alteration is typically zoned, with siderite proximal to the deposit, then ankerite and calcite in distal zones, and can be used as a basic vectoring tool towards the mineralization. However, trace elements in whole rocks and minerals are much more sensitive tracers of the hydrothermal fluids' evolution than a simple change in mineralogy of the alteration assemblage. The aim of this study is to investigate the spatial variation of trace elements in pyrite, hosted in carbonate-bearing units around the B26 prospect, in order to evaluate their potential as exploration tools for Mattabi-type VMS. The B26 Cu-Zn-Ag-Au prospect is an Archean VMS located in the Selbaie area in the northern part of the Abitibi greenstone belt and interpreted to be mainly formed by sub-seafloor replacement of the felsic volcaniclastic host rocks. Carbonate alteration is stratabound, most intense at the transition between the footwall and hanging wall of the mineralization, and continuous for 10 km. It is generally associated with chlorite, sericite and pyrite. Pyrite chemistry, analyzed by LA-ICP-MS, is used to characterize the signature of the hydrothermal fluids that produced the mineralization and their evolution with the distance to the orebodies. The pyrite database is composed of 52 samples, most of which are located within the carbonate-altered units, from proximal to the mineralization up to 6 km from it. It also includes data from the mineralization, regional graphitic shale, barren massive sulphide lenses and metamorphic overprint for comparison. Preliminary results show that pyrite from the carbonate alteration is volcanogenic in origin. Moreover, the combination of both raw data and advanced statistical tools shows that pyrite composition displays coherent variation both vertically and laterally, especially with volatile metals such as Ag, Bi and Te. Therefore, pyrite chemistry from these carbonate-bearing units could be used as a vectoring tool for exploration.

ADVANCES IN METHODOLOGY TO APPLY PALEO-RECONSTRUCTION MODELS IN MINERAL DEPOSITS EXPLORATION

Hoang Anh Tu Lavie Nguyen, Bruce Eglington, Dène Tarkyth
University of Saskatchewan.
E-mail: *hoanganhtu.nguyen@usask.ca*

The geological reconstruction period and the detailed geodynamics encapsulated in current paleo-reconstruction models have greatly improved in the last few decades. Hence, there is more interest in both academia and industry to use these reconstruction models to investigate the temporal and geographic distribution of ore deposits. The architecture of most paleo-reconstruction models contains two elements: a polygon features file and a rotation file. Each polygon feature represents a geodynamic building block for the model. Each record in the rotation file contains information to translate geodynamic blocks from the present day to any time in the past. Although most current reconstruction models have similar architecture, there are very few reported methodologies which can be consistently applied across different reconstruction models to study the distribution of ore deposits over time. Furthermore, there are some distinct differences among models: (1) the presence or the absence of plate tectonic boundaries; (2) the capability to perform Archean reconstruction; (3) the level of details in geodynamic building blocks (i.e. the geometry, the valid geological age, the number of building blocks, etc.). These differences among models create challenges to formalize methodology to work with reconstruction models. In this presentation, we present the method to distinguish igneous activity from various tectonic environments (i.e. volcanic arcs associated with convergence or rift zones associated with divergence) in relation to various types of mineral deposits by utilizing kinematic information derived from the paleo-reconstruction model. We use two distinct reconstruction models to demonstrate our methodology.

INFLUENCE OF FRACTURE APERTURE ON THERMAL WEATHERING PROCESSES IN FRACTURED SEDIMENTARY ROCKWALL

Julia P. Nielsen, Henry J.M. Gage, Carolyn H. Eyles
McMaster University.
E-mail: *nielsj2@mcmaster.ca*

The Niagara Escarpment is an actively eroding prominent geological feature that spans from southern Ontario, Canada, to northern Michigan in the United States. Minimal research has been conducted on the highly fractured sedimentary cuesta in Hamilton, Ontario, which is subject to thermal weathering processes in a temperate climate. Unfortunately, the inherent structural instability of the fractured rock wall poses serious threats to adjacent urban infrastructure and access routes. The focus of this study is to determine the influence of fracture aperture on the rock wall thermal regime and weathering processes. To examine this, thermistors were placed at a depth of 12 cm into four sub-vertical fractures varying in aperture from 6 to 32 mm. Each fracture thermistor was paired with a surface thermistor affixed to the adjacent rock wall surface. Data were collected between June 2022 and February 2023 and analyzed in one minute increments to capture rapid thermal changes which can trigger thermal shock processes. The data collected suggest that on a diurnal basis, a greater inversion of the surface fracture temperature gradient occurs for apertures greater than 15 mm in width. Increasing the number of thermistors employed in the study may allow a threshold aperture for increased thermal weathering processes to be identified in the aperture range of 6 mm to 15 mm. However, other factors that may have a greater contribution to the thermal gradient and weathering processes in the sub-vertical fractures, including roughness, fracture intensity and density, moisture, and their relative surface area volume ratios, must also be considered.

IN SITU MICA Rb–Sr GEOCHRONOLOGY, CHEMISTRY AND FLUID INCLUSION MICROTHERMOMETRY OF THE BRAZIL LAKE PEGMATITE, YARMOUTH COUNTY, NOVA SCOTIA

Adam Nissen[1], Dawn Kellett[2], Jacob J. Hanley[1]
[1]Saint Mary's University, [2]Geological Survey of Canada–Atlantic.
E-mail: *adam.nissen@smu.ca*

The Brazil Lake pegmatite (BLP) is a Li-Cs-Ta (LCT) style pegmatite hosted in metapelite of the Meguma Terrane in Yarmouth County, NS, Canada. The established geochronology of the BLP reflects a regional trend of post-emplacement thermal fluid processes partially or fully resetting geochronometers. Mica $^{40}Ar/^{39}Ar$ ages in the pegmatite post-date the emplacement (ca. 395 Ma) by 40 to 80 million years. We have investigated mica variants within the pegmatite with spatially constrained, in situ Rb–Sr geochronology in which mica is dated via laser ablation triple quadrupole mass spectrometry to better understand the microspatial distribution of age domains within the pegmatite. These age data are integrated with in situ major and trace element geochemistry (EMPA, LA-ICP-MS) and fluid inclusion microthermometry. In reconciling these data we aim to interpret the timing and nature of mica mineralization and metasomatism within the context of the magmatic–hydrothermal evolution of the pegmatite. Rb–Sr dates indicate distinct periods of mica growth between the previously established age of pegmatite emplacement (ca. 395 Ma) through the Late Devonian (ca. 370 Ma). Carboniferous ages from distinct mica textures and species in the margin of the pegmatite suggest the presence of metasomatic fluids between 360 and 315 Ma. Quartz cathodoluminescence imaging (SEM-CL) indicates extensive secondary dissolution–reprecipitation. Fluid inclusion assemblages in the dissolution "channels" exhibit salinities between 5 and 12 wt.% NaCl equivalent, with homogenization temperatures ranging from 150 to 300°C. These fluid inclusion data produce wide isochore fields, which suggest non-isochoric variation in pressure or temperature that may contribute to the variable resetting of lower temperature geochronometers. Ongoing work will map the microspatial age domains within the pegmatite to associate ages with textural and geochemical variation evident in the mica. These Rb/Sr ages will be compared to adjacent in situ and bulk mineral separate $^{40}Ar/^{39}Ar$ dates to contrast these two methods for mica geochronology in a setting with a complex thermal and fluid history. Major contributions from this work include (1) providing insight into the applicability of in situ Rb/Sr geochronology in a LCT pegmatite setting; (2) producing a framework for interpreting the microspatial relationships between disparate in situ data; and (3) informing critical mineral exploration and mining in the Canadian Appalachians.

TILL GEOCHEMISTRY AND INDICATOR MINERALS APPLIED TO CRITICAL MINERALS EXPLORATION: EXAMPLES FROM THE SLAVE GEOLOGICAL PROVINCE, NORTHWEST TERRITORIES, CANADA

Philippe Normandeau, Gideon Lambiv Dzemua
Northwest Territories Geological Survey.
E-mail: *philippe_normandeau@gov.nt.ca*

A research initiative for the Northwest Territories Geological Survey aimed at identifying signatures of rare earth elements (REEs) and other critical metals in till samples within the Slave geological province (SGP) was initiated in 2021 and expanded in 2022. Till samples were collected according to the most recent protocols from the Geological Survey of Canada and included collecting sample pairs for indicator mineral analyses and till geochemistry. In 2021, ten such sample pairs were collected over large igneous alkaline–carbonatite complexes. Six of the sample pairs were collected from the Squalus Lake complex (SLC) and four from the Big Spruce Lake complex (BSLC). Heavy mineral concentrates from these sites are characterized by high amounts of apatite, especially over the SLC where apatite accounts for over 60 wt.% of the nonferromagnetic heavy mineral concentrate, including one sample with 98 wt.% apatite. Large (5–10 cm), radiating, red-brown apatite crystals were also observed in outcrop at the SLC. Till samples from the BSLC contain lower amounts of apatite but also contain monazite, which is absent in the SLC till samples. Other picked minerals include scheelite, gahnite and tourmaline. Geochemical analyses were performed on the silt- and clay-size fraction using both aqua regia and 4-acid digestions. Results from both digestions indicate that Mo, P, La, Li, Y, Ce, Pr, Nd, Sm, Eu, Gd, Tb and Dy are all present in concentrations at least two times higher than the background values of the SGP. The 2022 sampling campaign was hindered by the thin, discontinuous and heavily reworked till present in areas with known pegmatite-related showings in the SGP. However, successful sampling down-ice of the Best Bet, Tan-Echo-Thor, Hidden Lake cluster, BEN, Van Dyke, and the VO pegmatite clusters resulted in twelve pairs of till samples. Indicator minerals recovered from the samples include monazite, zoisite, scheelite, tourmaline and rutile. Spessartine, almandine and grossular garnet were also picked. Geochemical anomalies are inconsistent between these pegmatites and between digestion methods, but include elevated values of Co, Mn, Cd, V, Ca, Y and Li. Future work will study the attrition process of spodumene and its relationship to the Li anomalies and fieldwork in 2023 will investigate pegmatites located in areas of thick till surrounding Aylmer Lake.

SULPHUR ISOTOPE DISEQUILIBRIUM IN THE RUM LAYERED SUITE, NW SCOTLAND

Brian O'Driscoll[1], Amy P. Parker[2], James M.D. Day[3]
[1]University of Ottawa, [2]University of Manchester,
[3]SCRIPPS Institution of Oceanography.
E-mail: *brian.odriscoll@uottawa.ca*

Base and precious metals partition strongly into sulphide melt during magmatism in the Earth's crust, so sulphide minerals play an important role in critical metal mineralization. The ~60 Ma Rum layered intrusion (NW Scotland) is a useful locality for examining sulphur cycling in basaltic magmatic systems, including the role of crustal contamination in providing the sulphur for platinum-group element (PGE) enrichment. Chromitite seams enriched to ppm levels of Pt and Pd occur within the intrusion. Gabbro and peridotite containing disseminated sulphide mineralization occur around the intrusion margins, for which assimilation of the surrounding Mesozoic sedimentary rocks has been interpreted as the driver for sulphide saturation in the parental magma. The sulphur isotope system is a powerful tool for assessing magma–crust interactions, and these marginal lithologies have previously been reported to have (relatively) isotopically light $\delta^{34}S$ (general form: $([^{34/32}S_{Sample}/^{34/32}S_{Standard}] - 1) \times 1000$) values; as low as ~ –18‰. Notably, the Mesozoic sequence contains Jurassic mudstone with a $\delta^{34}S$ range of –34 to –15‰. Here a combined laser ablation ICP-MS (LA-ICP-MS) and secondary ion mass spectrometry (SIMS) approach is applied to analyze PGE abundances and sulphur isotopes, respectively, in sulphide from the Rum intrusion. The aim is to assess links between sulphur isotope composition and PGE tenor/distribution at sub-cm length-scales, particularly in Rum chromitite where base metal sulphides play a key role in hosting the significant PGE mineralization. Chondrite-normalized PGE patterns for the marginal disseminated sulphides are similar; pentlandite and chalcopyrite have pronounced negative Pt anomalies, and positive Rh and Pd anomalies are characteristic of chalcopyrite. By comparison, chromitite PGE patterns are enriched by at least an order of magnitude, up to $10^3 \times$ CI-chondrite, and are generally much more variable. Significant inter- and intra-grain $\delta^{34}S$ heterogeneity (> 10‰ over length scales of µm to mm) is observed in all samples, with implications for cooling rates to below diffusive closure. Country rock assimilation accounts for coupled isotopically light $\delta^{34}S$ values (–15 to –12‰) and relatively high S/Se ratios (mean of 5090, n = 33) in the marginal samples, but relatively heavy $\delta^{34}S$ (up to +5‰) together with lower S/Se ratios (mean of 1120, n = 13) in PGE-rich chromitite point to localized sulphur loss. Appreciable (albeit accessory) quantities of sulphide remain in chromitite, so desulphurization may have occurred at < 800°C, perhaps associated with crystallization of the base metal sulphides and platinum group minerals, when only 40–50% of the sulphur budget needed to be lost (as SO_2).

GEOCHEMISTRY OF DETRITAL CORUNDUM RECOVERED BY HEAVY MINERAL SURVEYS: A POTENTIAL NEW METHOD FOR FINDING RUBY AND SAPPHIRE DEPOSITS IN CANADA

Ofure Onodenalore, Philippe Belley
Memorial University of Newfoundland.
E-mail: *oonodenalore@mun.ca*

Gem corundum deposits are usually discovered fortuitously, as exploration is currently limited by the lack of existing region-scale methods that could be used to identify potential for these deposits. Ruby and sapphire deposits form in a wide range of geological environments, many of which exist in Canada, where several gem and near-gem corundum occurrences are known. A collection of 380 corundum grains from till and fluvial sediments was provided by the Geological Survey of Canada, multiple provincial and territorial surveys (NL, NU, BC, NWT, YT) and an independent claim owner. Representative grains were selected from each study area in addition to grains that could be indicative of a gem deposit (i.e. highly transparent, coloured grains). These grains were characterized with regard to physical properties (including colour), mineral inclusions, adhering materials and trace element composition (Mg, Ti, V, Cr, Fe, Ga and others). The oxygen isotope composition of a selected subset of corundum grains was determined using in situ secondary ion mass spectrometry (SIMS). These data were compared to that of corundum from known deposit types. Bedrock geology and surficial geology ice direction maps were examined for each locality, and the bedrock geology of the probable source region was used to identify potential corundum-forming environments that are most geologically compatible with this local geology. Initial results from samples collected from the Mackenzie Mountains, NWT, show three main subpopulations of grains with trace element and oxygen isotope geochemistry that suggest likely formation in a skarn environment. This is consistent with the local geology of the region, where Cretaceous plutons intrude shale and carbonate strata and tungsten skarn mineral occurrences are known. The combination approach to detrital corundum provenance estimation – using (1) corundum trace element chemistry discrimination, (2) corundum mineral associations, and (3) geology of the sediment source region – offers a new way to identify potential ruby/sapphire greenfields using existing heavy mineral surveying efforts and adding minimal additional costs. Detrital corundum can originate from fine-grained and non-gem quality corundum sources. Thus, while fine-grained detrital corundum has the potential to be used as a pathfinder for ruby/sapphire deposits, survey results would require careful follow-up sampling and assessment to identify whether gem deposit potential truly occurs in the area.

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STRUCTURAL HISTORY OF THE UPPER BEAVER Au–Cu DEPOSIT, ONTARIO

Ruth Orlóci-Goodison, Bruno Lafrance
Laurentian University.
E-mail: *rorlocigoodison@laurentian.ca*

Upper Beaver is a Au-Cu deposit located midway between Kirkland Lake and Larder Lake (Ontario) in the world class Kirkland Lake gold camp. It is hosted on the north limb of the Spectacle Lakes anticline (SLA) at the contact between the Upper Tisdale (felsic/intermediate volcanic rocks) and Lower Blake River (mafic volcanic, volcaniclastic, and sedimentary rocks) assemblages, approximately 5 km north of the Cadillac–Larder Lake deformation zone (CLLDZ). Mineralization is spatially and temporally associated with the calc-alkaline, polyphase Upper Beaver Intrusive Complex (UBIC) and is hosted in steeply dipping panels, which trend ~035°, parallel to feldspar porphyry dykes emplaced with the UBIC. The segment of the Tisdale–Blake River contact proximal to the Upper Beaver deposit trends approximately northwest and dips steeply northeast, with bedding in the Tisdale assemblage on this segment striking parallel to the contact. Bedding in the volcaniclastic and sedimentary rocks of the Blake River Assemblage is nearly orthogonal to the contact, suggesting that the contact is faulted. The presence of the UBIC on both sides of this fault suggests that it formed early, prior to the emplacement of the UBIC and the deposit, most likely as a listric normal fault. The Upper Beaver deposit is overprinted by three distinct ductile deformation events correlated with regional D3, D4 and D5. D3 is characterized by an east- to southeast-trending, steeply dipping S3 foliation which is the prevailing fabric at the deposit scale and is axial planar to the SLA. The Upper Beaver deposit was likely tilted during the formation of the SLA. S3 is heterogeneously developed across the deposit due to strain partitioning within the Tisdale assemblage volcanic rocks, in areas of strong sericite ± chlorite alteration, and along the Tisdale–Blake River contact where it underwent strong dextral refraction due to flexural slip during SLA folding. Recrystallization of ore-phase veins during D3 suggests that structurally assisted gold remobilization may have occurred. S3 is overprinted immediately west and south of the deposit by a north-striking S4 crenulation cleavage, which formed during east–west D4 shortening, and sinistral-reverse reactivation of the northwest-trending segment of the Tisdale–Blake River contact. The deposit is subsequently weakly overprinted by a northeast-trending S5 cleavage which forms rare dextral shear bands and is related to the dextral reactivation of the CLLDZ to the south.

EARLY ANNELID EVOLUTION REVISITED IN LIGHT OF NEW DISCOVERIES FROM THE CAMBRIAN BURGESS SHALE

Hatena Osawa[1], Jean-Bernard Caron[2]
[1]University of Toronto, [2]Royal Ontario Museum.
E-mail: *hatena.osawa@mail.utoronto.ca*

Cambrian Burgess Shale-type Lagerstätten yield exceptionally preserved fossils of soft-bodied animals, including polychaetous annelids. Thirteen such polychaete species have been described so far, with six from the Burgess Shale in British Columbia alone. Three of these species were described by Walcott in 1911, and Walcott's specimens were revisited in the 1970s by Conway Morris, who added two species. One new Burgess Shale species, *Kootenayscolex barbarensis*, has been described since then. Outside of the Burgess Shale, two new Cambrian polychaete species were reported from Greenland in 2008 and 2011, followed by descriptions of five new polychaete species from China after 2015. While the number of described Cambrian annelid species has almost doubled in this past decade, our knowledge of the early evolutionary history of annelids remains relatively limited. Unfortunately, most of the new species described from outside of the Burgess Shale are not particularly well-preserved and are known only from a handful of specimens or, in some cases, from a single specimen. The poor preservation, low number of taxa, and limited morphological data available continue to impact the resolution of phylogenetic analyses and ecological interpretations. Studies of Burgess Shale annelids have historically been based on Walcott's collection at the Smithsonian Institution and, to a lesser extent, the smaller collections held by the Geological Survey of Canada. Royal Ontario Museum field expeditions started in 1975 and continue to yield many specimens, most of which have not yet been studied. Exceptions include *Kootenayscolex barbarensis*, which has provided key insights into the evolution of the annelid head, new specimens of *Canadia spinosa* that show that Cambrian annelids already had a complex nervous system, and an abundant new species, currently under review, which provides post-embryonic ontogenetic information. Ongoing work on the Royal Ontario Museum collection includes a thorough survey of all polychaete fossils, in particular those of prospective new species collected from recently explored sub-localities of the Burgess Shale in Kootenay National Park, as well as re-examinations of previously known taxa from classical localities in Yoho National Park. Together with other recent studies, our preliminary results suggest that Cambrian polychaetes were morphologically and ecologically more diverse than previously expected. Continued studies will improve our understanding of the diversity, disparity, and, more generally, the evolution of early annelids.

EXTRATERRESTRIAL SOURCES FOR CRITICAL MINERALS

Gordon Osinski
Western University.
E-mail: *gosinski@uwo.ca*

The Canada Mineral and Metals Plan released by Natural Resources Canada in March 2019 recommends that the federal government should develop a policy approach for mining "new frontiers". Among these new frontiers is the explicit inclusion of space resources and space mining. Once the realm of science fiction, the growing depletion of critical minerals and metals here on Earth is leading many companies to look towards space resources as a new frontier. Canada is not alone in expressing an interest. In Europe, the establishment by the Luxembourg government of the European Space Resources Innovation Centre (ESRIC) in partnership with the European Space Agency was a major step forward. And in September 2021, NASA announced a solicitation for private companies to extract and return lunar regolith to spur the development of commercial space resources technologies. When it comes to space resources, in the short term, there is a need for the extraction and use of resources in situ, commonly referred to as In Situ Resource Utilization (ISRU). While the near-term focus for ISRU and space mining is H_2O – for use as rocket propellant and for water and oxygen for astronauts – the extraction of critical minerals from asteroids is the topic of active studies. But how realistic is the mining of critical minerals in space? Canada's Critical Minerals List identifies 31 minerals and metals. In this contribution, we review the potential extraterrestrial sources of these minerals and metals. As a case study, the six platinum group elements (PGEs) – ruthenium, rhodium, palladium, osmium, iridium, and platinum – are highly sought after. Given their highly siderophile nature, PGEs partitioned strongly into the Earth's core during differentiation, leaving the crust and mantle depleted. Differentiated asteroids subsequently broken up by meteorite impacts thus offer a tantalizing target for PGE exploration in space. Iron meteorites can be used as analogues for metallic asteroids. While the literature contains limited data on the full suite of PGE contents in iron meteorites, studies by J. Wasson and colleagues have reported a mean concentration of 27 g/t. For comparison, this is approximately three times the ore grades in the Bushveld Complex, South Africa. Asteroids thus appear to be a viable source for critical minerals. Canada, with its long history of mineral exploration and mining combined with world-class expertise in space robotics and instrumentation, is ideally placed to play a leading role in space resource utilization in the decades to come.

GOLD MINERALIZATION ASSOCIATED WITH PROTRACTED ACCRETIONARY HISTORY OF THE CARIBBEAN LARGE IGNEOUS PROVINCE

Alexander Ovas[1], Richard E. Ernst[1], Hafida El Bilali[1], Simon Jowitt[2], Brett Kuzmicz[1]
[1]Carleton University, [2]University of Nevada Las Vegas.
E-mail: *alexovas@cmail.carleton.ca*

The Western Cordillera of South America is a region known to host extensive gold mineralization. Deposits vary but are most notably found to be volcanogenic massive sulphide (VMS), porphyry Cu-Au or vein-hosted epithermal type. Western Ecuador and Colombia, as well as the Isthmus of Panama all exhibit rich Au endowment with some deposits exceeding 100 Mt Au. This research postulates that a spatial and temporal relationship exists between Au mineralization within western terranes of all three nations, with a protracted emplacement and accretionary history of the Caribbean Large Igneous Province (C-LIP) between 90–58 Ma. The formation and accretion of C-LIP represents a significant magmatic and thermal event which can provide an explanation for Au endowment, and metal mobilization for some VMS, porphyry and epithermal gold deposits within plateau-related terranes. In the case of porphyry-type deposits, fractionation during stacking and imbrication of accreting C-LIP rocks induced multi-pulse silicic intrusions which were endowed in mobilized Au.

INTEGRATED 3D MODELLING AND ASSOCIATED MACHINE LEARNING TARGETING: THE JAGUAR GREENSTONE BELT EXAMPLE IN AUSTRALIA

Jean-Philippe Paiement[1], James Reid[1], Aurore Joly[1], Glenn Pears[1], John Hamill[2]
[1]Mira Geoscience Ltd., [2]Aeris Resources Ltd.
E-mail: *jeanphilippep@mirageoscience.com*

An integrated geological interpretation of the Jaguar greenstone belt (JGB) in Western Australia was completed. The 3D structural and stratigraphic regional model, consistent with geophysical data sets, was the foundation for the exploration model. The targeting and prospectivity analysis were based on quantifying exploration criteria and explicitly representing these criteria in the exploration model for subseafloor replacement-style volcanic-hosted massive sulphide (VHMS) deposits. First, the regional geological model was built from geological constraints (mapping, drill holes) but also developed in close integration with potential fields data, producing a viable starting model for geologically constrained inversion to solve for rock property variations within geological domains. When the model thus constructed was submitted to geologically constrained inversion to reconcile unexplained response as property variations within those domains, sensible/stable property variations were recovered in the inverted model, which it was possible to interpret in terms of alteration and potential targets. The exploration criteria were translated using the integrated 3D model to create exploration vectors that were representative of the mineral system. In other words, these vectors were numerical realizations of the various targeting criteria. The prospectivity analysis at Jaguar used a machine learning approach, namely Random Forests, to generate a 3D mineral potential index based on different combinations of input exploration vectors. This resulted in the identification of 41 separate targets within the JGB.

AUTOMATED INDUCTION HEATING OF QUARTZ FOR IN SITU COSMOGENIC C-14 MEASUREMENTS

Cody Paige, John Gosse, Lauren MacLellan
Dalhousie University.
E-mail: *cody.a.paige@dal.ca*

Cosmogenic isotopic compositions, such as ^{14}C, are produced when cosmic ray particles interact with atoms in exposed minerals. Owing to its relatively fast decay and high muogenic production rates, in situ ^{14}C has advantages above other long-lived radioactive or stable isotopes for a wide range of earth sciences applications. A new ^{14}C extraction system at Dalhousie University (DCELL) builds on recent innovations from other labs and introduces two additional features – ultra-high vacuum (UHV) without Viton seals and induction heating – to improve process blank levels (kiloatoms), reproducibility, and efficiency. DCELL is a fully automated, UHV stainless steel extraction line that uses induction heating to extract ^{14}C from quartz. The 10 kW induction furnace heats cleaned quartz sand in one or more platinum tubes within a sapphire combustion chamber so that the insertion of masses > 10 g is possible. Two system-integrated off-axis pyrometers with overlapping temperature ranges (200–1500°C and 800–2300°C) control the heating rates of the tubes. Tests using various platinum boat geometries suggest that a tube is an optimal geometry to maximize the conductive heating of the quartz. Safe ramp speeds of 50°C/s and platinum boat surface temperatures of > 1600°C were achieved (lab air T and P, no quartz) using less than 25% of available power. Although tests are required to verify the complete transformation of quartz to cristobalite for carbon diffusion from the quartz, DCELL is predicted to complete the extraction in less than 1 hour at temperatures above the commonly cited 1650°C threshold. The released gases are purified to CO_2 through a system with no carbon-bearing seals (only copper gaskets in conflat fittings and copper tips in the pneumatically operated valves) to determine if there is an improvement in blank relative to other designs. Liquid nitrogen variable temperature traps, CO_2 or O_2 gas spiking, an optional quartz bead heater, an Ag-Cu furnace, UHV pumps, and a helical LN trap are all automated, and system parameters are logged during each run to maximize reproducibility and optimization. Initial results will be reported.

MICROBIAL PROCESSES IN MINING: FOCUS ON ENVIRONMENTAL HAZARDS AND INDUSTRIAL APPLICATIONS

Eva Pakostova[1], David W. Blowes[2], Carol J. Ptacek[2], Samantha McGarry[3], Barrie Johnson[4], Neil Rowson[5]
[1]Coventry University, [2]University of Waterloo,
[3]Glencore Canada Corporation– Sudbury Integrated Nickel Operations,
[4]Bangor University, [5]Bunting-Redditch.
E-mail: *epakostova@seznam.cz*

One of the greatest concerns in mining is the generation of acid mine drainage (AMD) characterized by low pH and high concentrations of sulphate and metal(loid)s. Among the causes of AMD is accelerated sulphide oxidation catalyzed by acidophilic S- and/or Fe-oxidizers (e.g. *Acidithiobacillus*, *Leptospirillum*, *Ferroplasma*). The near surface tailings (at Long Lake Gold Mine, ON), showing signs of extensive sulphide oxidation (pH 2.0–3.9; up to 400 mg L^{-1} As), contained great proportions of mineral oxidizers (up to 32.3% of total reads), while significantly lower abundances (~6%) were detected in mill tailings from impoundments with multi-layer dry covers (Kam Kotia and a working Ni-Cu mine, ON). Acidity released through sulphide oxidation in mine wastes can be neutralized through carbonate dissolution. Circumneutral mine wastes are often dominated by neutrophils (e.g. *Thiobacillus*), as evidenced in samples from a historic waste rock stockpile at the Detour Lake Mine (ON). Reductive dissolution of Fe oxyhydroxides can lead to metal(loid) mobilization from oxidized mine wastes, catalyzed by obligately anaerobic Fe-reducers (e.g. *Geobacter*) as well as other groups (including facultatively anaerobic Fe-oxidizers). A high As content and complexity of As-bearing wastes make the abandoned Giant Mine (NWT) a challenging remediation project. The presence of both mineral oxidizers (2.5% of total reads in the vadose zone) and Fe reducers (1.4% in saturated samples) was detected in a mixture of flotation tailings and roaster wastes (0.4 wt.% residual S; ~18 wt.% Fe oxides; pH 7.6; 3.6 mg L^{-1} As). Therefore, As mobilization via both reductive and oxidative (bio)processes should be considered when developing a remediation strategy. A range of industrial technologies use microbial processes that occur in mine wastes. Several remediation technologies are based on sulphate reduction catalyzed by, e.g. *Desulphovibrio*, including different covers, permeable reactive barriers (abandoned Ni–Cu mine, ON), and sulphidogenic bioreactors. Bioleaching, which uses mineral oxidizers to extract metals in an environmentally friendly way, is applied in industrial processing of low-grade metal sulphides and gold concentrates. In recent years, bioleaching has attracted much attention and new applications are being developed, particularly for e-waste recycling. Two sequential bioleaching-based technologies will be presented: (1) for in situ extraction of base metals from deep-buried low-grade ores, and (2) for solubilization of base and platinum group metals from automotive catalysts.

PROBLEMS OF DATING IMPACT CRATERS: AGE OF THE SLATE ISLANDS IMPACT CRATER, NORTHERN LAKE SUPERIOR, ONTARIO, CANADA

Andrew F. Parisi[1], Michael E. Brookfield[2], Elizabeth J. Catlos[2], Daniel P. Miggins[3], Daniel F. Stockli[2]
[1]University of California at Los Angeles, [2]University of Texas at Austin,
[3]Oregon State University.
E-mail: *mbrookfi44@gmail.com*

The Slate Islands, 10 km southwest of Terrace Bay, Ontario, are remnants of one of the largest known impact craters (30 km diameter) in North America. Numerous shatter cones in basement, pseudotachylite, polymict allogenic breccia (including glass-bearing "suevite"), and monomict autoclastic breccia are proof of impact. Its

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age is poorly known; estimates range from late Proterozoic to Cambrian (800 to 500 Ma) to Late Devonian based on very indirect and suspect data. But accurate radiometric dating of impact craters is difficult because over 90% of the impacted rocks preserve their pre-shock ages, the rest are not entirely reset to the impact age in most cases, and all are commonly altered by post-impact processes, such as alteration by hydrothermal fluids. Our U/Pb and Ar/Ar dating of the Slate Islands structure give conflicting results. Uranium/Pb concordia intercepts of LA-ICP-MS zircon dates are 2706 ± 20 Ma and 469 ± 45 Ma; while the combined U/Pb and Ar/Ar dates indicate six distinct thermal events, only two of which can be explained by known geological events. Population 1 ranges from 2710 ± 21 Ma to 2632 ± 18 Ma; population 2 ranges from 1703 ± 26 Ma to 1603 ± 68 Ma; population 3 ranges from 641.0 ± 18.0 Ma to 578.0 ± 16.3 Ma (concordia age 614 ± 27 Ma); population 4 ranges from 487.3 ± 13.2 Ma to 432.0 ± 25.0 Ma (concordia age 481 ± 13 Ma); population 5 ranges from 337.9 ± 11.4 Ma to 319.8 ± 10.2 Ma (concordia age 331 ± 9 Ma) and population 6, the youngest group, with only 3 dates ranges from 34.4 ± 1.2 Ma to 4.6 ± 0.2 Ma. The mid-point of the population 4 age of 481 ± 13 Ma is earliest Ordovician (Tremadocian), and only just overlaps the Ordovician Meteorite Event parent asteroid breakup date of 468.0 ± 0.3 Ma. Of the known Ordovician impact craters, Charlesvoix (52 km), Slate Islands (32 km) and Clearwater East (26 km) are the largest on Earth.

LITHIUM DISTRIBUTION AT THE REGIONAL AND MICROSCOPIC SCALE: GEORGETOWN INLIER, NORTHERN QUEENSLAND, AUSTRALIA

Nicholas Parr, Patrick Hayman, Balz Kamber
Queensland University of Technology.
E-mail: *n2.parr@hdr.qut.edu.au*

Lithium is vital for rechargeable batteries in green technology, but half of global production is in geopolitically unstable countries, risking supply chain disruption. With the rapidly growing demand for lithium, efficient greenfield exploration is needed to find more of this metal. The Proterozoic Georgetown Inlier in Far North Queensland, Australia, measuring roughly 350 km by 350 km, has a long history of Au-Sn-Ta-W mining but has only one known lithium prospect (Buchanan's Creek). The state-wide geochemical atlas shows the inlier expresses a positive lithium 'anomaly', which may be linked to lower continental crust granulite being depleted in lithium, suggesting partial melting and remobilization to the upper continental crust. We use whole rock major and trace element geochemistry (n = 1285, major elements by X-ray fluorescence and minor elements mostly by inductively coupled mass spectroscopy), collated from academic, government and industry sources to better understand the distribution and controls on lithium enrichment in Queensland. Many elements correlate positively with lithium (e.g. gallium, tantalum and thallium), although the best correlations are with aluminum and cesium, making it possible to predict lithium content in the absence of lithium concentration data. Five groups are defined based on lithium content: group 1 (0–10 ppm Li, n = 496) is dominated by the mafic igneous and metamorphic samples and the lower end of common (quartz-K-feldspar-muscovite) pegmatites in the central metamorphic corridor, and the basaltic volcanic province to the east; group 2 (10–30 ppm, n = 469) is the typical continental crust concentration and consists mainly of felsic igneous and sedimentary rocks; group 3 (30–100 ppm, n = 286) is dominated by lower grade metamorphic rocks up to pelitic schist and gneiss, enriched felsic igneous rocks and the upper end of common pegmatite; group 4 (100–1000 ppm, n = 26) consists mainly of lower grade components of the Buchanan's deposit in the central-western and certain granite in the northern parts of the inlier; and group 5 (> 1000 ppm, n = 7) is the mineralized component of the Buchanan's deposit. The Buchanan's deposit (groups 4 and 5), hosted in Paleoproterozoic rocks, consists of lepidolite and montebrasite-amblygonite schist hosted in metapelitic schist and amphibolite sills. Future studies will track lithium in each group using mineral maps to document lithium-hosting minerals and lithium isotopes to assess source rock weathering. It is expected that results will provide insight into how lithium is accommodated into different minerals under different lithium concentrations and will have implications for regional lithium exploration.

PROBLEMS WITH BARROVIAN METAMORPHISM

David Pattison
University of Calgary.
E-mail: *pattison@ucalgary.ca*

Barrovian metamorphism is the classic type of regional crustal metamorphism in collisional mountain belts away from subduction zones. One would think that the pressure (depth)–temperature conditions of Barrovian metamorphism are well established. One would be mistaken in thinking so. The issue turns on interpreting the formation of mineral assemblages containing staurolite (St) and kyanite (Ky), the classic Barrovian indicator association. If thermodynamically calculated equilibrium assemblage diagrams are interpreted literally, St + Ky-bearing mineral assemblages in the dozens of Barrovian settings worldwide, from Barrow's zones in Scotland to the Himalaya, must have developed in a restrictive, high pressure window greater than ~6.5 kbar and ~650°C. Conversely, the large (in terms of pressure) predicted range for St + sillimanite (Sil) sequences (~4 to 6.5 kbar), in which neither kyanite nor andalusite is developed in the sequence, is represented by very few settings worldwide. Exacerbating this conundrum is the prediction that, for all but unusually aluminous bulk compositions, the incoming of kyanite is due to the consumption of staurolite, whereas in very few natural samples do textures suggest this relationship; rather, the two minerals most commonly appear to have developed independently at about the same time. In the absence of anything obviously wrong with the experiments on which the thermodynamic modelling is based, kinetic explanations need to be entertained.

QUANTIFICATION AND MONITORING OF CO_2 SEQUESTRATION IN ULTRAMAFIC MINE WASTES FROM AUSTRALIA, CANADA, AND SOUTH AFRICA USING GEOCHEMICAL MASS-BALANCE MODELS

Carlos Paulo[1], Ian M. Power[1], Nina Zeyen[2], Baolin Wang[2], Sasha A. Wilson[2]
[1]Trent University, [2]University of Alberta.
E-mail: *carlos.fernandesesilvapaulo@mail.utoronto.ca*

Passive carbonation is the spontaneous reaction of minerals present in ultramafic mine wastes with atmospheric carbon dioxide (CO_2) to form stable secondary carbonate minerals that are sinks for CO_2. Extensive mineralogical assessments were used to quantify the abundance of secondary carbonate minerals and estimate passive carbonation rates in ultramafic mine tailings. Examples include the Mount Keith nickel mine (Australia) and Diavik Diamond mine (Canada). Quantitative X-ray diffraction (QXRD) methods were used in these assessments, producing valuable information about cation sources and carbon sinks. However, this approach is technically demanding, cost-prohibitive, and likely impracticable for routine monitoring of CO_2 sequestration in active mines. As an alternative method for quantifying and monitoring of passive carbonation rates, we propose using mass balance geochemical models (inverse modelling) using data routinely collected by mines as input for the models. This data includes water quality datasets, tailings mineralogy, and operational information. The predictive capabilities of the models were tested with data from Mount Keith and Diavik mines, where carbonation rates were previously determined using QXRD. A new site, Venetia diamond mine (South Africa), was used to illustrate the potential of geochemical modeling for carbon accounting and as a long-term monitoring tool for CO_2 sequestration. The Mount Keith geochemical models, based on two water samplers, predicted passive carbonation rates (3900 g $CO_2/m^2/yr$) consistent with previous QXRD assessments (2400 g $CO_2/m^2/yr$; 172 samples). CO_2 removal rates for Diavik were found to be impacted by seasonality and ranged between ~375 to 510 g $CO_2/m^2/yr$, showing similarities with previous QXRD rates estimates (313–350 g $CO_2/m^2/yr$). With the long-term water chemistry records (2009–2018) available for Venetia, we predicted calcite as the main CO_2 sink and that ~15,000 t CO_2 were stored in the kimberlite residues impoundments (3.5 km^2) over nine years at a rate of ~470 g $CO_2/m^2/yr$. Moreover, long-term monitoring helped identify relationships between CO_2 sequestration, waste management practices, and seasonality. Our models provide a more straightforward and manageable approach for monitoring, reporting and verifying carbon removal by ultramafic mine tailings that can be readily integrated into the mine's existing water quality monitoring programs. The CO_2 sequestration prediction model is a novel tool with the potential to become essential for introducing new mine waste management practices that aim to optimize and enhance CO_2 removal in active ultramafic mines.

CHEMICAL CHARACTERIZATION OF TOURMALINE AND CHLORITE ALONG 900 m OF Au-MINERALIZED SHEAR ZONES IN THE TRIANGLE OROGENIC GOLD DEPOSIT (VAL D'OR, QUEBEC): APPLICATION FOR ORE SHOOT VECTORING

Giovanni Pedemonte[1], Bertrand Rottier[1], Georges Beaudoin[1], Jacques Simoneau[2]
[1]Université Laval, [2]Eldorado Gold Corporation.
E-mail: *giovanni.pedemonte.1@ulaval.ca*

The Triangle deposit (Eldorado Gold Corporation) is a classic example of orogenic Au veins, found in the Val d'Or district, Quebec. A detailed reconstruction of the paragenetic sequence of the deposit define three main mineralization events: The first event is characterized by early deformed quartz, chlorite, sericite, and carbonate veins with disseminated pyrite, and minor Au inclusions in quartz. This first event is associated with strongly deformed epidote, chlorite and carbonate alteration in the host rock, along with deformed pyrite. The second event consists of a zone of proximal alteration characterized by a pervasive quartz-sericite-feldspar with minor chlorite and undeformed pyrite in the strongly deformed host rock. This event includes the main vein filling stage, composed of massive quartz, tourmaline, ankerite and pyrite. Most Au occurs as inclusions in pyrite spatially associated with Au–Ag telluride minerals (krennerite and petzite). Lastly, the third event comprises late stage fracture-filling of pyrite and tourmaline with a third generation of Au commonly associated with chalcopyrite and Pb-Bi telluride minerals (altaite and tellurobismuthite). This study is focused on the systematic chemical characterization of tourmaline and chlorite formed during the second mineralizing event along approximately 900 m of the two main shear zones (C2 and C4). Tourmaline and chlorite have been analyzed for their composition of major elements using EPMA. The analyses reveal chemical trends that can be directly correlated with the sample depth. Tourmaline samples spans elevations from –399.5 to 231.7 m with an increase in Fe, and decrease in Al and Mg with depth, and an increase in Cr and Fe around the –147 m elevation. Chlorite samples spans elevations from –411 to 243 m, with a decrease in Al, and increase in Si, Mg, and Mn with depth, and slightly higher of Co, Ni and K, and lower Ti contents around the –90 m elevation. All elevations are in UTM and the surface is at about +320 m. For both tourmaline and chlorite, a direct correlation is observed between Si and Mg, and inverse between Mg and Fe, suggesting Fe^{2+} and/or Mg^{2+} substitutions in the octahedral layers, balanced by Si^{4+} substitution for Al^{3+} in the tetrahedral sites, responding to a Tschermak-type substitution mechanism. The systematic variation observed in the major elements composition of tourmaline and chlorite will be complemented by LA-ICP-MS analyses for minor and trace elements. The variability of the tourmaline and chlorite composition will be used to develop geochemical vectors towards ore shoots within shears.

TECTONOMETAMORPHIC EVOLUTION AND CRUSTAL RECYCLING IN THE EASTERN SUPERIOR PROVINCE: INSIGHTS FROM U–Pb AND Nd ISOTOPIC SIGNATURES FROM THE LA GRANDE, NEMISCAU AND OPATICA SUBPROVINCES

Rocío Pedreira Pérez[1], Alain Tremblay[1], Yannick Daoudene[2], Ross Stevenson[1], Jean David[2], Gilles Ruffet[3], Daniel Bandyayera[2]
[1]Université du Québec à Montréal,
[2]Ministère de l'Énergie et des Ressources naturelles,
[3]CNRS - Université de Rennes.
E-mail: *pedreira_perez.rocio@courrier.uqam.ca*

The integration of structural and geochronological data indicates long-lasting polyphase deformation and metamorphism in the eastern Superior Province. Two discrete tectonometamorphic events, known as pre-D1 (2815–2804 Ma) and D1 (2756–2736 Ma), may record mid-crustal decoupling between a rigid upper crust and hotter, middle-to-lower crustal plutonic rocks (TTGs) prior to the Kenoran orogeny (2720–2680 Ma). Maximum depositional ages (< 2724 Ma) for the Nemiscau subprovince indicates sedimentation during at least the early stages of the orogeny. This was followed by D2 (2704–2677 Ma) dip-slip deformation coeval with granulite-facies metamorphism and anatexis in the Nemiscau subprovince (2697–2685 Ma). A D3 dextral strike-slip deformation event at 2658–2621 Ma was accompanied by amphibolite-facies metamorphism. A D4 event associated with localized brittle-to-ductile conjugated shear zones and decreasing crustal cooling from amphibolite- to greenschist-facies conditions occurred at ≤ 2598 Ma. $^{40}Ar/^{39}Ar$ step-heating ages of hornblende grains suggest slow cooling following D3, between ~2625 and 2590 Ma, and crustal cooling following the emplacement of late-stage granitic intrusions between ~2590 and 2555 Ma. $^{40}Ar/^{39}Ar$ muscovite ages suggest retrogression in the greenschist facies at ~2535 Ma. Neodymium isotopic data (εNd –3.55, +1.61) and U–Pb ages of inherited zircon (3.46–2.91 Ga) argue for recycling of Paleo- to Mesoarchean continental crust during genesis of TTG suites (2800 Ma) in the La Grande (TDM 3.52–3.08 Ga) and Opatica (TDM < 3.07 Ga) subprovinces. The isotopic composition (εNd –1.12, +0.24) of younger TTG units (< 2755 Ma) and syn- to late-tectonic intrusions (< 2646 Ma) in the Nemiscau and Opatica subprovinces is consistent with the crustal evolutionary trend of the older Opatica TTG suites, suggesting that they originated by partial melting of these latter «basement» rocks. The emplacement of sanukitoid suites (εNd –0.61, +1.64) at 2704–2693 Ma in the La Grande and Opatica subprovinces suggest a renewed mantle source (TDM 3.02–2.85 Ga). Mafic-to-ultramafic rocks of the greenstone belts have juvenile signatures that are consistent with depleted mantle sources. The associated intermediate and felsic volcanic rocks exhibit a wide range of εNd values (–1.87, +2.01), likely reflecting mixing of ~3.0 Ga mantle and > 3.0 Ga crustal components. Our field and isotopic data suggest that the La Grande, Nemiscau and Opatica subprovinces most likely represent a single composite terrane instead of distinct crustal blocks or microcontinents. The overall structural characteristics of the region are consistent with the evolution of a 'hot' orogen, in which contemporaneous gravity processes and lateral extrusion of high-temperature crustal material affected the middle and lower crust.

DEVELOPING AN EXPLORATION GUIDE FOR REE-BEARING MINERALS USING REFLECTANCE SPECTROSCOPY

Jeanne Percival[1], David Turner[2], Jessica Tomacic[3], Pierre Pelchat[1], Marc Beauchamp[1]
[1]Geological Survey of Canada, [2]Turner Geoscience Consulting,
[3]Carleton University.
E-mail: *jeanne.percival@nrcan-rncan.gc.ca*

As the world moves toward a low carbon economy, the demand for critical metals, especially rare earth elements (REE), will continue to increase. Exploring for critical metal-bearing minerals can be difficult because they commonly occur as accessory phases in a variety of ore deposits. In this work, the applied use of field portable instruments is investigated for the detection and identification of these minerals to reduce timelines from discovery to production. In addition, lower detection limits and grain size limitations using hand-held instruments will be determined. Recently, reflectance spectroscopy was conducted on more than 480 mineral specimens from the National Reference Mineral Collection (NMC) held at the Geological Survey of Canada. The focus was on collecting high quality visible (350–700 nm)–near infrared (700–1300 nm)–shortwave infrared (1300–2500 nm) (VNIR–SWIR) spectra on minerals containing REE, Nb, U and Th. From these specimens, 29 minerals that are important for exploration and had the highest quality spectra were selected for more detailed analyses (pXRF, XRD, SEM and EPMA) to quantify their critical element abundances and relate how their concentrations impact the VNIR–SWIR reflectance spectra. Results from EPMA show variable concentrations of total REE across samples, and within some single specimens. Mineralogical purity ranges from poor (monazite NMC066167) to fair (bastnaesite NMC017454) and good (kainosite NMC064205). Minerals commonly known to have REE as minor elements (e.g. fluorapatite) have concentrations < 2% whereas those with REE as major elements (e.g. bastnaesite) contain > 75% total REE. From the suite, ten specimens were selected to illustrate the importance of detailed micro-characterization when creating reference spectral libraries. The specimens include the mineral species aeschynite, allanite, ancylite, bastnaesite, eudialyte, fergusonite, gadolinite, kainosite, monazite and tritomite. Their reflectance spectra are typical for minerals containing REE and exhibit diagnostic absorption features in the VNIR–SWIR regions. Once this mineral suite is fully characterized, these results will provide data for the devel-

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opment of a guide to explorationists and mineral processors, further development and sharing of the interpreted spectral library and fill knowledge gaps for the broader remote sensing community. This custom spectral library will be useable by multiple spectral interpretation software packages and accompanied by an interpretive guide so that users can compare results from their own spectrometers and samples in the field or lab.

PETROLOGICAL AND GEOCHEMICAL VARIATIONS IN THE MAIN MASS ALONG THE NORTH RANGE OF THE SUDBURY IGNEOUS COMPLEX – INSIGHTS INTO INITIAL MELT SHEET CHARACTERISTICS AND ITS DIFFERENTIATION HISTORY

Dustin Peters, C. Michael Lesher, Edward F. Pattison
Laurentian University.
E-mail: *dpeters@laurentian.ca*

The voluminous Main Mass of the Sudbury Igneous Complex (SIC) is interpreted as the crystallization product of a differentiated impact melt sheet. Along the North Range, it consists of a discontinuous lower unit of mafic norite, overlain successively by more continuous units of felsic norite, quartz gabbro, and granophyre. Although the crustal impact origin of the Main Mass is well established, its differentiation history is less well understood. There are currently two fundamentally different models: (i) fractional crystallization of a single melt, or (ii) gravitational segregation of lower mafic and upper felsic layers that homogenized and crystallized separately. To address the validity of these models, six new whole rock geochemical transects through the Main Mass along the North Range of the SIC were generated. Petrological observations show a consistent crystallization sequence along the North Range of orthopyroxene ± plagioclase (mafic norite) → orthopyroxene + plagioclase (felsic norite) → clinopyroxene + plagioclase + magnetite–ilmenite + apatite (quartz gabbro) → clinopyroxene/amphibole + plagioclase + quartz–potassium feldspar (granophyre), but variable onsets, crystallization intervals, and degrees of accumulation of cumulus phases along strike. Thinner portions of the Main Mass show less significant accumulation of cumulus phases and higher amounts of interstitial trapped liquid in the lower noritic and gabbroic units, whereas thicker portions show more significant accumulation of cumulus phases and less interstitial trapped liquid, suggesting that initial melt sheet thickness and rate of cooling influenced the degree of differentiation. Calculated bulk liquid compositions for each transect are relatively homogeneous along strike, at least in terms of major elements (~66–67 wt.% SiO_2, ~2 wt.% MgO), indicating an initially well-mixed impact melt sheet. This composition is more evolved than least-altered vitric Onaping Formation or average North Range offset quartz diorite (~61 wt.% SiO_2, ~4 wt.% MgO), both of which have been proposed to represent a good estimate of the initial SIC melt composition. Possible reasons for this discrepancy may include (i) crystallization of the Main Mass from a more evolved liquid that crystallized and lost a more magnesian component after dyke emplacement but prior to crystallization of the Main Mass, or (ii) incomplete preservation of the initial melt sheet. Our preliminary results show that the differentiation history along the North Range was not a uniform process and varied at least on a kilometre scale, reflecting differences in the initial melt sheet thickness, and thus cooling and differentiation rates.

IMPACT MELT HOMOGENEITY IN THE SUDBURY IGNEOUS COMPLEX AND RELEVANCE FOR Ni–Cu–(PGE) ORE FORMATION

Dustin Peters, C. Michael Lesher, Edward F. Pattison
Laurentian University.
E-mail: *dpeters@laurentian.ca*

The Sudbury Igneous Complex (SIC), generally believed to be the remnant of a large, 1850 Ma bolide impact, hosts one of the world's largest magmatic Ni-Cu-(PGE) sulphide mining camps. In contrast to most other magmatic sulphide deposits, which formed from mantle-derived mafic to ultramafic magmas, the sulphide mineralization in the SIC is associated with a crustal impact melt. Most current models explain the genesis of the ores by the exsolution of immiscible sulphide phases from a homogeneous impact melt sheet and subsequent settling to the base, but this process is slow and cannot account for the variably heterogeneous Pb >> Nd >> Hf isotopic compositions of the Main Mass (crystallized impact melt) and Pb >> Os > S isotopic compositions of the ores. Thermomechanical erosion of S-bearing footwall rocks by the superheated impact melt sheet can account for some of these variations, but only if significant amounts of Pb (and likely also S) are volatilized during impact. To test the validity of these models, it is crucial to establish whether the initial impact melt was well mixed, as any sulphide phases exsolved from the melt should inherit its isotopic composition. Limited Hf isotopic data for the Main Mass suggest that the impact melt was vertically homogeneous prior to crystallization, but there has been no study testing lateral homogeneity. Here, we report preliminary results of Hf isotope analysis on zircons by LA-MC-ICP-MS from four Main Mass transects across the North Range of the SIC. Our data show a narrow range in Hf isotope compositions ($\varepsilon Hf_{1850\ Ma}$ between –8 and –12), consistent with the well-established crustal origin of the SIC, and with previously published data for the South Range Main Mass ($\varepsilon Hf_{1850\ Ma}$ between –9 and –12). This suggests that the initial impact melt was both stratigraphically and laterally well mixed prior to crystallization, with small differences between the North and South Range Main Mass being attributable to minor contamination by post-impact thermomechanical erosion of different target rocks. Although our results do not entirely exclude a contribution from the impact melt sheet, our data support a model in which the sulphide ores formed dominantly at the base by local thermomechanical erosion of S-bearing footwall rocks. Additional analyses of Nd, Os and Pb isotopic compositions of the Main Mass are in progress to confirm these results.

STABLE ISOTOPES (O, H) TRACK SUBSOLIDUS FLUID:ROCK INTERACTION AND OPEN-SYSTEM BEHAVIOUR IN THE LCT-TYPE LITTLE NAHANNI PEGMATITE GROUP (NWT, CANADA)

Jérémie D. Pfister[1], Daniel J. Kontak[1], Lee A. Groat[2], Mostafa Fayek[3]
[1]Laurentian University, [2]University of British Columbia, [3]University of Manitoba.
E-mail: *jeremie.pfister@yahoo.com*

Granitic pegmatites have long been important sources of strategic metals (e.g. Li, Cs, Ta, Nb, Sn, U, REE), which are now critical to the global renewable energy transition. Although noted early that many of these metals were localized to metasomatic domains (e.g. Nb, Ta, Sn oxides in saccharoidal albite or fine-grained mica domains), a feature observed in pegmatites globally, overall this was historically overlooked by many favouring magmatic processes. While sub-solidus processes in pegmatites have been increasingly recognized in recent years, the nature and origin of such metasomatism remain enigmatic. In particular, whether pegmatites evolve as open or closed systems during metasomatism persists as an outstanding issue. To address these important issues, an integrated textural and stable isotopic study of the exceptionally well-exposed mid-Cretaceous (ca. 85 Ma) Li-Cs-Ta (LCT)-type Little Nahanni Pegmatite Group (LNPG; Northwest Territories, Canada) is presented here. This isotopic study, one of the most exhaustive of any LCT pegmatite to date, involves duel inlet isotope ratio mass spectrometry (DI-IRMS) analysis of mineral separates (quartz, K-feldspar, albite, muscovite, garnet), in situ secondary ion mass spectrometry (SIMS) isotopic analysis of quartz and albite, and in situ laser ablation inductively coupled plasma mass spectrometry trace element analysis of quartz, complemented with cathodoluminescence imaging and petrographic observations. The high $\delta^{18}O$ values of primary minerals (i.e. $\delta^{18}O_{quartz}$ = 10.0 to 16.3‰), which increase towards the border of the pegmatites, suggest localized melt:wall rock exchange at the time of pegmatite emplacement. An even larger range for $\delta^{18}O$ in metasomatic minerals, such as albite (–3.0 to +18.3‰), indicates a complex evolution involving multiple oxygen isotopic reservoirs, in particular incursion of meteoric water previously equilibrated with metasedimentary wall rocks. Finally, the acute isotopic disequilibrium between mineral pairs (e.g. $\Delta_{quartz–albite}$ = –5.1 to +14.3‰) and abundance of dissolution features in late-stage assemblages unequivocally implicates subsolidus fluid:rock interaction as responsible for the large observed spreads in $\delta^{18}O$ and δD values, although other processes (e.g. disequilibrium crystallization, thermal gradients, rapid cooling) may have also contributed. These observations suggest a partially open system behaviour during the evolution of the LNPG. In situ SIMS analysis of a complementary suite of 60 samples from global LCT-type pegmatites reveal similarly large ranges in $\delta^{18}O$ values, which we relate to post-emplacement modification of samples due to coupled dissolution–precipitation processes, as well as a historical bias towards bulk analyses of mineral separates, which artificially reduce the $\delta^{18}O$ range by averaging the values of various domains found within single grains.

VOLCANOGENIC MASSIVE SULPHIDE (VMS) DEPOSITS: NEW IDEAS AND FUTURE RESEARCH DIRECTIONS

Stephen J. Piercey
Memorial University of Newfoundland.
E-mail: *spiercey@mun.ca*

Volcanogenic massive sulphide (VMS) deposits have been historic metal contributors to the Canadian economy and will be important sources of base, precious and critical metals for the emerging green economy. While having been studied for considerable time and having modern analogues on the seafloor, new ideas continue to emerge regarding their setting, genesis, and exploration. New lithosphere-scale work has illustrated the importance of crustal architecture in potentially controlling the emplacement of magmatism and associated VMS deposits, particularly in Precambrian VMS environments. Considerable new insight into magmatic processes, magma metal abundances, physicochemical conditions of magmatism, refinement of petrological models, and their influences on VMS endowment have come from advances from the field through to nano-scale. Knowledge of the hydrothermal footprint of VMS ore systems and sources of metals and fluids in VMS deposits have been enhanced due to the integration of field-based research with evolving analytical methods and computer modeling. Further, improvements in U–Pb geochronology have illustrated that the rates of formation of VMS deposits are similar to modern seafloor massive sulphide deposits (SMS), despite antiquity of mineralization, rates that could not be determined until recently in the ancient record. Despite these advances, numerous questions remain regarding the controls and influences on VMS deposits genesis requiring continued studies at multiple scales from craton- to nano-scale and provide fruitful avenues of research for the coming decades.

RECONSTRUCTING MAASTRICHTIAN-MODERN SEDIMENT DELIVERY TO THE FOREARC GEORGIA BASIN USING DETRITAL ZIRCON U–Pb GEOCHRONOLOGY

Julia Pires Leandro, Joel Saylor
University of British Columbia.
E-mail: *jleandro@gmail.com*

Sediment delivery from the Cascade Range and Coast Mountain magmatic arcs to the Cretaceous forearc Georgia Basin has been well documented. However, the modern Fraser River transects the magmatic arc and delivers sediment from as far east as the Rocky Mountain Trench in the fold-thrust belt of eastern British Columbia. Where and when drainages breached the magmatic arc remains unknown. These questions are tackled using detrital zircon geochronology from samples spanning the latest Cretaceous through the modern period in age. Samples were collected from the uppermost Cretaceous Nanaimo Group, exposed in the northwest side of Stanley Park in urban Vancouver. Samples were also collected from the Eocene Huntingdon Formation, exposed at Stanley Park and at Sumas Mountain in Abbotsford. Finally, Quaternary samples were collected from the Quadra Sandstone at Wreck Beach, and from the modern Fraser River at the north side of McMillan Island. All samples feature age modes between 100–90 Ma and secondary modes between 65–45 Ma. The Huntingdon Formation at Sumas Mountain has less prominent modes at 220 Ma and 75 Ma which are not present in the Stanley Park samples. However, the Stanley Park samples have a minor 150 Ma mode. Finally, the Quadra Sands distribution also features modes at ~150 Ma and ~120 Ma and uniquely includes late Paleogene zircons. No pre-modern samples show significant input from east of the Coast Mountains Batholith. Compared to previously reported samples from Coniacian–Maastrichtian strata of the Georgia Basin on Vancouver Island, age distributions of the latest Cretaceous–Quaternary samples from the mainland contain a smaller portion of 150–120 Ma zircon populations and a complete absence of Proterozoic (~1400 and 1700 Ma) ages. Between the Maastrichtian and Eocene, the catchment for the Georgia Basin decreased in longitudinal extent. Proterozoic zircons in Maastrichtian strata of Vancouver Island require a catchment extending east of the Coast Mountains Batholith, potentially tapping sedimentary sources in the Lemhi sub-basin of the Belt-Purcell Basin. However, by Eocene time sediment sources were limited to the Coast Mountains. This history is consistent with dextral translation of the Georgia Basin away from an initial location outboard of northern California or Oregon to its present location between the latest Cretaceous and Eocene. However, this is not a unique explanation and alternate scenarios are possible. The Eocene–Quaternary provenance data also suggests that the catchment for the Fraser River did not reach its current trans-Cordilleran extent until the Holocene.

COMPARATIVE STUDY OF TWO HIGH-GRADE REE–Th–U DEPOSITS, DIBROVO FROM THE UKRAINIAN SHIELD AND ALCES LAKE FROM THE CANADIAN SHIELD: GEOLOGICAL SETTING, STRUCTURE, AND PETROGENESIS

Kateryna Poliakovska[1], Irvine R. Annesley[1,2], Olena Ivanik[1,3], Kahlen Branning[4]
[1]University of Lorraine, [2]University of Saskatchewan,
[3]National Taras Shevchenko University of Kyiv,
[4]Appia Rare Earths & Uranium Corporation.
E-mail: *jnrirvine@gmail.com*

Rare metals are at the forefront of critical commodities worldwide with the supply–demand balance tipped dramatically upwards toward a supply deficit as a result of more and more green technologies coming on stream and being used (e.g. EV cars). Understanding the mineral systems of the rare metals is an integral part of making new discoveries and thus reducing supply deficits. Successful exploration programs depend on the ability to access and apply fundamental knowledge around mineral systems, deposit type descriptions and ore genesis. Thus, the Alces Lake (Saskatchewan, Canadian Shield) and Dibrovo (West Azov, Ukrainian Shield) REE-Th-U mineralization areas provide an excellent opportunity to understand the geological setting, structure and petrogenesis of these enigmatic rare metal deposits. Mineral deposits of both study areas, Alces Lake within the Beaverlodge domain in Canada and Dibrovo within the Azov block in Ukraine, have a complex genesis, related to the Paleoproterozoic tectonic events that highly deformed and metamorphosed the primarily metasedimentary (and meta-igneous) Paleoproterozoic rocks. As a result, abundant granitic and pegmatitic sheets were generated throughout the Beaverlodge domain and the Azov block. Mineralization of both Precambrian areas marks the unconformity surface between the Archean basement rocks and the Paleoproterozoic metamorphosed metasedimentary/meta-igneous rocks. The main objective of this extensive interdisciplinary study of two different REE-Th-U deposits from two different Precambrian Shield areas (Canada and Ukraine) is to determine the lithostructural, petrological, geochemical and geophysical parameters responsible for the genesis of these high grade REE-Th-U deposits by using integrated/advanced lithological, structural, geophysical, geochemical, U–Pb geochronological, 2D/3D/4D geomodeling and geostatistical clustering methods. The final interpreted results reveal new information and extend our knowledge of the geological setting, history and petrogenesis of these selected deposits. Consequently, we are currently developing a comprehensive and comparative approach (i.e. an exploration targeting workflow to be presented here at the conference) for the identification of the key mineralization characteristics and parameters for identifying, targeting and evaluating economically REE-Th-U terrains (e.g. similarities and/or differences) within other Canadian and Ukrainian Shield areas. The end result will be the identification of new promising areas and new potential discoveries of critical metals.

DIFFUSION AND DISSOLUTION OF ANHYDRITE WITHIN MAFIC MELTS CONTRIBUTED TO THE END-PERMIAN EXTINCTION

Raven Polk, Don Baker
McGill University.
E-mail: *raven.polk@mail.mcgill.ca*

The end-Permian extinction (~251.941 ± 0.371 Ma) appears to have been triggered by the emplacement of the Siberian Traps Large Igneous Provinces (~252.28 ± 0.011 Ma) where 90% of terrestrial and 75% of marine species went extinct. Assimilation of the underlying sedimentary basin, containing evaporite units, is the likely volatile source that contributed to the extinction. We measured the diffusion of sulphur released from anhydrite during dissolution in a basaltic magma to quantify the rates of sulphur contamination, and measured anhydrite saturation to offer insight into the interaction between the mafic melt and evaporitic units during the emplace-

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ment of the Siberian Traps. Diffusion experiments were performed to simulate assimilation during Siberian Traps magmatism by using a dyke composition from the Central Atlantic Magmatic Province and a mixture of compressed anhydrite powder. Experimental conditions range from 1250–1450°C at 1 GPa and durations ranging from 600 to 3600 seconds. Diffusivity is dependent on both duration and temperature; therefore, diffusion values vary from 5.1 e^{-12} m^2/s to 3.0 e^{-11} m^2/s. The sulphur peak position indicates that the dominant sulphur species in the melt is sulphide, implying a reduction of sulphur after dissolution from the anhydrite crystal. Anhydrite solubility was determined from the melt concentration and extrapolated along the diffusion profile to the anhydrite–melt interface. Our measurements indicate that the concentration of S in the melt at anhydrite saturation suggests there is no strong relationship between increasing temperature and the concentration of S within the melt. The concentration of sulphate within the melt ranges from 0.69 wt.% to 1.85 wt.%. Understanding the rate at which contamination of basaltic magma by evaporite rocks occurs is now being used in the construction of a variety of models to predict the rate of volatile uptake within a magmatic system; these models will provide insight into sulphur storage and transport. These insights can help to give better estimations of the amount of sulphur released into the atmosphere and can help to determine the time frame of interaction during the intrusive phase of the Siberian Traps.

THE QUEST FOR TSUNAMI DEPOSITS IN ANCIENT SHELF AND EPEIRIC SEAS: WHAT ARE THE TELLTALE SIGNATURES?

Brian R. Pratt
University of Saskatchewan.
E-mail: *brian.pratt@usask.ca*

Despite recent devastating tsunamis, most sedimentologists studying offshore shelf and shallow epeiric sea deposits never suspect that their rocks might harbour evidence for this phenomenon. However, I consider there to be criteria robust enough to distinguish tsunami effects from those of storms. This is despite the theoretical uncertainties about tsunami behaviour in these kinds of settings. To do so also requires going beyond the constraints of textbook thinking but also having a broader consideration of the paleoclimatic context of individual sedimentary basins or regions and whether major storms were indeed likely and how frequent they may have been. Passive carbonate margins undergoing active rifting likely involved frequent normal faulting, often with displacement that would have generated tsunamis. Depending on bathymetry, waves may have shoaled and broken far offshore, with plunging waves causing localized erosion of the seafloor. Examples in the Mesoproterozoic through the Lower Ordovician of the Rocky Mountains include thick beds of flat pebble conglomerate in low energy lime mudstone successions. These clasts were imbricated by oscillatory currents likely generated by the passage of progressively weaker waves. Fault displacement in the centre of epeiric seas generated tsunamis but of lesser magnitude, and in a late Cambrian example, may have required that the cementing seafloor had to be cracked first by earthquake-induced ground motion. In muddy carbonate platforms, lenticular beds of rudstone composed of cemented burrow linings in the Precordillera of Argentina are interpreted to record breaking tsunami waves. With the effective disappearance after the Early Ordovician of both these facies, tsunami impact was expressed differently. In the Upper Ordovician of the northeastern side of the Williston Basin, cementing, irregularly shaped lime mudstone nodules were excavated and redeposited as a rubble bed capped by argillaceous lime mud. Tsunami run-up eroded nearshore and coastal deposits and sabkhas, potentially a considerable distance inland on peneplaned surfaces, and off-surge delivered these particles offshore. In the Mesoproterozoic Belt Basin they are preserved as interbeds of ooid grainstone and coarse sandstone, punctuating low energy successions of lime mudstone and siliciclastic mudstone respectively. Gutters may be present and oriented parallel to the draining currents. The combination of anomalous beds of coarse particles and episodic deep scour is key. Naturally, it is the stronger events that have left this evidence, so the frequency of tsunamis would be underestimated.

PRELIMINARY AGES FOR THE ARCHEAN RAMSEY–ALGOMA GRANITOID COMPLEX AND SURROUNDING PROTEROZOIC INTRUSIVE ROCKS

Sonia Préfontaine[1], Sandra L. Kamo[2]
[1]Ontario Geological Survey, [2]Jack Satterly Geochronology Laboratory.
E-mail: *sonia.prefontaine@ontario.ca*

An airborne high resolution gamma ray spectrometer and magnetic gradiometer survey was flown west-northwest of the Sudbury basin in 2018 by the Ontario Geological Survey. The survey covers the eastern portion of the Archean Ramsey–Algoma granitoid complex and the surrounding Proterozoic rocks. As a result, several multiyear compilation and mapping projects covering the geophysical survey were started. Presented are twenty-three new ages from samples that were taken in specific areas highlighted by the geophysical survey. Three mafic intrusive rocks of Proterozoic age were collected. Two have ages similar to the Nipissing Intrusive Suite (2214–2212 Ma), with the other sample yielding an age of 2470 ± 10 Ma similar to the East Bull Lake intrusive suite and Matachewan dyke swarm (ca. 2470 Ma). Most of the samples collected are from the Ramsey–Algoma granitoid complex. Based on U–Pb ID-TIMS and LA-ICPMS ages and petrography, two preliminary grouping can be made. The younger granite bodies, equigranular (locally porphyritic), medium- to coarse-grained with rare pegmatitic facies are generally massive to weakly foliated and range in age from 2682 Ma to 2620 Ma. A second group is generally more granodioritic to tonalitic in composition, commonly foliated to gneissic and range in age from 2713 Ma to 2670 Ma. Titanite crystals recovered from two samples of the older group yielded ages at ca. 2660 Ma. This age is identical to some found in nearby plutonic rocks, which may suggest that, during their emplacement, these intrusions thermally affected the host rocks. Finally, one intermediate metavolcanic rock was collected in the Benny greenstone belt where two previous volcanic events were identified by U–Pb geochronology at 2683 ± 2.3 Ma and 2701.6 ± 2.9 Ma. The new age of 2671.1 ± 2.5 Ma is the youngest age recorded in the belt. In comparison to the Abitibi greenstone belt, this volcanic age is similar to those commonly inferred for the Timiskaming assemblage.

SHOCKED AND JUVENILE ZIRCON IN IMPACT CRATER FOOTWALL, SUDBURY, CANADA: PARTIAL MELTING OF A REACTIVATED FOOTWALL MYLONITE ZONE

Stephen Prevec, John de Bruyn, Bukelwa Nxesi, Shawn Johnstone
Rhodes University.
E-mail: *s.prevec@ru.ac.za*

A regionally metamorphosed leucogabbroic sill in Drury Township, hosted by rocks affected by impact heating by the Paleoproterozoic Sudbury Igneous Complex (SIC) and localized shearing, has produced zircon U–Pb ages both by SHRIMP and TIMS reflecting only impact-aged lead loss, leading to an interpretation that the host rock itself represents juvenile, impact-induced magmatism. Furthermore, no evidence of shock deformation had been identified in these previously dated grains. This is believed to be inconsistent with 'circumstantial' evidence such as radioisotopic tracer and geochemical evidence, and comparison with other spatially and compositionally apparently equivalent leucogabbro sills regionally. Recent mapping and petrological and SEM-based study has revealed that the Drury Township leucogabbro hosts mylonitic rocks related to the regional scale South Range Shear Zone in areas where this was not previously recorded as such. Furthermore, the mylonite has been locally remelted syn- to post-deformationally, characterized by centimetre- to decimetre-scale melt veinlets. Within or proximal to these veinlets, populations of very small diameter zircon grains have been identified which display a variety of textures, in contrast to those previously extracted for geochronology, including clear evidence of shock metamorphism and subsequent new growth of zoned igneous zircon, which has been subsequently cataclastically deformed. The association of thorite with the zircon is also suggestive of thermal breakdown of existing zircon. These

textures clearly require the existence of magmatic zircon prior to fault deformation and high-grade thermal metamorphism, precluding the possibility that the intrusion is impact-related or -induced in origin. This also has implications for the prospective ability of large terrestrial impact craters to induce or access mantle partial melting.

INJECTION OF MELT SHEET INTO IMPACT CRATER FOOTWALL: IMPLICATIONS FROM OFFSET DYKES OF THE SUDBURY IGNEOUS COMPLEX, CANADA

Stephen Prevec, Steffen Büttner, Denis Pollney
Rhodes University.
E-mail: *s.prevec@ru.ac.za*

Radial and tangential offset dykes associated with the Paleoproterozoic Sudbury Igneous Complex (SIC), Canada, are believed to represent compositionally modified representatives of a large (> 200 km diameter) impact melt sheet. Two main facies of offset dyke have been distinguished, historically comprising an inclusion-poor quartz diorite (QD) and a distinctly inclusion-bearing equivalent (IQD). Proposed models for the broadly bimodal nature of the offset dykes can be divided into two gross categories, consisting of models which assume a 'significant' time interval between the injection of the two facies, and those which do not. We have proposed a mechanism which allows for sufficient time to allow for (a) local compositional modification of both QD and IQD prior to injection, (b) distinct thermal characteristics of QD and IQD to explain their xenolith populations (including zircon, sulphide, and silicate minerals), and (c) appeals to a systemic melt sheet-wide trigger to drive it. The model is based on progressive pressure increase on the cooling melt sheet, which provides a vertically competent hydrostatic column. Any source of pressure increase acting on the column will be instantaneously transmitted throughout the column. The thickness of the melt sheet becomes irrelevant in terms of loading and pressure transmission. In a context where the ca. 1.5 km of fall-back breccia (the Onaping Fm.) overlying the melt sheet apparently continued to behave as an incompetent mush for a prolonged period after the impact, this cover must be considered as part of the hydrostatic column, rather than an independent load superimposed upon it. That being the case, modest amounts of pressure increase within the melt sheet (consistent with pressure magnitudes predicted for magmatic degassing in subvolcanic magma chambers and layered intrusions) induced by progressively enhanced fluid pressure build-up from a combination of degassing of assimilated country rock from the footwall breccia and water saturation of crystallizing roof and basal melt sheets are sufficient to drive first fracture dilation and QD melt sheet injection soon (but not necessarily instantly) after impact, followed later by refracturing and dilation and injection of the IQD dyke facies.

ELECTRICAL RESISTIVITY PATTERNS OF MINERAL SYSTEMS

Alexander Prikhodko
Expert Geophysics Limited.
E-mail: *alexander@expertgeophysics.com*

Resistivity as a petrophysical property is sensitive to lithological units, structural differentiations, and mineralization-associated alterations. Resistivity mapping in ore-bearing regions is a powerful tool for mineral exploration, not only for directly identifying metal sulphide-rich ore bodies but for detecting modest contrasts in magmatic–hydrothermal systems and their structural and morphological features which control mineralization of different types. The airborne natural (passive) electromagnetic total field method implemented in the MobileMT system has a significant depth of investigation. It is sensitive to any direction of geoelectrical boundaries and to differentiations in a wide range of resistivity. MobileMT resistivity–depth images characterize and describe resistivity patterns of different types of mineral systems from different geological terrains around the world. The case studies include all main types of gold-bearing systems (orogenic, epithermal, IOCG types), porphyry and other hydrothermal ore systems.

EVALUATING BACKWATER VERSUS UPSTREAM TECTONIC CONTROLS ON THE GRAVEL–SAND TRANSITION, CRETACEOUS DUNVEGAN FORMATION, WESTERN CANADA SEDIMENTARY BASIN

Aneesa Rabbani, Janok Bhattacharya, Julie Zett
McMaster University.
E-mail: *bhattaj@mcmaster.ca*

The Cretaceous Dunvegan Formation in the Western Canada Sedimentary Basin extends for about 1000 km from proximal gravelly alluvial systems in the Liard Basin in the Northwest Territories to well-developed sandy deltaic and prodelta muddy shelf systems in Alberta. The mud to sand transition has been well documented and the sandy deltas were fed by tributive incised valley systems driven by cycles of high frequency sea-level change. These incised valleys in turn pass landward into the conglomerate alluvial systems, but the nature of these conglomerate units and the controls on the gravel–sand transition have not been well examined. Dunvegan Formation conglomerate in outcrops in the Liard Basin are moderately sorted and well-rounded reaching up to small cobbles in size. These have previously been interpreted as alluvial fans; however, our investigations show a domination of sharp to scoured-based metres-thick fining-upward facies successions consisting of dune- and bar-scale cross stratification. The conglomeratic units comprise highly amalgamated channel belt deposits that form cliff exposures that are about 70 m high. Paleohydraulic analysis shows that Dunvegan conglomerate was deposited in rivers < 3 m deep over slopes on the order of 2×10^{-3} (0.1°). There is an absence of debris flows or of sedimentary structures characteristic of supercritical flows, and we thus interpret these as likely deposited by metres-deep lower gradient gravel bed streams, rather than steep gradient, sheet flood-dominated alluvial fans. Trunk channels in the southeast sink area are associated with incised valleys and have a mean bank-full depth of 10–15 m, carry medium sand (< 200 μm) with slopes estimated to be on the order of 6×10^{-5}. Source to sink calculations indicate a back-water length of around 200 km. Based on paleogeographic reconstructions, conglomerate appears to have been deposited 300 to 500 km from the mapped deltaic shorelines, indicating that the gravel–sand transition is not related to the back-water and is likely not controlled by sea-level changes, thought to be important in generating the incised valleys in the sink area. Conglomerate appears to be confined within the Liard Basin, which is bounded to the east by the Bovie Fault expressed as a major kilometre-throw normal fault. Hence, excess accommodation, driven by movement on the Bovie Fault may have prevented gravel from escaping into the more distal parts of the Western Canada Sedimentary basin in combination with an order of magnitude lowering of channel gradient from the Liard into the Alberta basin.

RECONSTRUCTING PERMO–TRIASSIC SOURCE TO SINK SYSTEMS IN THE IVISHAK SANDSTONE, ALASKA AND THE TECTONIC IMPLICATIONS

Aneesa Rabbani[1], Janok Bhattacharya[1], Elli Papangelakis[1], Angelina Abi Daoud[1], Julie Zettl[2]
[1]McMaster University, [2]University of Guelph.
E-mail: *bhattaj@mcmaster.ca*

The Permo–Triassic Ivishak Formation in the supergiant Prudhoe Bay Field lies on the Arctic Alaska Block that has experienced significant rotation since the Late Permian, and the provenance and scale of formative rivers are thus in question. Was the Ivishak fed by the continental-scale Trans-Laurentian River that drained Pangea, or something smaller? The Ivishak consists of several hundred metres of sandstone, conglomerate and lesser mudstone that conformably overlies the marine Kavik Shale. Cores and well logs show the thickest unbroken fining-upward facies successions are about 12 m, placing an upper limit on maximum thickness of the largest formative channels and inferred flow depths. Despite gravel-bed rivers being dominant higher in the Ivishak, shoreline facies are gravel-free, indicating that the gravel–sand transition lay upstream of the shoreline. Observations of bedload conglom-

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erate with a pebble D_{max} of 2 cm suggest bed shear stress on the order of 14–20 Pa and critical shear velocity on the order of 0.12–0.14 m/s. Integration of bank-full shear stress estimates, flow depths, grain size and sedimentary structures suggest that the gravelly Ivishak rivers had a mean bank-full flow depth on the order of 6 m and flowed at a peak velocity of about 1.3 m/s over a slope on the order of 2 x 10^{-4}. Backwater length is on the order of 10 km. Empirical estimates suggest channel widths between 100 and 500 m and estimates of bank-full discharge range from 500–2600 m^3/s. Power functions suggest the maximum catchment areas for Ivishak rivers were on the order of 100 km^2, far too small to reflect an origin from the Trans-Laurentian Rivers. Detrital zircon data in Ivishak outcrops show local sources versus derivation from the Canadian Shield, and indicate sediment was derived from the adjacent Sverdrup Basin. The paleohydraulic analysis is supportive of moderate scale, steep gradient rivers and is consistent with local derivation from a relatively small source-to-sink system, despite the fact that continental-scale river systems were well developed in the Permo–Triassic. The detailed analysis shows how paleohydraulics and detrital zircon analysis are integrated to constrain the scale of a deep-time source-to-sink system.

PROVENANCE OF LATE CRETACEOUS TO EARLY NEOGENE STRATA IN THE CAMARGO SYNCLINE AND IMPLICATIONS FOR BASIN GEOMETRY IN SOUTHERN BOLIVIA

Muhammad A. Rafeeza, Samuel J. Shekut, Joel E. Saylor
University of British Columbia.
E-mail: *mrafeeza12@gmail.com*

Basin models for Upper Cretaceous–Middle Miocene strata in the Camargo Syncline in the Eastern Cordillera (EC) propose deposition in an eastward-migrating, retroarc foreland basin system that extended from the Western Cordillera (WC) to the craton interior prior to Late Paleogene exhumation of the EC. We test this hypothesis using 10 new detrital zircon U–Pb geochronology samples spanning Upper Cretaceous–Middle Miocene strata, which we interpret in the context of existing sedimentological and paleocurrent data. The samples are dominated by 0.5–0.7 Ga zircon grains; secondary age modes occur at 0.9–1.2 and 1.6–1.8 Ga. Ages between ~0.2 and 0.3 Ga became more common starting in the Eocene Cayara Formation. Possible sources for 0.5–0.7 Ga zircon include Famantinian and Pampean-Brasiliano basement from NW Argentina and Bolivia and Paleozoic–Mesozoic strata from the WC, Altiplano, and EC. Zircon grains aged 1.0–1.2 Ga may be derived from Grenville-aged basement, Paleozoic strata of the Altiplano, or directly from cratonic basement. Zircon aged 0.2–0.3 Ga are likely derived from Permo–Triassic strata of the EC. Provenance interpretations are grounded by unambiguous EC derivation of the Upper Eocene–Oligocene Camargo Formation based on eastward-directed paleocurrent orientations and thermochronological evidence for coeval exhumation in the EC. This is preceded by two provenance changes. The first (oldest) occurs between the Cretaceous El Molino Formation and Paleocene Santa Lucia Formation and is marked by dilution of a 600 Ma unimode via admixture of ~550 and 1080 Ma age modes which then persist through the remainder of the section. We interpret this admixture as the result of recycling of Jurassic–Cretaceous strata from the west. The second provenance change is introduction of 0.2–0.3 and 1.7–1.8 Ga zircon ages between the Paleocene–Eocene Impora Formation and the Eocene Cayara Formation. We interpret this as exhumation of Permo-Triassic strata in the EC possibly mixed with cratonic sources. The abundance of 1.7–1.8 Ga zircon ages decreases up-section, suggesting that the cratonic sources were displaced during continued EC orogenesis. The new provenance data allow a contiguous foreland basin extending from the WC to the interior in the Late Cretaceous–Paleocene. However, only one sample yields Late Cretaceous–Cenozoic zircon, which is difficult to reconcile with derivation from the WC magmatic arc. Introduction of 0.2–0.3 Ga zircon suggests that orogenesis in the EC was ongoing from the onset of deposition of the Eocene Cayara Formation or earlier.

SHUNGA FROM THE TUNDRA: ca. 2.15–2.05 Ga UNUSUALLY ORGANIC-RICH SHALES FROM NORTHERN CANADA

Robert Rainbird[1], Andrey Bekker[2], Malcolm Hodgskiss[3], Charlie Jefferson[1]
[1]Geological Survey of Canada, [2]University of California, Riverside,
[3]Norges Geologiske Undersokelse.
E-mail: *rob.rainbird@canada.ca*

The Shunga Event refers to a period of heightened accumulation of organic matter that is recognized in numerous sedimentary successions that were deposited broadly between 2150 and 1900 Ma (aka carbon burial episodes or CBEs). These black, organic-rich strata were initially discovered in the Zaonega Formation (Onega basin) of Russian Karelia, near the village of Shunga, which contains several distinct stratigraphic intervals that show concentrations of total organic carbon in excess of 25 wt.%, as well as sulphide and polymetallic enrichment. They are interpreted to have been deposited in quiet, relatively deep water settings, marking basin-flooding episodes. Other significant occurrences of this age include the Pilgujärvi and Il'mozero formations, located in the Fennoscandian Shield, on the Kola Peninsula of northwestern Russia. Worldwide, similar age CBE strata have been reported from South China, Greenland, West Africa, Australia and North America. Examples from northern Canada include (from west to east): the Union Island Group and Artillery Lake Formation from Great Slave Lake area on the southern Slave craton margin, the Resort Lake Formation of the Amer Supergroup and lower Ketyet River Group in the central Rae craton, the Lower Albanel Formation of the Mistassini Group on the Superior craton, and the Cod Island Formation of the Mugford Group on the Nain craton. Enhanced burial of ^{12}C-enriched organic carbon on a global scale could result in the ^{13}C-enrichment of atmospheric CO_2, which eventually would be recorded in the marine $\delta^{13}C_{carb}$ archive. $\delta^{13}C_{carb}$ values for marine carbonate rocks from the mid-Paleoproterozoic record one of the largest positive excursions in Earth's history, known as the Lomagundi–Jatuli Event (LJE). Many LJE carbonate examples are intercalated with and/or directly overlain by black shale units, suggesting a potential relationship between deposition and burial of these organic-rich deposits and the LJE. The advent of Rh–Os dating provides improved chronostratigraphic control to test whether these shale units represent widespread (synchronous) or local (asynchronous) basin-flooding events. We present new geochronological data that, combined with limited published data, suggest that the northern Canada occurrences are roughly correlative and deposited between 2150 and 2050 Ma. This indicates that they are older than some of the Russian examples, but possibly coeval with other global CBE occurrences and the end of the LJE. The occurrences of mid-Paleoproterozoic CBEs in northern Canada should be further explored to better characterize their distribution and depositional environments and how that contributes to a broader understanding of how these unusual deposits were formed.

PRIMARY EVIDENCE OF EARLY EARTH'S ATMOSPHERIC EVOLUTION IN THE HURONIAN

Robert Rainbird[1], Nabil Shawwa[2], Thomas McLoughlin-Coleman[2], Amy parkinson[3], Ian Coxon[3], Michael Babechuk[3]
[1]Geological Survey of Canada, [2]Carleton University,
[3]Memorial University of Newfoundland.
E-mail: *rob.rainbird@canada.ca*

One of the great debates in the Earth Sciences over the past 40+ years revolves around the timing of the oxygenation of the Earth's atmosphere and oceans, largely because of its link with the evolution of early life. The first evidence for oxygenation of the atmosphere was based on studies of the ca. 2.5–2.2 Ga Huronian Supergroup, north of Lake Huron, Ontario, in the 1960s by Stuart Roscoe of the Geological Survey of Canada, who noted that redox-sensitive detrital minerals such as pyrite and uraninite in sedimentary rocks at the base of the succession gave way to Fe-oxide phases in terrestrial red sandstone (red-beds), oxidized paleosols and

marine sulphate evaporites in its upper part. Similar, mechanically rounded grains of pyrite, uraninite, and siderite, which are not stable in contact with oxidized waters, were also observed worldwide in river deposits of similar and older age. Roscoe dubbed this atmospheric changeover the "oxyatmoversion", however his term seems to have been abandoned in favour of H.D. Holland's "Great Oxidation Event" (aka. the GOE). When did the GOE happen and how long did the process take? Was it a swift and irreversible change, such as a tipping point when oxygen reached a certain level, or did the changes in atmospheric oxygen take hundreds of millions of years to become a permanent and prominent fixture of the Earth? Our studies seek to assess these questions by establishing the primary nature of these mineralogical indicators of oxidizing or reducing conditions in sedimentary rocks of the Huronian Supergroup. Multiple S isotopic analysis suggests that the changeover took place leading up to the time of deposition of the Cobalt Group (upper Huronian Supergroup), although the validity of the data were questioned owing to evidence for metamorphic overprinting. Our field-based mapping and stratigraphic studies recognizes the oldest red-beds at the base of the Cobalt Group, within glaciomarine rocks of the Gowganda Formation and its transition to the overlying fluvial Lorrain Formation. Hematite is abundant in these rocks but most of it appears to have formed during later diagenesis, so it likely does not record earliest (pre-lithification) oxidative reddening. An exception is fine hematitic "dust rims" outlining rounded detrital quartz grains, imaged in pink quartz arenite from the Lorrain Formation. These rims are demonstrably early because they are rimmed by syntaxial quartz overgrowths that would have formed during initial compaction and lithification of the sandstone.

LINKING SURFACE HYDROLOGY AND GEOLOGY: A CASE STUDY OF THE NIAGARA ESCARPMENT (HAMILTON, ONTARIO)

Shania Ramharrack-Maharaj, Ethan Davies
McMaster University.
E-mail: *daviee3@mcmaster.ca*

The Niagara Escarpment is a cuesta, comprising Silurian–Ordovician sedimentary rocks, that bisects the city of Hamilton and is intersected by numerous waterfalls, which are of interest for both their role in the evolution of the region and their contribution to erosion and local geohazards. One key area with minimal research is the relationship between surface hydrology and geological processes. The overall goal of this project is to investigate the relationship between the key properties of a river and its surrounding geology at Princess Falls and Upper Sydenham Falls. Previous studies in Ontario have suggested that the underlying geological features are a primary control on the hydraulic condition in rivers, but the relationship between hydraulic parameters, lithology, and fracture characteristics has not been thoroughly examined. We focus on the Spencer Creek watershed, which includes many rivers that flow over the Niagara Escarpment, making Hamilton, Ontario, the "waterfall capital of the world". The escarpment contains many contrasting lithologies that fracture and erode differently, formed from approximately ten different sedimentary units. The upper layers, namely the Lockport unit, are composed of carbonate rock that is relatively resistant to erosion. Three perpendicular fracture sets were observed, one of which may coincide with the stream orientation. Rivers in the watershed were quantified using stream power, or the energy expenditure of the flowing water per unit length (W/m), which is strongly related to erosion potential and was calculated using the ArcMap tool called the Stream Power Index for Networks (SPIN). SPIN outputs stream power and predicts bed sediment size for each ~40 m segment within the river network. Fracture orientation, aperture, density, and intensity were measured at outcrops, and 3D models were built of key sites using imagery acquired with a DJI Mini2 and processed using ArcGIS Drone2Map. Results from the SPIN tool indicate large variability in stream power as rivers flow near and over the escarpment. Comparing the output SPIN data to the observed geological data allows us to analyze if there is a relationship between river stream power and fracture orientations as well as fracture attributes. This study will further contribute to our understanding of the geological evolution of the escarpment and could be used to predict areas with high potential for river erosion.

MAGMATIC EVOLUTION OF GRANITE ASSOCIATED WITH TUNGSTEN SKARN DEPOSITS IN THE NORTHERN CANADIAN CORDILLERA: A U–Pb, Lu–Hf AND MORPHOLOGICAL STUDY OF ANTECRYSTIC AND AUTOCRYSTIC ZIRCON

Kirsten L. Rasmussen[1], Hendrik Falck[2], Yan Luo[1], Graham D. Pearson[1], Pilar Lecumberri-Sanchez[1]
[1]University of Alberta, [2]Government of the Northwest Territories.
E-mail: *klrasmus@ualberta.ca*

The northern Canadian Cordillera is one of the richest tungsten districts in the world and hosts several of the most significant tungsten skarn deposits, including Cantung (10.796 Mt grading 1.2% WO_3) and Lened (0.75 Mt at 1.17% WO_3). Extensive new U–Pb, Lu–Hf, and morphological data for magmatic zircon from intrusions in the Cantung and Lened areas demonstrate that these deposits are associated with one or more relatively long-lived buried magmatic systems. All the exposed intrusive phases examined in the Cantung area contain antecrystic zircon defining a continuum of ages from ~110–100 Ma but peaking generally between 103 and 105 Ma. However, the presence of 120–115 Ma zircon in several intrusive phases suggest that the magmatic system was active up to 20+ M.y. prior to the main mineralizing events and final crystallization of the plutons at 99–96 Ma (defined by autocrystic zircon ages). Similarly, at Lened antecrystic zircon ranges as old as ca. 116 Ma but generally peaks at ~106 Ma for intrusive phases with final crystallization ages at 98–97 Ma. Corresponding Lu–Hf isotopic data show a large range in initial Hf isotopic compositions (εHf_i), but there is a subtle trend at both Cantung and Lened towards more radiogenic compositions on the order of 2 epsilon units with time. While zircon in most intrusive phases is dominated by low temperature morphologies, there is abundant evidence for zircon that crystallized at temperatures exceeding 800°C in all samples, which is consistent with the temperatures needed for biotite dehydration-driven anatexis—and, consequently, tungsten liberation—in the crustal source rocks. Although > 100 Ma magmatism is abundant farther west, it is not exposed at the surface in the study area. Our data suggest that large, buried batholiths began crystallizing ca. 120 Ma at Cantung and ca. 116 Ma at Lened, and continued to crystallize while evolving to slightly more radiogenic compositions and potentially enriching the melt with incompatible tungsten. After ~100 Ma, residual magmas containing abundant antecrystic zircon—documenting the prolonged crystallization history of the batholiths—were injected into the upper crust at the current level of exposure and are associated with some of the highest grade tungsten mineralization in the world.

MAGMA SOURCE ROCKS IN THE NORTHERN CANADIAN CORDILLERA: IMPLICATIONS FOR METALLOGENY AND BASEMENT

Kirsten L. Rasmussen[1], Hendrik Falck[2], Vanessa Elongo[3], Jesse Reimink[4], Yan Luo[1], D. Graham Pearson[1], Luke Ootes[5], Robert A. Creaser[1], Pilar Lecumberri-Sanchez[1]
[1]University of Alberta, [2]Government of the Northwest Territories,
[3]APEX Geoscience Ltd., [4]The Pennsylvania State University,
[5]British Columbia Geological Survey.
E-mail: *klrasmus@ualberta.ca*

The crust-derived Tungsten Plutonic Suite (TPS) in the western Mackenzie Mountains, northern Canadian Cordillera, is responsible for several of the world's most important tungsten (W) resources, but the source rocks for these exceptionally fertile magmas have never been identified. Detrital zircon studies have improved our knowledge of exposed supracrustal packages in the region and provide the template for a U–Pb study of inherited zircon cores in the TPS to determine the age and provenance of the mid-crustal magma source(s) for these magmas. Inherited zircon in the TPS is dominated by Neoarchean to Paleoproterozoic dates that are typical of a northwest Laurentian cratonic signature, with two dominant age populations from 2100–1750 Ma and 2800–2500 Ma. Additionally, a number of individual dates at approximately 1100–1000 Ma, 1550–1400 Ma, 2150 Ma, 2400 Ma, and 3000 Ma were measured. A combination of cross-correlation statistical analysis, multidimen-

sional scale mapping, and whole rock neodymium isotopic compositions indicate that Mid–Late Cambrian sedimentary rocks are the most likely melt source for the TPS magmas. Despite the presence of prospective intrusions and sedimentary rocks farther west, significant W concentrations in the region are limited to the narrow belt of TPS plutons paralleling the ancient continental margin, possibly due to local depositional and (or) structural thickening and (or) burial depths of these strata. The depth of the Moho below the western Mackenzie Mountains and estimated emplacement depths for the TPS together imply that the crust was up to 50 km thick in the region during the mid-Cretaceous. The lack of magmatic muscovite in the TPS plutons indicates anatexis was dominated by biotite-dehydration melting, requiring paleodepths of 25–30 km and placing the latest Neoproterozoic to Early Cambrian sedimentary source rocks to these magmas well within the middle crust. These source rocks to the TPS are younger than geophysical interpretations would suggest and, therefore, may necessitate modifications to our understanding of the crustal architecture below the western Mackenzie Mountains.

ENHANCED WEATHERING AND MINERALIZATION: NEGATIVE EMISSIONS OR CO_2 AVOIDANCE?

Kwon Rausis, Ian M. Power, Carlos Paulo, Justin Lockhart, Ben Bates, Karen Thompson
Trent University.
E-mail: *kwonrausis@trentu.ca*

Enhanced weathering and mineralization (EWM) have been proposed as a negative emissions technology (NET) with the potential to sequester gigatonnes of CO_2 at human-relevant timescales by spreading alkaline rock powders over large areas, including agricultural fields. However, carbon accounting during EWM has proven challenging, mainly due to the slow reaction of rock powders (e.g. basalt) and the complexity and heterogeneity of soil systems. This study aims to provide insights into carbon cycling during EWM and determine CO_2 removal rates when applying pulverized wollastonite ($CaSiO_3$; ~21 wt.%) skarn to agricultural soils in southern Ontario, Canada. Columns containing 5 kg of soil and wollastonite-amended soils (10 and 20 wt.%) were exposed to wetting and drying cycles for 5 months in the laboratory. CO_2 fluxes were mainly controlled by soil respiration, which depended on water content. Dissolution of pre-existing calcite ($CaCO_3$) and wollastonite skarn minerals limited soil CO_2 emissions. Amended soils only captured atmospheric CO_2 immediately after wetting events, while control soil continuously emitted CO_2. The equivalent of 38–65% of soil CO_2 emissions was sequestered during the first 30 days due to wollastonite dissolution. However, only the 20 wt.%-dossed plot continued to avoid CO_2 emissions after the initial reactivity of wollastonite. The slow weathering of wollastonite after the initial reactivity is likely attributed to surface passivation. CO_2 sequestration rates were up to 0.043–0.180 kg $CO_2/m^2/yr$ for amended soils. A field study using the same soil and amendments achieved rates of 1.5–2.9 kg $CO_2/m^2/yr$. Wollastonite applied on the field likely experienced less passivation than in laboratory experiments, thus, achieving greater CO_2 removal rates. The relatively high CO_2 concentrations in soil pore spaces (~0.1% and ~1% for lab and field experiments, respectively) and decreases in the $\delta^{13}C$ isotope values of carbonate minerals indicate that the captured CO_2 originated from microbial respiration rather than removing CO_2 from the atmosphere. While this conclusion does not negate the potential for EWM to offset CO_2 emissions, it provides a further understanding of the carbon cycle, which is essential for long-term carbon accounting and monitoring.

STYLE AND TIMING OF TECTONOMETAMORPHIC EVENTS IN THE NEOARCHEAN QUETICO METASEDIMENTARY BELT (SUPERIOR PROVINCE): INSIGHTS FROM ISOGRAD MAPPING AND U–Pb MONAZITE PETROCHRONOLOGY

Adrian Rehm[1], Antoine Godet[2], Douglas Tinkham[1], Carl Guilmette[2]
[1]Laurentian University, [2]Université Laval.
E-mail: *adrian.rehm@gmail.com*

The Quetico subprovince (QS) is a ca. 2.7 Ga metasedimentary basin, stretching over 1200 km across the west-central Superior Province. It is dominated by thick sedimentary successions of graded wacke and pelite, with minor volcanic interlayers, variably metamorphosed from greenschist at the margins to granulite facies at the centre of the basin. The geodynamic setting of the QS is strongly debated, with uniformitarian models viewing the belt as an accretionary wedge that formed during northward subduction and accretion of the Wawa (south) and Wabigoon (north) terranes and non-uniformitarian models invoking rifting and plume-driven tectonism for the formation of the basin. The metamorphic record in the QS is remarkably well-preserved and provides important insights into early geodynamic processes. Non-parallel isograds, overprinting of chlorite, biotite, and garnet-bearing assemblages on pre-kinematic cordierite and andalusite assemblages, and pressure–temperature (P-T) estimates from phase equilibria modelling indicate that two metamorphic gradients characterize the symmetrical sequence of isograds in the QS. In the centre, staurolite–andalusite → cordierite → sillimanite → melt → orthopyroxene reflects a high T/P gradient (~150°C/kbar). At the margins, the succession of chlorite → biotite → garnet zones reflects a lower T/P gradient (< 100°C/kbar). Furthermore, U–Pb monazite dating by in situ LA-ICP-MS analysis on four pelite samples points to at least two tectonometamorphic events. An M1/D1 event (ca. 2686–2672 Ma) involves high T/P assemblages and is coeval with flat-lying isoclinal folding, a weak bedding-parallel foliation, and ubiquitous sanukitoid plutonism. An M2/D2 event (2660 ± 3 Ma) involves both gradients, is coeval with upright folding, a strong subvertical foliation and may have continued into D3 transpression. These results suggest that the QS initially formed in a rift setting, as opposed to a compressional fold-thrust setting, and that subsequent verticalization of metasedimentary units was due to crustal overturn, as opposed to Barrovian-style crustal thickening of a coherent block. These processes are more consistent with a plume-driven tectonic model.

SEDIMENTARY CHARACTERISTICS AND PROVENANCE OF THE LATE ORDOVICIAN–EARLY SILURIAN SUCCESSIONS IN THE SOUTHEAST YANGTZE BLOCK: IMPLICATIONS FOR PALEOGEOGRAPHIC EVOLUTION OF THE SOUTH CHINA BLOCK

Peng Ren[1,2,3], Chuanlong Mou[3], Qiyu Wang[3], Shoufa Lin[2]
[1]China University of Geosciences, [2]University of Waterloo,
[3]China Geological Survey.
E-mail: *peng.ren@uwaterloo.ca*

The South China Block (SCB) is composed of the Cathaysia Block in the southeast and the Yangtze Block in the northwest. However, there is still some controversy regarding the final assembly time and geodynamic models of these two blocks during the early Paleozoic, which has resulted in varying opinions about the properties and evolution of the proto-basin located in the southeast margin of the Yangtze Block. To address these issues, we conducted a study of the sedimentary facies and provenance of the Late Ordovician to Early Silurian successions in the southeast Yangtze Block through field investigation, petrography, whole rock geochemistry, and detrital zircon geochronology. Sedimentological and petrographic analyses identified seven sedimentary facies in the Late Ordovician to Early Silurian successions, indicating a transition from neritic–bathyal to littoral–land environments during this period. Geochemical signatures suggest that the Late Ordovician–Early Silurian siliciclastic rocks were deposited in intraplate or passive margin settings and mainly derived from felsic igneous rocks and recycled sedimentary rocks. The detrital zircon samples were found to contain two major age populations of 1200–900 Ma and 880–720 Ma, respectively, as well as four minor populations, indicating a significant proportion of zircon with ages much earlier than the time of deposition. Based on our results and published data, we consider that the sedimentary facies of the Late Ordovician–Early Silurian successions transition continuously from the Cathaysia Block to the southeast Yangtze Block. It suggests that the sedimentary basin in the southeast Yangtze Block is an intraplate basin. During the Sandbian–early Katian, the basin was mainly dominated by deep water shale and shallow water carbonate sedimentation. The early Paleozoic orogeny in SCB led to intense uplift in the Wuyi–Yunkai area, resulting in the release of recycled detritus (1200–900 Ma) and the migration of the sedimentary centre towards the northwest, with the deposition of turbidites in the southeastern edge of the studied basin in the late Katian. In the Early Silurian, the supply of terrestrial detritus further increased, leading to deltaic sedimentation becoming the dominant depositional environment in the southeastern Yangtze Block. The unidirectional SE-sourced detritus suggested continuous uplift and erosion of the Wuyi–Yunkai region. Meanwhile, the appearance of a large

amount of detritus with ages of 880–720 Ma in the Early Silurian strata suggested synchronous uplift of the west part of the Jiangnan–Xuefeng mountain belt (JXMB), which may have resulted from intraplate orogenesis propagating from the Wuyi–Yunkai region to the southeast Yangtze Block.

TOWARDS QUANTIFYING THE CONTRIBUTION OF ANAEROBIC OXIDATION OF METHANE TO THE SULPHUR BUDGET OF THE HOWARDS PASS Zn-Pb DEPOSITS, CANADIAN CORDILLERA OF YUKON AND THE NORTHWEST TERRITORIES

Merilie A. Reynolds[1], Kenneth A. Hickey[2], Jinglin Xu[2], Darius Kamal[2]
[1]Northwest Territories Geological Survey, [2]University of British Columbia.
E-mail: *Merilie_Reynolds@gov.nt.ca*

Howards Pass is a world-class district of clastic-dominated massive sulphide deposits located in the Canadian Cordillera near the border of Yukon and Northwest Territories. Zinc–lead mineralization is hosted in the Ordovician–Silurian Duo Lake Formation, which is composed of organic-rich mudstone that is variably calcareous and siliceous. The Duo Lake Formation also contains abundant calcareous concretions that can be up to several metres in diameter. To our knowledge, these concretions only occur in sections of the Duo Lake Formation that contain intervals of Zn–Pb mineralization, which suggests some sort of genetic link between the processes that formed them. Previous work has shown that anaerobic oxidation of methane (AOM), a biogenic process that produces reduced sulphur (HS^-) and carbonate (HCO_3^-), was operating during diagenesis of the host strata and was likely a source of at least some reduced sulphur in the Zn–Pb(–Fe) mineralization. Evidence for AOM is preserved in the S isotopic signature of diagenetic pyrite and the C isotopic signature of carbonate, with the influence of AOM on the C isotopic signature being especially pronounced in the carbonate concretions. In this study, we propose to estimate the fraction of sulphide in the deposit that was derived from AOM. Towards this aim, the total length of core composed of concretions was measured during re-logging of two drill holes from the XY deposit. These data and bulk rock multielement data from the historical database were used to calculate the cumulative grade thickness of concretion Ca (and therefore concretion CO_3^{2-}) and sulphide S for each hole. The C isotopic data from previous work were used to estimate the fraction of carbonate in concretions derived from AOM. The results were input in a mass balance calculation using the chemical reaction for AOM to determine the fraction of the sulphide in each hole that was derived from methane. Preliminary calculations indicate that 15–24% of the sulphide in these holes was derived from AOM, suggesting that the process was a modest but significant contributor to the sulphur budget of the deposit but not a primary control on deposit formation. The nature of the relationship between the concretions and massive sulphide mineralization is likely more complex.

METAL AND LIGAND MOBILITY DURING PROGRADE METAMORPHISM OF METASEDIMENTARY BELTS IN THE SUPERIOR PROVINCE: IMPLICATIONS FOR Au ENDOWMENT

Diogo Ribeiro[1], Bertrand Rottier[1], Antoine Godet[1], Clifford Patten[2], Georges Beaudoin[1], Carl Guilmette[1], Jochen Kolb[2], Iain Pitcairn[3]
[1]Université Laval, [2]Karlsruher Institut für Technologie, [3]Stockholm University.
E-mail: *dirib3@ulaval.ca*

This study focuses on the Pontiac and Quetico subprovinces, two metasedimentary belts in the Superior Province. Representative metasedimentary rocks metamorphosed at different metamorphic grades, from greenschist to granulite facies, were sampled along three transects representing well-endowed (Rouyn-Noranda, Pontiac), moderately endowed (Geraldton, Quetico), and poorly endowed (Thunder Bay, Quetico) areas. We report whole rock geochemistry data for trace elements, and ultra-low detection limit data for Au acquired by pressed powder pellet (PPP)-LA-ICP-MS. The results show a systematic decrease of As and Sb concentrations with increasing metamorphic grade across the three areas: (i) 12.82–0.25 ppm As and 0.16–0.08 ppm Sb in Rouyn-Noranda, (ii) 22.44–0.44 ppm As and 1.02–0.06 ppm Sb in Geraldton, and (iii) 13.73–0.33 ppm As and 0.23–0.03 ppm Sb in Thunder Bay), suggesting mobilization of these elements during prograde metamorphism. However, decreasing gold concentrations with increasing metamorphic grade, indicative of Au mobilization, are only detected in endowed areas (from 1.03–0.16 ppb in Rouyn Noranda, and from 1.04–0.25 ppb in Geraldton), while no variation was recognized in the poorly endowed area. We evaluate the apparent contrasting Au mobility between the different transects by tracking the textural and chemical (LA-ICP-MS) evolution of sulphide phases throughout different metamorphic grades. Results from the Geraldton transect reveal an evolution featuring two main reactions: (1) Pyrite I–pyrrhotite gradual transition, from biotite to cordierite zones, involves poorly crystallized transitional sulphide phases of intermediate composition between pyrite and pyrrhotite. A progressive decrease of Au, As, and Sb median concentrations with increasing metamorphic grade is observed in pyrite I: 33.6 ppb Au, 410.3 ppm As, 17.4 ppm Sb in the chlorite zone; 22.3 ppb Au, 127.2 ppm As, 12.7 ppm Sb in the biotite zone; and 18.2 ppb Au, 93.5 ppm As, 2.2 ppm Sb in the garnet zone. The same trend is detected in pyrrhotite: from 16 ppb Au, 3.64 ppm As, 2.62 ppm Sb in the biotite zone to 3 ppb Au, 0.07 ppm As, 0.02 ppm Sb in the cordierite zone; (2) Pyrrhotite–pyrite II transition, at the sillimanite zone, marked by euhedral pyrite growing inside pyrrhotite. Since the median Au, As, and Sb concentrations of pyrite II (2.8 ppb Au, 1.79 ppm As, 0.04 ppm Sb) are identical to pyrrhotite, this transition had limited impact on the release of these elements. Both whole rock and in situ analyses reveal a decrease of Au, As, and Sb concentrations with increasing metamorphic grade suggesting that devolatilization of the metasedimentary belts may have sourced significant volume of these elements to the overlying Au-endowed greenstone belts.

GLACIAL DISPERSAL FROM A MIGRATING LAURENTIDE ICE SHEET ICE DIVIDE IN NORTHEASTERN QUEBEC AND WESTERN LABRADOR

Jessey Rice[1], Martin Ross[2], Heather Campbell[3], Roger Paulen[1], M. Beth McClenaghan[1]
[1]Geological Survey of Canada, [2]University of Waterloo,
[3]Geological Survey of Newfoundland and Labrador.
E-mail: *jessey.rice@nrcan-rncan.gc.ca*

The interior of the Laurentide Ice Sheet (LIS) had a dynamic polythermal base. However, the subglacial thermal organization of the LIS and its evolution throughout glaciation are poorly constrained. Specifically, the net effect of ice divide migration on subglacial processes and the resulting landforms and sediments remains poorly understood. The results of a regional scale till sampling program within the interior of the Quebec–Labrador sector of the LIS were used to explore dispersal patterns across a region known to have experienced ice divide migration. Indicator mineral and clast lithology analysis, coupled with multivariate analysis of the till matrix geochemistry, were used collectively and evaluated within the context of the relative ice flow chronology and subglacial thermal evolution to augment our understanding of how ice divide migration impacts subglacial erosion and sedimentary processes. Indicator minerals (e.g. goethite and orthopyroxene) and clasts (e.g. iron formation clasts from the Labrador Trough) form glacial dispersal patterns that are consistent with the earliest northeast-trending ice-flow phase identified in the region. This early ice-flow phase produced and transported till across the entire study area (> 175 km). However, till matrix geochemistry shows a strong relationship with the local underlying bedrock, especially the major oxides. This relationship is relatively common in areas of thin till cover and resistant bedrock lithologies. The results also indicate that following the northeast ice-flow phase, erosion and till production became more localized, without considerable transport in a single sustained direction. These results are consistent with a transition to more sporadic warm-based conditions and ice divide migration, as ice sheet reconstructions indicate, and are supported by targeted ^{10}Be data from erratics and bedrock surfaces. There are also spatial relationships between the dispersal of fresh or re-entrained debris and paleo-ice streams identified in the landform record, as evidenced by the dispersal of indicator minerals. The reworking of previously dispersed material during subsequent ice-flow phases resulted in complex dispersal patterns across the study area. These results provide important insights for ice sheet modelling and future mineral exploration programs in inner ice sheet regions of the LIS and demonstrate the importance of a thorough understanding of ice-flow history.

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IDENTIFYING CONTROLS ON ORE FORMATION IN HIGHLY COMPLEX BASIN-HOSTED MINERAL SYSTEMS BY 3D GEOLOGICAL MODELLING: A CASE STUDY FROM THE BLACK ANGEL Zn-Pb MINE AREA (GREENLAND)

Philip Rieger[1], John Güven[1], Koen Torremans[1], Mark Holdstock[2], Justinas Matusevicius[2], Frank van der Stijl[3], David Coller[3], Pierpaolo Guarnieri[4], Nigel Baker[4], Erik Vest Sørensen[4]
[1]Science Foundation Ireland, [2]Black Angel Mining A/S, [3]Independent Consultant, [4]Geological Survey of Denmark and Greenland.
E-mail: *philip.rieger@icrag-centre.org*

Much of the global Zn and Pb is hosted within Proterozoic sedimentary basins and these basins are actively explored for high value Zn-Pb deposits. In the Maarmorilik area (central West Greenland), the Paleoproterozoic Karrat Group hosts the Black Angel Zn-Pb deposit (11.2 Mt at 12.4 wt.% Zn and 4.2 wt.% Pb) and > 200 mineralized showings. The deposit is hosted by the Mârmorilik Formation, which consists of greenschist-facies marble (calcitic/dolomitic) and pelite, and has undergone at least two deformation phases. Previous studies suggested that mineralization at Black Angel is structurally and stratigraphically controlled, but this control is only poorly constrained. We present a first ever 3D structural–stratigraphic model of the Black Angel area that was based on integrated historical and recent mine, exploration, and mapping data. The 3D modelling indicates that (1) the Black Angel orebodies are hosted within distinct NE-trending facies belts of interbedded marble and pelite, and that (2) the highest grade ore zones are located along WNW-trending folds, in which the strain is often partitioned into relatively discrete areas. We suggest that these interbedded facies belts provided a combination of rock properties (reactivity, permeability, and rheology) that was favourable for focusing hydrothermal replacement and mineralization and later multi-layer folding.

MANGANESE OXIDES AND ATMOSPHERIC OXYGENATION

Leslie Robbins[1], Mojtaba Fakhraee[2,3], Chang-Le Wang[4], Albertus Smith[5]
[1]University of Regina, [2]Georgia Institute of Technology, [3]Yale University, [4]University of Chinese Academy of Sciences, Beijing, [5]University of Johannesburg.
E-mail: *leslie.robbins@uregina.ca*

Reconstructing the history of oxygen in the lead-up to the Archean–Paleoproterozoic boundary and Great Oxidation Event (GOE) has been an ongoing challenge and subject to intense debate. The existing paradigm that large sedimentary manganese (Mn) enrichments – particularly Mn(II) carbonates that are isotopically depleted with respect to carbon – are an indicator for incipient oxidation of surface waters is facing increasing arguments regarding alternative pathways for their generation. Possible alternative pathways that have recently been suggested include photosynthetic oxidation of Mn(II), photooxidation by UV light, and the direct nucleation of Mn(II) carbonates. Here we review possible Mn(II) oxidation pathways and view the record of Mn deposits in light of the question – do large sedimentary Mn enrichments provide direct evidence for early environmental oxygenation? We find the preservation of appreciable Mn carbonates that are depleted in ^{13}C are consistent with the precipitation of precursor Mn(IV) oxides and subsequent diagenesis. Moreover, the nucleation of alternative primary Mn(II) phases is likely unfavourable, thus indicating that large Mn deposits prior to the Archean–Paleoproterozoic boundary are indicative of the rise of oxygenic photosynthesis. Moreover, Mn/Fe ratios in banded iron formations increase towards the terminus of the Archean, further supporting increasing environmental oxygenation. Along with other isotopic and geochemical indicators the Mn record supports a relatively early emergence of oxygenic photosynthesis and subsequent rise in the importance of this critical metabolism.

MISTASSINI–OTISH IMPACT STRUCTURE II: MELT-BEARING IMPACT BRECCIAS OBSERVED AT THE VERY BASE OF THE MISTASSINI GROUP

Francine Robert, Serge Genest
Astroblèmes Québec Inc.
E-mail: *astroblemesquebec@gmail.com*

Three units are recognized in the Mistassini basin (MB), from base to top, the lower member of the Albanel formation (AF), the AF upper member, and the Témiscamie iron formation. The AF lower member has been subdivided into six subunits (A to F) totaling nearly 900 m in thickness. Subunits A and B are known for their copper potential. They are respectively described as a basal clast-bearing dolomitic sandstone unit, now defined as the Mistassini spherule layer (MSL), and a dolomite unit hosting black shale horizons. According to former workers, the basal subunit A is assumed to lie on a dolomite-cemented regolith composed of polymict breccia and conglomerate mixed with sandy dolomite and stromatolitic dolomite. The AF upper member and the subunits C to F of the lower member, are composed of massive dolomite totaling more than 600 m in thickness. The average aggregated thickness of the detrital components of both subunits A and B represents 3.1% of the AF total thickness, i.e. 46.9 m/1500 m according to DDH data. A total of 476 DDH logs have been assessed, of which 341 encountered the MSL and 76 intersected the entire subunit A. According to the DDH log descriptions, the main components of the subunit A can be summarized as followed: stromatolitic breccia, stromatolitic dolomite fragments, sandy dolomite breccia (MSL fragments), polymict regolith-like breccia, shattered granite fragments ranging up to 15.9 m across, dolomite-cemented breccia and conglomerate, pisolite-like and other coarse rounded fragments, graphitic and carbonaceous materials, nodular structures and fragments showing concentric rings of cherty and carbonate materials. Quenched textures around the fragments are a common feature and finely crystallized dolomite cement is ubiquitous within the intensely fractured basement underlying the AF. Shock features such as planar deformation features (PDFs), PFs and maskelynite have been found in quartz monzonite fragments observed in the melt-bearing polymict impact breccia which encloses MSL remnants. On cut slab from these fragments, fully altered feldspar appears as black grains. Decorated PDFs have been observed in a quartz grain. PDFs are quite common in microcline and orthoclase grains observed in the thin section. Two sets of PDFs have been observed in the most pristine sections of an unaltered rutile.

MISTASSINI-OTISH IMPACT STRUCTURE I: PETROGRAPHY AND GEOCHEMISTRY OF THE PHOSPHORUS-RICH MISTASSINI SPHERULE LAYER

Francine Robert, Serge Genest
Astroblèmes Québec Inc.
E-mail: *astroblemesquebec@gmail.com*

The Mistassini spherule layer (MSL) was found in 2016 on the north shore of Mistassini Lake. The HCl insoluble residues revealed the usual splash forms such as sphere, more or less concave discoid, oblate, pear-like, dumbbell, teardrop, gherkin, golf club, more or less elongate droplet, and other complex forms with coalescences of microspheres. Spherules and fragments make up 85% of the thin sections, the spherules being largely dominant (82%). Sub-angular to angular fragments compose the remaining 3%. The dolomitic matrix is shared between the fibrous rims which surround the spherules and fragments (10%) and the remaining true matrix is composed of dolomite, with traces of quartz (5%). The maximum spherule size is about 2.5 mm and the mean size is slightly under 1 mm. No less than 876 analyses have been done in order to characterize the spherule components with SEM–BSE, SEM–

CL and SEM–EDS. Obviously, there is a dichotomy in the composition of both spherules and matrix. The matrix is nearly totally devoid of trace elements whereas an important variable component of metallic elements is associated with the inner constituents of the spherules. The phosphatic materials, especially the phosphorous amorphous microspherule masses have larger and more various metallic contents than in the other spherule types. A sample was submitted for chemical analysis. The CaO, MgO and LOI contents totalize 82.7 wt.%, of which 12% is carbon with only 0.14% of organic origin. Other results of interest are mainly low Al_2O_3, Fe_2O_3 content of 2.17%, SiO_2 content that reflects the spherule composition, relatively high P_2O_5 content that confirms the phosphorous amorphous microspherules (and apatite crystals) observed in nearly 35% of the spherules, and a relatively high Y content that is often associated with the phosphorous spherules. Dr. Philippe Claeys performed XRF mapping of Ca, Sr, Si, P, Fe, Mn, S, Ni, and Y. Immiscible silicon and phosphorus appear to be the main constituents of the spherules besides calcium. Iron is associated with the siliceous shells of the spherules. Calcium is ubiquitous in the matrix and is found in some spherules as dolomite, calcite, phosphate glass and apatite according to microscopic observations. An interesting finding about the XRF mapping is a 3 mm-sized Ni-P-Y-bearing spherule.

THE PARADOXICAL INCOMPATIBLE BEHAVIOUR OF Sr IN HIGHLY EVOLVED GRANITIC MELTS AS AN INDICATOR OF POTENTIAL Li MINERALIZATION: THE CASE STUDY OF CASTILLEJO DE DOS CASAS (SALAMANCA, SPAIN)

Encarnación Roda Robles[1], Jon Errandonea-Martin[1], Idoia Garate-Olave[1], Alfonso Pesquera[1], Pedro-Pablo Gil-Crespo[1], Carlos Villaseca[2]
[1]University of the Basque Country, [2]Universidad Complutense de Madrid.
E-mail: *encar.roda@ehu.es*

The Castillejo de Dos Casas (C2C) Variscan plutonic complex (Central Iberian Zone, CIZ) comprises three granitic and two pegmatitic units that are hosted by the Neoproterozoic–Cambrian metasedimentary rocks of the Schist Greywacke Complex. The granitic units belong to the Villar de Ciervo batholith and include: (1) biotite-rich porphyritic granite; (2) two-mica granite; and (3) B + P ± F-rich leucogranite. The pegmatitic units comprise (4) a barren to Li-rich aplite–pegmatite cupola; and (5) Li-rich aplite–pegmatite dykes. Pegmatitic units are heterogeneous, showing different mineral associations that include quartz, plagioclase, Li-mica, K-feldspar and topaz, with montebrasite, Fe–Mn-phosphates, petalite, elbaite, cassiterite and Nb-Ta oxides as accessory minerals. Layered textures and feldspar-combed crystals are locally observed. Except unit (1), all units are highly peraluminous, Ca-poor and P-rich. From the less-fractionated granitic unit (1) up to the most fractionated pegmatitic units (4 and 5) a continuous decrease in Ca, Fe, Mg, Ti, Ba, Y and REE is observed; parallel to an increase in the incompatible elements Li, F, Rb, Cs, Sn, Nb and Ta. The Sr usually behaves as a compatible element in granitic systems replacing Ca in the feldspar structure. Hence, its concentration decreases in the residual melts as fractionation proceeds. However, this behaviour often changes in the most fractionated granitic units and the related Li-rich pegmatites in the CIZ. In the C2C plutonic complex the biotite-rich granite (1) presents a Sr content that ranges from 51 to 118 ppm. Lower values are found in the two-mica granite (2), in the range 27–48 ppm. The B + P ± F-rich leucogranite (3) shows a clear increase, with Sr values of 36–148 ppm and, finally, the pegmatitic units (4 and 5) show the highest Sr values, up to 323 ppm. This late Sr enrichment is also reflected in the apatite composition, with the highest values in the most fractionated units (3, 4 and 5), where plagioclase composition is very close to pure albite. Thus, the late incompatible behaviour of Sr may be due to the impossibility of this element to substitute for Ca in the feldspars structure when its composition becomes very Ca-poor. In these evolved units the only sink for Sr would be apatite, whose low proportion would allow for the late incompatible character of Sr. Therefore, a Sr increase in the most fractionated units of a granitic series (whole rock and/or apatite) could be an indicator of Li mineralization, at least in these P-rich granitic melts from the CIZ.

CHEMICAL AND TEXTURAL SIGNATURES OF HYDROTHERMAL SULPHIDES AS TRACERS OF THE PROTRACTED GOLD MINERALIZATION HISTORY AT THE AUGMITTO–BOUZAN SEGMENT OF THE CADILLAC–LARDER LAKE TECTONIC ZONE

Rita Rodrigues, Georges Beaudoin, Bertrand Rottier
Université Laval.
E-mail: *rodriguesdossantos.rita@gmail.com*

Orogenic gold deposits (OGD) usually consist of Au-rich veins spatially constrained to major crustal compressional to transpressional discontinuities and their subsidiary structures. At a deposit scale, OGD are often characterized by irregular distribution of Au grades. This feature is commonly the product of multiple vein generations with contrasting endowment illustrating a complex sequence of primary and secondary hydrothermal events that have taken place in areas marked by long-lived deformation. Recognizing these processes is critical to understand Au distribution and therefore to: (i) interpret Au grade patterns; (ii) accurately assess the prospectivity of targets; and (iii) identify ore-shoots. Straddling the Cadillac–Larder Lake Tectonic zone (CLLTz), the Rouyn Property (Augmitto–Bouzan transect) is a prime example of irregular Au distribution patterns. Gold grades vary along strike and economic grades are mostly restricted to W sectors (Augmitto–Astoria), whereas in the E sectors (East Bay–Bouzan) equivalent veins are largely barren. Four Au-bearing hydrothermal episodes have been identified at the property. The earliest Au input is related to the development of microcrystalline quartz–chlorite (MQC) veins synchronous to the main deformation fabric. The second Au episode consists of Au-bearing arsenopyrite located in (sericite/fuchsite) alteration halos related to syn-shear quartz-carbonate-tourmaline (QCT) veins. Both MQC and QCT account for a small percentage of the Au budget. The third episode is spatially related to QCT veins from endowed areas, however, micro-XRF chemical maps show that free Au within these veins is associated with late carbonate infillings (CI) that overprint QCT veins. The latest Au input is characterized by carbonate–chlorite–pyrite/pyrrhotite (CCP) veinlets, often with minor chalcopyrite, galena, and native Bi, that crosscut all previous vein generations. Gold related to this episode is particularly abundant when spatially associated with QCT-related arsenopyrite. Together, CI and CCP account for most Au endowment. Systematic EPMA analyses of arsenopyrite from QCT halos and of pyrite from CCP veinlets across the property have been performed. Arsenopyrite shows significantly different Ni + Co content between endowed (~0.30 wt.%) and non-endowed (~0.02 wt.%) sectors. Conversely, Zn + Cu incorporation is higher in non-endowed sectors (~0.10 wt.%) when compared to endowed ones (~0.06 wt.%). Pyrite shows opposite trends, with significantly higher Co + Ni and lower Zn + Cu values being recorded in non-endowed sectors (~0.17 and ~0.08 wt.%, respectively) compared to endowed ones (~0.08 and ~0.11 wt.%, correspondingly). Arsenic content from endowed sectors (~0.39 wt.%) is considerably higher than non-endowed ones (~0.22 wt.%). These data will be complemented by LA-ICP-MS analyses to better comprehend the relationship between observed chemical differences and the factors controlling Au precipitation.

RAMAN SPECTROSCOPY ON CARBONACEOUS MATTER APPLIED TO THE GRAPHITIC SCHISTS AT LONE STAR, KLONDIKE GOLD DISTRICT, YUKON

Nelson Román[1], Daniel Gregory[1], Peter Tallman[2], Nicole Eriks[2]
[1]University of Toronto, [2]Klondike Gold Corporation.
E-mail: *nelson.roman@mail.utoronto.ca*

Recent studies have highlighted the importance of carbonaceous organic matter for orogenic gold mineralization, which could act as source, transport medium or trigger of precipitation of gold in these systems. In the vicinity of the Lone Star orogenic gold deposit, the main known bedrock gold occurrence in the Klondike gold district, Yukon, minor graphitic schist units occur within the Klondike schist, the host rock

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of gold mineralization. These carbonaceous units are present around the deposit in unmineralized areas, and also within mineralized zones, for example, at Gay Gulch, about 2.5 km southwest from Lone Star. The provenance of the carbonaceous matter in these rocks is unknown, as is its role in gold mineralization. Particularly, it is not known if the carbonaceous matter was emplaced within schist by the mineralization event itself, or if it predates it. To better constrain the nature of the carbonaceous matter in graphitic schist near Lone Star, in this study we applied the Raman spectroscopy on carbonaceous matter (RSCM) technique. This method allows the study of the crystallinity of the carbonaceous matter, which is in turn related to the maximum temperature experienced by the rock. We considered samples from mineralized drill core intervals at Gay Gulch, as well as from outcrop samples from unmineralized areas in the vicinity of Lone Star and from outcrops along Eldorado creek. The average RSCM temperature of all samples is 454°C, with a range from 435 ± 18°C (Irish Gulch) to 482 ± 32°C (Gay Gulch). The RSCM temperatures for all analyzed graphitic schists overlap. The homogeneity of these temperatures, especially the temperature overlap of mineralized and barren zones, suggests that they represent the peak temperature of metamorphism in the area and are not controlled by the proximity to gold-bearing veins. This temperature range is consistent with upper greenschist- to lower amphibolite-facies metamorphic conditions, in agreement with previous studies. Further, these temperatures are higher than the fluid temperatures estimated by the study of fluid inclusions in the gold-bearing veins (200–350°C), suggesting that mineralization was asynchronous with peak metamorphism. These results, coupled with previous petrographic observations indicating that carbonaceous matter is concentrated along pre-mineralization deformation microstructures within the schist units, suggests that emplacement of carbonaceous matter pre-dates mineralization in the Klondike district. Finally, since the RSCM temperatures were not modified by the mineralization event, they also constitute an upper limit for the mineralizing fluid temperature at Lone Star.

GLACIAL SEDIMENT PROVENANCE ANALYSIS IN THE CONTEXT OF ICE FLOW SHIFTS, DRUMLINIZATION, AND GLACIAL LAKE INUNDATION

Martin Ross[1], Philippe Normandeau[2], Wenyao Liang[1], Nickolas Mesich[1]
[1]University of Waterloo, [2]Northwest Territories Geological Survey.
E-mail: *maross@uwaterloo.ca*

An important goal of glacial geology is establishing the source of glacial sediment, given its composition and the reconstructed ice flow history. Such provenance studies can improve our understanding of past glaciations. They are also routinely used to successfully trace indicator minerals and geochemical pathfinder elements back to their buried source of potential economic interest. However, several factors can complicate provenance studies in specific settings. It is thus critical to recognize these situations and understand how they affect results to improve interpretations. Here, we present interim results of an ongoing investigation from a drumlin field located west of Great Slave Lake in south-central Northwest Territories. Previous regional studies have documented a clockwise ice flow shift from SW to NW. The drumlins are part of the record of the WSW ice flow phase. However, new till fabrics from drumlin road cuts, outcrop-scale indicators, and pebble lithology show more complex glacial dynamics than indicated by the glacial landforms. These findings provide critical information as surficial sediment dispersal patterns may reflect the net effect of more than one sediment transport direction despite the drumlins being related to a single phase. In addition, during deglaciation, the study area was entirely inundated by Glacial Lake McConnell, which has variably modified what was previously primary subglacial traction till at the surface. Field observations and particle size distributions of surficial 'till' samples show evidence of reworking by glacial lake processes. Reworking includes the incorporation of glacial lake mud in the till matrix or, in contrast, the washing of fines by shoreline processes. Multivariate analysis of sediment matrix geochemistry shows a relationship with sediment texture. This study has revealed a complex setting where the typical assumptions used in sediment provenance analysis and related glacial dispersal trains may not be entirely valid. Specifically, there may be more than one till sheet at the surface leading to more complex dispersal patterns than suggested by the geomorphological record, and those patterns may also not exclusively reflect subglacial sediment transport. For sediment provenance studies to succeed in such geological settings, they require more comprehensive strategies than other, less challenging regions.

PLEISTOCENE VOLCANISM IN THE CANADIAN CORDILLERA

Kelly Russell[1], Ben Edwards[2], Glyn Williams-Jones[3], Cathie Hickson[4]
[1]University of British Columbia, [2]Dickinson College,
[3]Simon Fraser University, [4]Tuya Terra Geo Corporation.
E-mail: *krussell@eoas.ubc.ca*

The Canadian Cordillera hosts numerous Pleistocene and Holocene volcanoes and volcanic deposits, including a number that have erupted historically. The nature and composition of volcanic edifices and deposits are diverse and dictated by the complex configuration of tectonic plates featured along the western margin of British Columbia. Our modern knowledge of these is built upon more than a century of field- and increasingly laboratory-based studies. We recognize five distinct volcanic domains within the Cordillera and distributed across British Columbia, the Yukon Territory, and easternmost Alaska. These include: the Wrangell Volcanic Arc (WVA), the Northern Cordilleran Volcanic Province (NCVP), the Anahim Volcanic Belt (AVB), the Wells Grey–Clearwater Volcanic Field (WG–CW), and the Garibaldi Volcanic Belt (GVB) representing the northern extension of the Cascade Volcanic Arc. Volcanism in the Canadian Cordillera spans the full range of explosive to effusive events, encompasses the suite of common volcanic chemical compositions (nephelinite to peralkaline rhyolite), and is expressed by long-lived calderas, stratovolcanoes and shield volcanoes, as well as shorter lived tephra cones and associated lava flows. We suggest that given the range in tectonic settings (subduction to extension), eruption environments (subaerial, subaqueous, cryospheric), and background topography, the Canadian Cordillera is one of the most volcanically diverse, yet least studied, areas on Earth. Herein we summarize the current state of knowledge concerning volcanism within the Canadian Cordillera, including some of the latest research results. We conclude with thoughts on research areas that merit further effort.

RECONCILING MICROSCALE MINERAL REACTIVITY WITH MINE WASTEWATER QUALITY DYNAMICS

Nima Saberi, Bas Vriens
Queen's University.
E-mail: *nima.saberi@queensu.ca*

Mineral resource extraction generates vast amounts of mining waste, predominantly waste rock and tailings, that can produce poor quality wastewater upon exposure to air and water. To minimize negative environmental impacts, the weathering of waste rock and tailings and its control on leachate quality needs to be predicted on long terms. However, mineral reactivity can vary under dynamic oxygen- and water-limited conditions in mine-waste storage systems, leading to complex mineral dissolution and precipitation reactions that make such prediction difficult. Our research aims to quantify the mineralogical processes in weathering mine wastes in parallel to their leachate quality, under variable geochemical conditions. To be able to track microscale mineral weathering reactions, we first optimized a sample preparation technique that reduces bias during granular sample preparation for the automated mineralogical analysis of mine waste. Using synthetic reference materials (microspheres), blends with pre-characterized soluble minerals (gypsum) as well as real, heterogeneous weathered waste rock, we quantified particle settling and loss of water-soluble and redox-sensitive minerals during epoxy molding and polishing. Our results show that particle segregation during curing constitutes a significant bias (up to 25% segregation) and particle size more strongly controls phase segregation than density. Further, we found that sacrificing sample polish quality by limiting the exposure to water helps preserve soluble minerals but does not prevent phase recognition as long as the surface slope is corrected using internal contrast standards. In addition, we conducted accelerated weathering experiments with artificial waste rock under water and redox gradients, collecting information on leachate quality and mineral abundance and their geometric and textural features at a 2-week resolution. We found that there is a notable change in wastewater quality with different water saturation levels with 1.2 unit variation in pH when saturation reduces from 100% to 5%, and we are currently examining the controls of the observed mineralogical changes (modal mineralogy, phase liberation, particle geometry) on these trends. Our project shows the importance of understanding potential bias during sample preparation and will help understand the control of mineral weathering dynamics in mine wastes across spatiotemporal scales, paving the way for more effective effluent quality prediction models.

PETROGRAPHY AND SHOCK METAMORPHISM OF HOWARDITE SARIÇIÇEK

Radhika Saini, Chris Herd
University of Alberta.
E-mail: *rsaini2@ualberta.ca*

Howardites are part of the howardite-eucrite-diogenite group of meteorites that most likely originate from the asteroid 4 Vesta. Sariçiçek is a howardite that fell in Turkey in 2015 and was subsequently investigated by a large consortium study for details about the meteorite's fall, find, mineralogy, petrology, and geochemistry. The meteorite was classified as a "regolith breccia" and its petrographic investigation revealed that it is a clast-rich polymict breccia set in a fine-grained matrix of crushed and fragmented material. Fragmentation most likely was caused by impact events. Although there have been some observations reported on the mechanical deformation experienced by pyroxene and plagioclase, the shock effects in this meteorite have not yet been extensively studied. This study seeks to fill in this gap, through the characterization of one polished thin section using FESEM, EDX, and Raman spectroscopy, for diversity of material present in Sariçiçek and the shock effects in various clasts and the matrix. Sariçiçek contains a variety of clasts and mineral fragments set in a fine-grained matrix. Clasts include lithic, monomineralic, and impact melt clasts. The matrix consists of broken and crushed fragments of high-Ca pyroxene, low-Ca (ortho)pyroxene, silica, plagioclase, chromite, ilmenite, and troilite. A variety of impact melt clasts with varying size from ≤ 100 μm to ~400 μm were identified. They are either composed of recrystallized pyroxene, plagioclase and olivine set in a glassy to fine-grained crystalline matrix of variable composition (pyroxene or pyroxene + plagioclase), or relict mineral grains of pyroxene, plagioclase, and silica that are partially digested and set in a fine-grained matrix. Overall, Sariçiçek shows evidence for low shock conditions and a shock stage of S2, as pyroxene and plagioclase clasts in the matrix exhibit undulose extinction and some exhibit mosaicism. However, distinct shock features that represent potential higher shock conditions have been observed in various clasts and include a pyroxene clast (Clast A) with a glassy shock-induced melt vein, a pyroxene clast (Clast B) with a melt region, and an impact melt clast (Clast C) with garnet that might be of high-pressure origin. Since the shock effects are restricted to clast boundaries, they highlight the clasts' distinct shock histories prior to being incorporated in the Sariçiçek breccia and allude to the dynamic environment on the surface of 4 Vesta.

ZINC COMMODITY OVERVIEW: CANADA'S PLACE IN THE CRITICAL METAL WORLD

Frank Santaguida, Normand Dupras
Glencore Canada Corporation.
E-mail: *frank.santaguida@glencore.ca*

In many countries, including Canada, zinc is considered a critical mineral. The "critical" designation is largely due to a region or country's dependency on imports of refined metal. The distribution of zinc metal refineries around the world controls the supply chain pathways which consequently impacts criticality. Most of the zinc refining capacity in the world resides in Asia and specifically, China. Five refineries occur in North America which collectively do not support the domestic demand. Global zinc production is dominated by a few mines. The top twenty-five mines in the world account for approximately 50% of global production. The distribution of these top mines is widespread; however, China is the largest producer of zinc; accounting for over 50% of global production from 145 separate mines. Production in Canada amounted to 3% of the global zinc output from seven separate mines. A large number of the top zinc-producing mines also contain healthy resources to extend beyond a ten-year lifespan. Therefore, the criticality of zinc is unlikely to change in the near future. Over a longer term, a large number of zinc resources have been identified throughout the world, but many of these, especially in Canada, are not currently feasible due to a lack of infrastructure or due to mineral processing issues so may never be put into production. Exploration for new resources may be a means to alter the criticality of zinc. The diverse geological settings for zinc mineralization offer several opportunities worldwide and especially in Canada. Globally, sedimentary exhalative (SEDEX) deposits are the largest of the types and proportionally account for greater than 30% of zinc metal produced worldwide. Zinc metal is also derived from several other types with volcanogenic massive sulphide deposits (VMS) as another important source accounting for 16% of global production. Most of the zinc production in Canada comes from VMS-type deposits. Approximately 50 Mt contained zinc occurs in unmined deposits throughout Canada; a majority of which are SEDEX and VMS types. Current exploration activity throughout Canada demonstrates high potential for new zinc resources still exists. Interestingly, a more diverse set of deposit types is being explored where zinc is a secondary metal yet may provide a significant metal supply. Several active projects are targeting epithermal and intrusion-associated gold-silver with veins also bearing zinc and other base metal minerals. So Canada's place is well placed for change.

THE ROLE OF 3D TEACHING OBJECTS IN GEOSCIENCE EDUCATION

Tasca Santimano, Heidi Daxberger
University of Toronto.
E-mail: *tasca.santimano@utoronto.ca*

In geosciences, the ability to visualize three dimensional features like lithological beds, fault networks, or mineralized veins is fundamental. It aids in understanding the formation and architecture of local and regional geology, plate movement dynamics, localization of ore deposits, and climate change through space and time. However, the three-dimensional geometry of geological structures is usually taught by using two dimensional tools such as PowerPoint slides, a blackboard or paper. We noticed that visualizing and extrapolating the extent and geometry of structures in 3D space is one of the hardest tasks for students in Geoscience. Hence, it is important to first show such features in 3D before transferring the information into 2D space. To tackle this problem, we integrated exercises that illustrate the transfer of three-dimensional information to two dimensions based on custom 3D printed terrain models, strain ellipsoids and 3D Stereo spheres, in multiple structural geology courses taught at the University of Toronto. The chosen teaching objects were accompanied by exercises that allow learners to test the object's dimensional properties and achieve specific learning objectives that were scaffolded around the course learning outcomes. For example, topographical block models were used to help comprehend and visualize the orientation of planar structures. The 3D-printed strain ellipsoids help to comprehend and visualize the spatial relationship between deformation and the orientation of the three principal strain axes in comparison to principal stress axes. To evaluate the efficacy of the chosen 3D exercises and objects, we conducted anonymous surveys and data collection. The first survey included control data such as prior experience, background information, and included a set of mind experiments testing the students' initial 2D and 3D visualization skills. The two subsequent surveys were conducted each after a set of two exercises. These surveys consisted of more advanced visualization tests to evaluate the students' skill improvement. Over the past 4 years we have collected over 100 sets of student data for multiple courses. The surveyed student cohort consisted of Geoscience, Engineering and Environmental Science students. Results, including virtual assessments during the COVID-19 pandemic, show that students found the use of the 3D objects effective. Additionally, students found they grasped the tested concepts faster, and were able to apply and advance their skills as the exercises became more challenging. Most importantly the students appreciated how the exercises transcended their critical thinking skills, and students recommended 3D skill exercise integration in other geoscience courses.

OVERVIEW ON REE DEPOSITS ASSOCIATED WITH CARBONATITE TO ALKALINE COMPLEXES IN CANADA

Anne-Aurélie Sappin[1], L. Paul Bédard[2], Marc Constantin[3]
[1]Geological Survey of Canada, [2]Université du Québec à Chicoutimi, [3]Université Laval.
E-mail: *anne-aurelie.sappin@nrcan-rncan.gc.ca*

Although carbonatite and alkaline igneous rocks are relatively unusual on the Earth's surface (< 1% of all the Earth's igneous rocks), Canada hosts many of these uncommon units. They mainly occur within the Canadian Shield and Canadian Cordillera and range in age from Neoarchean (e.g. Shortt Lake carbonatite at ca. 2652 Ma) to Mesozoic (e.g. Oka carbonatite at ca. 135–113 Ma), albeit many of them are Proterozoic in age (e.g. Ashram carbonatite, Nechalacho alkaline complexes). Carbonatite

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and alkaline complexes are generally emplaced into intracratonic anorogenic or post-orogenic extensional settings and are commonly spatially related to major crustal structures. The Waswanipi–Saguenay structural corridor that hosts the Montviel, Shortt Lake, Dolodau, and Saint-Honoré carbonatite complexes and the Crevier alkaline complex in Quebec and the Kapuskasing Structural Zone that hosts the Clay-Howells, Nemegosenda Lake, and Lackner Lake alkaline complexes, and Argor carbonatite in Ontario are good examples of how major crustal-scale weakness zones control the emplacement of these igneous complexes. Carbonatite and alkaline igneous rocks crystallize from volatile-enriched carbonatite and alkaline parental magmas generated by low degrees of partial melting of metasomatized or crustally contaminated lithospheric mantle sources. These rocks are highly prospective units to host economic critical mineral resources. In particular, they are the major hosts of rare earth element (REE) deposits and most of the world's REE production is related to these igneous rocks. In Canada, Nechalacho in the Northwest Territories is currently the only REE mine in production exploiting a world-class deposit, with a global geological resource (i.e. measured, indicated, and inferred) of 94.7 Mt at 1.46% rare earth oxide, associated with a layered alkaline igneous suite. Advanced stage REE exploration projects are also numerous in the country, including the carbonatite-associated Niobec and Ashram deposits (Quebec), the carbonatite-associated Wicheeda Lake deposit (British Columbia), and the Strange Lake and Kipawa deposits hosted by alkaline complexes (Quebec). Canadian REE mineralization associated with carbonatite and alkaline rocks were mainly formed by magmatic (e.g. fractional crystallization, magma immiscibility) and/or hydrothermal ± metasomatic processes. However, hydrothermal remobilization appears to be essential for the formation of economic REE deposits. Overall, REE ore hosted within carbonatite complexes contains a range of REE-bearing fluorocarbonate phases (e.g. bastnaesite-(Ce), parisite-(Ce), synchysite-(Ce)), phosphates (e.g. monazite-(Ce), xenotime-(Y)), and oxides (e.g. aeschynite-(Y), fergusonite-(Y)). In comparison, in their counterpart alkaline complexes, the REE ore minerals also include REE-bearing silicates (e.g. eudialyte, mosandrite-(Ce)) and halides (e.g. gagarinite-(Ce), fluorite).

SCALED ANALOGUE MODELLING APPLIED TO MAGMATIC SULPHIDE DEPOSITS: WHY? AND WHAT'S NEXT?

Benoit M Saumur[1], Laura Vachon[1], Killian Milier[1,2]
[1]Université du Québec à Montréal, [2]Université d'Orléans.
E-mail: *saumur.benoit-michel@uqam.ca*

Intrusion-hosted magmatic sulphide deposits are complex dynamic systems. The transport and the accumulation of sulphide is controlled by several physical parameters, among which are the rheology and the density of two immiscible fluids, the velocities of these fluids and the geometry of the system. Over the last decade, numerical models have provided important insight on these problems. Scaled analogue modelling is complementary to the numerical approach, and used to ensure that studied geological phenomena are consistent with the physical properties of the components of the system. Immiscible liquids (oil vs. water-based) of varying or adjustable density and viscosity are readily available and provide potential for the scaled analysis of bimodal sulphide liquid–silicate magma systems. Analogue modelling was used in the early 2000s to analyze the evolution of sulphide droplets in magma chambers. More recently, scaled models tested whether accumulated sulphide liquid could be entrained by silicate magma; results suggest that, although coherent pulses of sulphide liquid could be generated by highly dynamic systems, downward percolation of dense sulphide liquid likely accounts for indications of sulphide-rich magma pulses at many mineral deposits. Next steps include the analysis of the role of conduit geometry on the evolution of sulphide liquid, which will be performed in scaled experiments with analogue silicate magmas of varying density and viscosity, at various flow rates.

NEW MAPPING PROTOCOL FOR LASER ABLATION COUPLED TO A TIME-OF-FLIGHT MASS SPECTROMETER FOR THE FAST QUANTIFICATION OF MULTIPLE MINERALS FROM MAGMATIC ORE DEPOSITS

Dany Savard[1], Sarah Dare[1], L.Paul Bédard[1], Sarah-Jane Barnes[1], Joseph Petrus[2]
[1]Université du Québec à Chicoutimi, [2]Elemental Scientific Lasers.
E-mail: *ddsavard@uqac.ca*

Because "an image is worth a thousand words", chemical mapping in all fields of science is growing in interest. For instance, mapping the trace elements of minerals by LA-ICP-MS at the micrometre-scale provides precious information of chemical composition and can reveal key information such as growth zoning, exsolution, micro-veins, resorption, diffusion and more. However, peak jumping mode operation of single quadrupole ICP-MS limits the acquisition speed whereas time-of-flight mass spectrometers (ICP-TOF-MS) can extract the full mass range simultaneously at a high rate (33 kHz), rendering the instrument attractive for routine chemical mapping. We have developed a new 2D mapping protocol using a 193 nm LA system (RESOlution, Applied Spectra) equipped with a small volume fast-response funnel device (Fast Funnel – FF) (Norris Scientific & Laurin Technic) allowing highly efficient transport of the aerosol to the attached ICP-TOF-MS (TOFWERK). Simultaneous quantification of major and trace elements of various minerals common in ore deposits (silicates, sulphides, oxides, apatite, calcite) within a single data processing, and without saturation of the ICP-TOF-MS detector, can be achieved by combining multiple calibration materials of varied matrices (glasses, sulphide, apatite). Based on normalization of major elements (without the use of an internal standard), a new data reduction scheme was used, the "3D-trace elements DRS" (IOLITE v4 software). The DRS can recognize the nature of each pixel to adjust the normalization summation according to each phase, by considering undetectable stoichiometric CO_2 in calcite and H_2O in serpentine, for example. An appropriate conversion factor for iron is also applied, for example Fe_2O_3 in hematite, FeO in olivine, Fe_3O_4 in magnetite and Fe in sulphides. Due to the fast washout of the aerosol, down to 97% of the ablation cell in about 30 ms using the fast funnel, it is possible to produce high-resolution images at a rate of 30 pixels per seconds. Using a rectangular beam of 12 x 6 µm in raster or boustrophedon mode, maps of 12 µm pixels in size are produced and a 1 mm² area is covered in about 10 minutes. An example map (2 x 5 mm) of Fe-Ti-P mineralization from the Sept Iles layered intrusion was acquired in 46 minutes and provides information on the spatial distribution of trace elements among oxides, apatite and silicates. Such fast quantitative mapping renders the 3D analysis of trace and major elements in minerals and melt inclusions possible, which is under development at LabMaTer (University of Quebec at Chicoutimi).

ENHANCED WEATHERING OF KIMBERLITE MINE RESIDUES IN FIELD EXPERIMENTS: IMPLICATIONS FOR CARBON ACCOUNTING AND VERIFICATION

Zivi Schaffer, Kwon Rausis, Ian Power, Carlos Paulo
Trent University.
E-mail: *zivischaffer@trentu.ca*

Enhanced weathering (EW) is a negative emissions technology (NET) with the potential to remove gigatonnes of atmospheric carbon dioxide. However, the slow reaction of CO_2 with Mg- and Ca-silicate phases, and the spatial and temporal variabilities of soil carbon in open systems present a challenge for accurate carbon accounting. Our study aimed to improve methodologies for monitoring, measuring, and verifying CO_2 sequestration rates in soils amended with pulverized rocks that include alkaline mine wastes. We conducted field experiments over two summers (2021, 2022) in Peterborough (Ontario), which included a control of local calcareous soil with a history of agriculture, and two experimental plots (1 m²) that were amended with 10 kg (K10) and 20 kg (K20) of kimberlite residues from Gahcho Kué Diamond Mine (Canada). These ultramafic residues contained 30.2 wt.% lizardite [$Mg_3Si_2O_5(OH)_4$] and 9.4 wt.% forsterite (Mg_2SiO_4). Soil moisture probes, pore water samplers, and CO_2 flux chambers were installed with the goals of measuring CO_2 removal rates and assessing impacts on water chemistry in kimberlite-amended soils. During the first summer, the major cation loadings (ΣCa, Mg, K, P; K20: 11.2–21.8 g/m², K10: 14.0–26.0 g/m², control: 8.0–11.6 g/m²) and alkalinity (K20: 30.6–55 g HCO_3^-/m², K10: 41.1–70.1 g HCO_3^-/m², control: 26.7–33.4 g HCO_3^-/m²) in the pore waters increased relative to soil, indicating that more CO_2 was trapped in waters due to EW of kimberlite residues. Although the amended plots initially caused CO_2 drawdown, all plots generally had CO_2 emission rates in the 1.3–13.5 kg CO_2/m²/yr range. In the spring of 2022, 30 kg of kimberlite residues were added to the K10 plot. CO_2 fluxes decreased from 8.9 kg CO_2/m²/yr to 1.9 kg CO_2/m²/yr immediately following the additional amendment. However, as kimberlite weathering slowed over time, soil CO_2 emissions showed no significant difference between the control and amended plots, raising the question of whether EW is a negative emission or CO_2 avoidance technology. Mineralogically, kimberlite has potential as an EW feedstock capable to offset mining emissions at respective sites while providing soils with essential nutrients. Compared to basalt, a widely accepted agricultural amendment, kimberlite exhibits similar macronutrient inputs and equally safe leached metal concentrations (ΣCr, Ni; K20: 1.7–5.6 ppb, control: 0.6–1.3 ppb). Results from this field experiment provide a comprehensive method for monitoring and accounting for the CO_2 flux in soils amended with ultramafic rock powders and are critical for understanding EW contributions to carbon removal processes.

GEOCHEMICAL CONTROLS ON MERCURY METHYLATION AND SULPHUR CYCLING IN PRAIRIE POTHOLE REGION WETLAND COMPLEXES

Jamie Schmidt, Zohra Zahir, Britt Hall, Leslie Robbins
University of Regina.
E-mail: *jd.schmidt@outlook.com*

The wetlands of the Prairie Pothole Region (PPR) of North America are susceptible to atmospheric mercury (Hg) deposition. In aquatic environments, the cycling of Hg can result in the microbial production of methylmercury (MeHg), a neurotoxin that may lead to the bioaccumulation of Hg in higher trophic levels. In Saskatchewan, the biogeochemistry and hydrogeology of these wetlands varies due to inconsistencies in surficial Quaternary lithology and changing land use, posing significant challenges in understanding Hg cycling. In addition, these wetlands may face significant pressures due to climate change, which could fundamentally alter the biogeochemical cycling in these wetlands further. Both dissolved organic carbon (DOC; sourced via decomposition of organic matter) and sulphate (primarily introduced through the oxidation of pyrite in regional glacial tills) fuel the anaerobic microbial metabolisms of sulphate reduction and methanogenesis that contribute to increased Hg methylation rates in select wetlands. As such, understanding biogeochemical cycling of Hg in PPR wetlands is critical for safeguarding the environment and mitigating high MeHg concentrations in aquatic biota. Previous studies have identified PPR wetland complexes to be biologically productive sites, with biotic Hg methylation associated with seasonal changes in water chemistry and anoxia. In addition, the wetlands of the PPR appear to host an active community of bacterial sulphate reducers capable of ongoing Hg methylation in sulphate-rich systems with sulphide-rich porewaters, indicating the influence of the local sulphur cycle on Hg methylation. Here, we explore the hydrogeological and geochemical controls, and influence of sulphur cycling on MeHg production at the St. Denis National Wildlife Area (SDNWA) within the PPR. Surface and groundwater chemistry datasets obtained from the Global Institute of Water Security (University of Saskatchewan) and previous studies conducted at the SDNWA were coupled with new water and bulk sediment geochemistry analyses. Additionally, stable bulk sulphur and sulphide isotope signatures were used to constrain variation in sulphur and trace metal cycling in wetlands characterized by different hydrochemical facies (calcium sulphate and calcium bicarbonate systems). Results indicate that topographic position, type of wetland (recharge or discharge), and prevailing bottom water and sediment redox conditions of the wetlands fundamentally influence both sulphur and metal cycling. Dependant on the concentration of sulphate and the availability of trace metals within the wetlands, Hg methylation could be sustained by different communities of methylating bacteria. These results may provide insight and context into geochemical Hg cycling in sulphate-rich aquatic ecosystems in areas beyond the PPR.

GEOCHEMICAL CONTROLS ON THE DISSOLUTION OF ARSENIC TRIOXIDE ROASTER WASTE FROM THE GIANT MINE, NORTHWEST TERRITORIES, CANADA

Valerie A. Schoepfer[1], Heather E. Jamieson[2], Joyce M. McBeth[3], Matthew B.J. Lindsay[1]
[1]University of Saskatchewan, [2]Queen's University, [3]University of Regina.
E-mail: *Valerie.schoepfer@usask.ca*

Arsenic trioxide roaster waste (ATRW) was generated during processing of arsenopyrite-hosted Au ore in Yellowknife, NWT, Canada. Approximately 237,000 tonnes of ATRW are currently stored in underground chambers at the former Giant Mine, and an estimated 20,000 tonnes ATRW were released via stack emission. Although arsenolite [As_2O_3] largely defines its chemical composition, the presence of minor and trace elements (e.g. Fe, Sb, Ca) may have implications for ATRW solubility and reactivity. We performed laboratory batch experiments to investigate geochemical controls on the dissolution of ATRW samples from the former Giant Mine. These samples were obtained from four different underground chambers that capture variations in ore characteristics and processing over time. Aqueous chemistry results revealed substantial ATRW dissolution after equilibrating for two weeks under different pH (4, 6, 8), ionic strength (0.02 M NaCl, 0.20 M NaCl), and temperature (5°C, 25°C). Among these geochemical variables, we found that ionic strength and temperature had the largest influence on ATRW dissolution. Bulk X-ray diffraction indicate that residual solids were dominated by arsenolite, while X-ray absorption spectroscopy reveal increased bonding of As with Fe and Sb. Statistical analysis of micro-X-ray fluorescence imaging data indicate stronger correlations between As and Sb in the residual compared to initial solids, which suggests the co-occurrence of As and Sb may inhibit dissolution. Ongoing scanning electron microscopy with automated mineralogy analysis will support further comparison of initial and residual solids. Together, this information may inform ongoing research into the environmental persistence of ATRW solids in the Yellowknife area and could support development of new strategies for ATRW stabilization and Giant Mine remediation.

BIOGEOCHEMICAL ASSESSMENT OF MICROBIAL COMMUNITIES IN LABORATORY-SCALE ADVANCED CUSTOMIZABLE LEACH COLUMNS

Gary Schudel[1], Mignon Le Roux[2], Collin Burelle[2], Jared Robertson[3], Benoît Plante[1], Joyce McBeth[4]
[1]Université du Québec en Abitibi-Témiscamingue, [2]University of Saskatchewan, [3]Okane Consultants, [4]University of Regina.
E-mail: *joyce.mcbeth@uregina.ca*

Laboratory-scale kinetic tests are commonly used to predict the geochemical behaviour of reactive mine wastes as they weather. Since these tests can be used to determine rates of acid generation and neutralization, as well as the sources and sinks of potential contaminants (e.g. metals, sulphate, salinity) and the overall water quality of drainage systems, they are essential tools in planning for the management and reclamation of solid waste materials. Though various tests are available, kinetic leached columns (KLCs) are often favoured for their flexible designs, customizable operating procedures, and adaptability to a wide variety of use cases. Prior studies have successfully used KLCs to investigate the effects of factors such as temperature, freeze–thaw cycles, degree of saturation, chelating agents, and the presence of engineered covers on geochemical processes in mine wastes. However, targeted analyses on the compositions and putative functions of microbial communities have seldom been reported despite the involvement of microbes in important weathering and metal cycling processes. Thus, while KLCs are generally considered to be effective representations of in situ hydrogeochemical processes, it is not clear how well these

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lab-scale physical models reproduce the diversity of real microbial communities or biologically mediated reactions such as sulphur and iron oxidation. The work performed here adapts Okane Consultants' advanced customizable leach columns (ACLCs) to allow for monitoring of microbial communities at all stages of kinetic testing. Two potentially acid-generating (PAG) lithologies and one non-PAG tailings sample from a precious metal mine were used in this case study. The PAG lithologies were each installed in two ACLCs, with one leached with deionized water and the other leached with connate water delivered from the study site; the NPAG tailings were only tested with deionized water. Microbiological characterizations (high throughput 16S rRNA gene sequencing) were performed on the initial and weathered materials, as well as in leachates at several timepoints throughout the tests. Differences were noted in the microbial community compositions of the solid and liquid samples, as well as between samples treated with deionized and connate waters. Initial results also indicate a markedly lower level of diversity in the NPAG tailings sample as compared to the PAG lithologies. Further analyses are being performed to examine the relationships between the observed microbial community compositions and diversity metrics and the evolving geochemistry of the leachates from the ACLCs.

CHROMIUM-RICH MEGACRYSTS FROM KIMBERLITE

Dan Schulze
University of Toronto.
E-mail: *daniel.schulze@utoronto.ca*

A new study of Cr-rich and Cr-poor megacrysts (≥ 1 cm, n = 258) from the Sloan kimberlite (Colorado, USA) corroborates the findings of a pioneering study by Eggler et al. and provides a useful framework for reevaluating megacrysts subsequently described in the literature as belonging to the Cr-rich suite. New data confirm coexistence of garnet, clinopyroxene, orthopyroxene and olivine, the high (and restricted) values of molar Mg/(Mg + Fe) and wt.% Cr_2O_3 (e.g. 0.925–0.929 and 0.78–1.70 in clinopyroxene, 0.791–0.837 and 6.1–13.0 in garnet) of Cr-rich suite megacrysts and the differences from equivalent minerals in the Cr-poor suite. Ilmenite is restricted to the Cr-poor suite. No other suites described in the literature as "Cr-rich megacrysts" or belonging to "the Cr-rich megacryst suite" meet these criteria. Elsewhere (e.g. Orapa, Bobbejaan, Lac de Gras), few "megacryst" garnet examples with Cr_2O_3 > 6 wt.% have been documented and, within those populations, there is typically wide compositional scatter, even to values below 2 wt.% Cr_2O_3. Most such garnet examples are peridotite xenocrysts. Many megacrysts of chromian clinopyroxene from elsewhere are not shown to coexist with garnet or orthopyroxene (e.g. Orapa, Bobbejaan), and in some populations coexist with ilmenite and/or phlogopite (e.g. Orapa, Bobbejaan, Balmoral, Attawapiskat). Such clinopyroxene examples are not equivalent in composition or paragenesis to those of the Sloan Cr-rich suite but are similar to Granny Smith suite clinopyroxene. Populations with large scatter in composition (e.g. Orapa: Mg/(Mg + Fe) = 0.820–0.943, Ca/(Ca + Mg) = 0.356–0.488, wt. % Cr_2O_3 = 0.19–2.88) may also include peridotite xenocrysts. Megacrysts and minerals in pyroxenite from Jericho and Muskox do not correspond to the Sloan Cr-rich megacryst suite in composition but are similar to a low-temperature group of anomalously magnesian, ilmenite-bearing Cr-poor megacrysts from Sloan. These Sloan megacrysts are interpreted as crystallization products of the parent magma of the main suite of Cr-poor megacrysts which had been contaminated by refractory lithospheric peridotite.

INFLUENCE OF STRAIN, FRACTURING AND DILATION ON VEIN FORMATION IN ORTHOGNEISS AND FOLIATED AMPHIBOLITE, WESTERNMOST GRENVILLE PROVINCE: PRELIMINARY RESULTS OF A FIELD-BASED STRUCTURAL STUDY

Walfried Schwerdtner[1], Dennis Waddington[2], Lingfei Liu[1], Fannie Yiu[1]
[1]University of Toronto, [2]Waddington Consulting.
E-mail: *fried.schwerdtner@utoronto.ca*

In migmatitic orthogneiss and foliated amphibolite of central Ontario and adjacent parts of the Sudbury and North Bay regions, the close spacing and geometrical pattern of cm- to m-scale, lenticular or sigmoidal leucocratic veins attest to mid- to upper-crustal fracturing and/or slippage on discrete, commonly coplanar, discontinuity surfaces. The predominance of veins parallel and/or perpendicular to foliation reveals that the spatially discontinuous deformation was guided by the strain-induced mineral shape fabric of the host rocks. East of Sudbury, we are studying the geometrical pattern of closely spaced veins in parautochthonous rocks overlying the Grenville Front. In the Parry Sound and Muskoka districts, such patterns are commonly developed in allochthonous orthogneiss and well-foliated amphibolite, locally defining clusters or short chains of mesoscopic foliation boudins. In the northwestern part of Huntsville, we are studying a family of vein-filled tension gashes within the southwestern nose of a 10 km-long rootless fold composed of monzodiorite gneiss (Unit 5 in the legend of Map P.3413, Ontario Geological Survey). As revealed by their geometrical style, these tension gashes were superimposed on the pervasive linear–planar mineral shape fabric of the host gneiss. More detailed studies are under way to clarify the temporal relationships between the vein-filled tension gashes, the fold nose and a regional set of superimposed cross-folds.

OPPORTUNITIES AND CHALLENGES RELATED TO THE CRITICAL MINERAL POTENTIAL OF MINE WASTE

Robert Seal, Nadine Piatak, Sarah Jane White, Sarah Hayes
US Geological Survey.
E-mail: *rseal@usgs.gov*

Meeting increased demand for critical minerals represents an important challenge. By-product and, to a lesser extent, co-product critical minerals are especially problematic because their recovery relies on the production of primary commodities, such as Cu, Pb, Zn, Ni, Au, or Ag. Historically, many of these by-product/co-product commodities were destined for waste streams due to their limited use. Even now at active mines, by-product critical minerals often still end up as waste due to the substantial investments required to add the specialized circuits required for their recovery. Opportunities for critical mineral recovery from waste streams vary based on ore deposit type and whether a critical mineral is a primary, co-product, or by-product commodity. For example, based on a diverse suite of tailings samples, Te concentrations are highest in tailings from porphyry Cu deposits and Au deposits. Nickel and Co concentrations are highest in tailings from mafic magmatic deposits. Orogenic Au deposits additionally have anomalous concentrations of a variety of critical mineral commodities, including W, As, and Sb. We used a mass-balance approach at a porphyry Cu-Mo-Au mine to target specific waste streams for additional recovery. Specifically, we documented the deportment of critical minerals and other commodities in concentrates and tailings throughout the ore-processing stages. Our analysis showed that roughly half the Au, Ag, Zn, Sb, PGMs, and Se in the ore is lost to tailings. In addition, two-thirds of the Te and most of the Co and REEs also end up in the tailings. Waste streams could be leveraged to make by-product recovery more economically feasible by reducing environmental impacts while adding additional revenue. For example, optical and scanning electron microscopy and electron microprobe analyses demonstrate the presence of electrum, telluride, and Co- and Ni-bearing inclusions in pyrite. Understanding its importance as a host for these valuable commodities highlights the potential for recovering a pyrite concentrate. Such an approach could both improve Au and critical mineral recovery while simultaneously enhancing long-term environmental management. In another example, critical minerals commonly associated with mafic host rocks include PGMs, Ni, and Co. The tailings and other mine wastes from these ores are dominated by olivine, pyroxene, calcic plagioclase, and serpentine. These minerals are prime targets for mineral carbonation – a potential source of carbon credits. Thus, the most tenable scenarios to recover critical minerals from mine waste will likely combine by-product critical mineral recovery with added primary commodity recovery and improved environmental management.

FLOW DIFFERENTIATION MODELLING AND FIELD CHARACTERISTICS OF OFFSET DYKES IN SUDBURY

Henning Seibel, Michael Lesher
Laurentian University.
E-mail: *hseibel@laurentian.ca*

The ca. 10 to 80 m thick impact melt-bearing Offset Dykes extend up to ~37 km radially and up to ~13 km concentrically from the base of the Main Mass of the

Sudbury Igneous Complex. They are typically nested with inclusion-poor sulphide-poor quartz dioritic (QD) margins and variably mineralized inclusion-rich quartz dioritic (IQD) cores. Despite a wealth of field, petrographic, geochemical, and isotopic studies, the emplacement mechanisms of Offset Dykes are poorly understood, and have been attributed to either flow differentiation of a single injection or multi-phase injection. Flow differentiation is a fluid dynamic process related to the Bagnold effect, in which shear-related grain dispersive pressures drive a particle population suspended in a flowing medium toward the core of a dyke. To evaluate this process at Sudbury, we have modelled the particle migration patterns for typical Offset Dyke geometries and clast size variations and compared the results with field relationships between QD and IQD. The maximum inward translation of a given inclusion size population, using the Barrière formulation, is highly dependent on i) the degree of non-Newtonian behaviour, ii) the initial volume concentration of clasts in proto-IQD, iii) dyke widths and lengths, and iv) inclusion radii. Our results indicate that flow differentiation can produce a maximum inward translation for a given inclusion size population (e.g. 2 cm diameter) comparable to observed QD–IQD relationships in some outcrops, but cannot produce the relationships in the same outcrops for a different inclusion size population (e.g. 20 cm diameter), while using the same parameters. Inclusion distribution profiles predict gradational QD–IQD contacts and a gradational increase in inclusion sizes towards the centre. However, field observations of multiple Offset Dykes show that i) many QD–IQD contacts are sharp, some are sharp to gradational over 10 cm, and fewer are gradational as predicted by flow differentiation, ii) inclusion sizes sometimes increase towards the centres of the dykes but IQD margins often contain decimetre-sized inclusions, iii) most dykes contain inclusions of QD in IQD, iv) IQD with < 10% inclusions (< 10 cm diameter) can have several metre-wide QD margins, and v) IQD is not always present in some dyke segments. The mismatch between the predictions from our modelling and field observations indicates that flow differentiation cannot explain the emplacement of most Offset Dykes. However, the field observations can be explained by a multi-phase emplacement model.

TRIPLE OXYGEN ISOTOPES IN SHALE FROM THE ARCHEAN–PALEOPROTEROZOIC FENNOSCANDIAN BASINS (2.5–1.9 Ga)

Marina Seraine[1], Christopher Spencer[1], Zachary Sharp[2], Aivo Lepland[3], Isabela Sousa[4], Matthew Leybourne[1]
[1]Queen's University, [2]University of New Mexico, [3]Geological Survey of Norway, [4]Université du Québec à Montréal.
E-mail: *marina.seraine@queensu.ca*

The interplay between tectonics, climate and surface processes remains under debate. The Earth is a complex system, and the study of geological, biological, hydrological, and atmospheric processes is generally individualized and investigated by different scientific areas. The Archean–Proterozoic boundary represents a period of substantial changes in the atmospheric, geologic, and paleoenvironmental conditions on Earth. The oxygenation of the atmosphere, widely known as the Great Oxidation Event, is an example of one significant shift that occurred across this boundary from 2.5 to 2.3 Ga. The increase of free oxygen in the atmosphere is commonly associated with the earliest global Huronian glaciation, disappearance of the S-MIF signal, emergence of continents above sea level, and the decrease of $\Delta^{17}O$ in shale units. To address the secular changes in Earth's surface during this period, the present work is focused on the investigation of samples from the Immandra-Varzuga, Pechenga and Onega basins, located in Fennoscandia, Russia, using X-ray diffraction (XRD), triple oxygen analysis and whole rock geochemistry. XRD analysis of shale shows that the primary and secondary mineralogy displays a predominance of quartz, albite, illite, biotite and clinochlore, indicating both mafic and felsic contribution as the source area during the deposition. The $\Delta^{17}O$ data show a significant step change around ~2.45 Ga corroborating previous studies. In this ongoing work, we expect to further investigate the significant geochemical changes in the Archean–Paleoproterozoic boundary with respect to weathering conditions, depositional environment and tectonic shifts.

STRATAL EVOLUTION AND PROVENANCE OF A PRECAMBRIAN DELTA IN A TECTONICALLY ACTIVE TERRANE: THE LOWER SIGNAL HILL GROUP, AVALON ZONE, NEWFOUNDLAND

Santiago Serna, David Lowe
Memorial University of Newfoundland.
E-mail: *sasernaortiz@mun.ca*

The Signal Hill Group comprises the youngest Neoproterozoic strata in the Newfoundland Avalon Zone, consisting of a coarsening upward clastic succession recording southward progradation of a molasse wedge during the ca. 600–540 Ma 'Avalonian Orogeny'. Structural and stratigraphic relationships in the Signal Hill Group on the Avalon Peninsula suggest episodic syn-sedimentary deformation and localized basin inversion. The most significant evidence is from the Flatrock thrust, where as much as 3.5 km of throw and synchronous alluvial growth strata sedimentation occurred in the upper units of the Signal Hill Group. More subtle structural and stratigraphic evidence from the lower Signal Hill Group in the same region suggests that the isopach distribution was affected by local syn-sedimentary intrabasin uplift during delta progradation. This study examines the effects of localized basin inversion on sedimentation of the lower Signal Hill Group and coinciding changes in sediment sources using stratigraphy, facies analysis, and provenance data from the lower Signal Hill Group (Gibbett Hill–Quidi Vidi formations). The Gibbett Hill Formation records continuous south/southeast progradation of a river-dominated delta front to lower delta plain, comprising amalgamated mouth bars and terminal distributary-channel fills. The overlying Quidi Vidi and equivalent Ferryland Head formations record south/southeast prograding delta-plain facies consisting of floodplain and distributary channel deposits affected by intense soft sediment deformation. The contact between these units is conformable and gradational in all the studied locations but one, where amalgamated trunk channels disconformably overlie delta-front facies, suggesting localized uplift and erosion at the delta front–delta plain transition. The framework petrography, heavy mineral assemblages, and detrital geochronology of these units suggest derivation from Ediacaran, Cryogenian, and Tonian basement sources, including intermediate to felsic plutonic and volcanic rocks and low-to-medium grade pelitic and psammitic metamorphic rocks. Changes in the framework petrography, heavy mineral assemblages, and detrital age modes between the Gibbett Hill and the Quidi Vidi formations suggest a shift from Ediacaran to Cryogenian granite to Ediacaran–Cryogenian volcanic and Tonian low-to-medium grade metamorphic sources, respectively. Maximum depositional ages calculated for the upper Gibbett Hill Formation and the lower Quidi Vidi Formation are 557 ± 11 Ma and 556 ± 22 Ma, respectively. The changes in provenance, intense soft sediment deformation, and the localized disconformity in the lower Signal Hill Group suggest deposition in a tectonically active basin. Moreover, localized basin uplift and erosion of the delta-front and delta-plain facies at ca. 557 Ma coincided with the exhumation of Tonian and older metamorphic basement sources in the hinterland.

POST-GLACIAL, ALLUVIAL–FLUVIAL DYNAMICS OF UPPER HURONIAN STRATA FROM THE EASTERN COBALT BASIN, LAKE TIMISKAMING REGION, ONTARIO AND QUEBEC

Nabil A. Shawwa[1], Thomas R. McLoughlin-Coleman[1], Michael G. Babechuk[2], James E. Mungall[1], Robert H. Rainbird[3]
[1]Carleton University, [2]Memorial University of Newfoundland, [3]Geological Survey of Canada.
E-mail: *nabilshawwa@cmail.carleton.ca*

The Huronian Supergroup is an early Paleoproterozoic sedimentary succession exposed in an outcrop belt extending from Sault Ste. Marie to Sudbury (Ontario) along the shores of Lake Huron, and northeastwards to Rouyn-Noranda (Quebec). The belt opens in the northeast to the Cobalt Basin, which is mainly filled with upper Huronian strata of the Cobalt Group, interpreted to have been deposited on

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a south-facing passive margin. Cobalt Group strata in the northern and eastern Cobalt Basin include the Gowganda Formation, comprising (1) a lower member of subglacial to glaciomarine deposits (Coleman member) that lies unconformably on Archean granitic and volcanic rocks, and (2) a gradationally overlying member of upward-coarsening deltaic strata deposited in a warm climate (Firstbrook member). The Gowganda Formation is gradationally overlain by the Lorrain Formation, a progradational succession of fluvial sandstone and minor conglomerate, including Earth's oldest terrestrial red beds. This work synthesizes new sedimentological and stratigraphic data from the Gowganda–Lorrain transition in the Lake Timiskaming area, along the Ontario–Quebec border, building on existing depositional models from other parts of the Cobalt Basin to better understand the paleoenvironments and regional paleogeography. The Ville-Marie area (Quebec) is situated at the easternmost margin of the Cobalt Basin, which is separated from the rest of the basin by the NW-SE trending Lake Timiskaming fault. East of the fault, deltaic rocks of the Firstbrook member pinch out such that fluvial strata of Lorrain Formation sit either gradationally above glaciomarine deposits of the Coleman member or directly on Archean basement. Basal Lorrain Formation strata include paleo-regolith and debris-flow breccia deposited in paleotopographic depressions. Away from Archean contacts, Lorrain Formation strata mainly comprise cross-bedded arenite with subordinate interbeds of conglomerate, deposited on a fluvial braidplain. The braidplain deposits include pink quartz arenite that preserves early diagenetic Fe-oxide coatings, providing firm evidence for the oxygenation of Earth's atmosphere. Paleocurrent data from trough cross-beds in the Lorrain Formation in the Ville-Marie area and west of the Lake Timiskaming fault indicate topographically controlled paleoflow to the southwest, perpendicular to the Lake Timiskaming fault. This, combined with the pinching of the Firstbrook member east of Lake Timiskaming, suggests that the fault was active during Huronian deposition, possibly as a large passive margin offset.

SEISMOLOGICAL, PETROLOGICAL, AND ISOTOPIC EVIDENCE FOR MODERN DIAMOND CRYSTALLIZATION BY DEEPLY SUBDUCTED FLUIDS

Steven B. Shirey[1], Lara S. Wagner[1], Michael J. Walter[1], D. Graham Pearson[2], Peter E. van Keken[1]

[1]Carnegie Institution for Science, [2]University of Alberta.

E-mail: *sshirey@carnegiescience.edu*

Deep earthquakes and so-called sublithospheric diamonds trace the release of C-O-H bearing fluids and metallic liquids in the mantle transition zone. Diamonds that form beneath the lithosphere at depths from ~350 to ~700 km have crystallized from three types of fluids: supercritical aqueous fluids, carbonatitic melts, or metallic liquids. Multiple stable isotopic systems such as oxygen in majoritic garnet, coesite, and calcium perovskite inclusions ($\delta^{18}O$ = +8 to +12‰), iron in metallic inclusions ($\delta^{56}Fe$ = +0.79 to +0.90‰), and carbon and boron in the host diamond ($\delta^{13}C$ = –4 to –28‰; $\delta^{11}B$ = –5 to +0‰) link the fluid sources to organic carbon-containing, seawater-altered oceanic crust and serpentinized oceanic lithospheric mantle produced at the Earth's surface. Pressure–temperature path modeling of the geometries of Earth's subducting slabs and phase assemblages for the mantle and crust, allows subduction to be divided into two regimes: warm slabs that dehydrate to feed the mantle wedge and island arc volcanism or cold slabs whose interiors do not dehydrate or melt to release fluids until they stall and warm in the mantle transition zone. We suggest that the fluids released from cold subducted slabs at these depths lead to fluid migration, fluid-enabled seismicity, and diamond crystallization. The correlation of cold slabs with sublithospheric diamond formation demonstrates a deep subduction pathway that effectively bypasses the mantle wedge and arc, hydrating and creating heterogeneity in the mantle transition zone. Deep focus earthquake hypocentres thus track this deep fluid migration and the loci of modern diamond formation.

PRELIMINARY OBSERVATIONS ON EMPLACEMENT CONTROLS AND Li MINERAL PARTITION OF PEGMATITE DYKES FROM THE WEKUSKO LAKE PEGMATITE FIELD, CENTRAL MANITOBA

David Silva[1], Tania Martins[2], Lee Groat[1], Robert Linnen[3]

[1]University of British Columbia, [2]Manitoba Geological Survey, [3]Western University.

E-mail: *dsilva@eoas.ubc.ca*

Electric-powered transportation and more sustainable electrical storage and energy production have increased demand for many critical minerals in recent years. Rare-element pegmatites enriched in Li, primarily in the form of spodumene, are currently desired targets for mineral exploration companies throughout Canada due to the need for these elements for industrial use. The need to increase Li production in Canada requires research into the formation and emplacement of spodumene-bearing pegmatites in order to find new Li deposits. Our study describes new field observations of Li-bearing pegmatite dykes in the Wekusko Lake District in north-central Manitoba, as well as probable pegmatite emplacement mechanisms and preliminary results on Li concentration in various minerals within a single spodumene-bearing pegmatite body, the Zoro pegmatite. Two main categories of pegmatite dykes are defined in the Wekusko pegmatite field: (1) barren pegmatite dykes, and (2) spodumene-bearing pegmatite dykes (Violet-Thompson, Sherritt-Gordon and Green Bay groups). Most of the spodumene-bearing pegmatite dykes have a coarse-grained mineral assemblage of albite, quartz, K-feldspar, muscovite, spodumene and tourmaline, and are located close to regional scale fault zones (Crowduck Bay shear zone, Herb Lake and Roberts Lake faults). These regional discontinuities facilitated melt transport, and emplacement at mid-crust level. Three mechanisms of emplacement of the spodumene-bearing pegmatites are proposed: (1) dykes oriented subparallel to the strike of shear zones in pull-apart openings (Violet-Thompson group); (2) dykes oriented subparallel to the main tectonic stress direction in tension gash openings (Sherritt-Gordon group); and 3) dykes oriented subparallel to the main tectonic stress direction, at a high angle to probable second degree shear faults and aligned in en echelon formation (Green Bay group). Preliminary LA-ICP-MS mineral trace element data of the Zoro pegmatite indicate that a significant amount of Li is partitioned into a variety of mineral phases (muscovite, feldspars, quartz, and columbite group minerals (CGM)) in addition to the significant amount of Li found in the non-typical Li-bearing mineral phases. Our quartz LA-ICP-MS data agree well with published quartz chemistry data for Li-Cs-Ta (LCT) pegmatites, placing our pegmatites between the RMG (pegmatites derived from residual melts of granite magmatism) and DPA (pegmatites as direct products of anatexis) groupings. Quartz crystals show Li concentrations in the range of ~24 to 67 ppm, albite ~2 to 145 ppm, K-feldspar ~25 to 300 ppm and CGM ~10 to 30 ppm, varying in concentration depending on the internal pegmatite zone location of the mineral phase and nearby presence of spodumene crystals.

A STRATIGRAPHIC FRAMEWORK FOR EARLY JURASSIC ORGANIC MATTER PRESERVATION INTERVALS AND CARBON CYCLE PERTURBATIONS

Ricardo L. Silva[1], Luís V. Duarte[2], Grant D. Wach[3], Micha Ruhl[4], Driss Sadki[5], Juan J. Gómez[6], Stephen P. Hesselbo[7], Weimu Xu[8], João G. Mendonça Filho[9], Bruno Rodrigues[2]

[1]University of Manitoba, [2]University of Coimbra, [3]Dalhousie University, [4]Trinity College Dublin, [5]Moulay Ismail University of Meknès, [6]University Complutense Madrid, [7]University of Exeter, [8]University College Dublin, [9]Federal University of Rio de Janeiro.

E-mail: *ricardo.silva@umanitoba.ca*

Lower Jurassic sedimentary successions in many central and northern Atlantic basins include relatively thick organic-rich intervals. Despite intense research, it is still

unclear which mechanisms led to the deposition of these sediments during the Early Jurassic. We present a detailed temporal and geographical framework of Sinemurian and Toarcian organic matter preservation intervals (OMPIs; subdivided into local, regional, and superregional) and broadly constrain the relationship of OMPIs with the Early Jurassic $\delta^{13}C$ record. For this, we combine an in-depth analysis of the distribution of organic-rich facies in the Sinemurian and Toarcian with new geochemical data [total organic carbon (TOC) and organic matter pyrolysis] from Portugal, Spain, and Morocco. The developed OMPI framework suggests a strong local control on organic matter preservation during most of the Sinemurian. Regionally widespread organic-rich facies are associated with the most negative $\delta^{13}C$ values of the broad Sinemurian–Pliensbachian negative carbon isotopic trend (including the Sinemurian–Pliensbachian Boundary Event). Pliensbachian OMPIs are expressed in the areas bordering the proto-Atlantic Ocean and are often linked with positive $\delta^{13}C$ excursions and short-lived warm intervals, but OMPIs are also observed for the late Pliensbachian cool interval. Toarcian maximum TOC content occurs with the positive $\delta^{13}C$ (recovery) trend following the $\delta^{13}C$ negative shift typically linked to the Early Toarcian Oceanic Anoxic Event (T-OAE). However, superregional OMPIs predate and postdate the T-OAE, indicating that conditions favouring the preservation of organic matter (increased productivity and/or enhanced preservation) were not restricted to the T-OAE interval. We also briefly discuss how future research should aim to disentangle (1) the complexities in estimating original TOC and organic carbon accumulation rates, (2) temporal and spatial variability in environmental or Earth system feedback mechanisms driving sedimentary carbon sequestration, and (3) their combined impact on the global carbon cycle.

INCOMPLETE SULPHIDE OXIDATION UNDER SUB-OXIC CONDITIONS: IMPLICATIONS FOR AQUEOUS SULPHUR SPECIATION IN MINE WASTE SYSTEMS

Matias Silva-Caceres, Trevor Bond, Bas Vriens
Queen's University.
E-mail: *17mesc@queensu.ca*

The oxidative dissolution of (detrital) sulphide minerals in mine wastes may generate oxygen depletion and redox gradients that can bear consequences for the mobility of various solutes of environmental concern. However, the extents and effects of oxygen depletion on mineral reactivity remain poorly constrained, complicating the long-term assessment of potential acid rock drainage and sulphur (S) mobilization in mine waste systems. Incomplete sulphide oxidation is being investigated under contrasting geochemical conditions, primarily leveraging analysis of aqueous intermediate S species and quantitative mineralogical dynamics, using controlled weathering experiments in the laboratory and field sampling of heterogeneous legacy tailings in Canada. Pre-characterized diluted samples with pyrite and sphalerite were weathered for 15 days under oxic (21% O_2) and sub-oxic (~40 ppm O_2) conditions at pH ranging from 3.5 to 9. Using titration assays, observed oxidation rates for pyrite range from 10^{-10} mol m^{-2} s^{-1} under oxic conditions to 10^{-12} mol m^{-2} s^{-1} under sub-oxic conditions, and for sphalerite range from 10^{-11} to 10^{-13} mol m^{-2} s^{-1} under oxic versus sub-oxic conditions, respectively. Speciation analyses revealed the presence of sulphate in all experiments, but several intermediate S species, including dissolved sulphide, elemental S, thiosulphate, and tetrathionate, were also detected. Among these species, thiosulphate was typically the most abundant incompletely oxidized S species, and as expected, intermediate S species were more abundant under sub-oxic conditions compared to the oxic experiments. Across the studied materials, different S speciation was observed in line with their oxidation mechanisms, whereby sphalerite weathering produced up to 85% incompletely oxidized S (relative to total S) and pyrite up to 21% intermediate S during the conditions tested. Surface water, porewater, and sediment cores from extensively weathered legacy tailings that were either exposed or submerged (up to ~2 m depth) were also analyzed. Strong redox gradients within the tailings were observed from ORP field probe data and analysis of other redox couples (Fe, As), which could be corroborated by the recorded S speciation, i.e. the relative abundances of sulphide, elemental S, sulphite, thiosulphate, tetrathionate, and sulphate. Across the investigated sites, sulphide mineralogy and the prevailing redox conditions exerted major controls on the aqueous S speciation. The stability and mobility of intermediate S species at the studied sites are currently being assessed. This work will ultimately help refine the assessment of in situ reactivity of sulphidic mine wastes under variable conditions and thereby help optimize mine waste management.

THE GREAT BEAR GOLD DEPOSIT: A GOLD-ENDOWED ARCHEAN LAVA DOME ASSOCIATED WITH A CRUSTAL-SCALE FAULT IN THE RED LAKE GREENSTONE BELT

Jack Simmons[1], Bruno LaFrance[1], Harold Gibson[1], Stefanie Brueckner[2], Mike Hamilton[3], Prestyn Sider[4], Ross Sherlock[1], Douglas Tinkham[1]
[1]Laurentian University, [2]University of Manitoba, [3]University of Toronto, [4]Brock University.
E-mail: *jsimmons@laurentian.ca*

The Great Bear deposit is a potential new world-class gold deposit in the Red Lake greenstone belt (RLGB) of the Archean Superior craton, preserving three key styles of mineralization within lithologically and compositionally diverse stratigraphy across a crustal scale fault (known as the LP Fault): (1) quartz veining in mafic volcanic rocks in the 'Hinge Zone'; (2) silica–sulphide replacement in mafic volcanic rocks in the 'Limb Zone'; and (3) disseminated gold within a high-strain zone in the footwall of the LP Fault. The stratigraphy in the footwall of the LP Fault consists of sericite-altered metasedimentary rocks (MS1, MS2, MS3), felsic volcaniclastic rocks (F1), and felsic porphyries (E31 and E32) that were metamorphosed to greenschist–amphibolite facies conditions. The felsic porphyries are interpreted as synsedimentary, emplaced as subvolcanic intrusions and lava domes within an interpreted structural basin. Uranium–Pb dating by LA-ICP-MS and ID-TIMS of detrital and magmatic zircon from the metasedimentary units and synsedimentary felsic porphyries constrain the age of sedimentation and magmatism to ca. 2730–2720 Ma, which is inconsistent with existing interpretations of the stratigraphy as part of the 2748–2742 Ma McNeely sequence of the Confederation assemblage. The stratigraphy is instead temporally equivalent with the younger ca. 2.73 Ga Graves assemblage and numerous felsic plutons in the NW RLGB (e.g. ca. 2.73 Ga Graves plutonic suite and the ca. 2.72 Ga St. Joseph plutonic suite). Gold mineralization in the LP fault zone is interpreted to have been the product of at least three local mineralization events, including two syn-intrusion or syn-tectonic events (i.e. disseminated free gold parallel to the primary NW–SE trending foliation in the host rock and in transposed quartz veins), the latter possibly associated with the regional 2.72 Ga Uchian Orogeny (D2), and one post-tectonic event (i.e. free gold in quartz veins oblique to the primary foliation). The interpreted chronology of gold mineralization in the footwall of the LP Fault is comparable to other established gold deposits in the 'Mine Trend' of the RLGB, including the world-class Campbell–Red Lake deposit. High-strain zones and structural basins associated with crustal scale faults, somewhat akin to the break- or fault-related orogenic gold deposits of the Abitibi Subprovince, may therefore represent important first-order targets for exploration in the RLGB and the adjacent greenstone belts of the Uchi Subprovince.

CONSTRUCTING, DECONSTRUCTING AND RECONSTRUCTING THE SW PROTEROZOIC FENNOSCANDIAN MARGIN

Trond Slagstad[1], Evgeniy Kulakov[2]
[1]Geological Survey of Norway, [2]Northland Pioneer College.
E-mail: *trond.slagstad@ngu.no*

The fundamental driving force for convergence in the late Mesoproterozoic Sveconorwegian Orogeny has proved elusive, reflected in a range of recent tectonic models including subduction of hyperextended continental crust, continent–continent collision, and density-driven vertical tectonics. Common to all these models is that they attempt to explain: (1) the long duration of orogeny (1140–930 Ma), (2) contrasting timing (up to several 10s of M.y.) of orogenic onset in different parts of the orogen, and (3) contrasts in tectonic style with high-temperature/medium pressure (HT/MP) metamorphism, apparent lack of crustal thickening, and voluminous crustal melting in the western hinterland of the orogen, and medium-temperature/high-pressure (MT/HP) metamorphism related to crustal thickening towards the eastern foreland. Here, we present more than 90 U–Pb/Lu–Hf zircon analyses from a > 1200 km-long transect from Archean (ca. 2800 Ma) rocks in northern Norway to ca. 1500 Ma rocks in SW Norway, along with compilations of U–Pb (magmatic and metamorphic) and Lu–Hf data from Fennoscandia. The data

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provide minimum estimates for the pre-orogenic distribution of Sveconorwegian units and the thermal state of the margin at the onset of compression. It appears that the part of the margin that became the locus of Sveconorwegian Orogeny was significantly thinned over a period of ca. 200 M.y. prior to contractional orogeny, most likely in a continental back-arc setting, and hot enough to allow decoupling of the strong upper and weak lower crust. Foundering of the dense lower crust was associated with at least 450 km of shortening, and likely significantly more, and resulted in crustal thickening in the eastern parts of the orogen. In contrast, crust in the western parts of the orogen remained thin and hot and appears to reflect a continued back-arc setting. Pre-orogenic extension, thinning and heating appears to have primed the units that would later form the Sveconorwegian Orogeny and, although overall contraction was likely related to plate movements, crustal shortening was largely accommodated by subduction of thinned continental crust. This interpretation contains elements of several seemingly contrasting models and makes testable predictions including diverse timing of shear zone activity, horizontal seismic reflectors in the lower crust and lithospheric mantle and a generally high heat-producing lithospheric mantle.

GEOLOGY AND MULTIPLE SULPHUR ISOTOPE SIGNATURES OF THE FENELON GOLD DEPOSIT, NORTHWESTERN ABITIBI GREENSTONE BELT, QUEBEC: STRUCTURAL CONTROLS, FLUID ORIGIN, AND ORE-FORMING PROCESSES

Evan Slater[1], Sébastien Castonguay[2], Anthony Williams-Jones[1], James Clark[1], Richard Stern[3], Robert Creaser[3]
[1]McGill University, [2]Geological Survey of Canada, [3]University of Alberta.
E-mail: *sebastien.castonguay@nrcan-rncan.gc.ca*

The Fenelon Au deposit (4.1 Moz) is in the northwestern Abitibi greenstone belt, proximal to the Sunday Lake Deformation Zone—the structure believed to have controlled the emplacement of the ~40 Moz Detour Lake gold mine ~70 km to the west. Fenelon differs from many gold deposits in the Abitibi in that it contains elevated base metal concentrations. Typically, base metals are associated with pre-orogenic gold deposits, however, the timing of much of the mineralization at Fenelon appears to be syn-orogenic. Ongoing research on the structural controls, mineralization, and S isotope characteristics will focus on the development of a genetic model for the deposit. The mineralization is hosted within metamorphosed ~2707 Ma argillite and < 2705 Ma greywacke, as well as in calc-alkaline intrusive rocks such as the ~2697 Ma Jeremie diorite and ≥ 2703 Ma gabbroic intrusions. In the diorite-hosted zones, auriferous veins are sub-parallel to the steep ENE-trending main foliation, whereas the mineralized zones hosted by metasedimentary rocks follow an ESE-trending foliation as well as high-strain zones along lithologic and intrusive contacts. Several deformation zones occur in the deposit area, the most significant of which is the E-W Jeremie fault that experienced several stages of ductile–brittle deformation. Gold mineralization consists of two main stages: 1) sulphide-poor quartz–Au–Mo veins, and 2) sulphide-rich with pyrrhotite, chalcopyrite, sphalerite, arsenopyrite, pyrite, galena, native Au, and Bi-tellurides. The timing of both stages appears to be coeval with ductile deformation. The alteration consists of quartz, sericite, biotite, chlorite, and albite, with a bulk geochemical signature characterized by the addition of S, base metals (Cu > Zn > Pb), Si, and K, and the removal of CO_2, Ca and Na. In situ multiple S isotope data for arsenopyrite and pyrite have mass-dependent fractionation $\Delta^{33}S$ values of < 0.2‰ and progressively increasing $\delta^{34}S$ from grain cores (~1.5‰) to rims (~3.5‰), with native Au and sulphide inclusions in intermediate growth zones. Data for chalcopyrite and pyrrhotite are also dominated by mass-dependent fractionation but display a mixing trend with mass independent fractionation $\Delta^{33}S$ values > 0.2‰. The data are compatible with the main S source being of mantle origin, either directly exsolved from an intrusion or released during metamorphic devolatilization of magmatic rocks, and a secondary sedimentary source, likely from local country rocks or from metamorphically derived fluids. Increasing $\delta^{34}S$ values throughout the paragenesis and the reduced sulphide assemblage (e.g. locally abundant pyrrhotite) suggest that reduction was an important ore-forming process.

RECONSTRUCTING THE PALEOENVIRONMENT OF THE MESOPROTEROZOIC NONESUCH FORMATION AND ITS RECORD OF LIFE

Sarah P. Slotznick[1], Nicholas L. Swanson-Hysell[2], Yiming Zhang[2], Katherine E. Clayton[3], Charles H. Wellman[4], Nicholas J. Tosca[5], Paul K. Strother[6]
[1]Dartmouth College, [2]University of California, Berkeley, [3]University of Oxford, [4]University of Sheffield, [5]University of Cambridge, [6]Weston Observatory of Boston College.
E-mail: *sslotz@dartmouth.edu*

The ~1075 Ma Nonesuch Formation and its microfossil assemblage provide an excellently preserved window into the environments and biosphere in the interior of Laurentia. The Nonesuch Formation formed following the cessation of widespread volcanism within the Midcontinent Rift as the basin continued to subside. Initially, terrestrial alluvial fan and fluvial plain environments transitioned into subaqueous lacustrine deposition of the Nonesuch Formation outcropping in present day Michigan and Wisconsin, USA. These units thin towards a paleotopographic high associated with the Brownstone Falls angular unconformity allowing us to explore the paleoenvironment laterally at different depths in contemporaneous deposits. Rock magnetic data constrain that when the lake was shallow, it was oxygenated with an oxidized mineral assemblage. Oxygen levels were lower at greater depth and in the deepest portions of the water body, anoxic conditions are recorded. An intermediate facies in depth and redox between these endmembers preserves detrital magnetite and hematite, which can be present in high abundance due to the proximal volcanic “Brownstone Highlands”. Using this detrital magnetite and hematite, a paleomagnetic pole was developed constraining a subequatorial paleolatitude. Sedimentary rocks of the intermediate facies preserve exquisite organic-walled microfossils with microfossils being less diverse to absent in the anoxic facies. In these anoxic environments, amorphous organic matter is more likely to be preserved whereas fully oxygenated environments are barren. The assemblage of cyanobacteria and eukaryotes (both heterotrophs and phototrophs, including some of the oldest crown group fossils to date) lived within the oxygenated waters of this tropical Mesoproterozoic water body.

ORE-FORMING PROCESSES OF THE OUTPOST ISLAND GOLD–TUNGSTEN DEPOSIT, NORTHWEST TERRITORIES

Peter D. Smith[1], Pilar Lecumberri-Sanchez[1], Hendrik Falck[2], Merilie Reynolds[2]
[1]University of Alberta, [2]Northwest Territories Geological Survey.
E-mail: *pdsmith@ualberta.ca*

Tungsten is a metal commonly associated with gold deposits but is rarely mined simultaneously in a single location. Gold-producing and tungsten-producing deposits are typically different in age, geological setting, and mineral assemblages. The Outpost Islands deposit is unusual as it was mined for both tungsten and gold. The mine is located on a set of islands in Great Slave Lake, approximately 90 km south-southeast of Yellowknife, Northwest Territories. Historic mining and milling from 1941 to 1952 produced 288.7 kg (10,185 ounces) of gold with concentrations of 93.75 grams per tonne (3 to 13 ounces per ton), over 17.3 tonnes of tungsten as WO_3, with an average concentration of 3 wt.%, and almost 60.9 tonnes of copper. The site was briefly tested using 10 shallow drill holes in 1988 and, with the exception of minor prospecting, there has been no further exploration or mining activity on the islands. Outcrops consist of micaceous quartzite, heavy mineral metasandstone and metapelite belonging to the Wilson Island Group and correlating to the Reinhardt formation. The Wilson Island Group is a series of metasedimentary rocks deposited during the Thelon orogeny (ca. 1.97–1.89 Ga). The Wilson Island Group is locally intruded by the Butte Island granite (ca. 1.84 Ga) and crosscut by both mafic and pegmatitic dykes. Regionally, deformation at the Outpost Islands is thought to be connected to the deformation of the Great Slave Lake Shear zone and short scale displacement (m scale) along shear zones has been identified in outcrop. However, the lack of outcrop continuity in the lake precludes correlation with any of the regional major faults. Associated with the deformation zones are hydrothermal features including veins of massive and hematized quartz with variable proportions of sulphide stringers, and massive sulphides with minor quartz occur. Mineralogically, these shear-related sulphides include pyrite, chalcopyrite, arsenopyrite, and/or sphalerite. Even though historical reports indicate tungsten at this deposit occurs as wolframite, in hand samples most of the tungsten minerals identified have been scheelite. This research aims to determine whether tungsten and gold are genetically related at Outpost Islands, the ore-forming processes in this fairly unusual deposit, and the implications for gold and tungsten cycling at crustal scales.

DISCOVERY OF OLIVINE IN THE SOUTHERN LAC DES ILES COMPLEX – SIGNIFICANCE AND IMPLICATIONS

William Smith[1], Liam Fay[2], Lionnel Djon[2], James Mungall[1]
[1]Carleton University, [2]Impala Canada.
E-mail: *Williamsmith3@cunet.carleton.ca*

Olivine-bearing cumulates have been discovered at depth in the southern Lac des Iles Complex (LDIC), a ~2.69 Ga arcuate mafic intrusion that hosts world-class Pd mineralization within heterolithic gabbronorite breccia units. These olivine-bearing cumulates are medium- to coarse-grained feldspathic lherzolite and harzburgite (Mg# 75.9–80.8) that are variably serpentinized and bracketed by (mela)norite. Weakly altered samples comprise subhedral nickeliferous olivine ($fo_{78.6–81.8}$; 1900–4200 ppm Ni) with polymineralic melt inclusions and peritectic orthopyroxene rims, cumulus orthopyroxene, subpoikilitic clinopyroxene, as well as plastically deformed plagioclase-rich clusters interpreted as autoliths. These cumulates contain no chromite and only sparsely disseminated pentlandite-chalcopyrite-pyrrhotite blebs were observed. With increasing degrees of alteration, olivine may be variably serpentinized or pseudomorphically replaced by an assemblage of talc, calcite, magnetite, and Fe-sulphide minerals. The whole rock and olivine compositions are distinct from olivine-bearing units analyzed in the northern LDIC; an adjacent, contemporaneous intrusion consisting of interlayered chromitiferous dunite, olivine websterite, and clinopyroxenite. Using thermodynamically constrained forward models of local mafic–intermediate dyke compositions, the southern LDIC olivine-bearing rocks can be replicated through the batch crystallization of a S-undersaturated and volatile-rich basaltic andesite magma (Mg# 55) that partially assimilated local tonalite and cognate feldspathic cumulates. The relatively low MgO and high volatile content of the assumed parent magma ensures a high value and transient olivine-only saturation, allowing olivine to rapidly deplete the co-existing silicate melt of Ni prior to significant segregation of immiscible sulphide melt. A peculiar feature of southern LDIC mineralization is that Pd/Pt values generally increase with increasing Pd grade – this peculiarity extends to the olivine-bearing rocks (whole rock Pd/Pt = 2.6–6.7). The Pd/Pt values of local mafic–ultramafic dykes broadly increase with decreasing MgO content, where dykes comparable in composition to the assumed parent magma have Pd/Pt values greater than 3. It is proposed that the progressive infiltration of increasingly Pt-depleted basaltic–andesitic magma may have given rise to the formation of this Pd-enriched mineralization, whereby Pt-depletion was driven by the pre-emplacement removal of Pt-Fe alloys. This proposition suggests that less evolved magma pooled beneath the southern LDIC, marking a possible genetic link between the northern and southern complexes.

PHYSICAL AND CHEMICAL PROPERTIES INFLUENCING INSECT BURIAL AND FOSSILIZATION

Johnathan A. Sorrentino, Paul A.E. Piunno, Marc Laflamme
University of Toronto Mississauga.
E-mail: *johnathan.sorrentino@mail.utoronto.ca*

The fossil record is biased against the preservation of soft tissues such as chitin and muscle. Soft tissues are highly susceptible to decay, leaving only a short window for preservation. Realistic controls on the timing and modes of soft-tissue fossilization can be determined by monitoring the early stages of extant organism decay under varying environmental conditions. Burial is essential for fossilization, and it is thus surprising to find that naturally buoyant organisms such as insects are fossilized with exquisite detail in offshore deep-lake depositional environments. Experiments have been designed to analyze how water salinity and wave action influences the initial stages of decay and sinking rates of insects. Greater water salinity should improve buoyancy while reducing decay rate by inhibiting the growth of bacteria. Wave action has the potential to increase insect disarticulation while also decreasing the time before sinking. Decay experiments with crickets (*Telogryllus oceanicus*) were conducted to determine how water salinity and wave action impact the preservation potential of insects. The crickets were euthanized by rapid freezing in a –86°C freezer and placed in individual containers filled with either artificial freshwater or artificial seawater. Decay progress was monitored through periodic photography (once every four hours) and the timing of feature loss (e.g. deformation and limb loss) and sinking was recorded. A second set of experiments was conducted with the individual containers placed on an oscillating platform simulating vertical wave motion. Decay progress was compared across wave–salinity conditions to place realistic bounds on the biases exhibited by fossilized insect collections in deep time.

PALEOZOIC EVOLUTION OF THE YUKON–TANANA TERRANE OF THE NORTHERN CORDILLERA, NW BRITISH COLUMBIA

Renaud Soucy La Roche[1,2], Alex Zagorevski[2], Nancy Joyce[2], Jim Crowley[3]
[1]Institut national de la recherche scientifique, [2]Geological Survey of Canada,
[3]Boise State University.
E-mail: *renaud.soucy_la_roche@inrs.ca*

The origin of, and primary relationships between, tectono-stratigraphic units are fundamental to the terrane concept in accretionary orogens but are challenging to assess in metamorphic terranes. In NW British Columbia, three tectonically bounded metamorphic suites of the Yukon–Tanana terrane formed in distinct tectonic settings based on high spatial resolution geochronology and immobile trace element geochemistry. The Florence Range suite comprises late Neoproterozoic to pre-latest Devonian metasedimentary rocks derived from continental crust, 360 ± 4 Ma calc-alkaline intermediate orthogneiss and 357 ± 4 Ma amphibolite with oceanic island basalt composition, consistent with rifting of a continental margin. The detrital signature is dominated by late Mesoproterozoic zircon, which indicates different sources than other parts of the Yukon–Tanana terrane. The Boundary Ranges suite comprises pre-Late Devonian metasedimentary rocks derived in part from a mafic source, amphibolite derived from subduction-zone metasomatized mantle, and 369 ± 4 Ma to 367 ± 7 Ma calc-alkaline felsic to intermediate orthogneiss, consistent with continental arc or continental rift settings. The Whitewater suite comprises metachert, graphite-rich metapelite and amphibolite with back-arc basin basalt composition consistent with an anoxic basin near a volcanic source. This study presents data that indicate that the Florence Range and Boundary Ranges suites were separate until at least the Early Mississippian and may have formed a composite terrane since the Permian, whereas the relationship with the Whitewater suite is uncertain. Paleozoic tectonic scenarios compatible with published and new data are illustrated with modern analogues.

WHAT MAKES AN OROGENY? TECTONOCHEMICAL INSIGHTS FROM THE GRENVILLE PROVINCE

Christopher Spencer
Queen's University.
E-mail: *c.spencer@queensu.ca*

The Grenville Orogen has historically played a prominent role in our understanding of Mesoproterozoic tectonics to the point it has become broadly synonymous with the global convergence associated with the assembly of Rodinia. Although most workers interpret the tectonics of the Grenville Orogen as a continental collision with Amazonia, there are several persistent alternatives that propose either that the Mesoproterozoic was characterized by an orogenic quiescence or stagnant lid. Constraining the geodynamic evolution of the Grenville Orogen and tectonic regime of the Mesoproterozoic Era are key in understanding the evolution of plate tectonics on Earth. In this presentation, I will discuss some of the recent attempts to constrain the geodynamics and tectonic regime of the Grenville Orogen and the assembly of Rodinia. Topics of particular interest include the flaws in constraining crustal thickness with zircon trace elements, the proportion of sediment-derived granitoid

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bodies as defined by oxygen isotopes, and the evaluation of terrane transfer during continental collision using Pb isotopes. All things considered, the Grenville Orogen carries the hallmarks of a hot collisional orogeny with a relatively thin crust, substantial sediment–magma interaction, and the transfer of tectonically emplaced terranes.

SHOCK VEINS IN METEORITES AND TERRESTRIAL IMPACT STRUCTURES: FORMATION MECHANISMS AND P–T–t CONSTRAINTS

John Spray
University of New Brunswick.
E-mail: *jgs@unb.ca*

Shock veins are distinct discontinuity planes within rock. They have been documented in many meteorite types, where they are a relatively common feature. More recently, they have been discovered in a few terrestrial impact structures. Shock veins are shock-related microslip systems. They are syn-impact to immediately post-shock (rarefaction) products generated during the contact and compression stage of the impact process. The frictional component is due to shock front offset arising from material impedance contrasts, which result in transient slip. Slip may be unidirectional or oscillatory, but it is typically submillimetre to, at most, a few millimetres. Slip is accompanied by local melting with quenching to yield glass or microcrystalline matrices. The frictional melting occurs during shock loading, so the melting temperatures are very high (commonly 2000°C or more). The high temperatures do not constitute superheating, but rather the melting points of mineral components at the prevailing shock pressure. The distinctive feature of shock veins is the development of specific high pressure–high temperature polymorphs, which occur within the veins and at their margins, but otherwise not throughout the host lithology. Shock veins thus capture distinct pressure–temperature–time windows that facilitate the potential transformation of mineral species to denser forms, e.g. quartz to coesite or stishovite, plagioclase to tissintite, olivine to ringwoodite. The transformations are close to isochemical but involve structural changes that modify the crystallography. The key driver for HP-HT polymorph generation is the thermal anomaly created due to friction along the transient slip system. The elevated temperatures provide the energy to expedite the mineral transformations. The bulk shock pressure does not change. Outside the hot veins, the shock pressure and associated compression–decompression temperature may be insufficient to force structural changes. However, in the case of certain meteorites (e.g. the Martian shergottites), maskelynite may be ubiquitous, with shock veins exhibiting even higher pressure/temperature phases. In this review, examples of shock veins in meteorites and terrestrial impact structures will be presented and discussed, with specific reference to the pressures, temperatures and critical dwell times endured. This will serve as an introduction to shock veins, their formation mechanisms and their likely source areas within the impact regime.

HOLTEDAHLINA (BRACHIOPODA) ASSOCIATED WITH UNUSUAL PHOSPHATIC TUBE-SHAPED FOSSILS FROM THE UPPER ORDOVICIAN AT WILLIAM LAKE, MANITOBA

Colin D. Sproat[1], Graham A. Young[2]
[1]University of Saskatchewan, [2]Manitoba Museum.
E-mail: *c.sproat@usask.ca*

The William Lake site in central Manitoba is known for exceptional preservation of uncommon fossil groups. Fossils are preserved within argillaceous dolomudstone in the Williams Member of the upper Katian (Richmondian) Stony Mountain Formation near the northern end of Lake Winnipeg. The unit was likely deposited in a restricted shallow lagoon on the edge of a large carbonate shelf that covered much of western North America during the Late Ordovician. This unusual setting preserved a variety of arthropods (including xiphosurids and eurypterids), cnidarian medusae, possible ctenophores, and unusual phosphatic tube-shaped fossils of uncertain affinity. More commonly preserved fossils such as linguliformean brachiopods and nautiloids have also been recovered from the site in addition to a few rhynchonelliformean brachiopods that have not yet been described including the strophomenide *Holtedahlina*. Several of these shells are directly associated with the problematic tube-shaped fossils and may have been attached via their pedicle in life position. Although brachiopods are commonly associated with other filter feeders in the Early Paleozoic, typically only small rhynchonellate shells with large pedicle foramens are found attached to other filter feeders. Large strophomenides such as *Holtedahlina* are more commonly found free-lying and likely most often lived a solitary life on the seafloor. The discovery of this association has implications for understanding the complex co-evolutionary interactions that evolved during the Great Ordovician Biodiversification Event (GOBE). The presence of *Holtedahlina* in both the Williams Member of the Stony Mountain Formation and the Fort Garry Member of the Red River Formation lower in the Ordovician in Manitoba may reflect adaptation of the brachiopod to shallow, restricted marine settings.

NEW STRATIGRAPHIC LOGS AND PETROGRAPHIC OBSERVATIONS FROM THE TONIAN REEFAL ASSEMBLAGE, YUKON

Charlotte Spruzen[1], Ashleigh V.S. Hood[2], Malcolm W. Wallace[2], Galen P. Halverson[1]
[1]McGill University, [2]University of Melbourne.
E-mail: *charlotte.spruzen@mail.mcgill.ca*

Well-preserved Neoproterozoic strata in northwest Canada, exposed through a series of erosional inliers, have provided some of the most important breakthroughs in the study of the Tonian period (ca. 1000–720 Ma). These include the discovery of complex eukaryotic fossils, the radiometric dating and correlation of the Bitter Springs event, and constraints on the nature and timing of basin evolution in Laurentia during the breakup of Rodinia. The Tonian Reefal Assemblage (ca. 850–800 Ma) is a 500–1700 m thick succession within the Fifteenmile Group in Yukon and consists of stromatolitic reef cores that prograde into basins of shale. Its stratigraphy has been well documented, with five sequences recognized and correlated across the Coal Creek inlier. Shales from the Reefal Assemblage have been used to elucidate Tonian redox conditions of seawater, and in the upper ten metres of the Reefal Assemblage in the Tatonduk inlier, organic-rich limestone micrite has been found to contain complex phosphatic scale microfossils. The Reefal Assemblage also records evidence for the Bitter Springs Anomaly, a carbon isotope excursion identified in Tonian successions worldwide. The age of the Reefal Assemblage has been constrained by a primary zircon U–Pb age of 811.51 ± 0.25 Ma, and a Re–Os age of 810.7 ± 6.3 Ma. However, there are no other radiometric ages within the Fifteenmile Group, therefore temporal constraints for its internal formations remain imprecise between ca. 1000 Ma (from detrital zircon geochronology) and 751.2 ± 5.1 Ma (Re–Os age of the overlying Callison Lake Formation). Here, we present new stratigraphic logs collected within the Fifteenmile Group, from which organic-rich black shale units have been sampled. These have the potential to provide robust Re–Os age constraints for the Gibben and Chandindu formations, and a date for the basal flooding surface of the Reefal Assemblage. From these logs, we will also present field and petrographic observations of the fine-scale carbonate fabrics present in the Reefal Assemblage, from a range of facies including the reef core, prograding fore-slope carbonates, and slope bioherms.

GEOCHEMICAL AND MINERALOGICAL CHANGES DURING SOIL DEVELOPMENT: PRELIMINARY STUDY OF A BRUNISOLIC SOIL FROM NOVA SCOTIA

Clifford Stanley, John Murimboh
Acadia University.
E-mail: *cliff.stanley@acadiau.ca*

Soils develop at chemical and physical gradients at the geosphere/atmosphere/biosphere/hydrosphere interface. Their horizons are commonly poorly understood because they tend to be thin, poorly crystalline, and fine-grained, making their geochemistry and mineralogy difficult to characterize. Historic pedogeochemical investigations have employed small sample numbers, restricted element suites, and limited digestion methods, largely ignoring heterogeneity in the parent material. Thus, historical attempts to characterize horizon development have provided marginal geochemical and mineralogical insight. Fifty 360 cm^3 soil samples within a 2 m thick vertical profile through a dystric (< 5.5 pH) elluviated (w/Ae horizon) brunisolic soil developed in a homogeneous, ~5 m thick, fine-grained glaciofluvial sand in Nova

Scotia's Annapolis Valley were collected to investigate soil profile development. This site is accessible via an excavator, lacks historical disturbance, hosts old growth species consistent with a mature Acadian forest, and displays a simple mineralogy (quartz, feldspar, biotite, and muscovite derived from the peraluminous South Mountain batholith). Variables measured include soil density, moisture, texture, Munsell colour, pH, conductivity, magnetic susceptibility, ICP–ES/MS geochemical analyses of $LiBO_3$ fusions (10 major/33 trace elements), aqua regia (36 trace elements) and deionized water (30 major/trace elements) digestions, LECO total carbon and sulphur analyses, Penfield H_2O+ analysis, and smear-mount XRD analysis on the –63 μm sample fractions. Results indicate that parent material heterogeneity persists despite all efforts, as different textures and modal mineralogy were encountered at various depths. However, molar element ratio analysis could model/circumvent this variability, providing an understanding of chemical reactions involving quartz, alkali feldspar (or_{90}), apatite, Na-phengite, and ferroan kaolinite within the soil profile. The depths where phengite breakdown took place (via Fe oxidation), apatite dissolved, and kaolinite replaced albite in a sub-soil aquifer could be identified. Surprisingly, only small amounts of feldspar hydrolysis occurred, likely due to limited weathering since the glacial retreat from Nova Scotia.

PETROLOGY AND LITHOGEOCHEMISTRY OF THE WILDCAT BROOK Mo-W DEPOSIT, CHARLOTTE COUNTY, NEW BRUNSWICK, CANADA: INSIGHTS INTO LOG–RATIO ANALYSIS

Clifford Stanley[1], Jacob Hanley[2], Abdul Asfour[2], Patrick Crouse[2]
[1]Acadia University, [2]St. Mary's University.
E-mail: *cliff.stanley@acadiau.ca*

The Wildcat Brook Mo-W deposit is located approximately 9 km east of the former Mt. Pleasant Sn-W-Mo mine in Charlotte County, New Brunswick. It is hosted by a leucocratic, quartz-feldspar porphyritic to aplitic, peraluminous, E-W-striking, moderately north-dipping dyke intruding turbiditic metasedimentary wacke/argillite of the Fredericton Trough north of the St. George batholith. High-grade Mo mineralization to 4% (per metre) occurs in two niches: (i) molybdenite blebs to 4 mm disseminated in miarolitic cavities within an albite- and muscovite-altered dyke, and (ii) medium-grade Mo mineralization at the margins/cores of 2–5 cm wide quartz veins cutting altered/unaltered dyke and adjacent metasedimentary rocks. Mineralized dyke has been intersected in 17 diamond drill cores spanning approximately 250 m along strike/dip. Dyke thickness ranges from 17 to 42 m (27 m average), with a length-weighted average grade of 0.27% Mo. Two styles of hydrothermal alteration occur in the dyke: albite, and muscovite–quartz. Molar element ratio (MER) analysis of 110 drill core samples, constrained by petrography, reveal the addition of Na and loss of K and Ca during albite alteration: microcline + Na^+ → albite + K^+, anorthite + 4 quartz + 2 Na^+ → 2 albite + 3 Ca^{2+}, and the addition of K and loss of Na during muscovite plus quartz alteration: 3 albite + K^+ + 2 H^+ → muscovite + 6 quartz + 3 Na^+. Because hydrothermal alteration recognized in the dyke can be described by balanced chemical reactions, these processes are mathematically linear. Furthermore, when plotted on MER diagrams, the data continue to form linear trends. Unfortunately, when plotted in logarithmic space, as log ratios, patterns become decidedly non-linear, significantly complicating data interpretation. Additionally, use of linear statistical procedures, such as principal components or regression analysis, on such log-transformed data is numerically invalid, and so is not an appropriate way to understand the causes of compositional variations in rocks.

GEOCHEMISTRY AND MINERALOGY OF ACID-GENERATING TAILINGS AT THE ABANDONED SOUTH BAY MINE, ONTARIO

Hannah Starzynski, Jeff Bain, Carol Ptacek, David Blowes
University of Waterloo.
E-mail: *hlstarzy@uwaterloo.ca*

The South Bay mine is a former Cu-Zn mine located in northwestern Ontario. The mine ceased operations in 1981, and oxidation of the sulphide-rich tailings has continued to generate acidic drainage waters with elevated concentrations of dissolved metals. Piezometers and soil–water samplers were installed within the tailings in 2021 to monitor spatial and depth trends in the tailings pore-water geochemistry. Continuous cores up to 7.5 m depth were collected from five different locations on the tailings, and the solid tailings samples were analyzed using optical microscopy, SEM-EDX, XRD, and total carbon and sulphur analysis. Pore gas concentrations of O_2 and CO_2 were analyzed at 5–10 cm depth intervals in the unsaturated zone of the tailings using a portable gas meter. Aqueous geochemistry results indicate acidic pore waters in unsaturated shallow tailings (minimum pH 1.3) with near-neutral pH in tailings below the water table. Elevated aqueous concentrations of Fe (up to 8300 mg/L), SO_4 (up to 24,000 mg/L), Zn (up to 820 mg/L), Cu (up to 59 mg/L), As (up to 12 mg/L), Co (up to 10 mg/L), and Pb (up to 5 mg/L) were detected in the tailings. Pyrite is the most abundant sulphide mineral in the tailings, averaging 45 at.%, with lesser amounts of sphalerite, chalcopyrite, and pyrrhotite. Pyrite is extensively depleted in the upper few centimetres and abundant below 10 cm depth of the tailings. Pyrrhotite displays partial oxidation characteristics up to several tens of centimetres depth below the tailings surface. The unoxidized tailings contain < 1 wt.% C, indicating low carbonate mineral neutralization potential. Gas profiles show a sharp decline in pore gas O_2 concentrations within the top 10 cm of the tailings, further indicating a shallow oxidation zone. The results from this study demonstrate that extensive oxidation of sulphide minerals is restricted to the upper 15 cm of the tailings 40 years post-closure. During this time, sulphide oxidation has released high concentrations of dissolved metals and metalloids. This study provides a baseline assessment to help guide remediation decisions for the South Bay mine site and will add to the overall scientific knowledge of abandoned mine sites.

EVIDENCE FOR REWORKING OF VARIABLE HADEAN SOURCES RECORDED BY THE ARCHEAN CRUST FROM THE SUPERIOR PROVINCE

Dan Stepner, Jonathan O'Neil
University of Ottawa.
E-mail: *dstep103@uottawa.ca*

The Superior Province represents the largest tract of Archean crust on Earth, yet rocks formed within the first billion years of Earth's history are almost absent, obscuring its earliest crustal evolution. The northeastern part of the Superior Province includes the craton's oldest rocks (> 3.6 Ga), but it is dominated by Mesoarchean to Neoarchean granitoid rocks from the tonalite–trondhjemite–granodiorite series (TTG), the archetypical felsic components of Archean cratons. Since granitoid rocks are typically produced from the melting of an older crustal component, isotopic tracers such as ^{143}Nd and ^{176}Hf have commonly been used to study the crustal history of Archean cratons, as these rocks inherit the isotopic signatures of their precursors. However, long-lived isotopic systems can often be disturbed in terrain that has recorded a complex and protracted thermal history, sometimes providing an equivocal picture of the earliest crustal evolution of cratons. The short-lived ^{146}Sm–^{142}Nd isotopic system is much less susceptible to post-magmatic disturbance and represents the ideal tool to decipher the earliest crustal history. Because ^{142}Nd is produced from the decay of ^{146}Sm, which has a half-life of 103 M.y., variations in the ^{142}Nd/^{144}Nd ratio can only be produced by Sm–Nd fractionation prior to ~4 Ga. Any Archean granitoid which displays a ^{142}Nd/^{144}Nd ratio deviating from the Nd terrestrial standard implies the involvement of a Hadean source. Here, we present new ^{142}Nd data for TTG and granite bodies from the Hudson Bay terrane of the northeastern Superior Province in order to constrain the nature and age of their crustal precursor source(s). A series of 3.2 Ga to 2.7 Ga samples from the Tikkerutuk, Bienville, Goudalie and La Grande domains exhibit variable ^{142}Nd/^{144}Nd ratios, mostly corresponding to μ^{142}Nd values ranging between –8 to +2. The negative μ^{142}Nd values measured in TTG from several crustal domains of the Hudson Bay terrane suggest that reworking of Hadean crustal material was an important and large-scale process involved in the formation of the Superior Province crust during the Archean. One tonalite sample attributed to the ~2.7 Ga Desbergères Suite yielded a high resolvable μ^{142}Nd value of +8.7 ± 3.4. Although most felsic samples from the Hudson Bay terrane displaying ^{142}Nd anomalies are consistent with reworking of a Hadean light rare earth element enriched precursor, the positive μ^{142}Nd value measured in this Desbergères sample suggests that the source material to the Archean TTG of the Superior Province may have been more heterogeneous, including an early depleted component.

CHARACTERIZATION OF NICKEL AND COBALT MINERALIZATION AT THE EASTER-DUFFY SHOWING, SIMPSON ISLANDS, NORTHWEST TERRITORIES

Caibre Stinnissen[1], Hendrik Falck[2], Merilie Reynolds[3], Pilar Lecumberri Sanchez[1]
[1]University of Alberta, [2]Government of Northwest Territories, [3]Northwest Territories Geological Survey.
E-mail: *caibre@ualberta.ca*

Clean energy technologies require the use of crucial mineral resources such as lithium, nickel, cobalt, and manganese in battery manufacturing. These metals are considered critical due to a combination of high projected demand, and highly localized sourcing that can pose a threat to the supply chain. Cobalt, with 70% of global cobalt production from the Democratic Republic of the Congo, and nickel, with a recent ban on exports from Indonesia, are two of these critical metals. In this context, there is a great deal of geological and socioeconomic value to identifying potential sources and refining genetic models for nickel and cobalt deposits. The Northwest Territories is known for several nickel-cobalt deposits including the NICO deposit in the Great Bear Magmatic Zone, as well as two past-producing nickel–cobalt mines, Blanchet Island and Copper Pass, in the East Arm of the Great Slave Lake. Recent geological studies have provided a new context for understanding the East Arm nickel–cobalt showings, including the Easter-Duffy, which is the focus of this study. The Easter-Duffy showing is located in the Simpson Islands of the East Arm of the Great Slave Lake, around 100 km SE from Yellowknife and 75 km NE from Fort Resolution. Historical exploration for silver, cobalt and nickel at the site included trenching and diamond drilling, but the mineralization remains poorly characterized. The dominant lithologies at the Easter-Duffy showing are Precambrian orthogneiss and granite, and variably magnetic mafic dykes. Mineralization includes silver, nickel, copper and cobalt, which occurs in all rock types but is preferentially localized at the contact between the dykes, the host gneiss, and pegmatites. A preliminary inspection suggests that the Easter-Duffy showing resembles a 5-element vein deposit. This style of mineralization consists of Ag-Co-Ni-Bi-As hosted in vein systems that can cut through a diversity of igneous, metamorphic and sedimentary host rocks with varied ages, ranging from Archean to Oligocene. The alteration style, mineral association, and fluid composition for 5-element vein deposits can be highly variable. This study aims to determine the relationship between the metals and alteration styles present at the Easter-Duffy showing, as well as evaluate the likely mechanisms of mineralization through petrographic characterization.

CRUSTAL GROWTH AND REWORKING IN THE WINNIPEG RIVER TERRANE ca. 3.3–3.25 Ga: ISOTOPE EVIDENCE FOR THE SURVIVAL OF AN ARCHEAN SUPER-CRATON

Jacob Strong[1], Jacob Mulder[2], Peter Cawood[3], Alexander Cruden[3], Oliver Nebel[3]
[1]Laurentian University, [2]University of Adelaide, [3]Monash University.
E-mail: *jstrong@laurentian.ca*

Spatiotemporal constraints on the growth and reworking of Archean cratons refine our understanding of the formation and stabilization of the oldest preserved continental crust on Earth. However, a key unknown is the prevailing geodynamic scenario(s?) responsible for the formation and assembly of plutonic-gneiss and granite–greenstone terranes, which typify Archean cratons worldwide. Resolving whether the plutonic-gneiss terranes in the Superior Province are dismembered fragments of a once contiguous Archean super-craton or a series of exotic accreted arc terranes is critical to understanding the early evolution of the Superior Province and Archean tectonics. We present zircon U–Pb and Lu–Hf isotope analyses for the Tannis and Cedar Lake gneiss units from the Winnipeg River terrane in the western Superior Province. The new isotopic data show that the Winnipeg River terrane experienced crustal growth from supra-chondritic sources and reworking of Eo–Paleoarchean crust between 3.3 Ga and 3.25 Ga with zircon $\varepsilon Hf(t)$ ranging from –6 to +4. Similar events of crustal growth followed by reworking are observed in the Winnipeg River, Hudson Bay and Minnesota River Valley terranes at 3.8 Ga and 3.5 Ga. These crustal growth and reworking events may signify episodic mantle overturns during the Eo–Paleoarchean growth of the Superior craton, while correlative histories among the three plutonic gneiss terranes suggest they once formed an Archean super-craton.

THE INFLUENCE OF PRE-EXISTING CRUST ON THE METALLOGENY OF ARCHEAN GREENSTONE BELTS: EXAMPLES FROM THE ONAMAN–TASHOTA GREENSTONE BELT, NORTHERN ONTARIO

Keaton Strongman, Harold Gibson, Bruno Lafrance
Laurentian University.
E-mail: *keatonstrongman@gmail.com*

The differential metal endowment of Archean greenstone belts has been a central question for decades, since the early days of mineral exploration in Canada, Australia, and South Africa. Early workers recognized that certain areas of Archean crust contained numerous base and precious metal deposits, while others contained comparatively few. The metallogeny of the most prolific mineral-producing Archean greenstone belts is dominated by tholeiitic volcanic successions containing volcanogenic massive sulphide, magmatic Ni-Cu-PGE, and orogenic gold deposits. This contrasts with Phanerozoic volcanic successions, which also contain abundant magmatic hydrothermal deposits that are genetically related to their host calc-alkaline magmatic and volcanic sequences. Similar volcanic successions are present within Archean greenstone belts; however, these have been historically low-producing belts and are generally regarded as unprospective. Growing recognition of atypical mineralization styles within these belts has prompted increased research into Archean magmatic–hydrothermal deposits, and crucially, the metallogenic processes responsible for their formation and endowment. This presentation highlights the metallogenic evolution of the Onaman–Tashota greenstone belt, a historically low-production belt devoid of any past or present base metal mines. We combine the results of Metal Earth's crustal-scale geophysical (seismic, magnetotelluric, gravity) surveys with belt-scale investigations of the volcanic successions to present a new model of the belt metallogeny. We show that key crustal features, such as pre-existing volcanic crust, had a strong influence on the evolution of the Onaman–Tashota belt, and on the resulting mineral occurrences. Finally, we discuss these results in the wider context of Archean metallogenic models.

TONIAN (975–955 Ma) MAGMATISM IN THE PINWARE TERRANE AND WESTERN NEWFOUNDLAND: A DISTAL LINK TO THE ASGARD SEA?

Susan Strowbridge, Aphrodite Indares, Gregory Dunning
Memorial University of Newfoundland.
E-mail: *susans@mun.ca*

Recently, 980–950 Ma bimodal volcanoclastic and sedimentary successions were discovered above Mesoproterozoic basement on the Baie Verte Peninsula, Newfoundland. The basement consists of ca. 1491 Ma orthogneiss units that are correlative with the Pinware terrane of the eastern Grenville province, southeastern Labrador. The Pinware terrane was formed in a continental arc setting at 1520 to 1450 Ma and was subsequently deformed and metamorphosed during the Grenville orogeny, by collision between Laurentia and Amazonia. In addition, it was intruded by 985–955 Ma granitoid rocks. The oldest of these intrusions (985–975 Ma) consist of anorthosite, fayalite-bearing syenite and alkali mafic dykes. The younger intrusions (975–955 Ma) are compositionally different and consist of ferroan, alkalic to alkali-calcic granite, monzonite and syenite whose origin cannot be explained by the current tectonic models for the Grenvillian orogeny. The 980–950 Ma supracrustal successions of the Baie Verte Peninsula, which also include ferroan, calc-alkalic sheet granite, are coeval with this late magmatism in the Pinware terrane and are inferred to have formed in the same tectonic environment. Based on location and paleogeographic reconstructions, the supracrustal successions are inferred to record late stages of opening of the Asgard Sea. Opening is interpreted as taking place from 1265–980 Ma by clockwise rotation of Baltica from its position adjacent to the northeastern margin of Laurentia to its new position adjacent to northern Amazonia. The current geometry inferred for the Asgard Sea triple junction at 990 Ma has it located off the Rockall bank between Greenland and Norway. However, with the identification of the new bimodal volcanoclastic and sedimentary successions, along with reconstructions on local regional faults, it is suggested that by 980 Ma, Asgard

rifting may have progressed farther to the southwest and both the supracrustal successions and intrusions are manifestations of this new event. The combined data not only suggest a new tectonic mechanism behind the post-Grenvillian magmatism in the Pinware terrane, but also link the end of Grenvillian orogenesis to Asgard Sea rifting through a change in tectonic regime.

EVOLUTION OF THE PINE LAKE GREENSTONE BELT: INSIGHTS INTO TECTONIC CONTROLS OF PALEOPROTEROZOIC OROGENIC GOLD IN THE SEABEE AREA OF GLENNIE DOMAIN, REINDEER ZONE, TRANS-HUDSON OROGEN

Devon Stuebing[1], Kathryn Bethune[2], Paul Kremer[1], Anders Carlson[1]
[1]SSR Mining (SGO Division), [2]University of Regina.
E-mail: *Kathryn.Bethune@uregina.ca*

Supracrustal rocks of the Pine Lake greenstone belt host numerous economic orogenic gold occurrences, collectively comprising SSR Mining's Seabee gold property. These include the now exploited main Seabee mine, hosted in gabbroic rocks of the Laonil Lake complex, and the more recently discovered Santoy deposits to the east, where supracrustal rocks are transposed along the Tabbernor fault and its related splays, including the Au-endowed Santoy shear zone. Multi-element geochemistry and isotopic study demonstrate that volcanic rocks of this belt's two main assemblages are juvenile and record an evolution from primitive arc tholeiites (Assemblage A) to evolved calc-alkaline rocks (Assemblage B). Geochemical study has also detected notable internal differences in Assemblage A: while the Carruthers Lake basalt has characteristics in common with island-arc tholeiite, the Santoy Lake basalt has signatures indicative of proximal back-arc or rifted arc settings. On this basis, it is contended that the Pine Lake belt originated (~1920–1875 Ma) as a juvenile island arc and accompanying back-arc basin in the ancient Manikewan Ocean. Convergence of oceanic plates (~1875–1860 Ma) led to collision and thrust intercalation of arc and back-arc components represented by the Carruthers Lake basalt and Santoy Lake basalt, respectively. Related crustal thickening increased buoyancy (~1860–1840 Ma), with related uplift, exposure and surface erosion marked by deposition of the Pine Lake conglomerate at the base of Assemblage B. Later relaxation may have caused reactivation of thrusts as normal faults, with increased accommodation space focusing conglomerate deposition along pre-existing (D1) faults. Continued or renewed subduction beneath the thrust-imbricated arc produced a second phase of (successor) arc magmatism (~1840–1810 Ma; upper Assemblage B). Uplift, sedimentation and deformation (D2) continued as the Sask craton impinged upon the arc complex with final assembly (< 1820 Ma) and latest D3 deformation driven by terminal collision of all bounding cratons. At this stage notable concentrations of gold accumulated along the Santoy shear zone, interpreted to have developed during latest stages of D3 folding and strain localization/fluid migration along the crustal-scale Tabbernor fault zone. While clearly late orogenic, gold mineralization here and elsewhere within the belt clearly represents the end-product of a protracted history of tectonic activity in fluid-rich environments (i.e. arc volcanic) that were amenable for scavenging and transporting Au. All told, gold at Seabee likely underwent significant recycling, being initially concentrated along D1 thrusts and potentially re-concentrated in D2 structures; with final migration into suitable structural sites during latest compressional–transpressional (D3) deformation.

EXPLORING THE ROLE OF LIGHTNING IN BIOGEOCHEMICAL CYCLES ON THE EARLY EARTH

Eva Stueeken
University of St Andrews.
E-mail: *ees4@st-andrews.ac.uk*

Lightning has long been considered as an important contributor to prebiotic chemistry since Harald Urey and Stanley Miller demonstrated the formation of simple organic compounds, including amino acids, which may have led to the origin of life on Earth. Subsequent computational models and experiments further indicated that lightning also generated bioavailable forms of inorganic nitrogen oxides (NO_x), which could theoretically have fulfilled the nitrogen demand of the early biosphere. However, this hypothesis has so far not been validated against the rock record. Also, the effects of this lightning-derived NO_x flux on Archean surface environments are unknown. Here, new nitrogen isotope data from lightning discharge experiments are presented, which suggest that the early biosphere was likely not dependent on lightning as a major nitrogen source. However, experiments carried out in the presence of pyrite reveal that NO_x is an effective oxidant of sulphide minerals. Hence lightning in terrestrial settings could have locally and temporarily enhanced the liberation of essential micronutrients on an otherwise anoxic world.

GEOLOGY AND MINERAL PARAGENESIS OF THE ARCHEAN UPPER BEAVER OXIDIZED INTRUSION-RELATED Au–Cu DEPOSIT, KIRKLAND LAKE, ONTARIO

Jonathan Sutton[1,2], Daniel Kontak[1], Olivier Côté-Mantha[2], Georges Beaudoin[3]
[1]Laurentian University, [2]Agnico Eagle Mines, [3]Université Laval.
E-mail: *jsutton1@laurentian.ca*

The Archean Upper Beaver Au-Cu deposit is an enigmatic oxidized intrusion-related Au-Cu deposit located in the southern Abitibi greenstone belt (AGB). The deposit is hosted in a composite intermediate to felsic intrusion referred to as the Upper Beaver intrusive complex (UBIC) constrained to an early Timiskaming age at ca. 2679 Ma. The UBIC is localized to the stratigraphic contact between the Blake River and Tisdale groups, and is associated with two distinct styles of mineralization: 1) an early concordant skarnoid replacement of sodic-calcic-potassic and Fe-oxide alteration with chalcopyrite (Ccp)-pyrite (Py1)-gold hosted in mafic volcanic rocks (i.e. stratabound) and plagioclase (Plg)-hornblende (Hbl)-phyric diorite; 2) steeply dipping discordant veins of Ccp-molybdenite (Mol)-Py2-magnetite (Mt)-hematite (Hmt)-gold spatially associated to Plg monzodiorite and quartz monzonite dykes. The early skarnoid zones and Plg-Hbl-phyric diorite are cut by Hbl diorite dykes, which are subsequently cut by discordant veins and associated monzodiorite and quartz monzonite dykes. These magmatic–hydrothermal events are cut by a ca. 2679 Ma post-ore Plg-Hbl phyric diorite and overprinted by the main stage of regional deformation (D3) and metamorphism. Fe-oxide and sulphide mineralization is subdivided into two distinct stages. An early skarnoid rock cut by Py1 that displays two growth events: 1) sieve texture Py1a that is overgrown by 2) massive Py1b. Au and bismuthinite inclusions are hosted in pits of Py1a and fractures of Py1a and b. Both generations of Py1 are overgrown by Mt. A later stage of Hmt-Mt-Py2 veins that cut the skarnoid rock display mushketovite and martite textures. The Py2 is infilled with Ccp that contains inclusions of gold, Mt and gersdorffite-cobaltite. Ccp is also intergrown with tetrahedrite and Mol, where the latter displays Au intergrowths. The distribution of Ccp and Mol varies throughout the deposit and displays a Cu-Mo metal zonation centred on the UBIC such that Mo/Cu values increase proximal to the intrusive complex. The latter suggests a magmatic–hydrothermal genesis for mineralization which supports the earlier Re–Os Mol ages of ca. 2680 Ma. The presence of deformed laminated ankerite-tourmaline-sericite veins in post-ore Hbl diorite and quartz-Mol xenoliths in these same veins suggest a later hydrothermal event likely related to the overprinting regional deformation (D3) in the southern AGB.

MEASUREMENT OF SULPHUR ISOTOPES USING NANOSCALE TECHNIQUES FROM SEDIMENTARY PYRITE FRAMBOIDS

Megan Swing[1], Daniel Gregory[1], Daniel Perea[2], Sandra Taylor[2], Mark Wirth[2], John Cliff[2], Maria Figueroa[3]
[1]University of Toronto, [2]Environmental Molecular Sciences Laboratory, [3]University of California Riverside.
E-mail: *megan.swing@mail.utoronto.ca*

Sedimentary pyrite has been hypothesized to be an important source of gold in orogenic systems. To better understand what factors may affect the concentrations of gold in pyrite, the process of the formation of sedimentary pyrite needs to be explored in detail. In marine ecosystems, pyrite (FeS_2) forms as spherical clusters of microcrystals, but the exact mechanisms of formation are poorly understood. Studies have shown these clusters, or framboids, are capable of recording the water column chemistry of their environment during different stages of crystallization. In low oxygen conditions sulphate (SO_4^{2-}) is utilized instead of O_2 for respiration, producing H_2S, which is ultimately incorporated in sulphide minerals, predominantly pyrite. As this pyrite forms in an open system, it is significantly isotopically lighter

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than the original sulphate, as it is energetically favourable to use the lighter isotope (^{32}S). Studies have also shown that S isotope fractionation is related to the rate of reduction, and low rates using H_2 exhibit lower fractionations. Differences in isotope ratios may provide detail not only on the formative environments but the types of microorganisms that may have been present at a given time. This makes the study of S isotopes extremely important for analyses of anoxic ocean sediment and the evolution of S metabolism. Recently, TEM analyses from the Cariaco Basin and the Demerara Rise have shown that there is a significant variation of trace elements in different parts of pyrite framboids. The relative timing of this later trace element enrichment and its relation to S isotope ratios is unknown. In the present study, sediment samples were taken from two sites located in Saanich Inlet (Vancouver Island, BC), a seasonally anoxic fjord, as the cyclic nature of the site provided chemically distinct conditions over a relatively short period of time. On average, framboids are ~10 µm, making nanoscale analyses critical to observe variations within a single framboid, indicative of periods of growth. This study employed the use of nano secondary ion mass spectrometry (SIMS) to identify heterogeneity in S isotopes within and between pyrite framboids to better understand the mechanisms involved in their crystallization. The nanoSIMS results will be compared to measurements collected via atom probe tomography (APT) to further develop the methods required to measure S isotopes at the nanoscale using APT. Results will be discussed through the comparison of different sizes and shapes of framboids found at varying sediment depths from the two sites.

ANALYSES OF ZIRCON GRAINS FROM THE SUDBURY IMPACT STRUCTURE: GEOCHEMISTRY AND MACHINE LEARNING APPROACHES

Ian Szumila[1], Veanessya Vazquez-Lopez[1], Dustin Trail[1], Miki Nakajima[1], Steven Shirey[2], Rasmus Haugaard[3], Taus R.C. Jørgensen[3], Michael Ackerson[4], Nicolas Litza[1], Scott Hull[1], James Darling[5]
[1]University of Rochester, [2]Carnegie Institution for Science, [3]Laurentian University, [4]Smithsonian Institution, [5]University of Portsmouth.
E-mail: *iszumila@ur.rochester.edu*

Zircon is a powerful geochemical tool, linking concentrations of specific elements and isotopes to concepts such as geothermometry (Ti in zircon thermometer) or continental crust growth (via Hf isotopes). The goal of this project is to build a model that can identify whether zircon formed by endogenous or exogeneous (impact-related) processes based on trace elements in zircon grains. Our progress to build a database of trace element analyses of zircon analyzed via laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) from terrestrial impact melt sheets started with zircon from the Sudbury melt sheet. These analyses will enable statistical, geochemical, and machine learning techniques to be used for the study of melt sheet zircon grains and impact geochemistry and facilitate a much greater general understanding of zircon grains that crystallized in impact melt sheets. Over 300 new zircon analyses from the 1.85 Ga Sudbury melt sheet lithologies currently pass screening and can be used for machine learning applications. Zircon grains were screened by comparing the Pb–Pb dates of the individual analyses to make sure they matched with the crystallization age of the melt sheet. The zircon dataset was further screened by checking for inclusions visually, checking that the LA-ICP-MS results have values > 30 for the Bell zircon alteration index, and that the Na and Ti contents are realistic for zircon grains. In addition to melt sheet lithologies, additional analyses of zircon from other rocks related to the footwall rocks (e.g. Levack gneiss and Huronian sandstone) and post-impact sedimentary rocks (e.g. Chelmsford Formation) of the Sudbury impact structure are also included. Scanning electron microscope and cathodoluminescence images of zircon grains are presented to better characterize the morphology of zircon grains that crystallized in an impact melt sheet. A neural network on the trace element geochemistry of our analyzed melt sheet zircon and zircon from other magmatic processes in the literature was trained using the GEOROC database. The model was validated by picking regions (including the Chelmsford Formation) where detrital zircon grains have been identified but are not considered to be sourced from an impact process and asking the model to make predictions on these results. This model was then applied to other previously analyzed zircon grains to make predictions on whether the zircon was from an impact melt sheet. By applying this to the detrital zircon record, regions for further investigation of potential undiscovered impact events can be identified.

THE MINERALOGICAL DIVERSITY AND SOURCES OF CANADA'S CRITICAL MINERALS

Kimberly Tait, Veronica DiCecco
Royal Ontario Museum.
E-mail: *ktait@rom.on.ca*

Canada has a list of thirty-one minerals currently that are "critical". To fundamentally understand what these minerals are, we need to start with identifying and understanding Canada's strong minerals ecosystem and the diversity of these deposits nationwide. The global demand for critical minerals is to advance modern technologies, such as solar panels, semiconductors, advanced batteries, and arguably Canada is in a particularly strong position to lead not only in production, but also in sustainable mining practices. Our immediate need is to reach a point where our actions do not result in any increase in atmospheric CO_2 – "net zero" – and shift away from fossil fuels and focus on renewable energy sources like solar and wind, hydroelectric power, and nuclear reactors. Some commonly recognized examples of critical "minerals" include lithium, nickel, cobalt, zinc, and rare earth elements. These elements are found in a wide variety of mineral deposits and this talk will be a broad overview of some of the types of minerals and deposits that will be of importance in Canada. One example is volcanogenic massive sulphide (VMS) ore deposits, which are a significant source of the world's copper, zinc, lead, gold, and silver ores. Perhaps more important here, there are metals such as cobalt, tin, tellurium, etc. that are co- or by-products of these types of deposits. A variety of "critical minerals" form in granitic pegmatites, such as spodumene (lithium), columbite and tantalite (tantalum and niobium), cassiterite (tin), apatite-group minerals (REEs) and pollucite (cesium) that are found in a variety of regions in Canada. Canada is the world's largest producer and exporter of sylvite and halite (potash), which is primarily used to produce fertilizer and the essential need to feed the world. With the war in Ukraine creating uncertainly and instability around potash coming out of eastern Europe, Canadian firms are increasing production for input for global food security. Carbon (graphite) is used in the metallurgical application that serve aerospace, electronics, telecommunications and transportation technologies, and for making steel and Canada is a leading producer of this mineral. Understanding not only the major mineralogy of these deposits, but how these metals are incorporated into the crystal structure of these minerals will be key to future extraction.

LITHOSTRATIGRAPHY OF THE RHYACIAN GREENSTONE BELTS OF NORTHERN GUYANA AND SURINAME

Michael Tedeschi[1], Stéphane Perrouty[1], La Donna Fredericks[2]
[1]Laurentian University, [2]Guyana Geology and Mines Commission.
E-mail: *mtedeschi@laurentian.ca*

The Rhyacian Trans-Amazonian Province of the northern Guiana Shield of South America is among the least studied and most enigmatic of the world's major Precambrian terranes. It consists of a series of deformed volcano-sedimentary greenstone belts contained within granite–gneiss domains. Like many other granite–greenstone terranes, the Trans-Amazonian Province is highly prospective for orogenic gold deposits but has seen only limited modern exploration. Exploration in the region is challenged by dense tropical forests, recent sedimentary cover (up to +50 m thick) and lack of access. Most crucially, the geology of the region is poorly understood, having been largely ignored by the geoscience community since the 1970s. To help address these shortcomings, this study seeks to unravel greenstone belt lithostratigraphy through detailed geological mapping of key transects across Guyana and Suriname along with the reinterpretation of historical datasets. A four-part preliminary stratigraphic sequence for the greenstone belts has been observed in both Guyana and Suriname. 1) A sequence of dominantly mafic volcanic rocks including massive to pillowed tholeiitic basalt, volcaniclastic rocks and lesser ultramafic rocks, laminated siltstone, carbonaceous shale, and chert. 2) Intermediate to felsic calc-alkaline volcanic rocks consisting of flows of porphyritic andesite, dacite, rhyolite, felsic tuff, volcaniclastic breccia and lesser laminated sedimentary rocks. 3) A sequence of siliciclastic sedimentary rocks composed of fine- to medium-grained turbiditic sandstone and shale. 4) A sequence of alluvial/fluvial sedimentary rocks, consisting of thickly bedded conglomerate and sandstone with trough cross-bedding and detrital magnetite grains. All sequences are metamorphosed from greenschist to amphibolite facies and are exposed in regional synclinal structures. Similar sequences of mafic and intermediate–felsic volcanic rocks and correlations between large siliciclastic basins in both Guyana and Suriname suggest a similar mode of formation across the Trans-Amazonian Province. More precise timing relationships between these components await new geochronological studies of volcanic and sedimentary rocks collected from across the region. Units such as the Muruwa Formation and Orocaima Group exposed to the SW of the Trans-Amazonian Province, do not belong to the greenstone belt sequence, and were likely deposited after a considerable period of uplift and erosion following the Trans-Amazonian Orogeny. The lithostratigraphic boundaries revealed by this study such as those between siliciclastic basins and the mafic volcanic/calc-alkaline sequences may be indicative of the early crustal structure and thus may provide an important guide to future exploration efforts.

INVESTIGATING THE BURIAL PATH OF VANADIUM IN HYPER-ENRICHED BLACK SHALE OF THE SELWYN BASIN BY EXAMINING ITS SPECIATION VIA MICRO-FOCUSED X-RAY ABSORPTION NEAR-EDGE SPECTROSCOPY

Ozgur Tekin[1], Daniel Gregory[1], Anthony Chappaz[2], Danielle McGill[1], Daryll Concepcion[1], Merilie Reynolds[3], Chelsey Merrick[1], Daisy Zhang[1], Stefanie Brueckner[4]
[1]University of Toronto, [2]Central Michigan University,
[3]Northwest Territories Geological Survey, [4]University of Manitoba.
E-mail: *ozgur.tekin@mail.utoronto.ca*

Vanadium (V) is a critical metal required to support the green energy transition and steel production, including its use in Vanadium Redox Flow Batteries (VRFBs). These batteries are essential components in integrating renewable energy sources such as wind and solar power into the electrical grid. Additionally, V can be added to steel to produce a stronger and more durable alloy while reducing energy consumption and improving the lifecycle of steel products. The need to identify new V deposits is urgent and strategic. Hyper-enriched black shale (HEBS) deposits are among these new potential resources. The Selwyn Basin in northwest Canada is a sedimentary basin that is known to have relatively high V enrichments (around 0.3 wt.%). However, the processes leading to economically relevant V concentrations remain a debated topic. Two mechanisms are being considered: (1) direct precipitation from seawater (top-down) or (2) seafloor hydrothermal activity (bottom-up). Although, V shows a wide range of oxidation states ranging from –III to +V, only +III, +IV and, +V occur under natural conditions. A recent study identified a new species of V in black shale that consists of V(+IV) bound to sulphur atoms associated with organic phases. The goal of our study aims to determine the speciation of V in hyper-enriched black shale. Synchrotron-based spectroscopy techniques can provide valuable insights into the chemical and structural properties of these materials. This powerful X-ray source provides highly precise results without regard to the sample size. It can collect measurements from an area as small as 10 μm x 10 μm. X-ray absorption fine structure (XAFS) involves exposing the sample to high-energy X-rays. By analyzing the data collected, researchers can gain information about the electronic and geometric structure of the atoms in the sample. X-ray absorption near-edge spectroscopy (XANES) provides information about the oxidation state and coordination chemistry. By characterizing the speciation of V and combining our new molecular insights with other geochemical analyses like isotope chemistry, whole rock analyses, and SEM, we will test the two models of V enrichment described above. Refining our understanding of V sequestration mechanism will contribute to improving the exploration efforts and securing additional V resources from the Selwyn Basin.

THE ROLE OF REMOTE SENSING IN MINERAL EXPLORATION

Ana Teodoro
University of Porto.
E-mail: *amteodor@fc.up.pt*

Remote sensing (RS) data and image processing techniques have been applied to the field of geology since the 1970s. Since then, and more recently, with the advent of new sensors and more advanced image processing techniques (e.g. artificial intelligence, AI), RS data provide a powerful approach to delineating target exploration deposit types. Several authors in the literature highlight the major contribution that RS offers to mineral exploration. They concluded that RS provides information in a quick, inexpensive, and non-intrusive way, which favours exploration activities. However, just recently, RS data and image processing techniques have been applied to the detection of Li-bearing pegmatites. Two recent European Union (EU) financed projects included tasks related to satellite image processing and spectral analysis applied to the detection of Li-bearing pegmatites. 1) The LIGHTS project. This was an ERA-MIN2 project (2018–2021), which aimed to develop software for easy and fast detection of Li-host minerals combining drone-borne RS data and field observations. More information regarding the LIGHTS project can be found at http://lights.univ-lorraine.fr. 2) The GREENPEG project is an ongoing project (2020–2024) with a dedicated work package to satellite image processing techniques (including AI techniques) and also spectroradiometric data (spectral libraries) of LCT and NYF pegmatites in three different areas in Europe (Ireland, Norway and Austria). More information regarding the GREENPEG project's overall objectives can be found at https://www.greenpeg.eu. From these two projects, we have concluded that it is possible to identify spectral features of Li-bearing pegmatites and also to discriminate Li-bearing pegmatites from host rock. We also concluded that the traditional image-processing algorithms are adequate for these tasks, but the AI algorithms, mainly machine learning algorithms, such as Random Forests, Support Vector Machines and Artificial Neural Networks are powerful algorithms for the identification and discrimination of Li-bearing pegmatites. A new Horizon Europe project (EU), called S34I (Secure and Sustainable Supply of Raw Materials for EU Industry) started in January of 2023, and aims to research and innovate new data-driven methods to analyze remote sensing data, supporting systematic mineral exploration and continuous monitoring of exploration, extraction, closure and post-closure activities to increase European autonomy regarding raw materials resources and to use remote sensing data and image processing techniques not only for the management of technical and environmental issues for a green transition but also to support public awareness, mining's social acceptance, and better legislation.

CONTINUOUS EJECTA DEPOSITS OBSERVED BEYOND LAYERED EJECTA RAMPARTS ON MARS

Livio L. Tornabene[1], Jennifer L. Piatek[2], Gordon R. Osinski[1], Joseph M. Boyce[3], James Burley[1]
[1]Western University, [2]Central Connecticut State University,
[3]University of Hawai'i.
E-mail: *ltornabe@uwo.ca*

Continuous ejecta deposits on Mars are generally divided into two main morphologic types: "radial" and "layered". While radial ejecta represents the most common type on the airless bodies, layered ejecta is dominant for craters on Mars (> 90% for craters ≥ 5 km in diameter). Volatile or ice content within (or on) the target, and/or effects from interactions between the ejection process with the atmosphere, have all been proposed to explain layered ejecta. Layered ejecta is also distinct from radial with respect to its morphometric profile including a distinctive terminal edge that manifests as a ridge or scarp, commonly referred to as a "rampart". Importantly, the layered ejecta rampart has often been assumed to be the terminus of the continuous ejecta facies and the start of discontinuous facies of an ejecta blanket. Based on observations with Mars Reconnaissance Orbiter (MRO), we describe a subtle, relatively thin, continuous deposit that flows off, and terminates well beyond the rampart of several of the best-preserved craters on Mars (up to 5 crater radii). We refer to this as the "Beyond-Rampart Continuous Ejecta" (BRaCE) facies. The clear relationship of these deposits to volatile-rich impact pitted and smooth deposits observed on the layered ejecta suggests an important role not only for target volatiles in their formation, but also for impact melt-production and emplacement. BRaCE is similar, and likely related to, Low Aspect Ratio Layered Ejecta (LARLE), which are proposed to form as a ground-hugging base surge. However, unlike LARLEs, all craters with BRaCE have generally shorter runouts (< 6 crater radii), are notably superior in preservation, and occur equator-ward of the mid-latitudes. Indeed, some LARLEs are found at lower latitudes, but these are much rarer (11; ~8%) and occur very specifically in deposits interpreted to be altered ash deposits (e.g. Medusa Fossae Fm.). Thus, we suggest that LARLE and pedestal craters are not unique ejecta classes but may merely be expressions of various degrees of preferen-

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tial preservation of BRaCE with the enhanced run-out distances and differences in preservation being likely attributed to target properties and local conditions, respectively. The recognition of these continuous beyond layered ejecta rampart deposits calls into question how we define crater ejecta on Mars (continuous vs. discontinuous), and possibly other bodies; as such, these deposits warrant further detailed study to make additional constraints on ejecta classification, our understanding of how ejecta blankets form, and how they degrade over time.

LIMITATIONS IN USING MAGNETITE AND ACTINOLITE CHEMISTRY AS TRACERS OF TEMPERATURE AND ORIGIN IN IOA–IOCG SYSTEMS

Fernando Tornos[1], John M. Hanchar[2], Matthew Steel-McInnis[3]
[1]Complutensian University of Madrid, [2]Memorial University of Newfoundland, [3]University of Alberta.
E-mail: *jhanchar@mun.ca*

The abundance of magnetite and actinolite in magnetite-apatite (MtAp) and iron oxide copper-gold (IOCG) systems has motivated the recent use of their compositions for distinguishing ore-forming events, to calculate temperatures, and to discriminate between magmatic and hydrothermal systems. The trace element geochemistry of magnetite and actinolite is a fundamental tool for identifying different mineral generations; however, their indiscriminate use without the framework of thorough understanding of the geological and geochemical background can potentially lead to undesirable, and more importantly, geologically unrealistic results. The incorporation of an element in the structure of a mineral depends on the availability in the fluid (aqueous or melt) to transport the element, the capability of the host to incorporate it (size and charge compatibility), and the K_D. When there are two phases in equilibrium, trace element partitioning can be used as a geothermometer provided the assemblage does not break the Gibbs rule and the activity coefficients are known. Otherwise, the system is multivariant and T–(P or x) cannot be constrained. Probably, the best example is the use, or misuse, of Ti-in-magnetite. Experimental and thermodynamic studies suggest that the equilibrium conditions for magnetite–ilmenite (as Ti-saturating phase) are independent of pressure but depend on both the temperature and the $f(O_2)$. At high $f(O_2)$, the isopleths are isochemical and the Ti content depends only on the $f(O_2)$. The inverse holds true at temperatures below ~600°C. If there is no Ti-saturating phase, then the system is multivariant. Application to the El Laco MtAp deposit in Chile suggests that in such a hot (> 700°C), oxidizing, and Ti-saturated system, the Ti-in-iron oxide content of the different assemblages depends on the $f(O_2)$ and not if the system is magmatic or hydrothermal, or equally important, the depth of formation.

DIFFERENTIAL GOLD ENDOWMENT DURING THE DEVELOPMENT OF ACCRETIONARY AND DOME-AND-KEEL GREENSTONE ARCHITECTURES: A CASE STUDY FROM THE EASTERN ARCHEAN WABIGOON SUBPROVINCE, CANADA

Zsuzsanna Toth, Bruno Lafrance, Benjamin Mark, Harold Gibson, Keaton Strongman, Anna Haataja, Douglas Tinkham
Laurentian University.
E-mail: *blafrance@laurentian.ca*

The eastern greenstone–granite Wabigoon subprovince in northwestern Ontario is sandwiched between the metasedimentary English River subprovince to the north and the Quetico subprovince to the south. It includes two volcanic sedimentary belts: the Onaman–Tashota Belt (OTB) and the Beardmore–Geraldton Belt (BGB). Located north of the BGB, the OTB has a dome-and-keel structural architecture characterized by Mesoarchean and Neoarchean supracrustal rocks tightly infolded between Neoarchean plutons and batholith. The supracrustal rocks young away from these intrusions and are overprinted by high strain zones along intrusion–supracrustal rock contacts, a steeply dipping and northerly striking foliation wrapping around these intrusions, and a down-dip stretching lineation along these foliation planes. The BGB forms a transitional belt between the metasedimentary Quetico subprovince to the south and the Wabigoon subprovince to the north. It consists of interleaved panels of Neoarchean metasedimentary and metavolcanic rocks, which are separated by thrust faults that were reactivated as transcurrent shear zones. It has a linear accretionary architecture that contrasts with the dome-and-keel architecture of the OTB, although both are coeval and formed between 2700 Ma and 2690 Ma during closure of the Quetico basin and collision with a greenstone–granite terrane to the south. The OTB and BGB differ in gold endowment. The OTB produced less than 120,000 ounces of gold, whereas the BGB produced over 4.1 million ounces of Au. Gold is typically associated with early quartz-carbonate veins hosted by high strain zones and shear zones that formed during the infolding of the supracrustal rocks against strong granitic domes in the OTB and during accretion and imbrication of supracrustal rock panels in the BGB. Gold was further emplaced during transcurrent reactivation of these shear zones in the BGB. The latter coincide with steeply dipping zones of low reflectivity and resistivity that extend down to crustal depths of 15 km in the Metal Earth seismic and magnetotelluric transect across the eastern Wabigoon subprovince. The shear zones acted as conduits for the upward migration of hydrothermal fluids and possibly magmas, which altered the rocks and produced the geophysical responses observed on the Metal Earth transect. Thus, the presence of deeply penetrating structures in the BGB explains its preferential gold endowment and suggests that the formation and reactivation of these structures during accretionary horizontal tectonics is more favourable for the emplacement of gold mineralization than vertical dome-and-keel tectonics.

DEPOSITION MECHANISM OF UNCONFORMITY-RELATED URANIUM DEPOSITS IN THE ATHABASCA BASIN: EVIDENCE FROM URANIUM SPECIATION IN HEMATITE AND GOETHITE

Ayetullah Tunc[1], Jinru Lin[2], Renfei Feng[3], Ning Chen[3], Yuanming Pan[1]
[1]University of Saskatchewan, [2]Chinese Academy of Sciences, [3]Canadian Light Source.
E-mail: *ayt413@usask.ca*

With the exception of the recently discovered stable $U^{(IV)}$ chloride species at high temperatures under reduced conditions, genetic models for the formation of uranium deposits had almost invariably invoked the pivotal roles of soluble $U^{(VI)}$ species for the transport of uranium-bearing fluids and their reduction to sparingly soluble $U^{(IV)}$ as the deposition mechanism. However, the questions of when and how this reduction in most uranium deposits such as those in the Athabasca Basin (Canada) and the Olympic Dam Cu-U-Au-Ag deposit (Australia) occurred are often not clear. The unconformity-related uranium deposits in the Athabasca Basin are commonly accompanied by extensive and intensive hematite-rich alteration halos. Previous U L3-edge X-ray absorption near-edge spectroscopy (XANES) studies of uranium-rich fluid inclusions and thermodynamic modelling also supported uranium transport as $U^{(VI)}$ species in hypersaline fluids in the Athabasca Basin. Similarly, Cu-U-Au-Ag mineralization in the Olympic Dam deposit is characterized by association with hematite–barite-rich assemblages, suggesting a possible transport of uranium under oxidizing conditions. Electron microprobe analyses reveal that hematite inclusions in different generations of secondary quartz overgrowth as well as disseminated hematite and goethite in clay mineral matrices, in both ore bodies and associated alteration haloes from several uranium deposits (Arrow, Cigar Lake, Eagle Point, Key Lake, McArthur River, and Phoenix) in the Athabasca Basin contain high concentrations of uranium (up to 2.16 wt.% UO_3). Synchrotron U L3-edge XANES analyses confirm that uranium in both hematite and goethite occurs dominantly as the uranyl species, providing unambiguous evidence for direct $U^{(VI)}$ deposition in the Athabasca Basin. Although this new deposition mechanism of uranyl coprecipitation with hematite and other minerals such as quartz alone cannot account for some of the highest grade uranium mineralization, it provides the first proof of uranyl deposition contributing to the formation of unconformity-related uranium deposits in the Athabasca Basin. This uranyl deposition mechanism is potentially important in the formation of other uranium deposits, especially those associated with extensive hematitization.

THE HYDROTHERMAL HISTORY OF THE VOLPA SEAFLOOR MASSIVE SULPHIDE DEPOSIT, SW PACIFIC

Jonathan Umbsaar, Melissa Anderson, Daniel Gregory
University of Toronto.
E-mail: *jumbsaar@gmail.com*

The Volcano P Site A (VOLPA) deposit is a previously uncharacterized seafloor massive sulphide (SMS) deposit that is located on the southern end of the Niua Volcanic Complex, which is an irregular arc volcano composed of coalescing volcanic ridges and accompanying fissures, craters and volcaniclastic mounds. This volcano is located at the northernmost end of the Tofua volcanic arc, along the Tonga–Kermadec trench in the SW Pacific. SMS deposits form through circulation of hydrothermal fluids in the underlying oceanic crust, which are driven by the anomalous geothermal gradients of the imposing magma bodies associated with the arc volcanoes. Circulation of seawater, and influx of magmatic volatiles collectively produce a fluid that is relatively high temperature, acidic, and reducing, which are favourable conditions for the transport of metal cations that tend to precipitate either via boiling or when mixing with seawater. These deposits are enriched in a variety of critical metals, and represent a modern analogue to volcanogenic massive sulphide (VMS) deposits which are most commonly mined on land for copper, zinc, lead, silver, and gold, but can also host a variety of critical metals, including As, Bi, Cd, Ga, Ge, In, Hg, Sb, Se, Sn, Te, Tl, and W. VOLPA is an interesting case study as it is composed of especially barite-rich chimneys, in sulphur-encrusted host rocks of variable permeability, resulting in deposit-scale zonation of mineral abundances. The presence of high-sulphidation state mineral assemblages, and the anomalous metal enrichments and depletions present at VOLPA have implications for the provenance, precipitation, and transport mechanisms of the metal cations. Petrography, elemental mapping, and whole rock geochemistry have allowed for sub-classification of the chimney types across VOLPA, which display consistent critical metal abundances, with implications for hydrothermal processes such as boiling, seawater mixing, magmatic volatile influx, as well as the pH, temperature, and redox conditions of the hydrothermal vent fluids. The conclusions of this research indicate that the distribution of critical metals across VOLPA is largely dependent on host rock permeability, depth, and the influx of magmatic volatiles, in addition to adsorption, colloidal gold transport, and structural influences. These results can be directly compared to adjacent SMS deposits such as Niua South and the Brother's Volcano, as well as the analogous but ancient VMS deposits that are actively mined on land.

MONITORING GROUNDWATER AND SURFACE CASING VENTS AT A CO_2 INJECTION FACILITY

Nicholas Utting[1], Kirk Osadetz[2], Tom Darrah[3], Bernhard Mayer[4], Don Lawton[2]
[1]Natural Resources Canada – CanmetENERGY, [2]Carbon Management Canada, [3]Ohio State University, [4]University of Calgary.
E-mail: *nicholas.utting@nrcan-rncan.gc.ca*

It is anticipated that geological storage of large quantities of CO_2 will be needed in order to reduce atmospheric concentrations of CO_2 to meet emissions reduction targets. The geological storage of CO_2 relies on the injected CO_2 remaining sequestered in the intended formations. At Carbon Management Canada's Newell County facility, CO_2 is injected at a depth of 300 m allowing researchers to study the migration of gas in the intended reservoir and study its migrations into other formations. In this study, we focus on the use of CO_2, CH_4 and noble gases, and their isotopes, to monitor the subsurface migration of the CO_2 plume, as well as the potential for unintended migrations. Samples for analysis of concentrations of gases (CH_4, N_2, O_2, CO_2 and noble gases) and their stable isotopes have been collected from a monitoring well completed in the injection zone, as well as from surface casing vents, and shallow groundwater wells. Breakthrough of CO_2 has not been observed at the geochemical monitoring well, however, there have been changes in geochemistry observed from surface casing vents which may be related to CO_2 injection. These changes point to the importance of scheduled monitoring to be able to detect CO_2 breakthrough and/or loss of containment of CO_2.

INTERACTION OF TANNINS WITH IRON OXYHYDROXIDE AND SULPHIDE PHASES: IMPLICATIONS FOR PASSIVE MINE WASTE REMEDIATION SYSTEMS

Janviere Uwanyirigira[1], Emily Saurette[2], James Dynes[3], Joyce McBeth[4]
[1]University of Saskatchewan, [2]University of Waterloo, [3]Canadian Light Source, [4]University of Regina.
E-mail: *joyce.mcbeth@uregina.ca*

Organic matter is used as a reactive material in passive mine waste remediation systems (e.g. permeable reactive barriers (PRBs)), removing contaminants such as metals from mine-affected water. Organic matter can release dissolved compounds such as tannins, and the effect of tannins on metal sequestration and transport requires further investigation. Iron oxyhydroxide and sulphide phases are important in passive mine waste remediation systems. Contaminant removal can occur through mechanisms such as co-precipitation with an iron sulphide phase or sorption/coprecipitation to/with iron oxyhydroxides. Their transformation from less crystalline to crystalline phases could lead to the contaminants' re-mobilization. In this study, we aim to examine the impact of tannins on iron oxyhydroxide and iron sulphide precipitate formation, using tannic acid (TA) as the model compound. We titrated ferric nitrate nonahydrate with sodium hydroxide (iron oxyhydroxide system, open to air) and reacted ferrous chloride tetrahydrate with sodium disulphide nonahydrate (iron sulphide system, in a glove box) with varying ratios of TA (TA/Fe molar ratios 0, 0.001, 0.01, 0.1). Powder X-ray diffraction, Fe K-edge X-ray absorption near-edge spectroscopy (XANES), and PDF data showed that in the presence of TA, Fe hydrolysis and precipitation was perturbed. In the absence of TA, only ferrihydrite was formed in the iron oxyhydroxide system, whereas in the presence of TA, a mixture of phases including ferrihydrite, lepidocrocite, and goethite were formed. In the iron sulphide system, only mackinawite was formed in the absence of TA, whereas a mixture of mackinawite and greigite was formed in the presence of TA. When TA was not present, lepidocrocite, goethite, and greigite formation were not favourable in either the iron oxyhydroxide or iron sulphide system. We hypothesize that redox cycling of Fe and S are influenced by the presence of organic matter, and TA-induced changes in the redox chemistry of our systems. Tannic acid might have induced Fe(III) reduction to Fe(II) favouring formation of lepidocrocite and goethite, and Fe(II) oxidation to Fe(III) favouring formation of greigite. Oxidation of S(–II) to elemental sulphur is evident in the sulphide system. This study demonstrates that the presence of TA, as well as other redox sensitive organic ligands, might change the outcomes of mineral precipitation processes involving iron or other redox sensitive metals, by inducing formation of crystalline phases. This may have implications for contaminant removal and/or remobilization in PRB systems.

APPROACHES FOR MINERAL RESOURCE ASSESSMENT OF SMS DEPOSITS

Merve Uygur[1], Melissa O. Anderson[1], John Jamieson[2]
[1]University of Toronto, [2]Memorial University of Newfoundland.
E-mail: *merve.uygur@mail.utoronto.ca*

Seafloor massive sulphide (SMS) deposits located on mid-ocean ridges and arc to back-arc settings may host significant metal sources for copper, lead, zinc, and gold. Mineral resource assessments for some SMS deposits were performed considering resource abundance and undiscovered areas; however, the estimation techniques based on detailed deep-sea drilling data are largely unavailable in most cases due to limitations of drilling technology. Furthermore, remotely operated vehicles that detect SMS deposits have difficulty spotting buried deposits covered by seafloor sediment even if they can detect active SMS deposits. This study aims to generate a resource estimation model that overcomes challenges such as the limited number of available data from sub-seafloor drilling of SMS deposits. One approach to estimate resources includes the evaluation of ore body volumes by multiplication of base area and thickness of the deposit, which requires the examination of drill cores. The methodology of this study includes a geostatistical approach that requires comparisons of well-characterized volcanogenic massive sulphide (VMS) deposits, which represent the on-land ancient analogues of the SMS deposits, to provide a better understanding of the geometry and composition of modern SMS. Therefore, the establishment of a grade–tonnage model using the probabilistic assessment approach eliminates the limitation of drill data in SMS deposits. Moreover, geostatistical models include variographic analyses that evaluate principal component values by applying ordinary kriging, turning bands simulations (TBSIM), or Gaussian simulations. Consistency between the produced model and primary data is controlled by visual inspection of estimated grades in plan and section compared into input composited data, checking for global and local bias, degree of grade smoothing, reconciliation of production data to the model, and re-evaluation of economic parameters. Quantification of SMS deposit size and grades has uncertainties associated with the resource estimation models, thus the perspective of the study aims to find answers to geological and geostatistical uncertainties in SMS deposits by finding the optimum resource evaluation methodology.

ASSESSING TOURMALINE AS AN INDICATOR MINERAL USING MULTIVARIATE STATISTICS

Eduardo Valentin dos Santos, Georges Beaudoin, Bertrand Rottier
Université Laval.
E-mail: *edvad@ulaval.ca*

Tourmaline occurs in several geological environments and mineral deposits. Due to its large stability field and low volume diffusion rates, it can preserve original chemical zonings that record its crystallization environments. Compositional data from ore-related tourmaline can provide information on hydrothermal processes, which makes tourmaline a potential pathfinder for different types of deposits. Nonetheless, the published tourmaline trace element datasets are inconsistent and incomplete in the number of analyzed elements. In this context, this project aims to build a homogeneous database and develop criteria for using tourmaline chemistry as a geochemical prospecting tool. Tourmaline mineral chemistry is investigated using EPMA (major and minor elements) and LA-ICP-MS (minor and trace elements). The data are processed and analyzed using standard exploratory and multivariate statistics. EPMA results of tourmaline from porphyry Cu-Mo, granite-related Sn, Li-bearing pegmatites, unconformity U, felsic to intermediate intrusive rocks, and metapelitic rocks demonstrate that their compositions mostly span through schorl–dravite, except for the unconformity U, Li-bearing pegmatites, and some granite related Sn, which are Mg-foitite, and elbaite–liddicoatite. LA-ICP-MS trace element principal component analysis (PCA) results in good separation of Li-pegmatites from the other classes, characterized by high Li, Mn, Pb, Zn, Cu, and REE. Unconformity U is characterized by an overall low concentration of trace elements. Granite-related Sn deposits tend to plot between Li-pegmatites and other magmatic and magmatic–hydrothermal rocks on the first, second, and third components and are characterized by higher REE, Na, Al, Ga, Sn, Nb, and Ta. Both Li-pegmatites and granite-related Sn are inversely correlated to orogenic gold deposits, which are characterized by higher Mg, Cr, Co, V, Ni, Sc, and Sr. Partial least-squares discriminant analysis (PLS-DA) results in good separation of Li-rich and Li-poor pegmatites, and unconformity U. Li-bearing pegmatites are positively correlated with Li, Nb, Ta, LREE, Pb, Sn, Mn, Ga, and Be, whereas Li-poor pegmatites are positively correlated with Fe, Th, U, and Y. The separation between the two classes is especially observed in the first and third latent variables (t1 and t3). Unconformity U is positively correlated with Al, B, Th, Y, and U. There is considerable overlap between other classes using PCA and PLS-DA. Further data collection and classification using machine learning (Random Forests) methods are the next steps of this project, as they will allow better discrimination of tourmaline from the investigated geological environments.

ORDOVICIAN TO SILURIAN SEDIMENTATION AND METAMORPHISM IN THE CENTRAL ASPY TERRANE OF CAPE BRETON ISLAND, NOVA SCOTIA, CANADA: A NEW STRATIGRAPHIC PARADIGM

Deanne van Rooyen[1], Sandra M. Barr[1], Chris E. White[1], Evelyne Sunatori[1], Amanda Smith[1], James L. Crowley[2]
[1]Acadia University, [2]Boise State University.
E-mail: *deanne.vanrooyen@acadiau.ca*

The Ganderian Aspy and Bras d'Or terranes in northern Cape Breton Island were juxtaposed along the Eastern Highlands shear zone (EHSZ) which was active between 424 Ma and 375 Ma. The two terranes have contrasting sedimentary, magmatic, and metamorphic histories but interpretations of their original affinities and links with other Ganderian terranes are complicated by abundant intra-terrane faults and deformation, combined with differences in metamorphic grade. Within the Aspy terrane multiple metamorphic packages with variable assemblages are bounded by shear zones and intruded by voluminous Neoproterozoic to Devonian plutons. Major units in the eastern Aspy terrane in the central Cape Breton Highlands include the Calumruadh Brook Formation (central), Sarach Brook Formation (south central), Cape North Group (north) and Clyburn Brook Formation (northeast). All these units contain varying proportions of metasedimentary and metavolcanic rocks but differ in metamorphic grade and rock type, thus making correlations challenging. Based on the U–Pb zircon ages of cross-cutting plutons and volcanic rocks they have been interpreted to be broadly Ordovician to Silurian. A new U–Pb zircon TIMS age of ca. 428 Ma for a mylonitic rhyolite in the lower part of the Calumruadh Brook Formation shows that the rocks were formed in the middle Silurian, and that previously suggested correlations between the Calumruadh Brook and Sarach Brook formations are likely robust. More importantly, this new age shows that the eastern Aspy terrane units are not the lower metamorphic grade equivalents of the Middle River metamorphic suite, Jumping Brook metamorphic suite and Pleasant Bay complex in the western half of the terrane as previously assumed because those units have Late Ordovician or older protolith ages. The relationship between these formations and the Cape North and Money Point groups is still uncertain. Juxtaposition of the Aspy and Bras d'Or terranes started soon after deposition of the eastern Aspy terrane sedimentary rocks, which were metamorphosed under greenschist-facies conditions and transported over the Bras d'Or terrane rocks along the EHSZ. In the central Highlands, the western Aspy terrane sedimentary rocks experienced amphibolite-facies metamorphism at ca. 395 Ma and were in turn transported over the lower grade eastern Aspy terrane rocks in the waning stages of the terrane collision before and during the intrusion of S-type granitic plutons (Black Brook Granitic Suite, Park Spur pluton) at ca. 375 Ma. By 365 Ma the tectonic setting had transitioned to an extensional environment marked by the intrusion of the Margaree pluton.

TIMING OF HIGH-GRADE METAMORPHISM AND MAGMATISM IN THE INDIAN HEAD LAURENTIAN INLIER, SOUTHWESTERN NEWFOUNDLAND, CANADA; CORRELATION WITH THE BLAIR RIVER INLIER IN NOVA SCOTIA AND THE GRENVILLE PROVINCE IN QUEBEC AND SOUTHERN LABRADOR

Deanne van Rooyen[1], David Corrigan[2], Sandra M. Barr[1], Brent V. Miller[3]
[1]Acadia University, [2]Consulting Scientist, [3]Texas A&M University.
E-mail: *deanne.vanrooyen@acadiau.ca*

Western Newfoundland and northwestern Cape Breton Island (Nova Scotia) contain Proterozoic inliers interpreted to represent Laurentian crustal rocks. The Long Range, Indian Head, and Steel Mountain inliers in Newfoundland have been correlated with the Blair River inlier in Cape Breton Island and are important components of the pre-Appalachian record of the Laurentian margin. Recent work in the Steel Mountain inlier has shown that it is late Neoproterozoic, and hence not Laurentian Mesoproterozoic basement. New laser ablation ICP-MS U–Pb zircon ages from the Indian Head inlier show that the rocks preserve a complex history of Pinwarian age (~1.50–1.35 Ga) magmatism and sedimentation, overprinted by late Mesoproterozoic (Grenvillian) metamorphism and renewed magmatism. Granulite-facies paragneiss contains major detrital zircon populations ranging from 1.7 to 1.4 Ga, and an array of ages ranging down to 1.1 Ga. Likewise, granulite-facies orthogneiss units contain major zircon populations ca. 1.45 to 1.4 Ga interpreted as protolith crystallization ages, with an array of younger ages clustered around ca. 1.1 Ga. These younger ages in the gneissic units are interpreted as metamorphic ages, likely accompanied by significant Pb-loss suggesting a metamorphic event at ca. 1.1 Ga. The strongly deformed gneissic rocks are crosscut by megacrystic K-feldspar–hornblende granite that is largely undeformed and yielded a U–Pb crystallization age of ca. 1.12 Ga. These new data strengthen the links between the Indian Head inlier in southwestern Newfoundland and the Blair River inlier in Cape Breton Island and suggest that Pinwarian-age sedimentation and arc magmatism typical of the allochthonous belts of the Grenville Province in Quebec and southern Labrador extend into the Newfoundland segment of the Laurentian margin. The ca. 1.12 Ga granitic pluton in the Indian Head inlier is, within error, the same age as anorthosite and related plutons in the Blair River inlier. This 1.1 Ga event overlaps in age with voluminous AMCG-type magmatism across the Grenville Province from the Adirondacks to the Grenville Allochthon north of Anticosti Island. Overall, our data provide more direct correlations of Grenvillian tectonic, magmatic, and metamorphic events between mainland and Appalachian inliers in Newfoundland and Cape Breton Island and highlight the important role of the St. Lawrence Promontory during Appalachian orogenic events.

UNCOVERING THE SECRETS OF NIOBIUM ORE-FORMATION – CLUES FROM THE ST HONORÉ CARBONATITE

Olga Vasyukova, Anthony E. Williams-Jones
McGill University.
E-mail: *olga.vasyukova@mcgill.ca*

The Neoproterozoic St Honoré carbonatite complex is one of three currently mined niobium deposits, in which pyrochlore is the principal ore mineral. At St Honoré, the pyrochlore occurs in biotitite, apatitite and a magnetite–biotite rock. In the first two rock types, it contains U-Ta-rich cores (with elevated Ti, Zr, Fe, Sr and REE concentrations), which are overgrown by Ca-Na-F-rich rims, whereas in the magnetite–biotite rock, the pyrochlore is exclusively Ca-Na-F-rich. The pyrochlore cores (U-Ta-rich) are interpreted to have crystallized from extremely evolved carbonatitic magma, as shown by their high concentrations of incompatible elements. This implies the consumption of a very high proportion of the magma (a mantle-derived dolomite carbonatitic magma) prior to its saturation with pyrochlore, which is consistent with the results of experiments showing that pyrochlore is extremely soluble in carbonatitic magma. We propose that such a large consumption of magma was achieved by transferring components from the magma (MgO and H_2O) to the host syenite (K-feldspar-rich) during biotitization (formation of biotitite) and was promoted by the very low viscosity of the magma, allowing it to infiltrate the syenite along a network of fine microfractures. This magma-induced metasomatism was very intense and produced massive biotitite that marks the contact between carbonatite and host syenite (the biotitite zones reach tens of metres in thickness). Consumption of MgO from the magma during biotitization triggered crystallization of calcite (evident from the spatial association of calcite carbonatite with biotitite), which caused further enrichment in niobium as well as other incompatible elements, notably phosphorus, and led to the formation of pyrochlore-rich apatitite. Exsolution of an aqueous fluid changed the composition of the magma drastically, i.e. it removed fluid mobile elements (U, Sr and REE) and increased the F/OH ratio, causing the crystallization of Ca-Na-F pyrochlore. We believe that the three processes discussed above, namely, biotitization, crystallization of calcite and exsolution of an aqueous fluid, were the 'secrets' to the evolution of the St Honoré carbonatitic magmas that allowed them to form a world-class niobium deposit. The presence of U-Ta-rich and Ca-Na-F varieties of pyrochlore and the occurrence of biotitite, apatitite and magnetite–biotite rocks in many other niobium-enriched carbonatite examples implies that the model presented here is also applicable to the genesis of pyrochlore in these carbonatite bodies and could provide an important guide to exploring for new sources of economic carbonatite-hosted niobium mineralization.

3D DEPTH TO BASEMENT GEOMETRY MODELLING NEAR THE NORTHEAST RANGE OF SUDBURY IMPACT CRATER

Rajesh Vayavur, Richard Smith, Rasmus Haugaard
Laurentian University.
E-mail: *rvayavur@laurentian.ca*

Three-dimensional depth-to-basement geometry modelling was carried out in the northeastern part of the Sudbury impact structure using the VPmg potential field inversion package implemented within the Mira Geoscience GOCAD mining suite. Along a transect, several geophysical datasets (gravity, high-resolution seismic, audio-frequency and broad-band magnetotelluric) were collected in the northeast range of the Sudbury impact crater. The Sudbury impact structure is known for hosting world class Ni-Cu-Co-PGE-Au deposits, many of which are near the base of the impact crater, so knowing the topography of the base is important. Generally high-resolution seismic reflection imaging can resolve the topography of the base of the impact crater. But further south of the north edge of the structure, the signal-to-noise ratio in the seismic section is poor. Therefore, the main aim of the current study is to constrain the topography of the base by 3D gravity inverse modelling. In doing so, we assume that the rocks in the upper part of the basin (Whitewater Group sedimentary rocks and granophyre) are low density and in the bottom part are higher density rocks (gabbro and norite). For this study, the top of the gabbro unit is referred to as basement top. The data used in the inversion was a complete Bouguer anomaly gravity grid (correction density of 2.67 g/cm^3) generated by combining ME and Geological Survey of Canada data. The initial two-layer 3D density model was constructed within a volume of dimensions of 6 km x 16 km x 8 km and a 300 m cell size. This model is then incised into a larger apparent density model to account for any regional variations of the data. The starting density model assumes all layers are homogeneous with the higher density basement having a density contrast of 0.1 g/cm^3 and the overlying lower density material has a contrast of ~0 g/cm^3. An initial flat basement surface at 1 km depth was assumed in the starting model, but this surface is adjusted to explain the gravity data. The final inverted surface dips southwards from the north range, as expected, but also identifies a large ~2 km, NE–SW striking anticline, which is not apparent on the seismic reflection section. The inverted surface not only complements the seismic reflection section but also helps to trace the seismic reflectors in areas of low signal-to-noise ratio.

ENVIRONMENTAL AND CRYSTAL CHEMICAL CONTROLS ON THE EFFICIENCY OF CARBON MINERALIZATION: IMPLICATIONS FOR CO_2 STORAGE IN MINE TAILINGS

Colton Vessey[1], Avni Patel[1], Maija Raudsepp[1], Connor Turvey[1], Siobhan Wilson[1], Anna Harrison[2], Vasileios Mavromatis[2]
[1]University of Alberta, [2]University of Bern.
E-mail: *vessey@ualberta.ca*

Integrating carbon capture, utilization and storage (CCUS) into mine operations and closure plans can significantly offset associated CO_2 emissions and could be used to design carbon-neutral mines. Of particular interest is the process of carbon mineralization, where CO_2 is stored in benign Ca- and Mg-carbonate minerals that remain stable on geological timescales. Ultramafic mine tailings are ideal feedstocks for carbon mineralization due to their high particle surface area, the availability of reactive phases, the elevated pH, and the high Ca and Mg abundances found within tailings storage facilities. Passive carbonation rates of ultramafic mine tailings are typically 2–3 orders of magnitude greater than natural carbon removal rates; but carbon-neutral or carbon-negative mining could be achieved through implementation of accelerated carbon mineralization during ore processing and tailings management. Many studies that have examined the efficacy of carbon mineralization have not acknowledged the importance of solid solution in minerals, instead assuming end member compositions. Stoichiometric Mg end-members of the most favourable minerals used for CCUS (i.e. forsterite (Mg_2SiO_4), serpentine [$Mg_3Si_2O_5(OH)_4$], brucite [$Mg(OH)_2$]) are uncommon in nature. Our research examines how Mg-Ca-Fe solid solutions impact carbon mineralization security and efficiency in various environmental conditions (temperature, reduction-oxidation, aqueous speciation). We integrated laboratory-based experiments with characterization of a natural, carbon mineralization analogue (Basque Lakes, British Columbia) to study carbonation efficiency in highly alkaline and saline systems containing Mg, Ca and Fe. Mineral (trans)formations were studied using a suite of diffraction (XRD) and spectroscopic techniques (ATR–FTIR, in situ Raman spectroscopy, and Fe K-edge XAS), and combined with aqueous geochemical data and geochemical modelling. Natural, low-temperature magnesite ($MgCO_3$) from the Basque Lake system contains Ca, as well as Fe(II), where incorporation of Fe(II) is likely a consequence of sustained reducing conditions maintained by microbial activity. Results from our abiological experiments show that magnesite formed at near ambient conditions is also Ca-bearing. The presence of Fe(II) or dissolved Si in carbon-rich fluids favours dypingite [$Mg_5(CO_3)_4(OH)_2\cdot{\sim}5H_2O$] formation over nesquehonite ($MgCO_3\cdot3H_2O$), which is typically the initial precipitate to form. However, addition of Ca and Fe(II) cations to Mg-rich solutions generally resulted in formation of metastable carbonate and layered double hydroxide phases within a complex mineral assemblage, which may affect the long-term stability of CO_2 storage. Overall, our results indicate carbonation efficiency and the long-term fate of stored CO_2 is dependent on the amount of substituted Ca and Fe(II) in both feedstock minerals and carbonate products.

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REASSESSING THE SUPRACRUSTAL ARCHITECTURE OF THE EASTERN MICHIPICOTEN GREENSTONE BELT, SOUTHERN SUPERIOR PROVINCE, ONTARIO

Lianna Vice[1,2], Stéphane Perrouty[2], Lise Robichaud[1], Joseph Walker[1]
[1]Ontario Geological Survey, [2]Laurentian University.
E-mail: *Lianna.Vice@ontario.ca*

The Michipicoten greenstone belt, in the Wawa–Abitibi terrane of the southern Superior Province, Ontario, is host to several past and currently producing gold mines, including the Renabie, Magino and Island Gold mines. Despite the economic success of the belt, there is a limited understanding of its supracrustal architecture and tectonic history. The belt was previously subdivided into 3 distinct volcanic assemblages primarily consisting of bimodal volcanism with iron formation in the uppermost sections of each assemblage, which include the 2900 Ma Hawk assemblage, the 2750 Ma Wawa assemblage, and the 2700 Ma Catfish assemblage. Additionally, in the central and western part of the belt, Doré metasedimentary rocks overlie and locally interfinger with the 2700 Ma assemblage and consist of siltstone, wacke and conglomerate, interpreted as a "Timiskaming-type sedimentary sequence". Detailed mapping and geochronological analyses in the eastern Michipicoten greenstone belt by the Ontario Geological Survey (OGS; 2013–2018) returned U–Pb ages that range from 2731 to 2695 Ma in metavolcanic and metasedimentary rocks, highlighting that volcanism in the region was more continuous than previously interpreted. Additional volcanic assemblages between 2750 and 2700 Ma, as well as a continuation of the Doré metasedimentary rocks into the eastern part of the belt may indicate a similar stratigraphy to the southern Abitibi subprovince. Continued OGS mapping of the eastern Michipicoten greenstone belt and a collaborative detailed study at Laurentian University seek to define the supracrustal assemblages and structural and metamorphic evolution within the region through detailed mapping, geochronology and lithogeochemistry. Defining supracrustal assemblages and their tectonometamorphic history will provide stratigraphic context to trace regional structures and intrusions with known metal endowment, such as the Renabie Mine, a hybrid intrusion-related/orogenic gold deposit, as well as prospective gold, VMS and intrusion-related nickel-copper-PGE occurrences. A review of the geology and preliminary results from detailed mapping shows semi-continuous magmatism, spatial variation in metamorphism and at least two major deformation events. The Michipicoten greenstone belt has similarities to greenstone belts in both the Abitibi and Wawa subprovinces; however, lithological and metamorphic variations, supracrustal interactions with intrusions, as well as moderate base and precious metal endowment highlight gaps in the understanding of the tectonic environment in which the belt formed. Characterizing its specific crustal architecture may therefore contribute to the identification of broad geodynamic processes contributing to the formation of a different style of greenstone belt in the Neoarchean.

VMS FERTILITY IN THE ABITIBI GREENSTONE BELT: GEOCHEMICAL COMPARISON BETWEEN THE WELL-ENDOWED BLAKE RIVER GROUP AND THE POORLY ENDOWED STOUGHTON–ROQUEMAURE ASSEMBLAGE

Octavio Vite-Sanchez[1], Pierre-Simon Ross[1], Patrick Mercier-Langevin[2]
[1]Institut national de la recherche scientifique, [2]Geological Survey of Canada.
E-mail: *octavio.vite_sanchez@inrs.ca*

Volcanogenic massive sulphide (VMS) deposits are stratigraphically and structurally controlled at the district scale. The reasons, however, for why some volcanic centres, some assemblages within greenstone belts, or some entire greenstone belts are more fertile than others, are not clear. For instance, in the Archean Abitibi greenstone belt (Quebec and Ontario), the Stoughton-Roquemaure (S-R) assemblage, despite being the largest assemblage of the belt in terms of surface area (33.5%), hosts < 1% of the VMS tonnage whereas the much less voluminous Blake River assemblage (BRG) hosts 46%. The geochemistry of the volcanic rocks provides a window into the main geological processes and contexts controlling VMS fertility. Therefore, the present work uses the available whole rock geochemical data from ultramafic, mafic, and intermediate volcanic rocks for both assemblages. Felsic rocks will be studied later, and the Blake River assemblage is only represented by rocks from the Rouyn-Noranda area. The compilation contains 2241 complete analyses for the BRG and 744 for the S-R. The rocks of the BRG and S-R were grouped based on immobile elements ratios, which were also used to assess their petrogenesis. Two major mantle sources are identified: a depleted one (somewhat similar to modern N-MORB); and a relatively enriched one (E-MORB-like). The magmas variably interacted with an older crust, possibly TTG-type, a process modelled using assimilation fractional crystallization (AFC) curves on the Th/Yb vs Nb/Yb plot. The basalt units are therefore classified into five groups based on the two mantle sources and a degree of crustal contamination ranging from very low (up to 5%), to low (5–20%), and moderate (> 20%). Intermediate magma bodies behave in the same way, yielding a further five geochemical groups. The N-MORB-like source is the main one for both the BRG and the S-R (53% and 47%, respectively). E-MORB-like rocks represent around 10% for both assemblages and contaminated signatures (over 20% contamination) comprise 42% of samples for the BRG and 37% for S-R. In the S-R, fractionation and contamination largely go together, but these processes can apparently decouple in the BRG, which exhibits both tholeiitic andesite and calc-alkaline basalt. E-MORB-like rocks and higher degrees of crustal contamination seem to be associated with greater VMS fertility in the BRG. Although still hypothetical, lower degrees of crustal contamination may explain a lower VMS endowment in the S-R assemblage.

RHYTHMIC GEOCHEMICAL FLUCTUATIONS DURING Zn MINERALIZATION AT DANIEL'S HARBOUR, NEWFOUNDLAND, REVEALED FROM LA-ICP-MS ANALYSIS OF GANGUE AND SULPHIDE PHASES

Chaneil Wallace[1], Daniel Kontak[1], Elizabeth Turner[1], James Conliffe[2]
[1]Laurentian University, [2]Geological Survey of Newfoundland and Labrador.
E-mail: *cwallace1@laurentian.ca*

Newfoundland Zinc Mines is a past-producing Zn-Pb sulphide carbonate-replacement deposit (7.2 Mt of 8% Zn) hosted primarily by the Upper Ordovician Catoche Formation dolostone. Previous work demonstrated that mineralization occurred by the late Devonian from heated (< 185°C for sphalerite), saline (20–27 wt.% equiv. NaCl) fluids. To refine the characteristics of the mineralizing fluids, this study addresses the deposit's mineral paragenesis using optical microscopy, SEM-EDS, and major- and trace-element signatures of the host, gangue, and ore phases via in situ LA-ICP-MS analysis. Two episodes of dolomite formation, pre- and post-ore, have near-stoichiometric chemistry; local post-ore calcite cement is also present. The PAAS-normalized REEY diagrams of dolostone (flat, PAASN ~0.05–0.1) and dolomite and calcite (flat to convex, PAASN 0.05–0.5) are relatively LREE-enriched compared to marine carbonate and have variably positive to negative Ce and Eu anomalies. Five different colours of sphalerite exist: dark red, red-brown, yellow-brown, yellow, and pale yellow. The dark red sphalerite has the highest Fe (1.5–2.5 wt.%) and Ge (up to 590 ppm) concentrations. Diagenetic pyrite is enriched in Tl (up to 60 ppm) relative to other pyrite types (< 24 ppm). Trace element mapping of dark red to red-brown sphalerite shows rhythmic geochemical fluctuations in some elements (Cd, Pb, and Ag) and at least 3 events from high (> 750 ppm) to low (< 300 ppm) Cd are evident. Trace element mapping of a second dark red sphalerite associated with pale yellow sphalerite indicates that it is enriched in Ge (> 500 ppm), whereas pale yellow sphalerite is depleted in Ge (< 200 ppm). Trace element mapping of large (0.5 mm), cubic hydrothermal pyrite grains shows two chemical zones: Pb-poor (< 200 ppm) cores and Pb-rich rims (> 600 ppm), whereas Zn showed the opposite trend; other metals analyzed (V, Cr, Co, Ni, Ga, Ge, Ag) were mostly at low levels (< 50 ppm). The above data suggest that: 1) LREE enrichment of the carbonates reflects interaction of ore fluids with a shale reservoir; 2) variable Ce and Eu anomalies in carbonates reflect variable redox conditions; and 3) rhythmic geochemical patterns in sphalerite (Cd, Pb, Ag) probably indicate coupled dissolution and precipitation during the sphalerite mineralizing event related to the periodic influx of a Cd-poor fluid that mixed with a Cd-rich fluid.

GEOCHEMICAL STABILITY OF VITRIFIED ARSENICAL GLASS PREPARED FROM ARSENIC TRIOXIDE ROASTER WASTE COLLECTED FROM THE GIANT MINE (YELLOWKNIFE, NWT)

Alana Wang, Carol Ptacek, David Wilson, Jeff Bain, David Blowes
University of Waterloo.
E-mail: *o3wang@uwaterloo.ca*

Historical roasting of arsenopyrite ore at the Giant Mine resulted in 237,000 tonnes of arsenic trioxide roaster waste (ATRW) stored in underground chambers and mined-out stopes, posing significant risks to the surrounding environment and local communities. Freezing of the underground chambers is currently undergoing pilot-scale testing as an approach for long-term waste stabilization. Efforts required to maintain the frozen conditions, the potential for chamber instability as well as bedrock fractures, and the risk of chamber flooding may impact the frozen block approach. Stabilization/solidification approaches that require minimum maintenance and suppress the leachability of ATRW are being investigated. The primary objective of this research is to evaluate vitrification as a potential approach for stabilizing As and other contaminants from ATRW at the Giant Mine. This study evaluated three vitrified-arsenical glasses (G5, G10, and G15), with different ATRW contents, using eight selective extractions with increasing dissolution strength and mimicking geochemically relevant conditions. The evaluated conditions included water-soluble, exchangeable metals on the surface, PO_4^{3-}-exchangeable, weak acid extractable, reducible, oxidizable, and strong acid extractable. Results of the selective extractions indicate the stability of vitrified arsenical glass depends on the pH of the leaching solution, the ATRW content, formulation used during the vitrification process, and particle size. Limited release of As was observed under neutral to near neutral conditions. Enhanced release occurred when dissolution solutions were acidic. Sample G15, with the highest ATRW content, released the highest As concentrations under most of the experimental conditions evaluated. Sample G5, with the lowest ATRW content, released the highest As concentrations in leachates targeting amorphous–crystalline reducible phases, likely related to a different formulation compared to G10 and G15. In strong acid extraction, the highest As concentration was 42% lower than concentrations observed in mine water that contacts with ATRW. Up to 48% of the total As within the vitrified arsenical glass was released in the strong acid extraction, indicating not all As within the vitrified arsenical glass is extractable even under strongly acidic conditions. The release of Sb followed a similar trend to that of As with the highest concentrations observed in leachate with G15. Crushing vitrified arsenical glass led to enhanced release of both As and Sb. Results of this study indicates converting ATRW to non-reactive glass has the potential for stabilizing As; however, conditions that are not suitable for final storage of the vitrified arsenical glass might need to be considered before using the vitrified arsenical glass as an alternative approach.

INFLUENCE OF SPECIFIC MINERALOGY ON ACCELERATED WEATHERING AND MINERAL CARBONATION POTENTIAL

Baolin Wang[1], Nina Zeyen[1,2], Maria Arizaleta[1], Siobhan Wilson[1], Wyatt Russell[1], Jessica Hamilton[3]
[1]University of Alberta, [2]University of Geneva, [3]The Australian Synchrotron.
E-mail: *baolin1@ualberta.ca*

Accelerated mineral carbonation can be employed to sequester CO_2 in carbonate minerals. In this study, three different ultramafic residues or rocks were used for column acid leaching experiments to study the influence of mineralogy on mineral carbonation potential. Processed kimberlite residues from Gahcho Kué mine (GK, NWT, Canada) and two serpentinite rock samples from the Record Ridge project (RRP1 and RRP2, BC, Canada) were treated with 16.6 mL 0.12 M HCl daily for 28 days. GK residues contain lizardite, saponite, phlogopite, albite, orthoclase, augite, a low amount of calcite (1.4 wt.%) and no brucite. Both serpentinite rock samples are rich in lizardite and forsterite, with RRP1 containing similar amounts of both minerals and RRP2 dominated by lizardite with minor (< 10 wt.%) forsterite. Neither RRP samples contain calcite and both contain minor brucite. These mineralogical contrasts resulted in very different leachate compositions. The pH values in leachates from GK columns were always > 7.0 throughout the 28 days while pH values in leachates from RRP1 columns were always < 2.2. The pH values in leachates from RRP2 columns varied between 0.6 and 9.2 as preferential flow paths opened and closed. Calcite dissolution in GK columns accounted for 29.8% of the leached Ca while augite, tremolite and saponite provided the rest of the Ca in solution. Clay minerals provided the Mg leached from GK and RRP columns. In the case of GK, this equates to an estimated CO_2 offset potential of 7.8% of the mine's annual greenhouse gas emissions. Leachates from RRP1 and RRP2 show a low concentration of Ca leached from tremolite, with an extraction efficiency of 11.1% and 10.8%. A total of 3.6%, 1.8% and 3.0% of the Mg was leached from the GK, RRP1 and RRP2 columns, respectively, with the highest extractions obtained from lizardite and saponite-rich samples and the lowest extraction obtained from the forsterite-rich sample. Our results show that the specific mineralogy of each ultramafic rock type, and even each ultramafic facies, plays a critical role in carbonation potential.

YANGTZE AND CATHAYSIA BLOCKS OF SOUTH CHINA: THEIR SEPARATE POSITIONS IN GONDWANA UNTIL EARLY PALEOZOIC JUXTAPOSITION

Lijun Wang[1], Shoufa Lin[1], Wenjiao Xiao[2]
[1]University of Waterloo, [2]Chinese Academy of Sciences.
E-mail: *l222wang@uwaterloo.ca*

The position of South China in Gondwana remains controversial and the proposed positions vary from near northwestern Australia, or the junction of eastern India, northwestern Australia and East Antarctica, to close to northwestern India. In all the previous models, the Yangtze and Cathaysia blocks, the two major components of South China, were amalgamated by the Tonian, and South China was considered as a single coherent block in Gondwana. It is proposed here that Yangtze and Cathaysia were not juxtaposed until the early Paleozoic and were located at two separate parts of the northern margin of Gondwana in the Ediacaran and early Cambrian. Yangtze was in close proximity with northwestern India in the Ediacaran and was in connection with the Arabian Gondwana margin in the early Cambrian. Cathaysia was close to or a part of northern Australia in the Ediacaran, when Australia and India were separated by the Kuunga Ocean, and amalgamated with the eastern margin of India in the late Ediacaran to Early Cambrian when the ocean closed. Our model implies that the early Paleozoic orogeny in South China could be related to two distinct events, the late Ediacaran to early Cambrian collision of Cathaysia/Australia with India (the Kuunga orogeny) and the Late Ordovician amalgamation of Cathaysia with Yangtze. It also implies that Yangtze and Cathaysia likely occupied two separate positions in Rodinia.

MAGNETOSTRATIGRAPHIC CONSTRAINTS ON THE END-TRIASSIC NORTH MOUNTAIN BASALT (NOVA SCOTIA, CANADA) ERUPTION TIMELINE

London Warburton[1], Joseph Biasi[1,2], Daniel J. Kontak[3], Sarah P. Slotznick[1]
[1]Dartmouth College, [2]University of Oregon, [3]Laurentian University.
E-mail: *london.c.warburton.23@dartmouth.edu*

The Central Atlantic Magmatic Province (CAMP) is a large igneous province with an age of 201.3 ± 0.2 Ma and is closely associated with the end-Triassic extinction. The rate and duration of large igneous province emplacement have been suggested as major factors that influence the effectiveness of volcanic gasses in causing extinctions by triggering climatic changes. Based on previous geochronological work, CAMP-related magmatism occurred over a period of less than 1 million years. This study presents a new magnetostratigraphy that brackets the entire emplacement of the 18 different lava flows (ca. 500 m thickness) of CAMP's northernmost formation, the North Mountain Basalt (NMB), Nova Scotia. We performed both stepwise thermal demagnetization and alternating field demagnetization, with similar results. In agreement with studies from other CAMP sites, the NMB was likely emplaced during the E24n chron. Analysis of the new magnetostratigraphy reveals distinct directional data for each of the three members that constitute the NMB, but not enough to average out paleosecular variation. Our results suggest that the entirety of the NMB was emplaced in under 20,000 years which requires significant volatile flux into the atmosphere during this period, and thus provides a plausible mechanism for mass extinction via volcanic forcing of a large climatic shift.

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PEGMATITE FORMATION BY DIRECT ANATEXIS: OXFORD COUNTY PEGMATITE FIELD, MAINE

Karen Webber[1], Skip Simmons[1], Alexander Falster[1], Encarnación Roda-Robles[2]
[1]Maine Mineral & Gem Museum, [2]Universidad de Pais Vasco.
E-mail: *kwebber4976@gmail.com*

Granitic pegmatites form as residual melts or by direct anatexis. Granitic melt can fractionate to a residual melt that separates to form pegmatite. In direct anatexis, granitic melt accumulates at the source, ascends, and is emplaced quickly, and subsequently fractionally crystallizes to form a pegmatite body. Over 100 pegmatites are distributed over ~70 km in the Oxford County Pegmatite Field (OCPF) of central Maine. There is no regional zonation or viable parent granite in the OCPF. Each pegmatite has a unique chemical and mineralogical signature. The late Alleghanian pegmatites (~270–260 Ma) are post-orogenic–pre-rifting (opening of the Atlantic) and were emplaced in Acadian migmatite and metasedimentary rocks (~376 Ma). We propose a direct anatexis model for OCPF pegmatite formation. Paleozoic sedimentary rocks in the Central Maine belt were metamorphosed and migmatized at ~13 km depth and ~376 Ma (Acadian), following delamination of lithospheric mantle and replacement by upwelling asthenosphere. After 100 M.y. of uplift/denudation migmatite was at ~9 km depth and 450°C prior to pegmatite formation. To initiate migmatite/metasedimentary rock melting to generate pegmatite melt, an additional ~200°C is needed. The Alleghanian Orogeny began ~320 Ma and involved the closure of the Rheic Ocean and collisions between Laurentia and Gondwana. Due to a low subduction angle, the Rheic plate underplated the lithosphere beneath Laurentia and then delaminated leading to mantle upwelling and thermal input for partial melting. There is a lag time of ~40 M.y. between when underplating occurs and when partial melting of migmatite/metasedimentary rocks begins. The new pegmatite melts segregate and ascend to ~8 km, 2.5 kbar, conducive for pocket formation, where they are emplaced and crystallize. We modeled the batch melting behaviour of Li, Rb, Sr and Cs in a model with 5% to 10% melting for leucosome and metapelite OCPF samples. Resulting trace element concentrations are very similar to Mt Mica pegmatite bulk chemistry. Metapelite/metapsammite and leucosome analyzed for boron contain average abundances of 384 and 330 ppm. Staurolite from Rangely phyllite has 504 ppm Li, 434 ppm B and 21 ppm Be analyzed by direct current plasma emission spectrometry. Clearly, the metasedimentary rocks and leucosome samples are not devoid of rare elements as previously suggested. We envision that melting took place over time and involves a large area of the OCPF buried migmatite–metasedimentary terrane producing the 100+ OCPF pegmatite bodies. Variability in the sedimentary source is reflected in the striking variability of the pegmatites.

THE PALEOREDOX CONTEXT OF THE MCARTHUR AND BIRRINDUDU BASINS, NORTHERN TERRITORY, AUSTRALIA

Margaret A. Whelan[1], Maxwell A. Lechte[1], Leigh Anne Riedman[2], Suzannah M. Porter[2], Angelo dos Santos Jr.[1], Galen P. Halverson[1]
[1]McGill University, [2]University of California, Santa Barbara.
E-mail: *margaret.whelan@mail.mcgill.ca*

The ca. 1.75–1.3 Ga Greater McArthur Basin of the Northern Australian Craton comprises multiple sedimentary successions that outcrop and occur widely in the subsurface of Northern Territory, Australia. The minimally deformed, mixed carbonate–siliciclastic successions record deposition in a range of marine depositional settings, from supratidal to offshore and host some of the oldest putative eukaryotic microfossils. In order to investigate the possible relationship between the interpreted paleoredox conditions of the depositional environment and the preserved microfossil assemblage, we present iron speciation data, total organic carbon content, and major and trace element geochemistry for 194 samples across 8 cored drill holes and 19 formations from the McArthur and Birrindudu basins. Paleoredox conditions of the water column can be inferred using the iron speciation data. Our results indicate deposition in settings spanning from anoxic (ferruginous or euxinic) to oxic marine, with oxygenated surface waters rarely occurring beyond the intertidal zone and deep waters, which are dominated by ferruginous conditions. Variations in this pattern can generally be explained by increased primary productivity, though temporal changes in sedimentary provenance could also impact redox proxy results. Our findings are consistent with the emerging model for redox stratified basins during a poorly oxygenated middle Proterozoic (i.e. ca. 1.8–0.8 Ga) and provide a more nuanced view of shallow water redox environments. These data provide an opportunity to explore the relationship between paleoredox data, sedimentary facies, and fossil occurrence, hence elucidating the habitats of early eukaryotic life.

INTRODUCED BIASES IN THE SILURIAN ERAMOSA LAGERSTÄTTE OF SOUTHERN ONTARIO

Anna Whitaker, Marc Laflamme
University of Toronto Mississauga.
E-mail: *a.whitaker@mail.utoronto.ca*

The middle Silurian (Wenlock Epoch; Sheinwoodian Age) Eramosa Formation (Ontario, Canada) represents a near-shore paleoenvironment during a critical transition in earth history: terrestrial colonization by multi-cellular life. Within the Bruce Peninsula, the Eramosa Formation contains a Lagerstätte preserving both biomineralized and soft-bodied taxa. The Eramosa Lagerstätte contains chordates (heterostracan fish, articulated conodonts), arthropods (trilobites, eurypterids, scorpions, phyllocarids, ostracods), echinoderms (ophiuroids, crinoids, lepidocentrid echinoids), lobopodians, brachiopods, cephalopods, polychaetes, and dasyclad algae. However, Lagerstätten, while sites of exceptional preservation, are not free from biases that impact interpretation (e.g. paleo-environmental, taphonomic, and anthropogenic biases). The Eramosa Lagerstätte is found across multiple localities, with varying faunal compositions, depositional environments, and collection efforts. Because of these potential conflating biases, understanding the anthropogenic influences at each locality is important for accurately interpreting the biodiversity and ecology of the Lagerstätte. The Royal Ontario Museum contains the largest collection of Eramosa material (~900 specimens) from the three main localities (Wiarton, Hepworth, and Park Head). Recent curation of the ROM Eramosa material has provided the opportunity to analyze the scope of the collection and identify areas of future focus. Collection efforts for each site are compared, as well as the faunal composition. Potential anthropogenic biases of the Eramosa (e.g. personal taxonomic attention, collection method) and their impact on the current understanding of the Lagerstätte will be discussed.

OCEAN, FRESHWATER, AND US: FOSTERING OCEAN CONNECTIONS USING AUGMENTED REALITY

Janice Williams[1], Diz (Lisa) Glithero[1], Jacques Gautreau[2]
[1]Canadian Ocean Literacy Coalition, [2]The National Film Board of Canada.
E-mail: *jae@colcoalition.ca*

The overall aim of the UN Ocean Decade (2021–2030) is to transform society's relationship with the ocean. How do we foster ocean connections and empower behaviour change that supports a healthier ocean and the waterways leading to it? Partnerships, collaboration, and collective action are essential. In June of 2022, Ocean Week Canada, a national celebration of ocean events, learning, and action was launched. Fifteen national content partners and more than 110 event partners, all working together across regions, sectors, and scales to co-develop engagement tools and a national program of events to empower Canadians – schools, families, communities, organizations, governments – to better understand, value, and care for the ocean. Accompanying this map is augmented reality (AR), a significant innovation developed to engage thousands of Canadians at events throughout summer 2022. Attendees are virtually transported across Canada and into Canada's marine protected areas through an immersive digital rendering of the giant floor map, *Ocean, Freshwater, and Us*. This interactive and immersive engagement tool transforms public understanding of ocean conservation and includes curated videos from coastal communities and Indigenous Water Guardians, as well as 360° video, and puts a spotlight on current protected areas, underscoring the importance of Canada's commitment to reach 30 x 30 targets. This map was developed by the Canadian Ocean Literacy Coalition, in collaboration with the Royal Canadian Geographical Society, Ocean School (of the National Film Board of Canada), and a team of national partners, with support from the Department of Fisheries and Oceans Canada. This was an engaging and interactive session where we experience low-tech and technology enhanced experiences on the giant floor map; explore the role of digital technologies in reducing the opportunity and access gaps; and consider how immersive technologies, such as augmented and virtual realities are being, and can be used to further geoscience outreach education.

CARBONATITE, SUPERCONDUCTIVITY AND NIOBIUM

Anthony E. Williams-Jones, Olga V. Vasyukova
McGill University.
E-mail: *anthony.williams-jones@mcgill.ca*

Niobium is a critical metal, today because of supply risk (90% of its production is by a single country), and tomorrow because within-country air travel will be replaced by magnetic levitation rail transport; niobium has the highest temperature threshold of superconductivity of any metal. With the exception of the Lovozero deposit (Russia), which is hosted by a layered silica-undersaturated alkaline igneous complex, all the deposits that are currently being mined for niobium are hosted by carbonatite, and most of the deposits with economic potential are also hosted by this rock. Niobium owes its concentration in carbonatite to its highly incompatible nature and the small degree of partial melting of the mantle required to generate the corresponding magma. The extremely high solubility of niobium in carbonatitic magma is another factor that explains the dominance of carbonatite as a host for niobium deposits. The primary control on the concentration of niobium to economic levels in alkaline silicate magmas is fractional crystallization, partly prior to, but mainly after, emplacement. In contrast, carbonatitic magma bodies undergo little to no fractional crystallization prior to emplacement. Moreover, fractional crystallization on emplacement fails to explain the textural evidence for the apparently early timing of pyrochlore (the main niobium ore mineral) crystallization. To resolve this problem, we propose an alternative mechanism to fractional crystallization in consuming magma and concentrating niobium in the residue. This mechanism involves the metasomatic interaction of carbonatitic magma with its hosts to form rocks like phlogopitite (glimmerite), which consumes much of the magma, leaving behind a phoscoritic residue from which pyrochlore crystallizes in amounts sufficient to form economic deposits. Although many niobium deposits display evidence of intense hydrothermal alteration, during which there can be major changes in the niobium mineralogy, the extremely low solubility of niobium in aqueous fluids at elevated temperature precludes significant mobilization and, thus, enrichment of the metal. Significantly, however, weathering of carbonatite-hosted niobium deposits leads to supergene enrichment (due largely to the dissolution of carbonate minerals) that can double the niobium grade and make subeconomic deposits economic. Pyrochlore is the principal niobium mineral in these laterite-hosted deposits, although its composition differs considerably from that in the primary mineralization. We propose a model for this mineralization involving leaching and hard soft acid base theory that successfully explains the chemistry of the pyrochlore and the formation of exceptionally high-grade laterite-hosted niobium deposits above carbonatite bodies.

EVIL SPRITES (KOBOLDS), BATTERIES, MAGMAS AND FLUIDS

Anthony E. Williams-Jones, O.V. Vasyukova
McGill University.
E-mail: *anthony.williams-jones@mcgill.ca*

Cobalt (kobold) is in high demand because of the role of cobalt-lithium-ion batteries in addressing the issue of global warming, particularly in the transition from the internal combustion engine to electrically powered vehicles. Economic cobalt deposits owe their origin to the compatible nature of Co^{2+}, its concentration in the mantle in olivine, and its release, after high degrees of partial melting, to komatiitic and to a lesser extent, basaltic magma. Primary magmatic deposits, in which Co is subordinate to Ni, develop through the separation of immiscible sulphide liquids from mafic and ultramafic magma bodies, and the very strong partitioning of the metals into these liquids. Predictably, Co deposits reach their highest grades when hosted by olivine-rich ultramafic rocks. Over 50% of the world's cobalt resource is of hydrothermal origin and is contained in sediment–hosted copper deposits in the Democratic Republic of the Congo. Using thermodynamic data and geological information, we have refined a model for these deposits, in which Co is leached from mafic and ultramafic rocks by oxidized, chloride-rich hydrothermal fluids, derived from evaporation, and deposited in response to decreasing $f(O_2)$ in carbonaceous sediment that accumulated in intracratonic rift basins. Cobalt is also concentrated in hydrothermal veins, notably in the Cobalt Embayment of Ontario and in the Bou Azzer district of Morocco, which currently supplies 2% of the world's cobalt. The ores are arsenides and sulpharsenides, and the ore fluids were oxidized high salinity brines. At Bou Azzer, the cobalt source was an adjacent serpentinized ophiolite and in the Cobalt Embayment, it was likely the Nipissing Diabase. We propose that the cobalt was mobilized from the mafic or ultramafic rocks as $CoCl_4^{2-}$ and deposited in response to pH neutralization by the felsic host rocks. The source of the As is unclear. The final important class of Co deposits is laterite-hosted and develops on olivine-rich ultramafic rocks. Our thermodynamic modelling shows that Co is leached from an ultramafic source by mildly acidic fluids as Co^{2+} and is transported down the laterite profile, eventually concentrating by a combination of adsorption on Mn oxides, incorporation in absolane, a Mn oxide, and precipitation as heterogenite, a cobalt oxy-hydroxide. The dissolution of cobalt at the surface and its deposition at depth are controlled mainly by pH, which decreases downwards; oxygen fugacity, which also decreases downwards, has the opposite effect, inhibiting dissolution of cobalt at the surface and promoting it at depth.

FINE-SCALE COMPOSITIONAL VARIATIONS IN THE ROOF ZONE OF THE MUSKOX INTRUSION, NUNAVUT

Marie-Claude Williamson[1], Rick McNeil[1], Erin Bethell[2], Simon Jowitt[3], Derek Wilton[4], Gary Thomson[5], Marc Beauchamp[1], Matthew Polivchuk[1]
[1]Geological Survey of Canada, [2]University of Ottawa,
[3]University of Nevada Las Vegas, [4]Memorial University of Newfoundland,
[5]College of the North Atlantic.
E-mail: *marie-claude.williamson@nrcan-rncan.gc.ca*

The Muskox Intrusion is a layered mafic–ultramafic intrusion located south of Coronation Gulf that is associated with the Mackenzie Large Igneous Province. The intrusion was originally mapped by C.H. Smith, at the Geological Survey of Canada, and further investigated in the 1960s by way of three diamond drill holes (DDH): Muskox South, Muskox North and Muskox East. The total length of continuous core exceeds ~3 km and the boxes are archived at the GSC Earth Materials Collection Facility in Ottawa. Here, the results of a detailed mineralogical and geochemical study of the Roof Zone based on high-resolution sampling of the cores from the Muskox East DDH are reported. The main objective of the project is to document fine-scale compositional variations at the transition from granophyric rocks to the chilled margin at the contact with country rocks. A corollary project compared mineralogical and geochemical profiles of the Muskox East DDH roof rocks with hyperspectral signatures acquired over the visible near infrared to the longwave infrared regions by the College of the North Atlantic hyperspectral scanning unit (HSU). The marginal rocks in the uppermost portion of megacycle #1 (0–270 m) in the Muskox layered intrusion have elevated concentrations of chalcophile critical minerals (e.g. Cu and the platinum group elements (PGE)) but the lithologies are complex. Revisiting the mineralogy and geochemistry of roof rocks sampled in the Muskox East DDH contributes to ongoing exploration efforts for Ni-Cu-PGE mineralization. A total of 90 samples were selected in the interval 0 to 30 m to obtain high resolution compositional profiles across the Roof Zone. Preliminary electron microprobe analysis of mineral phases suggests that quartz, orthoclase and chlorite predominate in many of the core samples. The presence of abundant minor and accessory minerals is characteristic of the Muskox Intrusion Roof Zone: rutile, apatite, zircon, thorite and monazite. Sulphide minerals comprise pyrite with inclusions of galena, sphalerite, pentlandite, and millerite. Sixty-five samples were submitted for whole rock geochemical analysis with half of these also analyzed for Au and the PGE. These data are integrated with mineral maps acquired by mineral liberation analysis and scanning electron microscope, and combined with the HSU results, to characterize the role of critical processes such as magma evolution and crustal contamination in the generation of magmatic sulphide mineralization.

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AGE AND COMPOSITION OF GABBRO SAMPLES DREDGED FROM THE ALPHA RIDGE, ARCTIC OCEAN

Marie-Claude Williamson[1], David Mosher[1], Nicole Rayner[1], Derek Wilton[2], Jamie Cutts[1], Keith Dewing[1], Thomas Hadlari[1], Christopher Lawley[1], Shuangquan Zhang[3], Brian Cousens[3], Daniel Macdonald[4], Duane Petts[1], Matthew Polivchuk[1]
[1]Geological Survey of Canada, [2]Memorial University of Newfoundland, [3]Carleton University, [4]Dalhousie University.
E-mail: *marie-claude.williamson@nrcan-rncan.gc.ca*

The Alpha-Mendeleev ridge complex (AMR) is the largest submarine feature mapped in the Arctic Ocean basin. Ice cover and remoteness of the AMR within the Amerasia Basin present operational challenges that limit the direct sampling of bedrock by dredging. Recent marine surveys carried out under Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS) have provided a wealth of new geophysical data that constrain the nature and origin of the AMR. Geological samples of bedrock are rare but provide direct evidence of voluminous mafic volcanism at ~90 Ma that is characteristic of large igneous provinces (LIPs). We report mineralogical, geochemical and geochronological data for sample ECS005041 recovered by dredging at Nautilus Spur by the US Coast Guard Ship Healy (3285 m depth). The samples consist of massive and medium-grained microgabbro in which sub-ophitic plagioclase and pyroxene predominate. Whole rock geochemical data indicate that the major element composition is typical of subalkaline magma emplaced in a continental setting. Rare, small zircon grains were analyzed in thin section by sensitive high resolution ion microprobe (SHRIMP) and yielded a $^{206}Pb/^{238}U$ age of 732.0 ± 7.8 Ma interpreted as the crystallization age of the microgabbro. This result falls within the range of published ages for intrusive rocks of the Franklin LIP in Arctic Canada, although a recent study suggests rapid emplacement of the LIP between 719.86 ± 0.21 Ma and 718.61 ± 0.30 Ma. Immobile trace element concentrations for sample ECS005041 are typical of transitional basalt with an enriched mid-ocean ridge basalt (E-MORB) geochemical signature (e.g. Th/Yb and Nb/Yb ratios). Chondrite-normalized rare earth element (REE) patterns are negatively sloped with minor light-REE enrichment (i.e. 20x chondrite), but are generally depleted in comparison with those of magmatic rocks emplaced in the Franklin LIP, and in other continental flood basalt provinces of Phanerozoic age. Isotopic analyses yielded $^{87}Sr/^{86}Sr$ ratios of 0.703815, εNd of +1.45, and εHf of +6.6. These results, and the HFSE trace element ratios, fall within the range of values reported for Franklinian intrusive rocks suggesting that precursor magmatism may have extended geographically beyond the known distribution of dykes exposed in the Canadian Arctic Islands.

NANOKI'KSILA: INDIGENOUS SCIENCE, INDIGENOUS YOUTH, AND PERSPECTIVES

Gavin Woodburn
Carleton University.
E-mail: *gavinwoodburn@cmail.carleton.ca*

Indigenous youth are the future when it comes to fluently bridging, braiding, and weaving Indigenous science with western science. Indigenous science is a distinct way of understanding regarding multiple knowledge systems about the environment and ecosystems of Indigenous peoples and their respective territories. I explore ways based on my own experiences as a Kwiakah First Nation member as to how Indigenous science can become an effective pathway for all students in STEM. Introducing Indigenous science into post-secondary education gives all students a new perspective into understanding the different ways of knowing that go beyond western reductionist methods and into the realm of holistic understanding. This also encourages Indigenous students to learn how they can put their teachings from their community and on the land to use with western science to enhance research in STEM and learn how to "walk in both worlds". Practical methods from my experiences at Carleton University include involvement in creating the Kinàmàgawin report for their revitalized Indigenous strategy, and creating my own Indigenous science learning bundle which provides the foundations of Indigenous science while also keeping information relevant to students in the Faculty of Science. In a western science setting, I focus on indigenizing the scientific method by using the same key factors in research such as observation, analysis, questioning, etc., but prioritize a holistic approach by collaborating, exploring language and teachings, and presenting my findings in a non-(Western) traditional format. Past and current projects have included methyl-mercury contamination in sediment and shellfish, Indigenous science indicators, and Loxiwe (clam gardens). Weaving Indigenous knowledge with western science adds a new dimension to STEM research which could be thought of as constructing a puzzle. Rather than focusing on individual pieces, we look at the whole puzzle to see how it will all fit together.

FIELD AND NUMERICAL ANALYSIS OF THE DEFORMATION PATTERN IN THE SWAYZE GREENSTONE BELT: IMPLICATIONS FOR NEOARCHEAN CRUSTAL DYNAMICS

Qihang Wu, Shoufa Lin, André Unger
University of Waterloo.
E-mail: *qihang.wu@uwaterloo.ca*

The crustal dynamics of the Archean Earth has been subject to controversies on whether a vertical tectonic style in the form of the Rayleigh-Taylor instability is widespread in the early Earth's history. If so, when the transition to horizontal style modern day-like plate tectonics took place and how that transition is manifested in the rock record remain poorly constrained. In this study, a regional structural analysis is carried out in the Swayze greenstone belt. Our study leads to the identification of multiple generations of ductile deformations. Among them, the first-generation structures are characterized by the regional upright folding of the stratigraphy and variable NW–SE to E–W-trending steeply dipping foliation, with the lineation varying from moderately to steeply plunging. The lineations also show a monoclinic pattern from the northern to the southern granitoid–greenstone boundaries. To elucidate the tectonic nature of the first-generation structures, we develop a numerical modelling scheme so that the information about lithological distribution, flow kinematics and finite deformation pattern is directly available as the numerical model evolves. Using this modelling framework, a numerical model is constructed where a density overturn develops under the backdrop of the horizontal shearing. By comparing the model results with the structural data, we conclude that the lithological distribution and structural patterns emerging from the numerical model are similar to what is observed in our synthesis of the geological data. By varying the shear strain rate and the crustal rheology, the numerical model produces a wide range of granitoid–greenstone belt geometry that compares favourably with granitoid–greenstone terranes in the Superior Province and worldwide. Therefore, we postulate that the vertical and horizontal tectonics were not mutually exclusive tectonic regimes and that they both contributed to the establishment of crustal architecture in many Neoarchean terranes. The co-existence of both processes in Neoarchean terranes suggests the Neoarchean as the time in the Earth's history when the transition from vertical tectonism to a modern day-like horizontal tectonics possibly took place. Furthermore, the curvilinear belts of large amount of accumulated strain developed in our models mimic the characteristics of the major deformation zones in the Superior Province, implying that the nucleation and development of such "crustal-scale" deformation zones in Neoarchean terranes may be the natural product of strain localization in a synchronous horizontal and vertical tectonic regime, rather than strike-slip shear zones with regionally significant lateral movements.

MELT INCLUSION EVIDENCE FOR LIMESTONE ASSIMILATION PRODUCING CALC-SILICATE MELTS AND "MAGMATIC SKARN"

Xinyue Xu, Matthew Steele-MacInnis
University of Alberta.
E-mail: *xxu20@ualberta.ca*

Skarn deposits related to porphyry systems are generally considered to be products of hydrothermal metasomatism. However, at the Chating porphyry deposit (China), we find evidence for the formation of 'magmatic skarn' by pervasive, infiltrative chemical exchanges between silicate melts and carbonate rocks in a shallow porphyry setting driven by assimilation, melting, and complex liquid immiscibility. In pods of endoskarn and associated veins from Chating, we find melt inclusions rich in sulphate and calc-silicate minerals (diopside, garnet, wollastonite, epidote). These inclusions were remelted in heating experiments showing a variety of liquid immiscibility and often coexisting with chloride-rich salt melt inclusions and CO_2 vapour inclusions. We argue that skarn at Chating was formed by fractional crystallization of an immiscible, calc-silicate-rich melt, and these melts were generated by the assimilation of limestone with interbedded gypsum evaporite layers, followed by coupled decarbonation and desilication. The coeval assemblages of anhydrous salt–melt inclusions found in Chating, as well as the occurrence of phases such as thenardite, celestine, apatite, and chondrodite in the calc-silicate-bearing melt inclusions, suggest that the skarn-forming melts were stabilized by a variety of fluxes including elevated Na^+, Sr^{2+}, Cl^-, F^-, PO_4^{3-} and SO_4^{2-}. Meanwhile, the coeval vapour inclusions represent the products of decarbonation of the assimilated material and degassing of the CO_2 thus produced. Moreover, the calc-silicate-bearing melt inclusions commonly contain sulphide daughter minerals, suggesting that these melts were rich in metals, and therefore may have played a role in ore mineralization. Based on these results, we argue that at Chating—and probably other skarn deposits where evaporite rocks are part of the host sedimentary package—assimilation of carbonate rocks and generation of calc-silicate-rich melts was a key process of skarn formation.

HIGH TEMPERATURE INCLUSIONS REVEAL A KEY ROLE OF MAGMATIC PROCESSES IN THE FORMATION OF IRON OXIDE–APATITE DEPOSITS

Xinyue Xu[1], Matthew Steele-MacInnis[1], Wyatt Bain[2]
[1]University of Alberta, [2]British Columbia Geological Survey.
E-mail: *xxu20@ualberta.ca*

We report the ubiquitous occurrence of high temperature, polycrystalline melt inclusions in iron oxide–apatite (IOA) deposits from around the world, revealing a direct genetic link between salt melts and these deposits. We studied the petrographic characteristics of thousands of inclusions at room temperature, identified their phases by Raman spectroscopy and EDS, and conducted microthermometry experiments to re-melt these inclusions in the lab. These polycrystalline inclusions show complex compositions of chlorides, sulphates, carbonates, silicates, calc-silicate minerals, and metal sulphides and oxides. Four main types of polycrystalline inclusions with end-member components are summarized based on their compositions: (i) chloride melt inclusions (including sylvite, halite, hibbingite, etc.); (ii) sulphate melt inclusions (including anhydrite, barite, cesanite, and gypsum); (iii) calc-silicate melt inclusions (including diopside, wollastonite, garnet, and tremolite/actinolite); and (iv) carbonate melt inclusions (including calcite, dolomite, natrite and trona). Although some examples of end-member type inclusions are reported, most studied inclusions are transitional between different types, underscoring that all four types are intimately related and represent different flavours of a broader category of salt melts. Polycrystalline inclusions across all studied deposits melt between 585°C and 1200°C, and thus represent high temperature ionic liquids. These high temperature inclusions are widely distributed in all deposits studied and seem to be a fundamental feature of IOA systems. Although the detailed characteristics, types, and distribution of inclusions vary between different deposits, taken together they suggest a key role of magma contamination and immiscibility. Therefore, we argue that these processes are central to the formation of IOA deposits.

GEOCHEMICAL CHARACTERIZATION OF HOT SYN-OROGENIC GRANITE OF THE CENTRAL GRENVILLE PROVINCE

Cheuk Yin Yip[1], Aphrodite Indares[1], Gregory Dunning[1], Abdelali Moukhsil[2]
[1]Memorial University of Newfoundland,
[2]Ministère des Ressources naturelles et des Forêts.
E-mail: *cyyip@mun.ca*

Conventional models of collisional orogens predict S-type granitoid emplacement during the orogenic climax, whereas A-type granitoid plutons can be formed by late orogenic extensional collapse. Yet, in the Grenville Province, S-type granite is rare to absent, but A-type granitoid plutons are emplaced in the orogenic hinterland throughout the 100 M.y. duration of the Grenville orogeny. These A-type plutonic bodies are particularly abundant in the central Grenville Province, where they occur as kilometre-scale plutonic bodies in the mid-P and low-P belts and as tens of kilometres-wide batholiths spatially associated with 1.1 Ga anorthosite in the low-P belt. Here, based on available data, we present a geochemical characterization of syn-orogenic granitoid bodies along the Manicougan–Escoumins transect in the mid-P and low-P belts of the hinterland in the central Grenville Province. These granitoid rocks were emplaced intermittently between ca. 1090 and 1015 Ma with no apparent spatiotemporal trend. In granitoid rocks, perthitic textures are common, while some contain magmatic orthopyroxene and display rapakivi texture. Geochemical classifications reveal that the granitoid rocks are broadly monzodiorite, monzonite to granite, while several plutons show a composite trend. The majority contain 55–75% SiO_2 and are distinctly ferroan. In terms of the aluminum saturation index (ASI), the granitoid rocks are predominantly metaluminous, with some marginally peraluminous. Based on the modified alkali–lime index, the granitoid rocks are classified as mainly alkali-calcic to alkalic. In the Y/Nb diagram, they fall in the within-plate granite field, with some data straddling the volcanic-arc field. The spatial association of large granitoid bodies with older anorthosite bodies in the low-P belt is consistent with the reactivation of long-lived lithospheric discontinuities. Overall, the granitoid magmatism in central Grenville indicates thermal influence from the mantle throughout the Grenville orogeny, and it is yet unclear how this can be accounted for in the continental collision model for the Grenville orogen.

FLUID INCLUSION ANALYSIS OF MINERALIZING FLUIDS OF THE MAW ZONE REE DEPOSIT, ATHABASCA BASIN – SIGNIFICANCE FOR REE AND UNCONFORMITY-RELATED URANIUM MINERALIZATION IN THE ATHABASCA BASIN

Nahanni Young[1], Guoxiang Chi[1], Victoria Tschirhart[2], Jeremy Powell[2], Duane Petts[2]
[1]University of Regina, [2]Geological Survey of Canada.
E-mail: *nahanniyoung@gmail.com*

Uranium (U) and rare earth elements (REE) are both considered critical metals under the Canadian Critical Mineral Strategy. Current Canadian uranium production is exclusively from the Proterozoic Athabasca Basin. While most REE deposits in the world are related to carbonatite and granite intrusions, significant REE mineralization has been observed in Proterozoic sedimentary basins, including the Athabasca Basin. The Maw Zone REE deposit represents the most significant REE mineralization in the Athabasca Basin. The uranium deposits in the Athabasca Basin, named unconformity-related uranium (URU) deposits because they mainly occur near the unconformity between the basin and basement, also contain elevated REE concentrations. The absence of U mineralization in the Maw Zone REE deposit and its proximity to REE-rich URU deposits have provoked considerations regarding the potential genetic link between URU and REE mineralization and the investigation of the overall REE potential of the Athabasca Basin. In order to address these considerations, it is important to know the compositions and pressure–temperature conditions of the ore-forming fluids. Fluid inclusions within minerals occupying the same paragenetic sequence as ore minerals provide the direct samples of the ore-forming fluids. Many fluid inclusion studies have been conducted for the URU deposits, including trace element analyses. Whereas a previous microthermometric study of the Maw Zone REE deposit suggested that the fluids related to REE mineralization are similar to those of the URU mineralization, no data on trace elements have been obtained from the fluid inclusions in the Maw Zone. Therefore, a new study on fluid inclusions in drusy quartz coeval with REE mineralization from the Maw Zone is undertaken, emphasizing trace element analysis with laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS), in addition to microthermometric, cryogenic Raman spectroscopic and scanning electron microscopy–energy dispersive spectroscopy (SEM-EDS) analyses. Preliminary results indicate that fluid salinities may be more variable than previously reported, suggesting that mixing of fluids from different sources may be involved in the mineralization. More detailed results from ongoing study of fluid inclusions from the Maw Zone will be compared to those from barren portions of the basin as well as to those documented in URU deposits. These results will contribute to a better understanding of the potential sources, fluid pathways and chemical traps responsible for U and REE mineralization in the Athabasca Basin, including the genetic relationships between the U-poor REE mineralization like Maw Zone and REE-rich URU mineralization.

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RELATION BETWEEN ADAKITE GENESIS AND SLAB BREAK-OFF WITH IMPLICATIONS FOR GENERATING FERTILE Cu–Au PORPHYRY SYSTEMS

Fazilat Yousefi, David Lentz
University of New Brunswick.
E-mail: *fazilat.yousefi@unb.ca*

The relationship between slab melting in generating fertile adakite and its link to subducting oceanic crustal slab failure is intriguing. The key geochemical characteristics that show high-silica adakite (HSA) is related to convergent plate boundaries with partial melting of subducting oceanic crust, whereas the melting of the mantle wedge creates calc-alkaline basalt–andesite–dacite–rhyolite series (ADR) of intra-oceanic island arcs and intracontinental margin arcs. Adakite bodies have key geochemical characteristics of high-silica (SiO_2 > 67 wt.%), Al_2O_3 > 15 wt.%, Sr > 300 ppm, Y < 20 ppm, Yb < 1.8 ppm, and Nb ≤ 10 ppm, with lower K_2O/Na_2O (~0.42) and MgO < 3 wt.%, with high Sr/Y (> 50) and La/Yb (> 10). Higher amounts of Mg# (avg. 0.51), Ni (avg. 924 ppm), and Cr (avg. 36 ppm) in HSA adakite are typical, in contrast to calc-alkaline arcs, while both groups show the same negative anomalies of Nb, Ta, and Ti. Garnet, hornblende, and refractory accessory phases, such as titanite, during assimilation–fractional crystallization (AFC) cause some of these geochemical features. Like in all arcs, higher redox is reflected in relatively lower FeOt/MgO (1.0–3.0), TiO_2 (0.15–1.15 wt.%), and V (25–250 ppm). Vanadium partitioning is also controlled by $f(O_2)$, with V highly enriched in more oxidized residual rutile, ilmenite, titanomagnetite, clinopyroxene, and garnet. The original hypothesis for generating HSA was formation in convergent margins where young, hot oceanic plates subduct. However, several hypotheses have now been proposed for generating of adakitic compositions, such as primary slab melting, slab melt hybridized by peridotite (HSA with low MgO (0.5–4.0 wt.%)), and melt-derived peridotite metasomatized by felsic slab melt (low silica adakite with high MgO content (4–9 wt.%)). Many researchers have noted that the difference in geochemical characteristics of adakite, such as MgO, Cr, and Ni, occurs because of interaction of the slab-derived adakitic melts with overlying lithospheric mantle during ascent. HSA magma associated with slab failure has unique geochemical properties, such as Sr/Y > 20, Nb/Y > 0.4, Ta/Yb > 0.3, La/Yb > 10, Gd/Yb > 2, and Sm/Yb > 2.5. The relationship between HSA magmatism and the formation of Cu porphyry systems has been widely recognized, with the genesis of these fertile magmas leading to Cu-Au porphyry plutons in various subduction settings. Metallogenic fertility is a recognized compositional evolutionary trend towards an extensional association; rapid ascent of HSA through the mantle and crustal lithosphere minimizes AFC. High T–P partial melting of the slab yields HSA with high activities of H_2O, SO_2, HCl, with metals of interest remaining incompatible at higher $f(O_2)$; these conditions readily occur in post-collisional subducting oceanic crust experiencing slab failure/break-off.

RE-EVALUATION OF THE PALEOZOIC STIKINIA AND IMPLICATIONS FOR THE PALEOZOIC WITHIN-PLATE MAGMATIC CRISIS IN THE CANADIAN CORDILLERA

Alex Zagorevski
Geological Survey of Canada.
E-mail: *alex.zagorevski@nrcan-rncan.gc.ca*

Within-plate magmatism, including OIB, forms an integral part of most intermontane arc terranes and has been attributed to intra-arc or back-arc rifting. Enriched magmatism forms a minor, but important contribution to modern back-arc settings. In these settings, enriched magmatism, and specifically OIB, generally marks back-arc regions far away from the arc front and either (i) is coeval with an active back-arc ridge (e.g. North Fiji Basin), (ii) overlaps an extinct back-arc ridge (e.g. Shikoku Basin), (iii) erupts onto rifted continental or arc crust in the back-arc basin (e.g. Sea of Japan), and/or (iv) is unrelated to arc development (e.g. northern Taiwan volcanic zone). The relatively restricted occurrence of enriched magmatism in modern arc–back-arc settings can be used to aid and evaluate tectonic reconstructions of the northern Cordilleran arc terranes. Paleozoic Stikinia has been interpreted as a juvenile arc and an along-strike correlative of the Yukon–Tanana terrane. Paleozoic Stikinia is characterized by predominantly IAT to CAB magmatism in the Late Devonian to Late Carboniferous. The character of magmatism appears to change across the Late Carboniferous, and Permian magmatism is characterized by eruption of OIB, followed by general cessation of magmatism and deposition of voluminous carbonate rocks. Previous workers interpreted OIB to have erupted in intra-arc rifts in a predominantly orogen-parallel transtensional arc system. In contrast, comparison to modern arc settings suggests that Paleozoic Stikinia has evolved from a Carboniferous arc to a Permian remnant arc ridge. The younger, active portion of this arc may be preserved in the Atlin terrane supra-subduction zone ophiolite bodies (264–245 Ma) and Joe Mountain–Kutcho–Sitlika arc sequences (252–242 Ma). Reinterpretation of the Permian Stikinia as a remnant arc (similar to Palau–Kyushu ridge) requires a re-evaluation of the tectonic development of Paleozoic to Early Mesozoic Stikinia. Similarly, other intermontane arc terranes preserve episodic OIB magmatism. These should be re-evaluated as OIB magmatism likely indicates that these arc terranes no longer lie along the arc front but rather have separated from the active arc front and formed remnant arc ridges. Re-evaluation of these terranes will help to improve the Cordilleran terrane framework and tectonic models.

THE PROVENANCE AND TECTONIC HISTORY OF DASHWOODS AND THE BAIE VERTE MARGIN

Alex Zagorevski, Cees van Staal, Nancy Joyce
Geological Survey of Canada.
E-mail: *alex.zagorevski@nrcan-rncan.gc.ca*

Dashwoods is a composite peri-Laurentian terrane in Newfoundland that forms the basement to the Early Ordovician to Silurian Notre Dame arc. The southern part of Dashwoods is characterized by polyphase Taconic to Salinic deformation, magmatism and high grade metamorphism. SHRIMP U–Pb zircon analysis of Dennis Pond Complex paragneiss yielded metamorphic rims ranging from ca. 395 to 500 Ma and abundant detrital grain cores ranging from ca. 546 to 1853 Ma. Data indicate that Dennis Pond Complex paragneiss was deposited between ca. 563 Ma (YSG) and 500 Ma (oldest metamorphic rim). Paragneiss is characterized by a distinctive population of Tonian zircon (ca. 926 Ma YGC) that helps to constrain Dashwoods provenance. Comparison of Dashwoods provenance to the Laurentian margin yields a high degree of dissimilarity to the Humber margin, Grampian and Hebridean terranes. However, Tonian zircon is common in the Baie Verte margin in Newfoundland (East Pond metamorphic suite: and Fleur de Lys Supergroup), Tyrone complex and Dalradian Supergroup in Ireland. These peri-Laurentian regions yield a high degree of similarity to the Dashwoods terrane. Although it has been recently suggested that Dashwoods is a peri-Gondwanan terrane, the similarity in provenance, combined with other geological evidence such as Ediacaran hyperextension, support the origin of Dashwoods and Baie Verte margin near the Rockall promontory. Dashwoods and Baie Verte margin was subsequently emplaced outboard of the Humber margin by Ordovician to Carboniferous motion along the Baie Verte–Brompton Line.

CARBONIFEROUS TO TRIASSIC IGNEOUS ROCKS IN THE AQISHAN–YAMANSU BELT, EASTERN TIANSHAN: IMPLICATIONS FOR TECTONIC AND CRUSTAL EVOLUTION

Liandang Zhao
Chang'an University.
E-mail: *zhaold@chd.edu.cn*

The Aqishan–Yamansu belt, eastern Tianshan, is characterized by voluminous late Paleozoic intermediate to felsic igneous rocks and associated magmatic–hydrothermal Fe (-Cu) and Cu deposits during the evolution of Kangguer Ocean. A systematic study has been conducted on the Carboniferous arc-related granitic rocks and Triassic adakite-like granitoid rocks from the Hongshanliang copper district as a representative to investigate the tectonic and crustal evolution of the Aqishan–Yamansu belt when combined with published regional data. The Carboniferous arc-related granitic rocks show large ion lithophile element (LILE) enrichment and high field strength element (HFSE) depletion, with positive zircon εHf(t) values (+1.54 to +7.15), crust-derived geochemical element ratios (e.g. Nb/Ta and Th/U) and low Mg# values (< 37), as well as negative to positive whole rock εNd(t) values (−0.3 to

+0.6) and their corresponding two-stage model ages (1.22–1.02 Ga), suggesting they were derived from partial melting of the Mesoproterozoic rocks with mantle-derived magma involvement. The Triassic adakite-like granitoid rocks exhibit LILE enrichment and HFSE depletion, with geochemical features of juvenile crust (e.g. low Nb/U and Ta/U ratios and depleted εHf(t) values) and mantle-derived magmas (e.g. high Th/U and Th/La ratios and Mg# values), which suggests that they were derived from partial melting of thickened juvenile lower crust with minor mantle-derived components. Integrating published cognition and our work, we propose that the Aqishan–Yamansu belt underwent obvious tectonic evolution from an Early Carboniferous fore-arc basin extensional setting during the Kangguer oceanic slab southward subduction, through a Late Carboniferous fore-arc basin inversion due to the Kangguer oceanic slab steepening to breakoff, to a Triassic within-plate setting after earliest Late Carboniferous to Early Permian closure of the Kangguer Ocean. In combination of zircon εHf(t) values and whole rock Sr/Y ratios from our data and published works of intermediate to felsic igneous rocks from the Aqishan–Yamansu belt and adjacent tectonic belts of the eastern Tianshan, we can preliminarily conclude that the major crustal growth in the eastern Tianshan occurred at ca. 444–270 Ma, with crustal reworking at ca. 250–200 Ma.

EXTREMELY FRACTIONATED GRANITIC SYSTEMS CONTROLLED RARE METAL MINERALIZATION: EVIDENCE FROM VARIOUS PETROGEOCHEMICAL SIGNATURES

Yiting Zhu[1,2], David Lentz[2], Xiaofeng Li[1]
[1]Chinese Academy of Sciences, [2]University of New Brunswick.
E-mail: *yiting.z@foxmail.com*

Extremely fractionated granitic systems are major global sources of important rare metals, e.g. Li, Be, Rb, Cs, Ta, and Sn. Over the past 50 years, several models were proposed to explain rare metal mineralization from magmatic to hydrothermal processes, such as partial melting, and deep to shallow level fractionation, as well as high-T hydrothermal processes. However, the relative contributions of these different processes in the enrichment and saturation and (or) precipitation of rare metals need more precise data to be better understood. We compiled the mineralogical and geochemical data of both the granitic system and related rare metal mineralization from many extremely fractionated granite systems worldwide, including the Mount Pleasant Granite (MPG) (Canada) rich in Sn-W-Mo-Bi-In and the Ganfang Granite (GFG) (China) rich in Sn-Be-Li-Nb-Ta, which represent cogenetic, multiphase, very highly evolved A-type and S-type granitic systems, respectively. MPG is high silica (> 74 wt.%), metaluminous to weakly peraluminous (A/CNK = 0.91–1.28), and GFG is relatively lower silica (68–74 wt.%), and strongly peraluminous (A/CNK = 1.23–1.72). However, they both belong to extremely fractionated granitic systems with variations, but lower ratios of Nb/Ta (0.6–7.6), Zr/Hf (7–31), Y/Ho (30–55), Al/Ga (1.8–3.9), K/Rb (25–70), Th/U (0.1–3.0), and have extremely high F, Li, Rb, Cs, Nb, Ta, and Sn, but also P and B in GFG. The two granitic systems have undergone long duration evolution and generate three separate but successive intrusive phases with different degrees of fractionation and linked affinity. Within each of these granitic phases, the longer the duration and higher the fractionation, the greater the rare metal concentration they have. In addition, GFG is rich in B, Li, F, and P_2O_5, whereas MPG is rich in Li, Cl, and F, which act as fluxes depressing liquidi, solidi and viscosities, increasing component diffusivities during the magma–hydrothermal evolution. Increases in volatile (H_2O, F, P, B, Cl) contents of granite phases results in changes in the cotectic and eutectic in Qz-Ab-Or ternary, when displayed toward An, facilitating extreme differentiation. The partitioning of crystal–melt and melt–fluids will also be strongly influenced by volatile phases, causing incompatible (including rare metal) elements to concentrate in volatile-rich melt and then separately as exsolved volatile phases partition metals and fluxes. Therefore, abundant flux compositions enhance the longer duration of magmas regardless of the nature of the source, as a result, producing extremely fractionated granite very much enriched in different types of volatiles and rare metals.

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