

Geological Association of Canada, Newfoundland and Labrador Section

ABSTRACTS

2020 Technical Meeting

ST. JOHN'S, NEWFOUNDLAND AND LABRADOR

The Annual Technical Meeting was held on February 17 and 18, 2020, in the Johnson GEO CENTRE on scenic Signal Hill in St. John's, Newfoundland and Labrador.

This year the meeting kicked off on Monday with a Special Session in honour of Charlie Gower entitled "Tectonics and Mineral Potential of Proterozoic Orogenic Belts". This day-long session was followed-up with an evening Public Lecture by Toby Rivers and Fried Schwerdtner on "Gravitationally-Driven Extensional Collapse of a Proterozoic Large Hot Orogen: The Grenville Example." Tuesday featured a General Session with presentations on a wide range of geoscience topics.

As always, this meeting was brought to participants by volunteer efforts and would not have been possible without the time and energy of the executive and other members of the section. We are also indebted to our partners in this venture, particularly the Alexander Murray Geology Club, the Johnson GEO CENTRE, Geological Association of Canada, Department of Earth Sciences (Memorial University of Newfoundland), and the Geological Survey of Newfoundland and Labrador, Department of Natural Resources. We are equally pleased to see the abstracts published in *Atlantic Geology*. Our thanks are extended to all of the speakers and the editorial staff of the journal.

Although the abstracts are modified and edited as necessary for clarity and to conform to *Atlantic Geology* format and standards, the journal editors do not take responsibility for their content or quality.

JARED BUTLER AND ANNE WESTHUES
TECHNICAL PROGRAM CHAIRS
GAC NEWFOUNDLAND AND LABRADOR SECTION

A gravity study of the Valentine Lake Gold Property, west-central Newfoundland

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The Valentine Lake Gold Property (VLP) is located in the west-central region of Newfoundland and encompasses four significant gold deposits, which are structurally controlled and of orogenic origin. These deposits, which have proven challenging targets for geophysical exploration, occur proximal to a major thrust-faulted contact between the Precambrian Valentine Lake Intrusive Complex (VLIC), which contains the majority of gold mineralization, and the Silurian Rogerson Lake Conglomerate. Hosted in the silicic quartz-eye porphyry and trondhjemite phases of the VLIC, the gold concentrations are associated with extensional and shear parallel quartz-tourmaline-pyrite veining. The VLP has undergone multiple complex stages of deformation and contains many generations of mafic dykes. Although geophysical techniques are commonly used to investigate mineral prospects, their ability to delineate the ore zone at the VLP has been unsuccessful. This failure is primarily because the gold is scattered throughout veins within the resistive, silicic host rocks and the relationship between the mineralization and the mafic dykes is unclear. This study employs the gravity method, a geophysical technique that has not previously been used over the property, to investigate the VLP. Although gravity methods are often used in mineral exploration, they are not typically applied to the type of gold deposits present at the VLP, where the density contrast between lithologies is small, topography is rough, and overburden is thick and irregular. A 2018 proof-of-concept survey over the gold-bearing alteration zone revealed a small but measurable negative gravity anomaly. Encouraged by this, in August 2019, we carried out a broad-scale gravity survey over the property to map the subsurface extent of the alteration zone and delineate areas suitable for exploratory drilling. Preliminary results indicate that there is a measurable response from the alteration zone, which suggests that gravity is a suitable technique for assessing the mineral prospects at the VLP.

Avalonia in the northern Appalachian orogen: a mainland perspective

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Avalonia in the northern Appalachian orogen extends from southeastern New England through southern New Brunswick, northern Nova Scotia, southeastern Cape Breton Island, and eastern Newfoundland. It may continue through Wales and southern England into Belgium and central Europe, where it has been termed East Avalonia, but this connection remains controversial. Although eastern Newfoundland is recognized as the type area for Avalonia, on-going field work, petrological studies, and especially geochronology in the “mainland” components have resulted in increased understanding of terranes within Avalonia and shown that the record is fragmentary and also that no single part represents the entire story. Avalonia is a collage of diverse Neoproterozoic terranes with complex and apparently divergent tectonic settings and histories, isotopic compositions, and temporal evolutions. In southeastern New England, remnants of passive margin sequences that include quartzite and carbonate olistostromes have ages from <950 Ma and >610 Ma. In the Cobequid Highlands of northern mainland Nova Scotia, the same(?) passive margin is better constrained at <800 and >750 Ma. Extensive arc magmatism is recorded at 750–730 Ma in the Cobequid Highlands, but nowhere else in mainland Avalonia. Arc magmatism is recorded at ca. 700–670 Ma in the Caledonia terrane of southern New Brunswick and in the Mira terrane of southeastern Cape Breton Island. The so-called “main phase” of arc magmatism in Avalonia is represented by 609–595 Ma magmatism in SE New England, 625–615 Ma in Caledonia, 630–610 Ma in the Cobequid Highlands, 625–605 Ma in the Antigonish Highlands, and 640–620 Ma in the Mira terrane. The late Ediacaran magmatic and sedimentary history differs markedly among these terranes and includes arc magmatism at ca. 575 Ma in Mira terrane and voluminous bimodal magmatism at ca. 550 Ma in the Caledonia terrane. These diverse histories need to be compared to the less(?) fragmentary rock record in Avalonian Newfoundland.

Ground penetrating radar over the abandoned Gullbridge Mine tailings dam, central Newfoundland, Canada

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This discussion explores the ground-penetrating radar (GPR) geophysical survey technique and its application to assessing the structure of the earthenware dam of an abandoned mine tailings facility. Ground penetrating radar is a non-intrusive high-resolution survey method that produces detailed images of the subsurface by emitting radio frequency pulses of electromagnetic energy through a transmitting antenna and detecting the reflections from interfaces by a receiving antenna. GPR picks up on subtle variations in reflections due to changes in the electromagnetic properties (permittivity and conductivity) of subsurface materials. These property changes can be related to changes in lithology, compaction or water content and composition.

The Gullbridge Mine is an orphaned and abandoned property in Central Newfoundland centered over a volcanogenic massive sulfide ore deposit containing mainly copper-zinc ore that operated between 1967 and 1972. As part of an ongoing dam monitoring study, GPR was deployed to characterize material variations within the Gullbridge earthenware tailings dam, in order to identify potential failure mechanisms which could be responsible for destabilization and large-scale breaching of the dam (as has happened in the past). At the Gullbridge site, GPR was used to examine the dam's internal structure, for which construction records are lacking, and seek seepage pathways of tailings water. This presentation outlines the applications, advantages, and limitations of the survey technique as well as basic survey design, processing techniques, and interpretation methods.

Paleolatitude of the volcanic rocks in the Devonian Fountain Lake Group, Cobequid Highlands, Nova Scotia, Canada, as a new constraint on Laurentia paleogeography

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The Acadian orogeny is interpreted to have been initiated in the Middle to Late Devonian by the arrival of the Meguma terrane at Avalonia, which by then had already been accreted to Laurentia. The broader paleogeographic context for the arrival of these terranes at Laurentia has been difficult to define, partly due to the scarcity of worldwide paleomagnetic data for the Devonian. The ca. 355 Ma Fountain Lake Group, in the Cobequid Highlands of Nova Scotia, is part of the transtensional basin fill, which formed during dextral strike-slip motion between Avalonia and Meguma following the Acadian orogeny. Paleomagnetic analysis of Fountain Lake Group volcanic rocks offers both a paleolatitude estimate for the Laurentian accretionary margin in the Devonian and locality-specific paleomagnetic directions. This help to restore local block rotations during the subsequent relative strike-slip motion along the Cobequid Fault zone. Stepwise demagnetization of >150 specimens taken from 20 sites in three Fountain Lake Group localities across the Cobequid Highlands (Squally Point, West Moose, Wentworth exposures) reveals remanence consisting of an easily-removed component of probable recent origin, and more persistent components. The latter are carried by magnetite and hematite, which in petrographic and electron beam analysis appear to be of primary igneous and volcanic oxidation origins, respectively. Sites from all three localities carry stable characteristic remanent magnetization (ChRM) directions that assume similar downward inclinations when tilt-corrected. Results indicate paleopoles at coordinates 272.1 E, 13.8°S; 191.8 E, 52.9°N and 303.9 E, 28.7°S respectively for the Squally Point, West Moose and Wentworth localities, representing relative rotations between the blocks that overall are variously clockwise (CW) rotated compared with a Laurentia cratonic reference frame. Inclinations at all three localities imply a subtropics paleolatitude for the margin (at Squally Point, 27.2° ± 9.4°; n = 7 sites), directly supporting the depicted location of Laurentia in most Late Devonian reconstructions.

The mineral potential of the Labrador Trough for iron oxide-copper-gold (IOCG) and affiliated deposits

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Iron oxide copper gold (IOCG) deposits and various affiliated deposits are a major global source of Cu and Au, as well as containing appreciable amounts of other metals (e.g., Ag, Co, Bi, Fe, Mo, Ni, PGE, Pb, REE, U, V, Zn). These deposit types are characterized by distinctive alteration facies and litho-geochemical footprints, which when incorporated into ore genetic models and deposit classes can provide effective vectors towards mineralization. In the Labrador Trough region of northeastern Québec and western Labrador, a number of prospective settings for IOCG-type mineralization have been recognized, including in the Romanet Horst in the central part of the Trough and in the Montgomery Lake area to the south. In the Romanet Horst, hydrothermal alteration and brecciation are associated with polymetallic mineral occurrences enriched in Cu, Au, Mo, REE, U, Co, and Ag. The most significant zones of mineralization identified in the Romanet Horst occurs in a corridor of albitites located in the fault marking the northern boundary of the horst, where significant Cu-Ag-(Au) and Au-Co-Cu mineralization occurs where higher temperature Ca-Fe-K and lower temperature K-Fe alteration facies brecciate the albitite. Other mineral showings and occurrences in the Romanet Horst consist of albitite-hosted Cu, U, Au-U, Au-Co-Cu and Mo mineralization, and zones of incipient magnetite-group IOCG mineralization. In addition to the regional Na ± Ca alteration (albitite) and the later stages and mineralized carbonate-bearing veins, the mineral systems include higher temperature Ca-Fe (amphibole-dominant) and K-Fe alteration (magnetite and biotite dominant) as well as lower temperature K-Fe (hematite and sericite dominant); the K-Fe facies are distinctive of IOCG deposits and locally host copper-sulphide mineralization. In the Montgomery Lake area, extensive Na ± Ca alteration (albitite) and brecciation has been identified in a ~2 km long corridor, with significant Cu-Au mineralization reported along the corridor. Current research is ongoing to identify whether other alteration facies and mineralization styles typical of IOCG-type mineralization can be identified in this area.

This presentation describes the geological setting of these prospective areas, with particular focus on the evolution of their alteration facies and their ore systems associated with mineral occurrences. It emphasizes the importance of alteration mapping, processing large databases in terms of alteration facies and metal associations and integration with geological and geophysical models in areas of poor exposure such as the Labrador Trough.

Metamorphic history inferred by microstructures of aluminous lower crustal xenoliths from the Mojave Desert, California, USA

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The Mojave Desert located in the Basin and Range Province, southeastern California, has experienced a complex geological history since forming on the edge of southern Laurentia in the Paleoproterozoic. A suite of lower crustal xenoliths exposed in an andesitic dike in the Mojave Desert holds details regarding the complexity of the pre-Tertiary extensional lower Mojave crust, a region otherwise inaccessible for direct study. This research focuses on representative aluminous xenoliths from the suite with an assemblage consisting of quartz + plagioclase + K-feldspar + garnet + biotite + rutile + kyanite, with rare sillimanite, and accessory zircon and monazite. Xenoliths preserve unique microstructures that are correlated with metamorphic reactions related to melt production, loss, and crystallization. Such microstructures include kyanite pseudomorphs, protoleucosomes containing sillimanite, and sector and oscillatory zoned aluminosilicate phases. These microstructures were identified using traditional microscopy, false colour thin section maps generated using SEM-MLA, and CL intensity images of aluminosilicate internal structures produced by an electron probe micro analyzer. Documented microstructures, along with mineral chemistry are integrated here with phase equilibria modelling techniques using THERMOCALC to provide insight into the metamorphic history of the Mojave lower continental crust. Mineralogical and textural evidence for anatexis and melt loss in the xenoliths is consistent with an extensive anatectic melting event in the lower crust that may be responsible for forming several strongly peraluminous Cretaceous granites in the region. According to the pressure-temperature (P-T) path predicted from phase equilibria modelling, the Mojave lower crust reached a peak P-T of 12 to 13 kbar, and 860 to 880°C. The presence of late sillimanite suggests that the lower crust experienced decompression following peak P-T. In the context of regional geology, decompression of the lower crust may have resulted from crustal thinning subsequent to the Laramide orogeny and Cretaceous granitoid emplacement.

Applications of machine learning to seismic facies classification

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Seismic facies classification is a pattern recognition task that uses seismic attributes to gain an understanding of subsurface geologic features. An efficient and automated approach to perform this task is to leverage machine learning techniques. Seismic facies analysis has traditionally been performed using two different machine learning methodologies. The first is unsupervised machine learning, which determines the natural clusters in the seismic data where the inputs are seismic attributes. The second is supervised learning, which learns a mapping between seismic attributes and their associated classes (e.g., facies determined from well data) using what is called the training (or labelled) data. This mapping can then be used to make class predictions for the data not used in training (i.e., the testing/unlabelled data). A challenge with these problems is the training data are characteristically sparse. This makes supervised algorithms prone to a phenomenon called overfitting, which causes the predictions to have high variance. An alternative is semisupervised learning (SSL) techniques because they incorporate both the labelled and the unlabelled data during training, and this has been shown to improve predictions in scarce training data situations.

Semisupervised algorithms are largely unexplored in geoscience applications, and we explore their potential here on a synthetic study. We provide a workflow for performing seismic classification of this synthetic model that consists of four stages. The earlier stages synthesize the seismic data from the model and build the classes for the labelled data using unsupervised learning. A latter stage involves estimating a ground-truth facies model using machine learning where the training data amount to roughly 0.2% of the full dataset. We show that our semisupervised algorithm can capture more detail compared to a popular supervised approach. This supports the hypothesis that semisupervised algorithms can recover better predictions than supervised methods in the context of minimal training data.

Structural, lithological, and geochronological constraints on the initial cycle of amalgamation of the Great Paleoproterozoic Accretionary Orogen (1.9–1.8 Ga): insight from the Makkovik Province, Labrador, Canada

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The Great Paleoproterozoic Accretionary Orogen marks a period of global amalgamation of Archean cratons and crustal slivers, as well as Paleoproterozoic juvenile crust and cover sequences along the margin of Laurentia from 2.0 to 1.0 Ga. The Makkovik Province of Labrador preserves part of this record of crustal growth. The Makkovikian orogeny resulted in the reworking of the southern margin of the Archean North Atlantic Craton (NAC) and the accretion of juvenile terranes during a period of protracted collisional events along strike, an event broadly coeval with the Ketilidian orogeny of southern Greenland.

Subduction-related magmatism in the Makkovik Province was coeval with crustal reworking and juvenile crustal growth from ca. 1883 to 1848 Ma. The crustal architecture is best illustrated by the foliated syntectonic plutonic rocks of the Aillik Group. The principal structural elements in the group are large, upward-facing, gently-plunging folds with axial-planar fabrics, concomitant with upper-greenschist to lower-amphibolite metamorphism. Regional mapping and structural analysis indicate a zone of structural divergence occurs at the Big Island Shear Zone. The resulting structural fan separates a region of northwest-verging folds and thrusts to the west, and contemporaneous upright to northeast-verging folds to the east; consistent with heterogeneous sinistral transpression. This fan is interpreted to have formed above a subduction zone and was subsequently translated northeast during the Makkovikian orogeny.

Subduction-related magmatism in the Makkovik orogen resulted in significant crustal reworking and juvenile crustal growth. The Aillik Group formed in a back-arc setting, with the data suggesting the substrate of the arc could have either been relatively juvenile crust or reworked ca. 2.6 to 2.3 Ga Archean cratonic material. In the latter case, the substrate may be related to similar aged blocks preserved in the Southeast Churchill Province, or equivalents that extended south of the NAC.

The Pinwarian Laurentian margin and the architecture of the central Grenville Province, Canada

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Despite pervasive high-grade metamorphism and deformation during the ca. 1.0 Ga Grenvillian orogeny, the Grenville Province in Canada preserves important record of the growth and evolution of the SE Laurentian margin (present-day coordinates) throughout the Mesoproterozoic. Most widespread crust formation occurred in the 1.50–1.35 Ga time period, the early part of which is known as Pinwarian. In Canada, the 1.50–1.35 event is manifested by two continental arc systems, separated by a composite arc belt (Quebecia) in the central Grenville Province. The later preserves a record of rifting at 1.5 Ga, building of island arcs on rifted, pericratonic crustal slivers at 1.5–1.45 Ga, and re-amalgamation of these slivers at 1.4–1.35 Ga with development of a Quebecia-scale felsic plutonic belt. Differences between Quebecia and the continental arcs elsewhere in the Grenville at 1.5–1.35 Ga are attributed to lateral variations in subduction dynamics under Laurentia at that time, comparable to the modern-day Andean system.

This configuration, and the lithospheric-scale scars that it entailed, may have been responsible, to some extent, for some later features unique to the central Grenville, such as: (a) the development of two, 1.1 to 1.0 Ga anorthosite clusters at the former boundaries of the different segments of the ca. 1.5–1.4 Ga subduction system (i.e., between Quebecia and the continental arcs to the east and west); (b) the location (broadly parallel to the former rift zone in Quebecia) and development of a major shear zone network including the St. Fulgence deformation zone (SFDZ), that was active throughout the Grenvillian orogeny and is linked to the emplacement of voluminous high-temperature magmatic bodies from ca. 1.1 to 1.06 Ga; and, (c) the presence, south of the SFDZ, of the most extensive section of the low-pressure belt preserved in the Grenville Province.

Investigating the role of Iberia and its interplay with the Newfoundland and Irish offshore margins using plate reconstructions

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The tectonic evolution of the southern North Atlantic is a subject of increasing interest due to its continental margins playing host to several world-class frontier regions for oil and gas exploration. The Newfoundland-Iberia conjugate margin pair serves as one of the best studied non-volcanic rifted conjugate margin pairs in the world, and is a topic of constant scientific debate due to its complex plate kinematic history and geological evolution. Recent adaptability of the GPlates freely available plate tectonic reconstruction software provides an excellent tool for gaining insight into complex plate kinematic problems. The ability to account for regions of deformation, integration of various geological and geophysical datasets, and the ability to calculate temporal variations in crustal thickness, strain rates, and velocity vectors provide an optimal environment for solving crustal-scale geological and geophysical problems. Building upon previous rigid and deformable plate tectonic modelling studies, the aim of this work is to create deformable plate tectonic models of Iberia with emphasis on the West Iberian margin and the Pyrenees to assess Iberia's evolution during the formation of the southern North Atlantic from 200 Ma to present day. A comparison of crustal thickness results calculated from GPlates models with those obtained from gravity inversion, passive and controlled source seismology, and geological field mapping, provided a good metric for investigating the plate kinematics of Iberia and assessing previous discrepancies when considering the crustal evolution of the West Iberian margin and the Pyrenees as an integrated plate kinematic system. Results from the GPlates models produced in this study also demonstrate the significance of continental fragments and their independent motion during rifting. In particular, we investigate the independent motion of the Galicia Bank and its role with respect to the deformation experienced within the Galicia Interior Basin and the role of the Ebro Block and Landes High during deformation prior to the Pyrenean Orogeny. In addition, this study highlights the importance of inherited structures with respect to the styles of deformation experienced during rifting of continental crust. Preliminary deformable plate modelling results of the West Iberian margin indicate that the independent motion of the Galicia Bank and its interplay with inherited structures is crucial for deriving the amount of deformation inferred by gravity inversion and regional seismic studies within the Galicia Interior Basin.

Exposed on Fogo Island: the magmatic history of a mushy intermediate system

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Sorting out the magmatic history of a batholith is fraught with issues. Magmatic systems which produce batholiths are large, long-lived (a few to several million years), open and pulsed. The individual pulses of magma, particularly toward the late stages of batholith formation, may have experienced a tortuous path through a complex plumbing system and components within them may be sourced and modified at varied times and locations along the path. A pulse may experience further modification (mingling, mixing, fractionation, fluid alteration, recrystallization etc.) during and after emplacement.

Fogo Island, off the north coast of Newfoundland, is underlain by the suitably complex Silurian-Devonian 'bimodal' Fogo Batholith, which was emplaced over ~13 Ma during transtensional motion along a major lithospheric suture. Through a series of fortunate circumstances, Wild Cove East, on the northeastern coast of Fogo Island, provides a window into the magmatic history of part of the batholith. The well-exposed outcrops along the cove are mainly chemically similar tonalite to quartz diorite. The similar, intermediate compositions allowed a wide liquidus-solidus interval and no chilled margins between units. The units are nevertheless distinguishable based on colour or by the abundance of darker magmatic enclaves, allowing contacts to be mapped in detail. Based on field relations and petrography, we conclude that the oldest unit, 'enclave poor tonalite' (EPT) emplaced in a series of pulses under a warm granite roof, with venting and crystal compaction. A late diorite intrusion formed a small sill, which compressed the underlying EPT mush generating tube and ladder structures. 'Enclave rich tonalite' (ERT) with a crystallinity of ~20% and including dark, rounded mush enclaves, intruded fluid pockets of EPT mush, with no chills and little chemical exchange, and did not vent. A slab of overlying granite stopped into the underlying mush, revealing the relative rheologies of the units. After ERT intrusions, the mushes cooled with little further motion. A few later intrusions cut the stiffer mushes as dykes. Distinct variations in the compositions of enclaves now in close proximity indicate magma mingling on or prior to emplacement. On a smaller scale, variability in crystal compositions and textures within single thin sections indicate complex mixing histories at deeper levels.

Geothermal energy in Canada: the basics

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We report on our takeaways from a recent workshop "Geothermal Technology in Canada: Future Pathways" held by the Waterloo Institute of Sustainable Energy. Geothermal energy is often the "forgotten renewable", and it has a patchy history of commercial applications, however it is timely to consider investment in this technology in Canada.

Canada is a cold country. This provides two positives for geothermal energy. First, the efficiency of conversion of temperature differences ($\Delta T = T_{hot} - T_{cold}$) to electricity depends on $\Delta T/T_{hot}$, and if T_{cold} is lower, T_{hot} can also be lower. Second, more than 60% of Canada's energy needs are related to heating of space and water. Geothermal heat can supply these needs directly and efficiently, without requiring electricity or fossil fuels, of particular use in remote northern communities, which today rely on costly transport of diesel and propane.

There are two basic ways of accessing geothermal heat: closed systems, where cold fluid is pumped down the centre of a pipe and returns along the outside, absorbing heat from the surroundings; and open systems, where hot water from a briny aquifer is pumped up and the cooled water returned along a separate drill hole which ends at some distance from the uptake. Both require drilling, often the major cost. Closed systems are most efficient with wider boreholes than conventional oil wells, and open system boreholes must be carefully lined to avoid ground water contamination.

The sedimentary basins underlying Alberta and southern Saskatchewan, dotted with oil wells and therefore rich in geothermal data, are obvious locations for exploitation. The Canadian Shield, the site of many remote communities, presents challenges.

Varied sources of late-orogenic magmatism in the Grenvillian hinterland: chemical signature of intracontinental subduction and implications

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Late Grenvillian magmatic signatures in the hinterland of the Grenville Province are diverse as a result of involvement of varied sources including asthenosphere, enriched lithospheric mantle, and crust. Recent studies have reported several within-plate type, alkalic syenite-granite plutons and anorthosite-mangerite-charnockite-granite (AMCG) suites followed by pink leucogranites, rare-earth element (REE)-rich pegmatite granite dykes, peraluminous two-mica garnetiferous leucogranite and pegmatites, and potassic to ultrapotassic dyke suites. Among these, the ca. 1005–1002 Ma REE-rich pegmatites yielded zircon with enriched Hf isotope and supra-mantle O-isotope compositions that were interpreted by others to have derived from melting of foreland paragneiss beneath the hinterland. Conversely, whole-rock major and trace element and Sr-Nd-Pb-O isotope data from the ca. 1000–980 Ma potassic to ultrapotassic dykes suggest involvement of subduction-metasomatized, heterogeneous, veined peridotite sources within EM-I type sub-continental lithospheric mantle (SCLM) that was further metasomatized at source by a latest phase of late-Grenvillian fluids/melts derived from subducted continental crust.

These new geochemical and geochronological data, combined with previously published structural and geophysical evidence, suggest the late-Grenvillian flat subduction of foreland Superior lithosphere beneath the Grenvillian hinterland. The intracontinental subduction was short-lived and probably terminated because of buoyancy constraints related to the refractory character of the subducted Archean lithosphere. These findings also suggest that post-collisional melting of subducted foreland crust and underlying enriched SCLM, as a result of possible orogenic relaxation or delamination of thickened lithosphere, have broader tectonic and economic geology implications similar to those reported from the Himalayan-Tibetan collisional orogen.

A missing link between active and ancient seafloor hydrothermal systems? Magmatic volatile influx in mafic VMS: the exceptionally preserved Mala VMS, Troodos, Cyprus

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Reconciling observations between ancient Volcanogenic Massive Sulfide (VMS) and actively forming Seafloor Massive Sulfide (SMS) deposits is critical in understanding the source and processes that govern metal enrichment in VMS hydrothermal systems. The Mala VMS deposit of the Troodos Ophiolite, Cyprus is unusual for a mafic VMS deposit as pyrite is enriched in magmatic volatile elements (Au, Te and Se), and sulfide $\delta^{34}\text{S}$ values average -3.8‰ ($n = 28$), and gypsum averages $+14.5\text{‰}$ ($n = 26$). This is a stark contrast to the bulk Troodos VMS pyrite which averages $+4.6 \pm 0.8\text{‰}$ ($n = 160$). To date this combination of features has only been observed in actively forming SMS deposits in immature, subduction influenced environments. Traditionally, the leaching of igneous lithologies is considered the primary source of metals in these mafic VMS systems, however, at Mala this may not be the case. At Mala, and perhaps the wider mafic VMS environment, we suggest that metals were initially sourced from the direct contribution of a magmatic volatile phase where SO underwent disproportionation, a signature that may be overprinted by seawater during deposit maturation and therefore not preserved in ancient analogues. Thus, Mala provides a missing link between active immature magmatic volatile-dominated SMS in subduction-influenced systems and ancient on-land analogues.

Discovery Global Geopark: a North American candidate for UNESCO Global Geopark designation on the Bonavista Peninsula, Canada

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Discovery Aspiring Geopark is located on the Bonavista Peninsula of Newfoundland Labrador, Canada. The region of the aspiring Geopark includes approximately 280 km of stunning rugged coastline and covers an area of 1150 km². The Bonavista Peninsula's diverse geology reveals a unique opportunity to connect how this area's geological past shapes the landscape, where people live, what they eat, and economic activity. Discovery promotes itself as "Half a

Billion Years in the Making”, connecting stories of people and their coastal backdrop.

The coastal geology offers a unique opportunity to observe, study, and celebrate one of the most significant transitions in Earth’s history: the Ediacaran Period, and its associated rise of animal life. With rocks over half a billion years old, the aspiring Geopark is host to some of the most spectacular and exceptionally preserved Ediacaran fossils anywhere in the world. As a site of continuing scientific research, new discoveries are still being made, including the recent find of *Haootia quadriformis*, the first fossilized evidence of muscular tissue, and possibly the oldest animal fossil.

The Bonavista Peninsula is a key tourism destination, showcasing a rich cultural heritage, local folklore and traditions, and an enchanting colorful history. The hiking trails within the aspiring Geopark give visitors remarkable vistas of a host of coastal formations, including caves, arches, and sea stacks. Through these stunning landscapes, active geomorphological processes can be viewed at the interface between land and sea. The aspiring Geopark initiative aims to raise awareness about the region’s geological heritage so everyone can experience and enjoy the geology. The aspiring Geopark engages local communities and its residents in the planning and management of the Geopark, to promote geoconservation and to contribute to local economies through sustainable geotourism.

Unraveling cryptic signatures in fine-grained sediments from parts of southeastern Nigeria: a geochemical approach

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Geochemical signatures of sedimentary rocks provide reliable proxies that allow a better understanding of sedimentary processes. Representative shale samples from the Enugu and Awgu shales, southeastern Nigeria, were studied using geochemical tools. The purpose of the research is to apply inorganic geochemical proxies and discriminant tools used in sedimentary geology to appraise the degree of source area weathering and to reconstruct the provenance and paleo-depositional environment of the sediments.

The result reveals the depletion of most major elements, notably CaO, MgO, Na₂O, K₂O, and MnO, suggesting high mobility during weathering processes. This was affirmed by the high values of several weathering indices such as

Chemical Index of Alteration (CIA; 85.48–95.70), Chemical Index of Weathering (CIW; 95.76–99.73), Plagioclase Index of Alteration (PIA; 95.18–99.70) and the Al₂O₃-(CaO + Na₂O)-K₂O ternary relationship, indicating intense weathering in the source area. The remarkable enrichment in light rare-earth elements (LREE), the negative Eu anomalies (0.70–0.91) and elemental ratios (La/Sc, La/Co, Th/Co, Th/Cr, Cr/Th, Th/Sc) diagnostic of provenance suggest derivation from predominantly felsic sources. The geochemical data also support that the sediments were deposited in a passive margin setting. An oxic paleo-environment of deposition that alternated between marine and continental depositional settings was suggested for the sediments based on redox-sensitive geochemical parameters (Ni/Co, V/Cr, Cu/Zn, U/Th), the (K₂O/Al₂O₃)/(MgO/Al₂O₃) relationship, and the paleo-salinity proxy (Sr/Ba; 0.25–2.04).

By implication, this research presents an improved understanding of the geology of the area, particularly from a geochemical perspective, and offers a chance to observe the sensitivity of some key trace elements in constraining provenance signatures. Due to the paucity of inorganic geochemical data for the sediments, subsurface studies of core samples as a comparative approach to the outcrop information reported in this research are recommended.

Gravitationally-driven extensional collapse of a Proterozoic large hot orogen: the Grenville example

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In the late 1990s, empirical evidence for mid-crustal flow and upper-crustal extension in the hinterland of the Himalaya-Tibet Orogen initiated a paradigm-shift in understanding of the tectonic evolution of large hot orogens with double-thickness crust under an orogenic plateau. The gravitationally-driven flow of melt-weakened mid-crust under the mass of the overlying upper crust suggested that late-orogenic crustal extension (aka orogenic collapse) was inevitable in ancient large hot orogens—and that it may exercise fundamental control on the subsequent gradual return of crust to normal thickness and thermal profile. This prediction has been tested in the Mesoproterozoic–Neoproterozoic Grenville Orogen over the last 20 years, which some now consider as one of the best Precambrian examples of a collapsed large hot orogen (although there

remains abundant scope for additional study). This presentation focuses on the signal of late-orogenic collapse at various scales in the Grenville Province.

Orogen-scale evidence for collapse of the Grenvillian hinterland comes from the post-peak extensional juxtaposition of belts of gneisses with contrasting peak-Ottawan metamorphic pressures, ranging from ≥ 1.1 to ≤ 0.6 GPa (orogenic infrastructure), to remnants of the orogenic superstructure (“orogenic lid”) that lack evidence for significant Ottawan metamorphism and ductile deformation. Regional-scale evidence includes the juxtaposition of orogenic infrastructure and superstructure in large extensional metamorphic core complexes, and outcrop-scale evidence includes recognition that much of the structural and metamorphic character of the gneissic infrastructure developed after the Ottawan metamorphic peak during extension, exhumation and retrogression.

Recent results from the western Grenville Province are discussed in order to illustrate progress in understanding the late-tectonic evolution. We conclude that, in addition to the paradigm-shift in understanding of tectonic processes, it is the regional scale of the metamorphic core complexes, which greatly exceeds the purview of most mapping and structural-metamorphic studies, which has led to under-appreciation of the profound role of extensional orogenic collapse in the Grenville Orogen until recently.

compare calculated deposit growth rates to geochemical flux data determined from estimates of hydrothermal fluid flux and fluid elemental concentrations to calculate efficiency of entrapment and precipitation of hydrothermally mobilized Cu, Zn, Fe, Mn, and Si at the seafloor.

The precipitation efficiencies differ for different elements, following a predictable pattern where elements associated with minerals that precipitate at higher temperature (e.g., Cu) are more efficiently trapped in the deposit than elements that precipitate at lower temperatures (e.g., Mn, Si). Striking differences of efficiencies of metal precipitation are also found when comparing two mounds in the Lucky Strike field. We attribute this difference to mound maturity as one of the mounds is older, larger and has a higher content of barite that helps seal the system and prevent metal to escape to the seafloor. These results highlight the importance of the barite cap that can enhance zone refining and produce larger deposits.

We find that rates of formation at the vent field scale are comparable to other sites along mid-ocean ridges. However, efficiencies of metal entrapment at Lucky Strike appear to be higher than previous estimates for depositional efficiency of metals at the seafloor.

Assessing the growth rates and the fate of metals during the formation of VMS deposits: a case study from the Lucky Strike Vent Field, Mid-Atlantic Ridge

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One of the fundamental questions in ore deposit research is the rate at which mineral deposits form. Often, studies rely on dating methods to try to answer these questions. However, often the answer is within the calculated error of the different dating methods (e.g., U–Pb zircon dating). In this study, we present metal concentrations, U-series geochronology (²²⁶Ra/Ba) of hydrothermal barite, and sulfide tonnage estimates from the mafic-hosted Lucky Strike vent field, an actively forming volcanogenic massive sulfide (VMS) deposit on the Mid-Atlantic Ridge. We

New insights into ca. 1.88 Ga ocean redox conditions from the Sokoman Iron Formation, Labrador Trough, Canada

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The ca. 1.88 Ga Sokoman iron formation (IF) in the Labrador Trough is an economically important sequence hosting a range of iron ore deposits from low-grade taconite (least-altered), metataconite, and high-grade (>55 wt. % Fe) direct shipping ore. The Sokoman IF, along with other similarly aged Late Paleoproterozoic IFs, are important archives of ocean-atmosphere chemistry during a punctuated return of massive IF deposition in the Late Paleoproterozoic (relative to the Archean when such conditions were more common). Previous studies have examined various geochemical, mineralogical, and sedimentological aspects of the Sokoman IF deposition, but none have yet applied a comprehensive, modern geoanalytical reconstruction of the least-altered taconites – the units with the highest potential to record basin paleo-redox architecture and marine solute

sources and thus new insights into the Proterozoic Earth surface.

This contribution will focus on samples collected from four drill holes (12-SL-1018D, 12SL-1017D, 12SL-1011D, 12-SL-1005D) across the Sheps Lake Property (New Millennium Iron Corp.) and will incorporate quadrupole-inductively coupled plasma mass spectrometry (Q-ICP-MS) ultra-trace element data, with emphasis on the rare-earth elements and yttrium (REE + Y), along with mineralogical observations derived from petrography and scanning electron microscopy-mineral liberation analysis (SEM-MLA). Preliminary observations will outline: (1) negligible overprinting of IF chemistry by insoluble element-rich detrital particles (ultra-low Al, Ti, Nb, Zr, etc.); (2) pervasively terrestrial over hydrothermal sources of soluble REE + Y (minimal Eu anomaly and positive La-Gd-Y anomalies); and (3) Fe/Mn-redox-stratified basin conditions with Fe-Mn-(oxyhydr) oxide shuttles resulting in both positive and negative Ce anomalies. The chemostratigraphic REE variations appear to track depositional depths in the water column and are in general agreement with depositional sequences defined previously with sequence stratigraphy. The Sokoman IF is understudied relative to other ca. 1.88 Ga IFs and collectively, these new data are important to establishing a more global perspective on ocean-atmosphere chemistry in the Late Paleoproterozoic.

Uranium potential within Proterozoic rocks of the eastern Central Mineral Belt of Labrador, Canada: a comparison of the 1980s to the 2020s

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The Central Mineral Belt (CMB) of Labrador has long been recognized for its uranium potential and has been the focus of intermittent uranium exploration since the first prospect was discovered in the late 1950s. Proterozoic rocks of the CMB are locally host to significant concentrations of uranium mineralization, which were largely investigated during the early 1950s to the mid-1980s, when a decline in demand in world uranium markets marked an end to exploration in the region. One of the first regional summaries, which included a review of the early exploration activities, descriptions of significant uranium occurrences and a discussion of potential deposit models, was previously published. Much of this work remains relevant some forty years later, and formed the basis for renewed uranium

exploration activities during the late 2000s. Despite some modifications in the overall timing of mineralizing events, much of the initial information provided in the regional synthesis of the 1980s is still applicable to the development of uranium mineralization within the eastern CMB.

Optimizing the CO₂ sequestration rate of ultramafic rocks of the Tablelands, Newfoundland and Labrador, Canada

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Increasing levels of carbon dioxide (CO₂) in the atmosphere and its effect on global climate has become the focus of international concern and research. An important area of research has been investigating mitigation methods through the removal and storage of CO₂ from the atmosphere. One promising method for the storage of carbon dioxide is through the naturally occurring process of serpentinization of ultramafic rocks and the resulting precipitation of carbonate minerals (carbon mineralization). Carbon mineralization requires both the dissolution of ultramafic rocks and the precipitation of carbonate minerals. The serpentinization process produces two types of water, Type I (Mg²⁺ and OH⁻ rich, pH 9–10) and Type II (Ca²⁺ and OH⁻ rich, pH 12–13), both of which may play an important role in the carbon mineralization process. Our study focused on the rocks of the Tablelands, a part of the Bay of Islands Ophiolite Complex located in western Newfoundland. Previous studies of these ultramafic serpentinized rocks discovered sites of natural carbon mineralization in the form of a series of ultra-basic springs of Type I and Type II waters. This study focused on the optimal conditions for CO₂ sequestration and mineralization. We performed bench-top CO₂ sequestration experiments using whole and crushed rock from the Tablelands and varied parameters such as pH, water chemistry, and CO₂ concentration to determine their effect on the rate of carbon mineralization. We found that: (1) higher pH waters increased the rate of CO₂ sequestration and also showed evidence of carbonate precipitation, (2) at lower pH values, there was evidence of increased mineral dissolution compared to the higher pH experiments, and (3) the effect of increased surface area varied as pH values increased.

3D modelling and inversion of airborne gravity gradiometry data from the Budgell's Harbour Stock, Newfoundland, Canada

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Airborne gravity surveys have developed and become a popular tool for mineral exploration in the past three decades, mostly because of considerable improvements in equipment. Airborne methods make the data acquisition process rapid, more straightforward as no direct ground access is required, and hence potentially cheaper than ground gravity surveys. Also, the data coverage can often be much denser than for a ground survey. Here, 3D modelling and inversion of a gravity gradiometry data-set from Budgell's Harbour, located in north-central Newfoundland, is carried out. Reef-type platinum group mineralization is present in the area, as well as a large scale, deep igneous intrusion termed the Budgell's Harbour Stock. The intrusion is thought to be related to the same tectonic activity that resulted in the formation of the basins off-shore Newfoundland that is now being actively explored for hydrocarbons. The gravity gradiometry survey was performed by Bell Geospace using their Air-FTG system. Line spacing was 200 m, covering a total of 407 km, with an 80 m altitude. The topography of the survey area is moderate. 3D forward modelling and inversion, specifically taking into account topography, were done on this data set. The inversions were typical unconstrained, minimum-structure inversions. The Earth model was parameterized in terms of an unstructured tetrahedral mesh, which allowed the topography to be modelled to the same accuracy with which it is known. The goal is to develop a 3D density model of the area, thus further assessing the mineral potential of the area and better delineating the Budgell's Harbour Stock.

Geothermobarometry and $^{40}\text{Ar}/^{39}\text{Ar}$ incremental release dating in the Sandwich Bay area, Grenville Province, eastern Labrador, Canada

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The determination of metamorphic pressure and temperature estimates and $^{40}\text{Ar}/^{39}\text{Ar}$ incremental release dating of hornblende in the Sandwich Bay area, Grenville Province of eastern Labrador were used in an attempt to distinguish between pre-Grenvillian and Grenvillian metamorphic effects on three contrasting regional-scale lithotectonic terranes, namely the Groswater Bay, Lake Melville and Hawke River terranes. Geothermobarometric conditions calculated from kyanite- and sillimanite-bearing assemblages in paragneiss and garnet-pyroxene assemblages in mafic rocks revealed similar metamorphic temperature ranges of ~615 to 900°C in each lithostructural terrane, but exhibited a marked contrast in metamorphic pressures of 9 to 12 kbar for the Groswater Bay Terrane in the north and 6 to 10 kbar for the Hawke River and Lake Melville terranes to the south. Discordant $^{40}\text{Ar}/^{39}\text{Ar}$ spectra suggest variable argon loss or the introduction of excess argon during regional metamorphism. However, five well-defined plateau ages range from ca. 1260 to 980 Ma and imply that the effects of Grenvillian metamorphism were variable and modest in the two northern terranes, whereas Grenvillian thermal effects on the Lake Melville Terrane were more pervasive. High grade pressure-temperature estimates derived from mineral equilibria in paragneiss and mafic rocks from these terranes may reflect the depth from which the pre-Grenvillian rocks were exhumed during Grenvillian orogenesis.

Paleomagnetic evidence for late Carboniferous (or younger) counter-clockwise rotation of Meguma terrane, southern Nova Scotia, Canada

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Paleomagnetic results have been obtained from the Mavillette gabbro, a plagioclase-rich gabbroic sill in southwestern Nova Scotia closely related to metavolcanic and metasedimentary rocks of the Silurian White Rock

Formation. This rift-related magmatism took place in turbiditic rocks of the Halifax Group, and likely marks the beginning of Meguma terrane drift towards Laurentia. The age of the Mavillette gabbro has been determined to be 426 ± 2 Ma (U–Pb baddeleyite), making it notably younger than, and probably not co-magmatic with, ca. 440 Ma bimodal volcanic rocks of the White Rock Formation. The Mavillette gabbro forms an arcuate body, folded about a regional southwest-plunging syncline of Neoacadian age (ca. 390 Ma). Paleomagnetic investigation of thirteen sites (136 specimens) distributed along the synclinal limbs of the gabbro revealed ancient magnetizations carried by magnetite that fail a fold test and are therefore not related to the emplacement of the intrusion. The post-folding remanence, with a mean direction of $D = 153.4$, $I = 17.1^\circ$; $\alpha_{95} = 6.5^\circ$ ($n = 12$ sites), is similar to a pervasive Kiaman overprint magnetization in North America, acquired in Late Carboniferous time, but is significantly rotated $21^\circ \pm 5^\circ$ counter-clockwise from the reference Kiaman direction. Previously published results from the White Rock and Cheverie Formations in exposures along the Annapolis Valley also have late Carboniferous remanence directions with similar $\sim 20^\circ$ CCW discordance, implying that Meguma experienced a post-Kiaman rotation with respect to North America. Remanence acquisition in the region is coincident with regional muscovite and hornblende $^{40}\text{Ar}/^{39}\text{Ar}$ ages, and with the ca. 318 Ma arrival of Meguma in SE New Brunswick. The regional CCW rotation of Meguma post-dates this ca. 320–300 Ma tectonothermal and remanence acquisition event, and must mark either a final CCW rotation of Meguma terrane during the Alleghenian orogeny, or possibly a rotation of Meguma during the Mesozoic opening of the Bay of Fundy.

The Central Mineral Belt, Labrador, Canada: 800 myr of metallogeny defined by Re–Os molybdenite dates

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The Central Mineral Belt (CMB) comprises a series of six successive Proterozoic supracrustal sequences and

associated Archean basement rocks occupying a 260-km by 75-km area in central to coastal Labrador. The CMB juxtaposes and contains elements of the Nain, Churchill, Makkovik and Grenville structural provinces of the Canadian Shield. The belt hosts most of the known base metal and uraniferous deposits in Labrador, along with significant molybdenum and rare-earth element resources. The constituent Proterozoic sequences are the Post Hill, Moran Lake, Aillik, Bruce River, Letitia Lake and Seal Lake groups, which range in age from ca. 2000 to ca. 1275–1225 Ma. The CMB supracrustal sequences have been variously overprinted by the ca. 1900–1780 Ma Makkovikian, ca. 1710–1620 Ma Labradorian and ca. 1080–970 Ma Grenvillian orogenic events. There were also four significant plutonic events within the CMB at ca. 1895–1870, 1815–1790, 1720–1715 and 1650–1640 Ma.

We have dated molybdenite separates via Re–Os techniques from five different syngenetic occurrences across the belt, which coincide with peaks in magmatism/ metasomatism/ metamorphism in the CMB and a set of two samples from sediment-hosted stratiform copper mineralization in the Seal Lake Group, which formed as vein systems related to the Grenville Orogeny. As a complete set, these samples are brackets to CMB metallogeny. At Tom's Cove, near Makkovik, molybdenite, from a silicate skarn hosted by amphibolite rocks that are part of the ca. 1883–1865 Ma Aillik Group, has been dated at 1868.2 ± 7.5 Ma; this sample also contains the most elevated Os (4395 ppb) and Re (221.2 ppm) contents of all CMB molybdenites. Molybdenite from quartz veins at the partially developed, subeconomic Aillik Mo Deposit (11 km NE of Tom's Cove) returned an age of 1786.2 ± 23.7 Ma; the sample curiously also contained the lowest Os (1.47 ppb) and Re (0.077 ppm) contents of all CMB molybdenites. At the LM-12 showing, 10 km east of Tom's Cove, molybdenite from a well-developed Aillik Group-hosted stockwork was dated at 1787.4 ± 7.5 Ma. A small granite cupola at Duck Island, 15 km SW of Tom's Cove, contains molybdenite within miarolitic cavities that was dated at 1665.7 ± 10.1 Ma. The Burnt Lake showing, 65 km SW of Tom's Cove, contains molybdenite in ca. 1670–1650 Ma granite along its contact with Aillik Group host rocks; the molybdenite here returned a 1659.2 ± 6.7 Ma age. Finally, two molybdenite separates from the Whisky Lake Cu Showing (185 km SW of Tom's Cove) hosted by the 1270–1225 Ma Seal Lake Group, were dated at 1069.6 ± 4.7 Ma and 1064.6 ± 5.1 Ma, respectively similar to a previous published Re–Os age of 1084 ± 5.1 Ma reported a for molybdenite.