Geological Association of Canada Newfoundland Section

ABSTRACTS

2014 Spring Technical Meeting
February 17-18, 2014

JOHNSON GEO CENTRE, SIGNAL HILL, ST. JOHN'S, NEWFOUNDLAND

The 2014 Spring Technical Meeting was once again held in the depths of the Newfoundland winter in the Johnson GEO CENTRE on scenic Signal Hill in St. John's.

The meeting featured a special session on Monday afternoon entitled "Offshore Petroleum Basins: A New Frontier" which covered a wide range of subjects related to offshore petroleum basins, including geology and geophysics, plate reconstruction, offshore engineering and environmental considerations In addition, general sessions (Monday morning and all day Tuesday) included papers on an eclectic range of topics, as is normally the case at these meetings.

Due to unforeseen circumstances the "Public Lecture" series, sponsored by the Professional Engineers and Geoscientists of Newfoundland and Labrador (PEG-NL) was postponed to a later date. The speaker would have been Dr. Andrew Kerr from the Department of Natural Resources, Geological Survey with a talk entitled "Holmes and the Indelicate Question: Measuring the Depth of Time with the Clocks of the Earth."

As always, this meeting is brought to you by volunteer efforts, and would not be possible without the time and energy of the executive and other members of the Newfoundland and Labrador Section of the Geological Association of Canada. We are also indebted to our partners in this venture, particularly the Alexander Murray Geology Club, the Johnson GEO CENTRE, the Newfoundland and Labrador Department of Natural Resources and our corporate sponsors. 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.

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Nalcor Exploration update: The deep water potential

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The Canadian province of Newfoundland and Labrador (NL) is currently experiencing its highest levels of exploration and development activity and its oil production, though declining, is still high. In 2011, NL production represented 10% of Canada's total oil production, 32.5% of Canada's conventional light oil, and more than 85% of Atlantic Canada petroleum output. Development work is proceeding on the Hibernia Southern Extension and White Rose Growth projects and the sanction of the Hebron Project is scheduled to occur in Q1 of 2014. The most recent exploration activities offshore Newfoundland includes drilling, acquisition of large 2D and 3D seismic surveys, and satellite seep survey studies carried out in the Mesozoic Labrador, Jeanne d'Arc, Flemish Pass, and Laurentian basins and in the Paleozoic Anticosti and Magdalen basins off western Newfoundland.

In 2009, Nalcor Energy initiated an exploration strategy to better understand the frontier basins in the province's offshore through the acquisition of new geoscience data. The intent was to reduce exploration risk and stimulate more exploration activity. In 2010, a satellite seep survey was conducted by Astrium that indicated the presence of oil seeps in some unexpected areas, like the deep water off Labrador. In 2011, Nalcor partnered with the MKI consortium (TGS and PGS) to acquire a large, long-offset, broadband 2D seismic survey in the area off Labrador. Over 70% of this 22,000 km survey area had no previous data coverage. The survey has extended the previously known basins into the slope and deepwater, has delineated three new deepwater basins and improved our understanding of the petroleum geology of Canadian Labrador margin.

In 2012, the survey was extended south to the Orphan and Flemish Pass basins. By the end of this year, 50,000 km of new regional seismic data will be shot and available for licensing. This dataset has provided a number of new insights and leads in this frontier region and has better imaged exciting undrilled prospects in the Flemish Pass Basin where Statoil recently announced their "high-impact" Bay du Nord light oil discovery. Early seismic AVO analysis on multiple seismic lines has revealed attributes that may be positive hydrocarbon indicators. They especially show interesting anomalies within basin floor fans that may be analogous to those off West Africa.

Additional offshore Newfoundland and Labrador studies include regional pore pressure, rock physics, and source rock studies, as well as biostratigraphy and seabed core analyses. The finished reports will be made available on the Nalcor's website to any interested company.

All of this exploration and development activity in the region points to the potential of major increases in production and development in the years to come. Newfoundland and Labrador is on the threshold of an amazing new era for the petroleum industry.

Adsorption and dissolution experiments of acid mine drainage from the former Consolidated and Gullbridge mines, Newfoundland and Labrador, Canada

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Acid mine drainage (AMD) is an environmental concern because it produces low pH waters which are contaminated with high concentrations of dissolved metals. We performed adsorption and desorption experiments to investigate natural and potential enhanced remediation of AMD at two abandoned mining sites in central Newfoundland: the former Consolidated Mine and the former Gullbridge Mine. In conjunction with previous work, data obtained through in situ field measurements and laboratory analyses of samples collected at the two sites indicate that these sites are actively leaching AMD into downstream water bodies. Water and sediment samples were obtained from each site for use in a variety of adsorption and dissolution batch experiments.

Laboratory Experiments: Uncontaminated background sediment collected upstream from the Consolidated Mine showed little ability to neutralize pH. The background sediment, however, did substantially reduce copper and lead concentrations. Background sediments collected upstream from the Gullbridge Mine showed a much stronger ability to neutralize pH and reduce copper, zinc and aluminum concentrations. Further batch experiments tested the addition of biofoul (a mixture of mussels and seaweed that accumulates on aquaculture nets) as a method of enhanced AMD remediation. Preliminary results indicate that biofoul has the ability to neutralize pH of AMD taken from each mine, as well as reduce concentrations of some pH-dependent contaminants. The biofoul, however, contained high levels of arsenic and copper which were released into the water. Based on these preliminary results, small quantities of biofoul were chosen for batch dissolution kinetic experiments with the overall goal to partially neutralize pH and limit the levels of copper and arsenic that would be released from the biofoul. Dolomitic lime was added to assist in neutralizing the pH. However, even small quantities of biofoul yielded substantial increases in the copper concentration. Arsenic concentrations remained low throughout the experiments.

The Geological Survey of Newfoundland and Labrador, 1864–2014: Arcing 150 years of science and service

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The Geological Survey of Newfoundland and Labrador celebrates its sesquicentennial in 2014, marking a century and a half of geological mapping and resource investigations. Inaugurated in 1864 under founding Director Alexander Murray, the then-named *Geological Survey of Newfoundland* benefited from the epiphanies in the nascent science of geology of the late-eighteenth and early-nineteenth centuries (e.g., Hutton and Lyell). Explorations of a geological bent were first undertaken in Newfoundland in the early-to-mid-nineteenth century (Cormack and Jukes), and were formally inaugurated in Canada in 1842 as the Canadian Geological Survey (under the now-famous Sir William Logan, and his able assistant, the Scotsman Alexander Murray). By 1855, Newfoundland had achieved Responsible Government, and in 1864 invited Mr. Murray from Canada to head up the country's own Geological Survey.

Murray soon hired the local James P. Howley to be his assistant, and Howley eventually succeeded Murray as Director. Together these two remarkable pioneering geologists left a legacy of exquisite geological mapping, topographical surveying and geological-resource documentation. After Howley's retirement in 1909, the Survey went into abeyance until the 1920s, emerging as a vital institution in the 1930s and beyond through the infusion of intellectual vigour by the so-called Princeton Expeditions. Newfoundland-born and Princeton faculty member Alfred K. Snelgrove was the leader of these research initiatives, serving as both faculty mentor and Government Geologist: Princeton provided the graduate students; the Geological Survey the field support.

In the 1940s, former Assistant Government Geologist under Snelgrove, Claude K. Howse, became Director and facilitated a number of mineral deposit studies (he was especially involved in the exploration developments for iron ore in Labrador West). After Confederation, for most of the Fifties, the Survey was led by illustrious geologist David M. Baird, who published the most up-to-date compilation of Newfoundland geology in 1955. Throughout the Sixties, the Geological Survey, then a small organization with the appellation Mineral Resources Division, focused on specific known mineral occurrences, industrial and metallic, with the goal of enhancing development. At this time, geologists John McKillop and John Fleming were providing steady leadership, as well as being prescient harbingers of the soon-to-be born modern Geological Survey.

The 1970s and 80s were the halcyon days of the MDAs (Mineral Development Agreements). With planning by Fleming and colleagues already in place for the contemporary infrastructure of a modern geoscience institution, the Geological Survey blossomed with substantial federal-provincial funding into the acclaimed, multidisciplinary, scientific institution that it is today. With geological maps, reports and databases of every description and discipline, available to a world-wide audience via the Internet, the excellence of the current Geological Survey makes it a worthy inheritor of its venerable origins 150 years ago. Government should recognize this historic institution's preeminence in our province, in this its sesquicentennial year, by formally enshrining its name as the *Geological Survey of Newfoundland and Labrador*.

Bathyurus Perplexux Billings, 1865, not so perplexing

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The type specimen of *Bathyurus perplexus* Billings, 1865 is a pygidium (GSC 632) from faulted limestones exposed in East Arm, Bonne Bay, in western Newfoundland's Gros Morne National Park. Because of the lack of other sclerites, some workers have regarded it as a junior subjective synonym of *B. extans* (Hall, 1847); others have compared it to *Acidiphorus pseudobathyurus* Ross, 1967. The discovery of additional sclerites (cranidia, librigenae, thoracic segments, pygidia) confirms its distinctness. *Bathyurus perplexus* is widespread in western Newfoundland; it has a restricted stratigraphic range and is the nominate species of the *Bathyurus perplexus* Zone. It generally occurs in dolostones or dolomitic lime mudstones of the uppermost Aguathuna Formation (St. George Group). At Table Point, however, it ranges into the basal bed of the Spring Inlet Member of the Table Point Formation (Table Head Group). *Bathyurus perplexus* typically is associated with leperditiid ostracods (*Bivia*), an assemblage characteristic of the long-ranging, low diversity, nearshore *Bathyurus* biofacies.

Olivine composition as a fertility indicator of mafic intrusions: Examples from Voisey's Bay and Pants Lake, Labrador

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The distribution of Ni-Mg-Fe in olivine is conventionally used to assess if sulfide saturation and segregation of a potentially economic sulfide liquid have occurred in a mafic intrusion. Despite the limited geochemical resolution of this traditional application, olivine multi-trace element studies have never been adopted to expand the geochemical sensitivity of olivine as tracer of multiple ore-forming processes.

We present major and trace element data (Ca, Sc, Mg, Si, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Sr, Y, and Zr) that show informative geochemical variability in olivine from both barren and mineralized olivine-gabbro and troctolite lithologies in the Voisey's Bay (VBI) and Pants Lake intrusions (PLI). Both intrusions have broadly similar lithologies and petrographic characteristics and are approximately coeval (1.34 Ga and 1.32 Ga, respectively) members of the Mesoproterozoic Nain Plutonic Suite. However, the VBI hosts a producing economic Ni-Cu-Co sulfide deposit, whereas in the PLI, although it displays evidence of Ni-Cu sulfide mineralization, a viable ore deposit has not yet been discovered.

In general the olivine chemistry in the VBI varies systematically – more primitive (~Fo_{77}, ~1,600 ppm Ni) in barren intervals, more evolved (~Fo_{62}, ~800 ppm Ni) in mineralized sections – with a pronounced increase in especially Mn (+~7,000 ppm) and Zn (+~350 ppm) towards the mineralized base of the intrusion. These, locally abrupt, changes in composition (also in, for instance, Co, Sr, and Y) indicate: (1) that olivine crystallized from separate pulses of magma with variable degrees of differentiation, and (2) that the Fe-Mn-Zn-rich olivine in the mineralized basal intervals crystallized from an increasingly country rock-contaminated, sulfide-saturated mafic magma. The distinct element signature of this latter olivine population can be used to infer the relative vertical proximity to massive sulfides and potentially predict if economic mineralization is expected in the proximity of a drill hole terminus in the VBI.

The olivine composition from the PLI is, compared to the VBI, fairly homogeneous and more evolved (~Fo_{60}, ~340 ppm Ni, ~4,300 ppm Mn, ~460 ppm Zn) with higher concentrations of incompatible elements (e.g., Ca, Sc, Ti, and Y). It also commonly lacks the mutually Mn-Zn-rich signature of olivine from the mineralized intervals in the VBI that is characteristic of contamination of the parent magma by country rock gneiss, and there reflects a close proximity to massive sulfides. As a result, the distinct chemical variations in olivine from the economic VBI (bimodality, primitiveness) and the presently sub-economic PLI (homogeneous, evolved) provide potential as a regional-scale mineralogical indicator of fertility in mafic intrusions.

Overview of advanced drilling and geomechanics research at Memorial University of Newfoundland

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Drilling is the primary means of reaching subsurface exploration targets for oil and gas exploration and the primary means of reservoir production. In the past few decades, there has been significant progress in the tools and technology for drilling, ranging all the way from advances in bit design to development of mobile drilling systems for the harshest Arctic and deepwater environments. In 2011, several major drilling technology companies invested more than 1B USD each in drilling research, with many other smaller companies, universities, and research institutes investing millions more.

At Memorial University, the Advanced Drilling Group (ADG), consisting of 5 faculty members and nearly 30 Highly Qualified Personnel lead by Principal Investigator Dr. Stephen Butt, has been focused on laboratory infrastructure development and fundamental investigation of fixed cutter drill bit penetration mechanisms using integrated experimental and numerical simulation methods. This presentation will give an overview of the ADG research from 2006 to the present, including plans for ongoing and future research. Research to be reviewed includes: (1) influence of cutter vibration and rock-cutter compliance on penetration rates and mechanisms; (2) modeling of drill string vibration induced by drillstring rotation and bit penetration for vertical and directional well trajectories; (3) evaluation of drill string and bit vibration on bit wear and drilling tool damage; (4) development of advanced experimental drilling and geomechanics simulators; and (5) evaluation of the influence of drilling from a floating MODU and influence on bit penetration and drill string vibration.

These research areas address many of the factors that limit drilling capability in terms of offshore water depth and extended reach, drilling costs and efficiencies, and penetration rates, and ultimately contribute to defining the economic and technical barriers to drilling in deeper and harsher offshore environments. Incremental advances in drilling research and technology by the ADG at Memorial University can assist with extending drilling capabilities for future exploration and development in challenging environments, in particular those relevant for NL and Canada.

The Sawyer Lake iron-ore deposit, western Labrador: Potential for future high-grade iron-ore deposits in the Labrador Trough

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The Sawyer Lake deposit, located about 65 km southwest of Schefferville, is a new type of high-grade iron deposit that differs markedly from other deposits in the northern Labrador Trough. The deposit was initially discovered in the 1930s and sporadic exploration since then has defined a significant iron-ore resource with up to 12 million tonnes of high-grade iron ore (>60% Fe). The main ore zone at the Sawyer Lake deposit is located in the lower Sokoman Formation, below a thick sequence of volcanic rocks of the Nimish Formation. The ore forms a stratiform orebody with a saddle-reef morphology and consists of hard, massive to weakly banded high-grade hematite, containing >90% fine-grained, microplaty hematite and minor microgranular quartz. The hard hematite ore is commonly brecciated, containing angular fragments of hematite in a quartz and hematite matrix. Brecciation is associated with the collapse of hematite into open spaces created by the leaching of silica. The high-grade hematite orebody is surrounded by oxidized iron formation consisting of alternating hematite and cherty bands, and displays abundant evidence for the remobilization of hematite and quartz, and secondary hematite enrichment.

In contrast to high-grade Direct Shipping Ore deposits in the Schefferville area, no evidence of supergene enrichment has been recorded at the Sawyer Lake deposit, and syndiagenetic iron enrichment is also considered unlikely. Macroscopic and petrographic studies and comparisons with other high-grade hematite deposits worldwide indicate that enrichment is related to hypogene processes, in which hydrothermal fluids leached silica and precipitated secondary hematite. Preliminary isotopic and geochemical analyses are also consistent with a hypogene enrichment model. Although the source of hydrothermal fluids is unknown, they may be related to dewatering of underlying shales during the Hudsonian orogeny or circulation of basinal brines during regional-scale thrusting.

Onshore and offshore petroleum activity update – 2013, Newfoundland and Labrador

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The province of Newfoundland and Labrador is home to some of the largest unexplored sedimentary basins in the world, encompassing an area of about one million square kilometres. From this total, <6% of the offshore and <9% of onshore acreage is currently held under license. The offshore is regulated by the conjoint federal / provincial Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) whereas all onshore activity falls under authority of the provincial Department of Natural Resources, Energy Branch (DNR).

In the offshore, the Jeanne d'Arc basin contains four producing fields – Hibernia, Terra Nova, White Rose and North Amethyst with total annual production in the 100 million barrel range. This production accounts for approximately 30% of Canada's conventional light crude and since first oil at Hibernia in 1997, the fields have produced in excess of 1.4 billion barrels. Total discovered recoverable resources are placed at 3.6 billion barrels oil, 12 trillion cubic feet of natural gas (tcf) and about 500 million barrels of natural gas liquids. These resource numbers are based on 26 oil/gas discoveries from a total of 155 exploration wells. This represents a drilling success ratio of 1 in 6 for the entire offshore region. Currently, the total hydrocarbon endowment for the province is estimated at 10 billion barrels oil and >72 tcf natural gas.

Over the past couple of years, a number of large scale offshore seismic programs have been completed and exploration drilling in 2013 has taken place in the Jeanne d'Arc, Flemish Pass and Orphan basins. Results released thus far indicate several major discoveries by Statoil and partner Husky Energy in the Flemish Pass basin. From a regulatory perspective, the C-NLOPB offered parcels in three offshore areas for inclusion in their upcoming offshore land sale. These parcels are situated in the Flemish Pass basin, Carson basin and Gulf of St. Lawrence. They also announced, in late December 2013, implementation of a new land tenure system, proposed changes to the terms of exploration licenses, and the 2013 Call for Nominations.

In western Newfoundland, onshore operators conducted minimal exploration activity in 2013, opting to step back and re-assess exploration strategies. A number of wells currently operated by Investcan Energy Inc. in the Bay St. George basin were re-entered for work over purposes and Hurricane #2 Whip #1 well was deepened to evaluate additional potential targets. Elsewhere in the region, Black Spruce Exploration has been engaged in negotiation with other onshore permit and offshore license holders with respect to farm-in opportunities.

As part of the provincial Energy Plan released in September 2007, policy actions were introduced to encourage and promote onshore and offshore exploration activity in the province. This translated into two funded programs – the Offshore Geoscience Data Program (OGDP) and the onshore Petroleum Exploration Enhancement Program (PEEP). The OGDP was funded to the tune of $20 million dollars and accepted projects to date include a potential fields survey for offshore western Newfoundland, a satellite seeps survey for most of the offshore and a multi-client 2D seismic program targeting a vast expanse of the offshore, from northern Labrador to the southern Grand Banks. From the $5 million allocated for PEEP, a large percentage of funding went towards source rock studies, regional mapping, aeromagnetic surveys and a data scoping study. The OGDP and PEEP initiatives are jointly administered by the Department of Natural Resources and Nalcor Energy – Oil and Gas Division.

Can onshore sediments be used to fingerprint distinct sediment sources that fed offshore basins in the Labrador Sea? Preliminary results from provenance studies of onshore sediments in northern Labrador

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A collaborative study between the Geological Survey of Newfoundland and Labrador and the Geological Survey of Denmark and Greenland commenced in 2012. The project aims are to (1) investigate the orogenic development of the landscape of northern Greenland, northeastern Nunavut and Labrador since the Cenozoic, and (2) to examine the subsequent weathering of the rocks and resultant processes of sediment transport and deposition into the adjacent Labrador Sea. Representative samples of fluvial sand and gravel from major rivers and intertidal zones, as well as representative bedrock samples were collected in the fall of 2012 to determine the source and provenance of the continental shelf sediments.

The samples will be analyzed to characterize the age and nature of the sediments to determine the source (provenance) of the sediment. This will help identify the representative source/bedrock in the region that may have supplied sediment into the Baffin Bay, Davis Strait and Labrador Sea. In addition, samples will be analyzed to constrain the timing of uplift in the region. This study compliments ongoing research in Greenland and Baffin Island. Questions that will be addressed: Is the sediment on the Labrador coast distinct in age (or chemistry) to "fingerprint" it? Can we distinguish between the sources of sediment along the coast of Labrador? Is Labrador sediment different from Greenland sediment sources? These onshore provenance studies will be utilized to fingerprint distinct sediment sources that have fed the deep offshore basins in the Labrador Sea. This is an initial reconnaissance sampling project that covers a great deal of land mass. More detailed local projects will be planned from this research should the results be promising.

The plate tectonic revolution and MUN paleomagnetism are fifty years old!

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Fifty years ago, most geologists and geophysicists interpreted the paleomagnetic record as evidence for true polar wander, not continental drift. This suddenly changed when Vine and Matthews realized that the magnetic anomaly pattern on the sea floor was a paleomagnetic record of sea floor spreading. They published in the fall of 1963 and precipitated the plate tectonic revolution. This was also when paleomagnetism (and geophysics) began at MUN with the appointment of Ernie Deutsch who was already a strong supporter of continental drift. Deutsch soon attempted paleomagnetic tests of Tuzo Wilson's ocean cycle hypothesis and in 1970 G.S. Murthy and I joined him. We found that tests for primary magnetization were crucial for success because the early Paleozoic and older rocks that we studied were often remagnetized.

Paleomagnetism at MUN has come full circle and is now focused on testing for radical true polar wander. Paleomagnetic evidence from Laurentia has been used to hypothesize that the entire mantle and crust "tumbled" through 90 degrees and back again in the mid-Ediacaran. If so, this tumbling should be recorded paleomagnetically on all continents. Data from Avalonia does not support the hypothesis as I shall briefly demonstrate.

Holmes and the indelicate question: Measuring the depth of time with the clocks of the earth

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The development of geology involved several great controversies, long-standing conflicts with the forces of organized religion, and with the dogma of other scientific disciplines. The fierce and acrimonious debate about the true age of the Earth was perhaps the most important of such conflicts, because so many other ideas in science - notably evolution - depend upon this foundation. One hundred years ago, long before his career was established, a young geologist named Arthur Holmes wrote an eloquent book in which he evaluated the ideas of the times, and outlined the principles for what we now call geochronology. Holmes was the very first timekeeper of the Earth and although remembered mostly as the father of geological time scales, he had a profound influence on many other aspects of our science.

The debate around the age of the Earth involved some famous names, such as James Hutton, Charles Darwin, Lord Kelvin, Henri Becquerel, Marie Curie and Ernest Rutherford. It pitted the fluid observational science of geology against the firm bastion of 19th century physics, then ruled by intransigent dogma. But in the end its resolution actually came from within physics, with the world-changing discoveries of radioactivity and subatomic particles. Ironically, the clock that gives us the power to unravel the history of the Earth is the very same substance that gives us the potential to destroy it forever. This lecture will trace the course, characters and ideas of this great debate, and also explain how modern geochronology works, and why we must have confidence in its findings. Arthur Holmes died fifty years ago, but his legacy remains vital even in our 21st century, when fundamental scientific knowledge continues to be challenged through the irrational faiths of creationism and so-called 'intelligent design'.

Constraining deformation history and recent activity along the Tuz Golu fault zone, central Anatolia, Turkey: Implications for uplift of the Central Anatolian Plateau

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The 200 km-long, northwest-striking Tuz Golu fault zone is located in Central Anatolia, Turkey, along the eastern margin of the Late Maastrichtian Tuz Golu basin. It is a highly significant structure in that it lies within the transition zone between the Western Anatolian Extensional Province and the Eastern Anatolian Contractional Province, and offers insights into how this region is affected by microplate extrusion originating in the east and gravitational pull forces associated with Aegean subduction in the west. Proposals for the formation of the Tuz Golu fault zone range from Late Cretaceous to Neogene as an extensional structure. However, the fault system has undergone multiple episodes of inversion and reactivation since this time. In this study, we use a combination of paleostress, morpho-tectonic, and strain analysis to further delineate the geologic history and evolution of the Tuz Golu fault zone. Paleostress and strain analysis offer insight into the deformation history of the region as well as the modern-day stress regime. Two principal phases of deformation are delineated through our paleostress analysis – pre-Upper Miocene compression and Late Miocene to Quaternary extension, supporting a regional changeover from compression to extension in Anatolia during the Late Miocene. Additionally, we conducted a morphometric analysis of over 300 drainage basins along the range-front, which suggest migration of deformation into the basin interior, which may be related to lithospheric-scale processes such as uplift of the Central Anatolian Plateau or the onset of crustal thinning associated with slab-tear propagation in the subducting African lithosphere. Application of these techniques provides greater insight into plateau growth and development, as well as the surface expressions associated with processes such as lithospheric thinning and slab tearing or breakoff.

Lithogeochemistry and sulfur isotopic composition of hydrothermal mudstones associated with the Lemarchant volcanogenic massive sulfide (VMS) deposit, Tally Pond Belt, central Newfoundland

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The Cambrian precious metal-bearing, Zn-Pb-Cu, bimodal felsic volcanogenic massive sulfide (VMS) Lemarchant deposit is located within the Tally Pond Group, central Newfoundland. It contains abundant hydrothermal mudstones with both stratigraphic and spatial relationships to mineralization. Yet, the nature of this relationship of the mudstones to VMS genesis and their exploration significance is unresolved.

The Lemarchant mudstones occur either immediately on top of the massive sulfide mineralization and laterally along strike, or as interflow mudstones within the hanging wall basaltic rocks. The sulfide-rich hydrothermal sedimentary rocks comprise brown to black graphite-rich mudstones and shales, and can have intercalations of siliciclastic, volcaniclastic and/or amorphous chert layers, as well as fine laminae of organic matter. The main sulfide phases are pyrite (framboidal and euhedral) and pyrrhotite, with minor amounts of chalcopyrite, sphalerite, arsenopyrite and galena; barite is a common sulfate phase. Analyses of the mudstones

show a range of Fe/Al and base-metal values from samples with hydrothermal signatures, indicated by high Fe/Al and base-metal values, to those with noticeable detrital input, indicated by lower Fe/Al and base-metal values.

The Lemarchant exhalites have positive shale-normalized Eu anomalies (Eu/Eu* ≥ 1) and negative Ce anomalies (Ce/Ce* ≤1), as well as an Y/Ho ratio of ~27. These values suggest precipitation from reduced, high-temperature hydrothermal vent fluids with a short residence time within the plume and thus, a vent-proximal setting under oxidizing conditions. In-situ analyses of sulfides (euhedral and framboidal pyrite, anhedral chalcopyrite and pyrrhotite, and euhedral arsenopyrite) were determined by secondary ion mass spectroscopy (SIMS). $\delta^{34}S$ values from -38 to +8‰ indicate the sulfides have a predominantly diagenetic-biogenic sulfur source and formed under open system conditions with abundant seawater sulfate present. The predominantly biogenic signatures in the sulfides suggest that most of the sulfides in the mudstones formed during diagenesis and are not primary, hydrothermal sulfides.

Development of extension over time during rifting of the Jeanne d'Arc Basin, offshore Newfoundland

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The Jeanne d'Arc Basin formed during multiple rift events and passive subsidence associated with the opening of the North Atlantic Ocean through the Mesozoic and Tertiary. It is frequently reported that crustal thinning in rift zones is greater than extension due to brittle faulting. Previously, there have been estimates of total extension from fault analysis along single transects across the basin or from change in crustal thickness. This study has established the timing, direction and quantity of extension for each rift phase using detailed fault analysis.

2D and 3D seismic data and well data were used to create time structure maps at the start of each rift phase. These maps were restored to their position before each rift phase using beta values derived from fault heave extension estimates as input into GeoArctic's proprietary PlateDEF software. The restored maps were compared with restorations produced using change in crustal thinning to measure beta. It was established that fault heave measurements from the 2D data underestimates extension by approximately 50% when compared with measurements from the 3D data. This observation was incorporated into the extension estimates.

Extension was most significant during the Late Triassic to Early Jurassic rift phase. The total amount of extension measured using fault heaves in this study corresponds closely with the total amount of extension measured using change in crustal thickness in the regional North Atlantic deformable plate model, for total extension with beta values generally around 2. This indicates that stretching is uniform with depth in this area. This detailed study can be used to refine the regional North Atlantic deformable plate model.

Physical and biological seafloor processes in the marginal-marine Redmans Formation, Bell Island Group, Newfoundland: Implications for organic carbon cycling in an early Ordovician wave-dominated delta

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Understanding the processes that control the sequestration of organic matter are critical to reconstruct atmospheric CO_2 levels on geological time scales, and to predict the shelf-wide extent of potential source and seal-rock facies. Muddy, high-energy coastlines are subject to frequent wave reworking, tide-controlled grain-size sorting, and bioturbation. These processes control the remineralization efficiency of organic particles and impact the total organic carbon content (TOC, wt %) and quality ($\delta^{13}C_{(org)}$, ‰) of sedimentary organic matter.

This research presents combined sedimentological and geochemical data from a mud-rich, wave-dominated deltaic succession, namely, the Ordovician Redmans Formation, Bell Island, Newfoundland. Approximately 76 m of core was obtained from an aquifer exploration well and logged at a cm-scale. In the Redmans Formation, metre-thick packages of medium- to coarse-grained quartz arenite are interbedded with metre-thick intervals of silt- and clay-rich mudstone. Twelve sedimentological facies have been identified from these packages, comprising of proximal, central, and distal distributary mouth bars, with significant wave and tidal reworking. Sandstone facies are typically sparsely bioturbated (0–10%) and contain a low diversity of trace-fossil assemblages of *Diplocraterion* and *Planolites*. Sandstone facies are distinguished due to varying sedimentological features and depositional energies. The Redmans Formation has unbioturbated mudstones (interpreted as fluid muds) that were deposited under high-energy conditions unfavorable for organism colonization. However, facies of intensely bioturbated (30–90%) silt- and clay-rich mudstone facies with diverse ichnological assemblages including *Cruziana, Planolites, Trichophycus,* and *Diplocraterion* were favorable for these trace-producing organisms due to a suitable environment with both high

quality and quantity of organic matter.

Samples of mudstone, siltstone, and silty sandstone exhibit TOC values less than 0.8 wt %. A significant compositional heterogeneity of sedimentary organic matter in mudstones, siltstones, and silty sandstones is explained by a combination of organic carbon sources and varying amounts of oxygenation due to both physical and biological seafloor reworking processes. Additionally, this is supported by a difference of 4.3‰ observed in $\delta^{13}C_{(org)}$ data. The combination of detailed facies descriptions with geochemical analysis of mudstones and siltstones can be integrated into a chronostratigraphic framework that allows for a shelf-wide correlation of potential source, seal, and (unconventional) reservoir rocks.

If information flowed from the offshore like oil we'd all be better off

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Offshore hydrocarbon production and exploration influences marine ecology and exposes oceanic animals to new environmental risks. As exploration and production moves into deep water and more extreme marine environments, the associated risks and influences intensify. Understanding of these influences is required to mitigate and minimize negative environmental and wildlife effects. Robust scientific protocols for the application of independent arm's-length interrogation of environmental effects have been proposed for offshore platforms. Yet the structure of federal – provincial regulatory regime in Canada is, owing to industry influence, inadequate to permit these and to avoid crisis management when errors and accidents occur.

To illustrate, I will draw on recent and ongoing examples from the Newfoundland offshore and from the *Deep Water Horizon* disaster from which so many claims about "lessons learned" have been made. It is obvious that the present situation is flawed, and it is not only foolhardy but also dangerous to ignore it.

Gravity and magnetic surveys of a Proterozoic mafic sill in Cape St. Francis, Newfoundland

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The Cape St. Francis region, near Pouch Cove, is underlain by Late Neoproterozoic rocks. These include flow-banded rhyolite overlain by siliceous siltstone and subarkosic sandstone, and epidote-rich pillow basalt of the Wych Hazel Pond Complex (585–580 Ma), overlain by siliceous sandstone and siltstone of the Mannings Hill Member of the Conception Group (<580 Ma). The youngest rocks in the area are mafic intrusions of the Beaver Hat Intrusive Suite. One distinct feature of the Cape St. Francis region is a 600 m-long, ENE-trending ridge located southeast of Jacobs Cove. The ridge consists of pillow basalts, basaltic intrusions, pillow breccias, and interbedded sandstones, and lines of diabase dykes run NNE on the west side of the ridge, and ENE on the east side of the ridge. This south-eastern part of this ridge has a cliff face with scree at its base, which contains a mafic sill. The sill has been determined from previous surveys to be dipping towards the north-west and is highly magnetic.

The objective of this project is to determine the thickness and the extent of the sill in the subsurface by performing geophysical surveys in the area. These surveys include an elevation survey using a TopCon Hiperlite + DGPS, a gravity survey using a Scintrex CG-5 Autograv Gravity Meter, and a magnetic survey using Scintrex Envi Proton Precession Magnetometer.

The DGPS survey determined the UTM coordinates for the stations and their elevations. These elevations were then used for Free-Air and Bouguer Correction for the gravity data. Density measurements were done using the Archimedes' Principle on rock samples obtained by Tammy Perry during her survey in 2003 to 2005. The Bouguer-corrected gravity data shows that the sill gives a NW-trending positive anomaly, trending to the NW, within the surrounding sedimentary rocks. Most of the magnetic data used were also obtained in 2003 to 2005. A survey was conducted in 2013 to obtain additional data and correlate these two groups of data due to secular magnetic drift. The magnetic survey shows a total magnetic intensity (TMI) along the sill that is higher than the surrounding sedimentary rocks, which are the same intensity as the Earth's magnetic field. The concentrated high-magnetic intensity at different spots along the sill suggest that rather than the sill being highly magnetic, it may be smaller, younger diabase dyke intrusions throughout the sill that may be highly magnetic. These dykes most likely belong to the Beaver Hat Intrusive Suite.

Hammerdown Basalt, Springdale Peninsula, Newfoundland: Lithostratigraphic unit or lithotectonic collage?

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The Hammerdown Basalt separates two of the oldest tectonic constituents of the peri-Laurentian Western Notre Dame Bay volcanic belt. It forms a narrow map unit situated near the regional boundary between the Ordovician Catchers Pond Group and the Cambrian Lushs Bight Group on the southwestern part of the Springdale Peninsula.

Picrobasalt, basalt, basaltic andesite, and andesite flows in the southwestern part of the Hammerdown Basalt comprise base metal-enriched suites of tholeiitic and subordinate calc-alkalic rocks. Such strata may be correlated with the mid-ocean ridge basalt, back-arc basin basalt, and transitional arc tholeiite seen in the lowermost Indian Brook Formation of the Catchers Pond Group. They are probably also the partial equivalent of the sequence of basaltic andesite, (normal and low-Ti) island arc tholeiite, and dacitic crystal tuff that typifies the overlying Long Pond Formation. Such marine lavas comprise the depositional substrate of the felsic pyroclastic strata that dominate the middle and upper part of the Catchers Pond Group.

A precise 477.3 ± 1.3 Ma U-Pb crystallization age of a quartz–feldspar tuff from the middle Long Pond Formation indicates that some of the earliest felsic eruptions in the Catchers Pond Group occurred near the base of the Floian stage of the Early Ordovician. Magmatic zircons from a limestone-bearing crystal tuff below the uppermost formation of Catchers Pond Group give a new U-Pb age of 475 ± 1.4 Ma. Early Arenig bioclastic carbonates (post-477 Ma), the earliest Middle Arenig tuff (ca. 475 Ma) and the youngest undated strata of the Catchers Pond Group are preserved in stratigraphic order within a tectonic window below the sole thrust of the Hammerdown Basalt.

The late Tremadocian – early Floian volcanic strata of the Indian Brook and Long Pond formations, including the imbricate slices present in the Hammerdown belt, also occur in the hanging wall plate of the sole thrust. Inversion of the Catchers Pond basin-fill was governed by a northeast-dipping, foliation-parallel thrust zone that had developed prior to the intrusion of a quartz–feldspar porphyry sheet dated at 474 ± 1.6 Ma. The southwest-directed fault movements effected an allochthonous slice of the Lush Bight Group and the tectonically dismembered Early Ordovician strata immediately underlying these Cambrian basement rocks. Rapid orogen-parallel displacement was probably related to the Taconic II accretion documented in the metamorphic hinterland.

The unit mapped as Hammerdown Basalt therefore represents an arcuate tectonic collage of several Cambrian and Early Ordovician lithostratigraphic units. The Hammerdown imbricate thrust stack is deformed by an upright train of dome-and-basin fold structures that are responsible for exposure of the Indian Brook and Long Pond formations of the Catchers Pond Group in their type area near the Indian River.

Phytoremediation of heavy metal contaminated soil at the former Consolidated mine site, Baie Verte, Newfoundland

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Soil contamination by heavy metals is a worldwide issue. This contamination not only has an effect on human health but also leads to loss of biodiversity, soil structure, and essential microbes, due to interruptions to nutrient cycles. Heavy metals are notoriously difficult and expensive to remove; therefore, remediation of heavy metal contaminated soils is a challenging issue. Phytoremediation is a promising technology as it is cost-effective, non-intrusive, and aesthetically pleasing. In this study an amendment-assisted phytostabilization leaching experiment was conducted. The goal was to test biochar and lime, both together and separate, to see what effect they have on the immobilization and phytoavailability of heavy metals as well as biomass production of *Lolium perenne*, a commonly researched phytostabilizing plant.

Along with the laboratory experiment, a field study of the soil and plants growing at the former Consolidated Mine site in Baie Verte, Newfoundland was conducted. In the field study, six species of plants that were abundant on the site were collected along with the soil around them. The biological concentration factor, translocation factor, and biological accumulation factor was calculated for each plant to determine if there is potential for further research for phytoremediation purposes.

Observations on the geological environment of the Cambrian-Ordovician Cu-Au Ming VMS deposit, Baie Verte Peninsula, Newfoundland

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The producing Ming Mine is a Cu-Au volcanogenic massive-sulphide (VMS) deposit. It is located in the Cambrian-Ordovician Baie Verte Belt, host to numerous past producing Cu and Cu-Au VMS deposits. The deposit contains 3.65 Mt at 2.26 wt % Cu, 1.13 g/t Au, 6.78 g/t Ag, and 0.32 wt % Zn and is hosted by intermediate to felsic volcanic and volcaniclastic of the Early Ordovician (ca. 487 Ma) Pacquet Harbour Group, which is part of a regional mafic-dominated rock assemblage of boninitic to tholeiitic affinity.

The deposit is characterized by elongated Cu-Au-Zn±Ag massive to semi-massive lenses, gently plunging northeast, and the ore zones are separated 30 to 50 metres from each other along the same stratigraphic horizon. A Cu-rich zone, consisting primarily of chalcopyrite and pyrrhotite in a strongly chloritized felsic volcanic rock, is located 50 to 100 m below the main sulphide lens. Distinct alteration assemblages have been identified based on the distribution and relative abundance of specific alteration and metamorphic minerals such as sericite, chlorite, quartz, biotite, tremolite, Mn-garnet, rhodochrosite, green mica, epidote, magnetite, and pyrite. The variations in alteration assemblages are possibly, in part, due to varying rock composition and spatially controlled by syn-volcanic structures.

Preliminary lithogeochemical results indicate that the footwall is composed of at least three distinct intermediate to felsic calk-alkaline (i.e., Zr/Y >7) volcanic and volcaniclastic facies. The immediate hanging wall is lithologically heterogeneous throughout the deposit, varying from a highly silicified (SiO_2 >88 wt %) volcaniclastic rock to a magnetite-rich volcanogenic siltstone. Locally, the predominantly mafic syn-obduction ophiolite cover sequence is in structural contact with the massive-sulphide as a result of post-mineralization deformation. Three generations of mafic to intermediate sills and dykes have been distinguished in the field based on cross-cutting relationships but also supported by whole-rock lithogeochemistry. Hence, determining the volcanic, stratigraphic, structural, and petrogenetic context of the Au-rich Ming VMS deposit will help define the various footprints critical for understanding the genesis of Au-rich VMS systems, which is one of the main objectives of the current project.

Biogeochemical carbon cycling at sites associated with active continental serpentinization: The Tablelands, Newfoundland, Canada

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The Tablelands in Newfoundland, Canada contain terrestrial peridotite-hosted groundwater springs associated with serpentinization. These springs act as windows into subsurface systems and provide insight into their biogeochemistry. However, at sites where ultra-basic water pools and mixes with overland flow, the reactions in the pools must be considered when trying to source organic compounds. We will present data from a pool (WHC2) located in the Tablelands to determine the biogeochemical carbon transformations at this mixing site.

The ultra-basic, reducing groundwater springs had higher concentrations of alkanes (C_1-C_4) and organic acids (acetate and formate) than the overland flow, suggesting that these organics originated from the groundwater source. A two-component mixing model was developed to predict what the concentrations of alkanes and organic acids would be in the WHC2 pool based on physical mixing of groundwater and overland flow. Acetate and C_2-C_4 alkane concentrations were fairly well predicted by the mixing model, suggesting little consumption or production of this organic acid and these alkanes in the pool. However, methane concentrations were under predicted by the model at one sampling point in the pool, suggesting production of methane at this site. At the same sampling location, formate concentrations were over predicted by the model, suggesting that formate was being consumed in the pool. The water at these sampling times was highly reducing; therefore, oxidation of formate was not likely responsible for the consumption of formate. Organic acid fermentation using formate is one possible sink for formate and source for methane. However, the genomic data from the site has shown little evidence for microbial methanogenesis.

Geochemical measurements of the carbon in the pool can help elucidate the most dominant source of methane. On a Bernard plot (C_1/C_{2+} vs. $\delta^{13}C_{CH4}$ (‰)) the alkanes measured at the springs plot in the thermogenic region. However, this plot cannot be used as the sole diagnostic tool because the microbial methane in at least two studies of thermophilic methanogens would plot outside of the microbial field on this plot. The carbon isotope fractionation between inorganic carbon and methane ($\alpha C_{DIC-CH4}$) was within range of acetate fermentation and the $\alpha C_{DIC-CH4}$ from putative abiogenic methane from the Precambrian. Further elucidation of methane source will require δ^2H measurements of H_2O and CH_4.

Geology, lithogeochemistry, and mineralization at the South Wood Lake gold prospect (Staghorn property), Exploits–Meelpaeg subzone boundary, western-central Newfoundland

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The Staghorn exploration property, in NTS map area 12A/4 of central-western Newfoundland, is situated along the southwestern boundary area between the Exploits, Meelpaeg and Notre Dame subzones of the Newfoundland Appalachians. The property includes three significant gold showings (Hilltop, Sure Shot, and Falls) and one drilled prospect called the South Wood Lake (Main) zone. These discoveries have occurred episodically since the 1970s as the direct result of dedicated grassroots prospecting. Exploration work, including detailed ground geophysics, trenching and drilling, along with mapping, petrography and lithogeochemistry, collectively demonstrate that the mineralization at the Main zone is hosted by variably textured, mylonitized and brecciated, commonly strongly lineated, Mu ± Bt monzogranite to granodiorite of the Ordovician (464 ± 4 Ma) Peter Strides granite suite. Mineralization consists of a network of thin (≤10 cm), anastomosing, quartz-pyrite-hematite-siderite±arsenopyrite veins and mineralized fractures accompanied by wall rock sericitization, albitization and silicification. Gold is associated with elevated Bi, Sb, Cd, Ag and Te, and, in particular, strongly elevated As. Native gold occurs as tiny ≤5μm amorphous blebs intergrown with albite and sericite and is locally accompanied by Bi-telluride, possibly tellurobismuthite.

The mineralized, brecciated and mylonitic monzogranite occurs as a number of imbricate panels in the structural hanging wall of the northeast-trending, south-dipping Silurian Victoria Lake shear zone. The South Wood Lake prospect occurs in the antiformal core of an open, km-scale, post mylonitization, Z-asymmetric flexure of the shear zone. Mineralization is likely Devonian in age.

Outer limits of Canada's continental shelf in the Atlantic Ocean

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In December 2013, Canada filed a partial submission defining the outer limits of its continental shelf in the Atlantic Ocean under the United Nations Convention on the Law of the Sea. This submission identified an area of approximately 1.2 million km^2 of extended continental shelf, i.e., beyond the 200 nautical mile (nm) limit. It will take several years before the submission will be reviewed by the Commission on the Limits of the Continental Shelf and Canada will receive their recommendations.

This presentation summarizes the main steps in defining the outer limits of the continental shelf and will also briefly describe what is included in Canada's extended continental shelf in the Atlantic. In the Labrador Sea, the extended continental shelf extends to the 200 nm limit of Denmark (Greenland). The continental shelf in the Grand Banks region extends beyond Orphan Basin, Orphan Knoll, and Flemish Cap. The thickness of the sediments in the Sohm Abyssal Plain defines the outer limits of the continental shelf in the Nova Scotia region beyond the 200 nm limit. The area of the extended continental shelf in the Atlantic Ocean includes most of the deep sedimentary basins in the Grand Banks region, as well as offshore Nova Scotia and Labrador.

Comparison of lithosphere structure across the Orphan Basin/Flemish Cap and Irish Atlantic conjugate continental margins from constrained 3-D gravity inversion

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Regionally-constrained 3-D gravity inversion results on the Orphan Basin/Flemish Cap and the Irish Atlantic conjugate continental margins are compared in order to investigate crustal structure, early rifting history and geological evolution of this part of the North Atlantic. The full-crustal density anomaly distributions provide some of the first depth images of how rifted structures compare along and across these conjugate margins. Broad similarities in crustal structure are identified with some noticeable differences, linked to rifting and crustal stretching processes. Extreme crustal thinning (stretching factors >3.5) is indicated beneath much of the southern Porcupine Basin, the western half of West Orphan Basin, the eastern half of Jeanne d'Arc Basin, the southeastern half of East Orphan Basin and in pockets beneath Rockall Basin. This appears to have resulted in the serpentinization (and possible exhumation) of mantle lithosphere on the Irish Atlantic and Flemish Cap margins but not beneath Orphan Basin. A simple evolution model is proposed for the early stages

of rifting between the margins. It is suggested that ancient orogenic sutures played an important role in controlling the northward migration of rifting and the rotation and displacement of Flemish Cap out of Orphan Basin.

Dating pegmatites to constrain the exhumation of granulite-facies mid crust, Central Gneiss Belt, western Grenville Province of Ontario: Dealing with inherited zircon

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Recent tectonic models for the hinterland of the Grenville Province distinguish domal-shaped regions of granulite-facies crust metamorphosed at ~1080 Ma (Ottawan orogenic phase) from adjacent basinal-shaped regions of crust comprising the Orogenic Lid that escaped penetrative Ottawan deformation and high-grade metamorphism. Juxtaposition of these Ottawan crustal levels is interpreted to have occurred during exhumation of the granulite-facies mid crust by post-convergent extension and to be a signal of crustal-scale orogenic collapse. The exhumed mid-crustal granulites are cut by one or more suites of undeformed to slightly deformed granite pegmatite dykes. In this study, U-Pb analyses of zircon from two pegmatite dykes, samples TR-04-11 and TR-05-11, were carried out by LA-ICP-MS to constrain the timing of exhumation of the granulite-facies rocks.

Approximately 30 zircons from each sample were imaged using back-scattered electron (BSE) and cathode luminescence (CL) methods to define rims and cores. Analyses were obtained by the wet co-aspiration method using a 10 μm laser beam, a 1 μm/s line raster. Zircon from TR-04-11 comprise on average ~ 110 by 60 μm prismatic to blocky grains, with weak oscillatory zoned cores and ~ 20–40 μm wide, high Th-U rims. The U-Pb analyses of 11 concordant rims yielded ages between ~1000 Ma and 1150 Ma, whereas the cores yielded ages between ~1129 Ma and 1270 Ma. Eight discordant analyses intersect Concordia at 1043 ± 28 Ma. The best estimate of the crystallization age of the pegmatite, from an analysis of a high Th-U rim about 20 μm wide is 1004 ± 10.6 Ma.

Zircon from TR-05-11 are on average ~ 150 by 70 μm acicular to sub-rounded; some grains have cores with sharp and continuous oscillatory zoning towards the margins, whereas others have cores with weak and irregular zoning that becomes diffuse towards the margins. A few grains have new recrystallized thin rims (≤10 μm). The core and mantle/rim ages range between 1500 and 1050 Ma. The youngest grain is acicular, exhibits continuous diffuse zoning from core to rim and yielded a rim age of 1046 ± 10.6 Ma.

Zircon in both samples, including many small acicular grains, is predominantly inherited from the source region. Oscillatory zoning in inherited cores commonly becomes less sharp towards the grain margins, implying later modification by diffusion during melting in the source region and/or transport in the fluid-rich pegmatitic magma. Sub-populations of discordant grains that lie on a chord may signify an episode of Pb loss. The inferred age of emplacement for TR-04-11 was determined from the recrystallized rim of an inherited zircon, whereas that for TR-05-11 was determined from a diffusely zoned acicular grain. These ages are ~50–90 Ma after the metamorphic peak and provide upper estimates for the time of exhumation of the granulite-facies crust and the emplacement of the pegmatite dikes.

This study has shown that the pegmatite magmas carried abundant inherited zircon and that very little new zircon was formed during crystallization. Hence zircon may not be the most appropriate mineral to determine emplacement ages. Current work is focusing on monazite, titanite, and rutile.

