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Atlantic Geoscience Society

ABSTRACTS

43rd Colloquium & Annual General Meeting 2017

FREDERICTON, NEW BRUNSWICK

The 2017 Colloquium & Annual General Meeting was held at the Fredericton Inn, Fredericton, New Brunswick, on February 10th and 11th. On behalf of the society, we thank Colloquium organizers David Lentz, Dave Keighley, Chris McFarlane, Anne Timmermans, Robin Adair, Jim Walker, Susan Johnson, and Mike Parkhill, as well the numerous student volunteers and judges, for facilitating an excellent meeting with a record 110 abstracts. AGS acknowledges support from the corporate sponsors of the meeting: the University of New Brunswick Fredericton, New Brunswick Branch of the Canadian Institute of Mining, Metallurgy and Petroleum, Engineers and Geoscientists New Brunswick, New Brunswick Department of Energy and Resource Development, New Brunswick Department of Environment, Wolfden Resources Corporation, AMEC Foster Wheeler, Dillon Consulting, Mining Matters, Avalon Advanced Materials Incorporated, Potash Corporation of New Brunswick, and Pretium Resources Incorporated.

In the following pages, we are pleased to publish the abstracts of oral and poster presentations from the meeting, which included a Symposium on "The Northern Appalachian Orogen: Correlations and Conundrums" and five Special Sessions: (1) Museum and University Geology/Paleontology Collections" – in memory of Don Reid, ONS (1922–2016); (2) Magmas and Metals; (3) Environmental Geoscience in the Atlantic Provinces and Beyond; (4) Advances in Carboniferous Geology in the Atlantic Provinces – in memory of Dr. Wouter van de Poll (1932–2017); (5) Where on Earth?: Education, Integration and Development of Earth Science for Social Benefit in Atlantic Canada, as well as General Sessions on "Current Research in the Northern Appalachians and North Atlantic Margin." Gesner Medal 2017 recipient, Rebecca Jamieson, presented the Geological Association of Canada, Howard Street Robinson Lecture "How do large hot orogens work? Lessons from the middle crust". Stephen Piercey presented his GAC Hutchison Lecture on "The importance of magmatism in the genesis of the Wolverine volcanogenic massive sulphide (VMS) deposit, Yukon, Canada: constraints from lithogeochemical, Nd-Hf isotope, and in situ U-Pb-Hf isotope data" in the special session on Magmas and Metals on Saturday afternoon.

Also included with the conference was a half-day workshop on "pXRF applications in Geologic Research and Exploration" by David Lentz (University of New Brunswick). A two-day teacher's workshop and an evening Earth Science Café, organized by Anne Timmermans and Catherine O'Connell-Cooper (University of New Brunswick, Quartermain Earth Science Centre), were also part of the weekend. The guest speaker at Saturday evening's banquet and social was Randy Miller (Emeritus New Brunswick Museum, UNB Adjunct) who gave an enlightening talk on the history of the New Brunswick Museum, its collections, and early New Brunswick Geologists, titled "Maybe I could try geology".

THE EDITORS

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Inferring post-Jurassic movement of the Oak Bay Fault through acquisition and modelling of magnetic profiles across the Ministers Island Dyke in Brooks Cove, Maine, USA*

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The Ministers Island Dyke in southwestern New Brunswick trends ENE-WSW from eastern Maine across the St. Croix River, St. Andrews peninsula, Ministers Island and beyond into Passamaquoddy Bay. The dyke is a quartz tholeiite, approximately 180 Ma in age, and it crosses the near-perpendicular Oak Bay Fault beneath the St. Croix River. An aeromagnetic survey acquired in 2001 revealed a kink in the trend of the strong linear magnetic anomaly associated with the dyke beneath the river, and prompted re-evaluation of an earlier conclusion that all significant movement on the Oak Bay Fault had ceased prior to dyke emplacement. In particular, it has long been questioned whether elevated seismicity in the region is a result of recent movement along this fault.

In 2005, University of New Brunswick researchers conducted a higher resolution marine magnetic survey in the St. Croix River in an effort to confirm whether faulting has displaced the dyke. This survey delineated the dyke anomaly on the eastern side of the Oak Bay Fault, but the boat could not travel sufficiently far into the shallow waters of Brooks Cove, Maine, to define the dyke anomaly to the west. In 2016, a shallow-water marine magnetic survey was undertaken by kayak to acquire additional magnetic profiles that follow the coastline more closely.

The kayak survey was centered in Brooks Cove and spanned approximately 1 km on either side of the cove. A proton precession base station magnetometer was set up onshore, while the surveying Overhauser magnetometer was aboard the kayak. The surveying magnetometer collected readings once every second along lines approximately 50 m apart, while a Garmin GPS receiver, carried 2.5 m behind the magnetometer, recorded a position every two seconds. Preliminary gridding of the data into a magnetic field map shows dramatic weakening of the anomaly over a span of 100 m across the Oak Bay Fault – suggestive of demagnetization in the fault zone – as well as curving of the dyke anomaly on either side of the fault – suggestive of dextral offset of approximately 300 m. This dextral offset opposes sinistral displacement that has previously been inferred for the Oak Bay Fault based on older cross-cutting relationships. Further investigations will include forward modelling of variations in dyke orientation, and depth to top across the fault constrained by measurements of remnant magnetization, magnetic susceptibility, and dyke width available from previous studies.

Winner of the AGS Rob Raeside Award for best undergraduate student poster

Diagenetic effects and fluid flow along erosional boundaries and unconformities in the Triassic Wolfville Formation at Rainy Cove, Nova Scotia, Canada

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Rainy Cove lies along the south shore of the Minas Basin on mainland Nova Scotia. Outcrops along the beach preserve fluvial barforms and channel deposits of the Wolfville Formation, a member of the Fundy Group. The Triassic Wolfville sandstones lie unconformably over the steeply dipping metasedimentary rocks of the Carboniferous Horton Group. Within the Wolfville Formation, there is a hierarchy of erosional surfaces and unconformities separating lithofacies packages. These range from barform surfaces marking small reactivations in fluvial sedimentation to an intra-Triassic unconformity that incises 10 m into previously deposited barforms. The infill is a multi-storied channel complex demonstrating several episodes of cut and fill. Previous research on the Wolfville Formation has not investigated these erosional surfaces. Heterogeneities in porosity and permeability along erosional boundaries could create preferential pathways, baffles, or barriers to fluids in the subsurface. The objective of this study is to investigate diagenetic variance across the erosional boundaries and the potential impacts on fluid flow. Measured sections from the outcrop describe the lithofacies changes across the surfaces, and handheld gamma ray scintillometer/spectrometer measurements record changes in radioactive mineral content to supplement lithologic observations. The Wolfville Formation at this location is a coarse-grained, subangular to angular red sandstone that is well cemented with carbonate. Petrographic analyses of samples above and below bounding surfaces show that the sandstones have undergone varied paragenetic processes including burial cementation, limited mechanical compaction, partial dissolution of unstable feldspars and cements, and alteration. Cements tend to be sparry and void filling, which is characteristic of the phreatic zone. Some samples also show bladed grains or thin cement rims. Dull cathodoluminescence of the cement

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suggests formation in a burial environment with higher Fe/Mn ratio, and zoning of some cement crystals indicates multiple phases of diagenesis. Presence of pore-filling cement impedes fluid flow within lithofacies packages, which may create preferential pathways along the varied erosional surfaces.

Trace-element variation associated with diagenetic phosphate and sedimentary organic matter in organic-rich mudstone beds, Green River Formation, eastern Uinta Basin, Utah, USA

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The Green River Formation is a >2 km-thick succession of fine-grained strata variably rich in organic material that accumulated in several lacustrine basins during the Eocene. In the Uinta and Piceance Creek basins of Utah and Colorado, the Green River Formation hosts the world's largest oil shale resource. This resource is concentrated in 8 organic-rich mudstone (ORM) intervals (up-section from R1 to R8), the richest being R7, also known as the Mahogany Oil Shale Zone (MOSZ) which marks the base of the informal upper member of the Green River Formation. Ongoing studies relate to several beds of oil shale sampled from the lower R8 zone, ~60 to 130 m above the base MOSZ, both from core and outcrop. Microscale variations in trace-element geochemistry have been identified in ORM using ICP-MS, indicating values obtained from bulk analyses might obscure the details of trace-element compositional variation in the stratigraphic record. While attributed to abiogenic processes this variability might have been biogenically mediated, or influenced by the nature, accumulation, and abundance of sedimentary organic material. Organic material content is similarly variable, occurring as thin, laminar, non-particulate, C-dominated layers of matter in ORM — interpreted as kerogen agglomerations formed from the degradation of algal and bacterial oozes. SEM analyses indicate the presence of disseminated heavy metal accumulation within both matrix and non-particulate organic material in the study samples. Analyses have indicated some relationship between organic material and trace-element variability, with systematic enrichment patterns of lanthanides, actinides, and toxic heavy metals occurring in phosphatic intervals of these ORM. The relationship between trace-element geochemistry and organic material is examined using a combination of inorganic geochemical data and organic geochemical indices to highlight compositional variations related to the nature and type of organic material, source rock maturity trends and organic richness in the Green River Formation. As a consequence of deposition in low-energy lacustrine environments, shallow burial, and the general immaturity of Green River Formation source rocks, some sub-millimetre scale sedimentary structures and features have been preserved and might enable further insight into any relationships between the elements of this study. While the influence of microbial communities and organic material on pore-water chemistry is not precisely understood, some contribution to the variance in trace-element chemistry might perhaps be observed in this study due to the relationships between trace-element abundance and sub-millimetre scale sedimentary features.

Exploration and development of large diameter water wells in Quaternary deposits in a regulatory environment: a case study of the exploration and development of community and industrial water supplies

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Exploration and development of water supplies for municipal, industrial, and commercial use are subject to the regulatory regime for the area in which it is being developed. Several example scenarios will be presented focusing on the exploration and development of both industrial and municipal water supplies in New Brunswick while navigating provincial Environmental Impact Assessment regulations and guidance.

When facing budget and timeline constraints along with a rigorous regulatory environment, innovative approaches and methods were utilized to work through each phase of exploration and development. In particular, larger-scale water supply developments in unconsolidated stratigraphy pose some advantages and disadvantages with respect to location, drilling methods, and aquifer protection. In the early stages of water exploration, multiple well site locations are proposed to a broad spectrum of regulatory reviewers such that environmental impacts of the entire anticipated project are considered. At this stage wellfield protection is also considered for each drill target location and potential land-use issues and sources of contamination are examined. Once drilling locations are approved the intrusive field testing can begin including additional drilling and aquifer testing. For high-yielding wells alternate methods to standard air rotary drilling were used pending anticipated conditions. As well, remote water-level monitoring technology (telemetry) has been integrated into long term yield testing to collect

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data and reduce costs.

Canada's geomorphology is, in part, the result of the planet's last glaciation and modern day alluvial processes. These Quaternary sediments, combined with a constant head of fresh water supply in the right setting, can deliver ideal hydrostratigraphy for water supply development. This is what has been observed for communities and industries situated along one of New Brunswick's major river systems, the Saint John River.

A design approach for improving structural survivability of buildings under large earthquake forces

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Design is an area over which the engineer has the most control, both technically and financially, in creating structures which can withstand destructive forces of earthquakes. The most widely applied philosophy is to design for earthquake-resistant structures with the idea that stronger and stronger building materials are needed to resist larger and larger forces from earthquakes. This approach may be adequate when designing for protection against small earthquakes, but has serious shortcomings when designing for large earthquakes, as is evident from many after-earthquake scenes. In this presentation, a force-management approach is illustrated where the emphasis is on management of the earthquake forces. The concepts of stress concentration, dispersement and re-direction, and the shape of the structure, play a significant role in this approach. Using numerical modelling results and field data, it is shown that the shape of buildings can be designed to disperse the earthquake forces on impact, minimizing the stress concentration in the buildings and greatly improving the overall safety.

Examining the relationship between trace-element characteristics and the cathodoluminescence colour exhibited in apatite from Devonian felsic intrusions of New Brunswick, Canada

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New Brunswick is a part of the Canadian Appalachians and contains two suites of Devonian-aged felsic intrusions. However, just those associated with the crustal thickening processes of the Acadian orogeny, and post-Acadian uplift, are mineralized with granophile elements. These intrusions geochemically define affinities ranging from primitive to highly evolved A-, S-, and I-types granitoids. The geochemical characteristics of apatite grains from thirty-one of the Late Silurian to Late Devonian intrusions were studied in situ by electron probe microanalysis (EPMA) and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). In addition, the texture of the crystals was imaged and studied using a cathodoluminescence (CL) imaging system at the University of New Brunswick. The results established unique trace-element characteristics in apatite from each of the intrusions believed to reflect host magma evolution history.

The CL-imaging study indicated yellow, shades of blue, and purple as the three main colours of CL emission among the studied apatite grains. Interestingly, these three colours have distinctly different trace element compositions. For example, the light blue luminescing apatite grains have the highest Eu contents, whereas yellow CL apatite grains have the highest Mn. The apatite grains also have characteristically different rare-earth element content, which increases from the yellow to dark blue and reach their highest values in the light blue luminescing apatite. A further examination of CL was completed with the collection of detailed CL spectra at the University of Regina, confirming the result of the trace element studies. Apatite with yellow CL emission show a distinctive peak at about 570 nm, that has been previously attributed to elevated Mn^{2+} in these apatite grains. Blue-shaded apatite CL displays a characteristic peak at about 400–500 nm reflecting the incorporation of variable amounts of Eu^{2+} and Ce^{2+} as the main causes of CL in the studied apatite grains. Interestingly, the shape of the collected spectra clearly reflects the geochemical conditions of the parent rock. For example, a purple apatite from the Nicolas Denys granodiorite display almost flat spectra with only weak peaks at about 400 and 600 nm. This may indicate hydrothermal alteration and/or secondary fluid interaction that have modified the CL-emission spectra for apatite within this intrusion. Results of this study display a direct relationship between the trace-element content and the colour of the CL emission in apatite and have proven LA-ICP-MS as a valuable resource in studies of CL emission colour in this and other minerals.

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Diagenetic history of the Bashkirian Grand Anse Formation, Maringouin Peninsula, southeast New Brunswick, Canada

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The lower Pennsylvanian Grande Anse Formation is exposed in the western part of the Cumberland Basin, including the Maringouin Peninsula of southeast New Brunswick. Based on the sedimentological analysis of coastal outcrops, several sandstone-mudstone depositional cycles have been recognized. Predominantly clean, pinkish-grey and reddish-brown, medium- to coarse-grained sandstone and conglomerate, chiefly quartz-rich arenite, were deposited as fluvial sedimentary rocks. Fine-grained facies include reddish-brown and minor bluish-grey siltstone, mudstone, and very fine- grained to fine-grained sandstone, deposited on associated floodplains.

Petrographic investigations indicate the Bashkirian strata have undergone minor clay infiltration and various diagenetic alterations. These include: (1) cementation by iron oxide which imparted the red colour to the sandstone and mudstone; (2) replacement of feldspar and muscovite by kaolinite in sandstone; interpreted to the influx of meteoric waters and alteration of unstable detrital grains under conditions of slight acidity (pH ~ 5). The formation of kaolinite is associated with the creation of intragranular porosity, and thus porosity enhancement; and (3) diagenetic quartz that occurs mainly as syntaxial overgrowths which partly to completely cover detrital quartz grains and fill either partially and/or wholly the adjacent intergranular pores. The distribution of quartz cement within depositional facies is controlled by the spatial and temporal extent of grain-coating clays, carbonate, and iron oxide cement. Cementation by quartz overgrowths has resulted in reduced porosity during late eodiagenesis. Several samples also indicate unusual replacement of carbonate by silica and multiple intergrowths of the two. Timing of these phases is uncertain and may have occurred during early burial diagenesis of lacustrine or palustrine sediments or silicification of paleosols, or during later telogenetic uplift. However, the replacements and intergrowths of carbonate and silica in the fluvial sediments suggest more alkaline conditions with fluctuating pH of ~ 9.

The role of downslope versus along-slope sediment transport over the last glacial cycle on the Scotian Rise, Canada

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The Scotian Rise was built by two principal modes of sediment transport: downslope turbidity currents with proglacial sediment and along-slope transport by the Western Boundary Undercurrent. A 14 m long core, for the first time, provides a record back 80 000 years, of how ice advances and retreats played a role in this sediment transport.

Six sediment units were recognized in two piston cores sampled from the central Scotian Rise south of Western Bank. These cores were analyzed to identify the sources of the sediment. ^{14}C dating and the recognition of Heinrich events established the overall framework for age. The age model corresponding to the units could then be linked to stadial and interstadial times via marine isotopic stages (MIS). The sources of sediments were mostly from glacial supply from the Appalachians and erosion of the Scotian Shelf, as indicated by numerous physical properties, such as clay mineralogy, Nd isotopes, pXRF, and spectrophotometry data.

The sources and the corresponding ages of the units developed in this study indicate the Scotian Rise typically experienced downslope transport during stadial periods (units II, III, V, VI) and along-slope transport during interstadials in unit I (MIS I) and IV (early MIS 3). The data confirm that a major glacial advance (Caledonia phase) took place in Nova Scotia in MIS 4, reaching the edge of the shelf.

A tale of two ore zones in the East Kemptville granite-hosted Sn-Cu-Zn-Ag-In deposit, Nova Scotia, Canada

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The previously mined (1985–1992) East Kemptville Sn-Cu-Zn-Ag-In deposit, southwest Nova Scotia, remains a potential metal resource of value to the technology sector based on recent ore delineation. The deposit is hosted in the East Kemptville muscovite leucogranite, a highly-fractionated portion of the Davis Lake pluton (DLP). The DLP is one of several differentiated granites in the large (7800 km^2) Late Devonian (ca. 375 Ma) South Mountain Batholith (SMB) that intruded Lower Paleozoic meta-sandstone and meta-siltstone/slate. The crustal-derived SMB complex was emplaced during the waning stages of deformation related to the Neoacadian Orogeny.

The deposit consists of two main ore zones: (1) the high-tonnage, low-grade, fracture-controlled greisens of the Main Zone; and (2) the low-tonnage but higher grade, pipe-shaped greisenized breccia body of the Baby Zone. Both ore zones are interpreted to have been intensely altered to form the Sn-mineralized quartz-topaz-sulphide greisens by F-rich fluids, which also mobilized even generally immobile trace elements (e.g., LREEs). The least altered portion of the Baby Zone is a leucogranite at depth which is inferred, based on its geochemistry, to be like that found in the Main Zone, and is thus feasibly contiguous at depth.

The greisens host cassiterite, sphalerite, chalcopyrite, and stannite, representing the Sn-Cu-Zn-Ag-In resource. Initial findings from ore petrology, SEM-EDS analysis, and fluid inclusion work indicate that the mineralizing fluid was of moderate salinity (25–28 wt.% NaCl-$FeCl_2$) and was exsolved from a highly evolved melt at high pressure and temperature (ca. 3.5–4 kbars and 650°C). These conditions are unusual for typical Sn deposits, which were emplaced at shallower depths (<1 kbar), as well as for the shallow-depth nature of intrusive-hydrothermal breccia observed in the Baby Zone. The massive greisens in the Baby Zone are also markedly more Sn-enriched than the discontinuous, fracture-controlled greisens of the Main Zone, which are localized by a major sub-vertical fault, the East Kemptville Shear Zone (EKSZ). This study will: (1) constrain the structural evolution of the EKSZ with respect to mineralization; (2) describe the mineralization and alteration in the ore zones and ascertain what controlled ore precipitation; and (3) characterize the fluid evolution of the deposit.

Sedimentology and stratigraphy of the Kettle Point Formation: implications for widespread marine anoxia and the extensive deposition of Upper Devonian black shales in eastern North America

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The Upper Devonian Kettle Point Formation of southwestern Ontario is characterized by intervals of organic-rich interlaminated black shale interbedded with organic-poor greyish green mudstone and rare red beds, separated by metre-scale sequences of non-interlaminated black shale. The formation shows a largely consistent background value for the black shales around 20‰ $\delta^{34}S$, punctuated by a substantial positive excursion of ~32‰ (up to + 12.87‰) coincident with a significant section of greyish green mudstone and red beds. Organic content, in conjunction with the sulphur isotope data, indicate that the black shales were deposited during periods of anoxia with thick intervals of non-interlaminated black shales representing the acme of anoxic conditions. Greyish green mudstones, with their lack of organic-content, increased bioturbation, and higher, more-positive, sulphur isotope values, therefore record deposition in more oxygenated environments. A new 4-stage, 2 cycle depositional model for the Kettle Point Formation is proposed with relative water depth interpreted as the key control on the vertical diffusion of oxygen in the water column, and therefore on the distribution of the Kettle Point lithofacies. Interbedded black shales and greyish green mudstones were deposited in relatively shallow water where minor, short-lived falls in relative sea level promoted dysoxic to oxic conditions and the deposition of organic-poor lithologies. Non-interlaminated black shales are indicative of substantial rises in relative sea level, resulting in widespread anoxia and the deposition of thicker and more laterally extensive packages of organic-rich sediment. The sedimentology and stratigraphy of the Kettle Point Formation and other syndepositional black shales, suggests that the extensive deposition of organic-rich sediment across eastern North America during the Late Devonian was a product of widespread anoxia related to fluctuating water depth and restricted circulation in intracratonic and foreland basin depositional centers.

Sulphur solubility of reduced iron-rich melts

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Although much work has been done to understand the controls on the sulphur content at sulphide saturation (SCSS) for low FeO terrestrial melt compositions, little information exists to evaluate the SCSS for the high FeO compositions typical of lunar magmas, and at the reduced conditions of the Moon's interior. Such results are also applicable to terrestrial ferro-picrites, and to the effects of assimilation of reduced crustal material. Experiments were done to measure the SCSS for a model low Ti mare basalt with 20 wt.% FeO at 1400°C as a function of fO_2 and pressure. Synthetic lunar basalt was encapsulated along with stoichiometric FeS in capsules made from Fe-Ir alloy. The fO_2 of the experiment can be estimated by the heterogeneous equilibrium: $Fe_{metal} + ½ O_2 = FeO_{silicate}$.

Variation in the metal composition, by addition of Ir, serves to change the fO_2 of the experiment. Capsule compositions spanning the range $Fe_{25}Ir_{75}$ to $Fe_{96}Ir_4$ (at%) were synthesized by sintering of pressed powders under reducing conditions. Fe_{100} capsules were fabricated from pure Fe rod. For a melt with 20 wt.% FeO, this range in capsule composition spans the fO_2 interval of ~IW-1 (Fe_{100}, $Fe_{96}Ir_4$) to IW+2.2 ($Fe_{25}Ir_{75}$). Experiments were done over pressures of 0.1 MPa to 2 GPa. Results involving Fe_{100} capsules indicate that the SCSS decreases from ~2000 ppm (0.1 MPa) to 700 ppm (2 GPa). Experiments done at 1 GPa, involving the range of capsule compositions indicated, show a marked decrease in SCSS as the Fe content of the capsule increases (fO_2 decreases). Complementary to the decrease in SCSS is a drop in the sulphur content of the coexisting sulphide melt, from ~50 at% at ΔIW = +2.2 to ~20 at% at ΔIW-1. This is consistent with a decrease in the activity of FeS (a_{FeS}) in the sulphide melt, which results in a lowering of the SCSS, as predicted by a simple thermodynamic treatment of the sulphide-silicate equilibrium. Data for experiments done with $Fe_{96}Ir_4$ and Fe_{100} compositions are nearly indistinguishable in terms of sulphide melt composition and SCSS, reflecting the rapid drop in a_{FeS} as Fe saturation is approached. Results thus far indicate that at reduced conditions and high pressure, the SCSS for high FeO lunar compositions is low, and overlaps with Apollo 11 melt inclusion data. Importantly, such low SCSS does not require Fe metal saturation and suggests that some lunar source regions could be saturated in a low-sulphur, sulphide melt.

A high-resolution Holocene marine sedimentological record from Pond Inlet, Nunavut, Canada: is there a paleoseismicity signal?

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Arctic fjords often have sedimentation rates sufficient to preserve a high resolution record of the local and regional environment. Baffin Bay is one of the most seismically active areas in Canada with a seismic hazard similar to coastal British Columbia. Pond Inlet, a fjord in Northern Baffin Island, has had high sedimentation rates since deglaciation (0.8 mm/a), which gives it the potential to preserve a paleoseismic record for the region. Relatively little is known about what depositional processes are responsible for the stratigraphic record preserved in Pond Inlet. Newly acquired submarine geological data from sediment cores and seabed and sub-seabed geophysics reveal deposits interpreted as mass transport deposits (MTD) and turbidites. The processes responsible for these deposits could include local glacial outbursts, storms or flood events, or earthquakes.

Detailed sedimentology on the cores, radiocarbon geochronology, grain size analysis, multibeam bathymetry, and seismic stratigraphy of 3.5 kHz data will help test if these deposits are related to regional paleoseismicity, or if climate or storms are more likely triggers. This will involve (1) comparing the sedimentology and grain size patterns of the MTDs with each other and with other MTDs that have been related to modern or paleoseismicity, and (2) determining if deposits are approximately synchronous across the basin based on relative or radiocarbon dating, or, alternatively, if the MTDs were deposited during known Arctic Holocene paleoclimate anomalies. If linked to seismicity, the recurrence interval of large earthquakes may be evaluated, which will improve understanding of the seismic risk for the hamlet of Pond Inlet. Detailed study of this system will contribute to improved assessment of the geological hazards in Baffin Bay and help to understand the changes in strain and seismic risk along passive continental margins.

Post-glacial sedimentation in the Saint John River Valley and comparison with First Nation oral history explaining the origin of the Reversing Falls, New Brunswick

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Examination and finite radiocarbon dating of core samples from the Grand Lake - Saint John River Valley (SJRV) denote changes in the depositional environment and timing of geological events. Four post-glacial geomorphic phases are recognized commencing with deglaciation and

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marine transgression across isostatically depressed terrain, forming the open-phase DeGeer Sea prior to 15 000 calyBP. During Phase II, ~14 000 to 8000 calyBP, isostatic rebound enabled the capture of sea water that was constrained due to glacial burial of previous fluvial outlets, developing the large inland DeGeer Sea that was slowly transformed to the freshwater Lake Acadia. Phase III, ~8000 to 3000 calyBP, is associated with a return to a fluvial-dominated SJRV system when a new outlet was established by down-cutting of the Reversing Falls gorge. Phase IV ~3000 calyBP to present, denotes establishment of estuarine conditions and flow 68 kms up-river, of brackish water from breaching of the Reversing Falls due to rising sea level and higher tides in the Bay of Fundy.

The four-phase geological model complements First Nation spoken histories for the region. The Wolastoqiyik (Maliseet) have always lived, hunted, and traded throughout the Saint John River drainage basin. Their oral history describes extensive flooding of land due to blockage of the Saint John River by a dam constructed by 'Big Beaver', and the subsequent return to a smaller lake (Grand Lake) after the smashing of the dam by 'Glooscap', an ever watchful legendary warrior and protector. The Mi'kmaq also have flood stories that talk about Ice Giants and rushing water that when considered with the scientific data, suggest an association between the geoscience model and aboriginal legends. These observations suggest that First Nation peoples may have been quick to explore the area as glaciers retreated, handing down observations of nature and terrain in a way that made the oral accounts understandable and memorable to subsequent generations.

Recent earthquake swarms in New Brunswick, Canada

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An earthquake swarm is a series of earthquakes that occur over a short period of time (days to weeks), in which there is no clear large magnitude earthquake, followed by aftershocks, but there is instead continuing activity of low magnitude events, confined to a small localized region. For the 382 earthquakes recorded with epicentres in New Brunswick during the 4-year period from 01 January, 2012 to 31 December, 2016, 175 events have been associated with three such earthquake swarms. The two most predominant swarms happened close to the village of McAdam in 2012 and in 2015 and 2016. In September and October of 2016, another smaller earthquake swarm was recorded in the Hammondvale area, about 25 km south of Sussex, New Brunswick. In both areas, the earthquakes were shallow focus (less than 5 km deep). As the two sets of swarms occur close to the contacts between metamorphic rocks and granitic intrusions, the similarities of the geology in the McAdam and Hammondvale areas will be examined and the idea explored that these earthquake swarms may be associated with small fractures within weakened and deformed rocks, rather than repeated movement along a single regional-scale fault plane.

It is also of interest to examine the public reaction to the two sets of swarms. The McAdam swarms, with its many felt earthquakes and close proximity to the village, caused widespread public concern. On the other hand, because of the isolation of the area, the Hammondvale earthquakes were not reported felt and caused no public reaction.

Recent case studies that illustrate the need to identify, value, and protect our natural and cultural geoheritage in Atlantic Canada

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To some geoscientists who are trained to understand the significance of geology and Earth history, the formal recognition of geoheritage can seem unnecessary. But, as argued elsewhere, geoscientists cannot expect support for our work and of the value of geological resources if we do not make the effort to inform the public and government of their significance. Worldwide, the best approach to achieve these ends is through the recognition of our geoheritage. Since beginning the exercise of formally identifying geoheritage assets across Nova Scotia, several instances have occurred that underscore the importance of such an undertaking both to the geoscientific community and to the broader public. Some of these cases have had positive outcomes, at least one has not, and for yet another time will tell. These include: (1) the aborted development of a large monument and infrastructure on the geoheritage site at Green Cove, Cape Breton Highlands National Park, after heated opposition; (2) demolition of the cultural geoheritage site at Crystal Cliffs by Saint Francis Xavier University, without public consultation; (3) the debasement by graffiti of the exceptional geological exposures at Cape Dauphin (Cape Breton Island) and adjacent Kluscaps Cave, highly sacred to the Mi'kmaq, which has not been brought to public attention until now; and (4) the relocation of the

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cairn at Moose River, commemorating the 1936 Moose River mine rescue, a case where the value of a site has been acknowledged by the mining company, although its relocation is not without debate in the community. These case studies indicate that ignorance and lack of public scrutiny can lead to negative outcomes (cases 2 and 3), whereas shared knowledge and public awareness do not (cases 1 and 4). The formal recognition of geoheritage sites puts an onus on the geoscience community, private sector, public, and governments alike to value our natural and cultural geological heritage.

Finding the International Appalachian Trail in the Atlantic Provinces, Canada: the Last Spike

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The Appalachian Mountains have a meaning to geologists that may not be as readily known by the public who hike the Appalachian Trail, or dream of doing so one day. To geologists, the Appalachians are inextricably tied to plate tectonics and the assembly of Pangea. The Atlantic Ocean intervening between North America, north Africa, and western Europe is an inconvenient distraction in reconstructing that world. But to those less fortunate than those who have studied Earth Science, the concept of retracing a world united by tectonic movement and later ripped asunder, to actually trace that connection on foot, is a revelation. It was the idea of visionary scientists in Maine, championed by their Governor, to extend the famed hiking trail northward from Mt. Katahdin to eastern Québec. In so doing, the trail became both a gesture of international goodwill and an exercise in geological education. Today, eighteen countries on both sides of the Atlantic as well as Greenland and Iceland have joined hands in the International Appalachian Trail. Tracing a route through the Maritime Provinces has posed challenges, due to the complex geological terranes and also to the lack of lengthy trail systems. The push to complete the Trans Canada Trail for Canada's 150th birth year is helping to bridge this gap, but its route in some cases avoids the ancient highlands more than guiding the hiker along them. This year, a route will be proposed, if not completed, that will connect the Appalachians in New Brunswick with western Newfoundland, and Pangea will be reunited, if only to intrepid through-hikers and geoscientists. The opportunity to engage the public along portions of this grand route however, has deep potential for learning and for exceptional outdoor experiences. Perhaps most of all, the completion of this idea to join hands comes at a time in human history when nations can afford to be inspired by the ancient ties that bind.

Preliminary results of investigations of seabed cold seeps along the outer continental margin south of Nova Scotia, Canada

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Cold seeps occur where fluids, such as hydrocarbons, migrate from depth and escape at the seabed. They are relatively common features in petroleum basins around the world. The detection of seeps at the seabed is often a strong indicator that an active petroleum system is present and provides critical information about the hydrocarbon source, migration pathways, and maturity. In addition, seabed seeps often host unique biological communities and are indicators of excess pore fluid pressures in shallow sediments. Seabed seeps are notoriously difficult to sample because of their ephemeral nature and environmental complexities. In 2015, a joint research project was undertaken by the Geological Survey of Canada and the Nova Scotia Department of Energy to investigate and sample potential seabed seep features along the continental slope south of Nova Scotia. Since that time, two research expeditions have occurred; the first in June–July 2015 and the second in June-July 2016.

In order to determine the most appropriate areas for sampling, a multidisciplinary approach was applied which utilized all available seismic reflection data, interpretations of sea-surface satellite imagery, and near real-time assessment of seabed and water column anomalies using multibeam bathymetric echosounder and high resolution seismic reflection systems. During the expeditions, core samples were processed on board and subsampled for conventional organic geochemical analysis and geomicrobiology. Besides understanding the petroleum system, the core samples collected during this research project serve other important research needs including improved understanding of the microbiology of bacteria living in the sediment and geological hazard assessment. Results are preliminary, but to date the project has identified a number of active seafloor seeps in water depths from 2700 to 3800 m, and for the first time offshore Nova Scotia, gas hydrates have been recovered from the seabed confirming the interpretation of their occurrence on the margin from geophysical methods and numerical modelling.

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Late-stage propagation of the Grenville orogen: implications of U-Pb ages from Sudbury metadiabase, Georgian Bay, Ontario, Canada

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Did the final (Rigolet) phase of the Grenvillian orogeny result from renewed convergence or post-convergent ductile flow? This question remains unresolved, in part because of limited data on the timing of late Grenvillian tectonism in the parautochthonous Britt Domain in central Ontario, which occupies the critical region between the Grenville Front and the orogenic core. U-Pb data is reported from Sudbury metadiabase, part of a ca. 1235 Ma dyke swarm that intruded Laurentian crust after pre-Grenvillian tectonism, but before the onset of Grenvillian orogenesis (ca. 1100 Ma), and which therefore records exclusively Grenvillian metamorphism.

Representative samples were collected from the southern, central, and northern Britt Domain along Georgian Bay, spanning a 40-km transect across the parautochthon. All samples preserve relict igneous textures overprinted by granulite-facies corona assemblages recording metamorphic conditions of ca. 720–790°C at 13–15 kbar. Fine-grained (10–20 μm) metamorphic zircon decorates grain boundaries of relict Fe-Ti oxides within biotite coronas, forming "string-of-beads", overgrowths, and replacement textures. Zircon was analyzed in situ by LA-ICP-MS at the University of New Brunswick. Metadiabase from H.A. Gray Island in the southernmost Britt Domain yielded a weighted mean $_{206}$Pb/$_{238}$U age of 1031 ± 14 Ma, with ages of 1020 ± 9 Ma and 1011 ± 11 Ma obtained from metadiabase bodies at Byng Inlet and Key Harbour in the central and northern Britt Domain, respectively.

The ca. 1030 Ma metamorphic age of the southern sample overlaps with ages of synkinematic pegmatite dykes within the nearby Shawanaga Shear Zone (ca. 1042–1021 Ma), which record normal-sense ductile reactivation of the precursor Allochthon Boundary Thrust. The ca. 1010 Ma age from the northern Britt Domain sample is similar to other metamorphic ages from the Grenville Front Tectonic Zone (1010–990 Ma), interpreted to mark the final stage of thrusting at the orogenic front. Collectively, the new ages from Sudbury metadiabase are interpreted to reflect ca. 2 mm/y propagation of Grenvillian metamorphism and deformation from SE to NW across the parautochthon. This is compatible with model predictions for post-convergent ductile flow involving thinning and extension in the orogenic core, coeval with thrusting at the orogenic front, although assumed model viscosities may be somewhat too low.

A geotraverse across the Kingston arc-Mascarene-backarc basin in southwestern New Brunswick, Canada

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New exposures along Highway 1 in southwestern New Brunswick provide an oblique cross-section through the dismembered Silurian Kingston arc - Mascarene backarc basin system. Observations made on these new exposures have better defined the relationships between volcanic and plutonic rocks in the Kingston and Mascarene groups. Much of the Kingston arc in this area is comprised of medium- to coarse- grained, and generally highly sheared mafic plutonic rocks assigned to the Andys Pond Gabbro; composite dykes of fine-grained, sheared, porphyritic granite and diabase intrude the gabbro. Highly strained, Early Silurian host rocks of the Kingston Group along the southeastern margin of the gabbro include felsic tuff and mafic tuff locally intercalated with marble. Kinematic markers indicate that shearing in the volcanic and plutonic rocks was associated with dextral strike-slip motion along the boundary with Precambrian basement granitic rocks of the Brookville terrane to the southeast. The depositional age of a thin fault sliver of high-pressure, garnetiferous psammite along this boundary is uncertain.

Backarc volcanic and sedimentary rocks of the Mascarene Group are separated from the Kingston Group to the southeast by Precambrian basement rocks of the New River terrane. Late Ordovician to Early Silurian, shallow-marine limestone and tuff of the Goss Point Formation, the lowest part of the Mascarene Group, likely correlate with the highly strained marble and mafic tuffs in the Kingston Group. Steeply-dipping, Early Silurian tuff and black shale of the Letete Formation represent deeper-marine deposits within the Mascarene backarc basin. Late Silurian strata in the upper Mascarene Group are gently dipping and display well-preserved volcanic and sedimentary structures indicative of shallow-marine to terrestrial deposition. Dyke offshoots of the Utopia Granite intrude the Mascarene volcanic sequence. Conglomerate of the Oak Bay Formation along the northwestern boundary of the backarc basin can be observed lying unconformably on polydeformed black shale

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of the Cambrian-Ordovician Cookson Group of the adjacent St. Croix terrane. Intercalated, brachiopod-rich, Early Silurian shallow-marine sandstone, siltstone, and felsic tuff of the Waweig Formation overlie the conglomerate. A thin unit of black shale in the middle of the Waweig section may correlate with the much thicker siltstone-shale sequence of the Jones Creek Formation, exposed in the more distal, deeper part of the backarc basin to the northeast along Highway 7.

Correlation of the Early Cretaceous Naskapi Member, Scotian Basin, Canada, and its implications

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The Naskapi Member of the Logan Canyon Formation, a 150 m thick shale-dominated unit, overlies the sandy Upper Missisauga Formation and is overlain by the sandy Cree Member. Previous studies have suggested that the great decrease in sediment supply resulted from tectonic and/or eustatic changes. The tectonic hypothesis suggests that uplift of the Meguma block diverted rivers draining Labrador along the re-activated Cobequid-Chedabucto-SW Grand Banks fault system. This resulted in sand supply through the Bay of Fundy to the Shelburne subbasin, consequently allowing shale to accumulate farther east in the Scotian Basin. The eustatic hypothesis proposes that global high sea-level stand during the Aptian allowed a fully marine environment for the deposition of the shale of the Naskapi Member, trapping coarser sediment inboard in flood plains and estuaries.

Wireline logs and recent biostratigraphy of 27 wells from the Scotian Shelf and Georges Bank were examined. Minor sandy intervals based on gamma and sonic log signatures from the type section in the Cree E-35 well were correlated to progressively more distant wells, on the assumption that the sands represent periods of lowered eustatic sea level, as demonstrated from conventional core in the Panuke B-90 well. Correlation was confirmed by the distribution of highstand black shales in washed cuttings and biostratigraphic markers identified in some wells. The bottom of the Member is characterized by an abrupt change in sedimentation from sandy to shaly, corresponding to the Barremian-Aptian Unconformity. The top of the Member is more complex and its boundary with the sandy Cree Member is diachronous, but in most wells, including the type section, it corresponds to a relatively thick and blocky sandy unit. This lithostratigraphic marker is not seen in the more shaly outboard wells, for example, Evangeline H-98.

The eustatic model is not consistent with the known rates of progradation in the under- and overlying sandy deltaic sequences. Thick Naskapi Member sands are lacking in wells on the southwestern Scotian margin and in the COST G-2 well on Georges Bank. Rather, the shales show similarities of key markers and overall thickness within the Naskapi Member between the Scotian Shelf and Georges Bank wells. This implies that the Labrador rivers were not diverted through the Bay of Fundy. They may have been directed from the Gulf of St. Lawrence northeastwards along the Humber Valley fault system to the Orphan Basin, where Aptian sands were intersected in the Great Barasway F-66 well.

Sandstone provenance of the COST G-2 well, Georges Bank; relevance to the SW Scotian Basin

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The Georges Bank is a large (~250 km) shallow bank, in a chain of banks along the continental shelf of eastern North America. It formed during rifting of North America and northern Africa in the Late Triassic and Early Jurassic. In the existing literature, the Mesozoic to Cenozoic stratigraphy of Georges Bank Basin is interpreted to be similar to the southwestern Scotian Shelf. Nevertheless, the sources of clastic sediments deposited on the bank during this time have not been previously studied. Both Georges Bank and the SW Scotian Basin could have been sourced by the same rivers, either local rivers draining Maine or rivers coming from the Canadian Shield and Appalachians through the Bay of Fundy.

This study aims to determine the source of the sandstone, and hence river patterns, by analyzing the modal composition and chemical variations of detrital minerals in the COST G-2 well at different stratigraphic levels. Modal composition was determined by counting stable detrital grains from back-scattered electron images for samples from the Late Jurassic to Late Cretaceous.

The data show two distinct mineral assemblages, which might indicate either potential sources or the effects of diagenesis with increasing depth. The first assemblage,

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including Early and Late Cretaceous samples, contain major amounts of tourmaline, zircon, staurolite, and apatite with minor monazite, xenotime and andalusite. The second assemblage from a Late Jurassic sample contains zircon, hornblende, orthopyroxene, garnet, and tourmaline, with minor amounts of monazite.

Chemical fingerprinting of stable detrital minerals, such as tourmaline, garnet, and zircon; less stable detrital minerals, such as micas; and detrital lithic clasts are used to identify potential sediment sources. Late Jurassic and earliest Cretaceous tourmaline chemistry suggests a granitic and/or metapelitic and psammitic source, with tourmaline types 1 and 4 dominating. Towards the Late Cretaceous, tourmaline type 4 predominates with minor type 1 and 3, indicating metapelitic and psammitic source rocks with a small influence from granitic and meta-ultramafic sources.

Understanding the principal sediment sources and river pathways at the COST G-2 well in Georges Bank will be useful in understanding the dispersal of coarse clastic sediments from the shelf to the slope in the southwestern part of the Scotian Basin. Furthermore, detrital petrology influences diagenesis and reservoir quality in oil and gas reservoirs. Future work will involve the comparison of the findings to equivalent formations in the Scotian Basin.

Geological setting of Au-Cu-Ni-Pb occurrences in the Second Gold Brook area, southwestern Cape Breton Highlands, Nova Scotia, Canada

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Exploration and mining activity in the Gold Brook area of the southwestern Cape Breton Highlands dates back to the late 1800s, and focused on auriferous quartz veins in metasedimentary and metavolcanic rocks of what was then called the Precambrian George River Group. As a result of mapping in the 1980s, these metamorphic rocks were re-assigned to the Silurian Sarach Brook Metamorphic Suite (SBMS). Subsequent work in the southern Cape Breton Highlands did not include the Gold Brook area, in spite of its apparent economic potential. Hence, this study was undertaken to provide enhanced understanding of the geology of the area, and included mapping, sampling, petrographic interpretations, and chemical analyses (whole-rock powder and portable XRF methods). Mapping showed that the area is underlain mainly by metavolcanic rocks interlayered with metasedimentary units including quartzite, slate, phyllite, and schist. The abundance of metavolcanic rocks increases from south to north across the area; most are mafic "amphibolite" with minor felsic layers. These rocks are intruded by granite of the Bothan Brook pluton to the east and by the Gillis Brook diorite and associated granite of the Leonard MacLeod Brook suite to the south. In the north, the study area is bounded by an inferred faulted contact with higher-grade metamorphic rocks of the Middle River Metamorphic Suite. Carboniferous sedimentary rocks unconformably overlie the older rocks on the west and southwest.

Chemical characteristics of the mafic metavolcanic rocks indicate that they are tholeiitic and display both MORB and volcanic-arc signatures. Their chemical signatures combined with abundance of interlayered quartz-rich sedimentary rocks suggest that they may have formed in a backarc setting. Chemical similarity suggests that they are related to the Silurian Sarach Brook Formation, although at higher regional metamorphic grade.

No visible gold was observed in quartz, and less abundant calcite, veins in the area and little evidence for gold anomalies was found in whole-rock or portable XRF analyses. Samples of massive sulphides (pyrrhotite, chalcopyrite, pyrite, pentlandite, sphalerite, and galena) were collected from mine waste piles but no sulphides were observed in outcrop. Background levels of Cu, Pb, Zn, and Ni are low in the metavolcanic and metasedimentary rocks. The lack of evidence for economic mineralization in the area suggests that such occurrences may be confined to the areas of historical mining activity in Second Gold Brook.

Mapping fluvial geomorphology, hydromorphologic feature extraction and classification from high-resolution aerial imagery and artificial neural network

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The ability to rapidly and accurately assess hydromorphic features is crucial to monitoring and modelling change in evolving river ecosystems. Imperative to understanding these environments and their changing structures, is the evaluation of spatial and temporal variation in the progression of hydromorphic features, which ultimately characterizes a stream and its dynamic capability. Rivers are systems in dynamic equilibrium, maintaining balance

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in water flow and sediment transport. When river channels are altered under dynamic hydrologic conditions, the river readjusts itself with respect to dimension, profile, and hydromorphologic feature assemblage to reach a balance or equilibrium state. The ability to detect alteration in these hydromorphic feature assemblages is a powerful tool, giving insight to properly predict subsequent system changes, useful in determining correlations between near stream activity and river structure change. This can lead to better understanding of anthropogenic activity in the surrounding riparian area and its associated impacts on river systems, of recent interest and note are those of river system progressions in association with dam removal. Advanced techniques for image processing and computer vision, allow for the mapping and modelling of these systems in detail. The ubiquity of Unmanned Aerial Vehicles (UAVs) has made non-invasive river assessment accessible. Feature assemblages extracted from high-resolution aerial imagery can be correlated to fish species habitat and spawning locations, allowing for the quantitative and qualitative assessment of these river environments, useful in the conservation and management of natural waters.

Regional Cenozoic stratigraphic correlations on the passive margin of the North Atlantic Ocean: comparison between Orphan Basin and the Labrador Margin, Canada

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The extensive passive margin of offshore eastern Newfoundland and Labrador developed during rifting and opening of the North Atlantic Ocean. Rift grabens are typically filled with sediments that exhibit growth against the controlling faults and are draped by late-rift and/or post-rift units. New age constraints from palynological analyses of Labrador Shelf and Orphan Basin wells, combined with paleoenvironmental and seismic interpretations, have allowed us to make regional stratigraphic correlations in the latest Cretaceous and Cenozoic sections. The Base Tertiary horizon of Orphan Basin is a regional seismic marker of late Maastrichtian–Danian age, and a similar-aged maximum flooding surface is observed in a condensed late Maastrichtian section in offshore Labrador. The Gudrid Formation on the Labrador Shelf represents shingled, Paleocene to basal Ypresian forced regressive lobes. A similar shingled package can be recognized along the northern rim of Orphan Basin, where related distal sediments are preserved in Hare Bay E-21. In the middle Eocene of offshore Labrador, the Leif Member of the Kenamu Formation forms a thin sheet of sandstone — a tertiary play for that area. This unit correlates in age to a well-developed shelf-edge delta in Orphan Basin related to a significant regression. Another major regression is documented in offshore Labrador in the lowermost clinoform of the Saglek Formation. New palynological constraints put the age of the base of this unit in the late Rupelian, which correlates with another major shelf-edge delta in Orphan Basin. It is unclear whether the younger Miocene Saglek clinoform of the Labrador margin has a correlative unit in Orphan Basin. However, a major regression is well constrained in Orphan Basin around the Miocene–Pliocene boundary. This section is well preserved in the basin, but was removed across much of the Labrador margin during the Laurentide Glaciation. These correlations show that global sea-level fluctuations are one of the main influences on sedimentation across the two margins, resulting in regional transgressive and regressive events. Local variation related to elevated continental basement blocks, proximity to fluvial discharge, and glacial lowstand erosion, result in stratigraphic variation across the margin; although, key surfaces and packages are similar. Correlations between basins along this vast margin reveal a common geologic evolution in the latest Cretaceous and Cenozoic. This model will extend north into Baffin Bay, where shelf-building packages can be recognized and Neogene stratigraphic intervals are constrained by the ODP 645 well.

Mineral property valuation

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One specialty for geologists to pursue is that of “Valuer”, which is defined by the International Mineral Valuation Committee (IMVAL) as one who: (1) is a professional with demonstrated experience and Competence in the Valuation of Mineral Properties; (2) has experience relevant to the subject Mineral Property or has relied on an “Expert” with experience relevant to the subject Mineral Property, and; (3) is regulated by or is a member in good standing of a Professional Organization. The July, 2016 IMVAL Template which was issued by the Committee provides standards and guidelines for the harmonization of international mineral valuation codes and standards. It defines “Valuation” as the estimation of the Value of a Mineral Property in money or monetary equivalent. The reasons for conducting a Valuation

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can include determination of the sale or purchase price of a Mineral Property, comparison of alternative investment opportunities, fulfillment of a requirement under securities legislation, determination of the base for value-related imposts or taxes, quantification of assets in company balance sheets, determination of entry or participation levels in joint ventures, and assessment of the potential for adding value by exploration or development. Among other things specified in the applicable national code (Canada's CIMVAL, Australia's VALMIN, South Africa's SAMVAL or the USA's SME Valuation Standards), it is the responsibility of the Valuer to select and reconcile results from two or more Valuation Approaches, of which the three generally accepted are based on sourcing market evidence of Valuation for similar properties, estimation of income generating potential, and cost of incurred exploration and development. The IMVAL Template stresses that each Valuation is time and circumstance specific. Fundamental principles to be respected by Valuers are: Competence, Materiality, and Transparency plus Objectivity, Independence, and Reasonableness if applicable under the national code or standard and all as defined.

Geology in the age of technology (using technology to understand our world)

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Unmanned aerial vehicles (UAVs) are becoming a tool or instrument for videography, but more important is the adaptation of instrument payloads for UAVs/drones. A View From Above demonstrates examples in the province of New Brunswick using UAVs for protection monitoring and prevention including erosion, forensics, spills, shoreline maps, and ice monitoring. There are many types of commercial drones and the licensing to help teachers capture and monitor their shoreline maps but need help in acquiring LIDAR equipment and support. Once mounted and tested A View From Above will feature and provide training and workshop support, with analytics, to gain a learning profile and needs for each community. This will include high-resolution mapping support and the demonstration of UAV/drone software tools.

A View From Above can help communities monitor their own resources from energy efficiency to mapping, using lower cost UAV services. With an up-to-date UAV drone fleet, A View From Above can offer the best quality instrument data, mapping, and images technology for their assessments. The UAV/drone industry has become the dominating force in environmental, geoscience, and industrial imaging, allowing a low cost alternative with greater precision and quality. With our unique 2nd person view system the pilot and camera operator can be directed by you to get perfect video and images of your choice. Our commitment to the earth science community has always been a high priority for education.

Vibrations, liquefaction, and immiscible break-up: a new model for peperite formation

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Peperite is a genetic term for a rock formed by the disruption of magma intruding into and mingling with unconsolidated or poorly consolidated, typically wet sediments. The current models of peperite formation (magma mingling and breakup driven by sediment fluidization and explosive fuel coolant reactions) do not explain the wide variety of features seen in rocks with peperitic textures. In addition, the peperitic textures catalogued by over 90 authors do not show any evidence of fine-scale break up, as would be expected if mingling and explosive fuel coolant reactions were driving the process. The inherent space problem associated with moderate- to large-scale fluidization can also not be addressed using the current models.

To gain a thorough understanding of peperite formation, sediment liquefaction, heat flow and boiling at the sediment interface, and the fluid dynamic breakup of viscous liquids have been examined. It is the combination of these factors working together that drive the formation of peperites and control the textures observed in the rock record. It is well known that unconsolidated sediments, especially non-plastic ones, respond to high frequency oscillations. The vibrational forces provided by vapour film perturbations and oscillations during magmatic intrusion into wet sediments leads to an increase in the pore pressure of trapped water causing the effective stress to decrease to the point where it vanishes, and all of the weight bearing capacity of the sediments is lost. When this occurs, the insulated magma is capable of deforming under the same principles that produce load, resulting in a situation where the dense magma will sink below the less dense liquefied sediments. This can be modeled by numerical simulations of immiscible fluid breakup using OpenFOAM.

A new model is proposed to explain the formation of peperitic textures — the vibrational-liquefaction model. This

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model accounts for the effect that the vibrational energy of the vapour film oscillation and collapse has on transmitting mechanical energy to the surrounding sediments, inevitably leading to liquefaction, providing the magma with the space needed to behave in a ductile or brittle fashion, producing peperite without the need of moving large volumes of sediment out of the immediate surrounding area.

The first unambiguous pterygote ichnofossil from the Joggins Fossil Cliffs, UNESCO World Heritage Site, Joggins, Nova Scotia, Canada

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A discovery made in the Pennsylvanian-aged Springhill Mines Formation in1989, by Don Reid "The Keeper of the Cliffs" and his son Doug Reid, at Dennis Point within the Joggins Fossils Cliffs UNESCO World Heritage Site, of a dragonfly-like paleodictyopterid (Megasecoptera) has been re-interpreted as the first unambiguous winged-invertebrate ichnofossil at the site. After its discovery, this fossil became the emblem for Don Reid's Fossil Centre and remains on display at the new Joggins Fossil Centre.

The terrestrial invertebrate fossil record at Joggins is best represented by ichnofossils. Globally the pteralious invertebrate ichnofossil record is almost non-existent with the exception of some landing traces that are represented by appendage impressions (i.e., *Tonganoxichnus and Rotterodichnium*). The specimen of interest here is the only known unambiguous example of a winged trace fossil that demonstrates the anatomical details of the trace maker, and is the first definitive evidence of flying invertebrates at Joggins, despite depictions dating back to writings by Sir William Dawson which were based on a putative compound insect eye preserved within a tetrapod coprolite. One additional carbonized wing fragment identified as Paleodictyopterid has since been found.

The trace fossil is here discussed and tentatively interpreted as the body impression (cubichnia) of a winged invertebrate, righting itself after an inverted landing into soft sediment that may preserve a microbial surface. The fossil lacks carbonized remains, and shows no evidence of a compressed thorax, appendages or cephalon. The posteriorly shallowing dorsal impression has four deep wing impressions and a curved abdomen impression that exhibits drag impressions suggesting movement. The anteriorly deepening wing impression and abdomen drag is consistent with traces left by a modern dragonfly dislodging itself from wet sediment.

Don Reid's contribution to the growing knowledge of the Joggins Fossil Cliffs spans nearly a century. If correct, the re-interpretation of this specimen as a trace fossil of Megasecoptera has implications for its taxonomic status, and it would be only fitting to name it in his honour.

Crowdsourcing the classroom for collections management

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Collections-based learning has been at the foundation of many natural sciences such as geology and biology. Representative specimens in teaching collections provide learners with specimens to examine, describe, measure, and compare. Online collections databases of major international museums are important resources for paleontology research. By introducing students to the principles of collections care and how collections are organized, students gain an insight into the 'value' of collections for learning and future research.

The principles of collections management were integrated into the lab component of an Introduction to Paleontology class at Dalhousie University. As a lab activity, each of the forty-five undergraduate students was provided with one specimen from the teaching collection. The students were instructed on how to complete a prepared lab sheet with information related to their specimen. The students gathered the required information from labels that accompanied the specimen and looked up supplemental information (taxon, range) in reference books. After receiving a general introduction to photography, the students also photographed each specimen and scale bar with a digital camera that was set up in the room. The students noted the file number of their photo on the record sheet. As homework, the students had to enter their specimen information into an online record (Google Form). When submitted, the form automatically added their data into an online spreadsheet. The Google spreadsheet became the basis for a digital collections database. The instructor uploaded all the photographs to a server and linked the file locations to the spreadsheet data.

Students can learn collections management principles

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that involve specimen labelling, photography, database development, and record maintenance, which are all valuable scientific research skills. By developing labs that introduced the students to the principles of collection management they were involved in a learning activity that produced a useful product of a digital collection database. The process was easy to organize and a popular activity among the students.

Sixty years of citizen science: significant dinosaur trackways, Carboniferous fish, insects, and amphibian footprints from Nova Scotia's Bay of Fundy region, Canada

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Eldon George began looking for beach shells and fossils in 1940 after experiencing a traumatic injury to his right arm when 8 years old. He opened the Parrsboro Rock and Mineral Shop and Museum in 1948, and was then featured prominently in the 1957 National Geographic Magazine article *The Great Tides of Fundy*. Eldon worked as a field geologist, but he had a passion for museums and learning after working at the Nova Scotia Museum from 1966–67. Eldon has devoted over sixty years of discovering and collecting fossils and minerals from sites along the Fundy coast near his hometown of Parrsboro, Nova Scotia, and he received the Order of Nova Scotia in 2013. The Cumberland Geological Society purchased the Parrsboro Rock Shop in 2015 in order to build a permanent exhibit and Eldon has donated his collection of fossils to the Fundy Geological Museum. A preliminary inventory of significant specimens is offered here to encourage research interest in the collection.

The inventory was developed with contributions from Beth Ann McCarthy and Dr. John Calder in 2003, Dr. Helen Tyson in 2008, and from subsequent consultations with Eldon George since August 2015. Initial taxonomic identifications had been suggested by Dr. Donald Baird, Dr. Paul Olsen, and several other researchers who have collaborated with Eldon George. The initial list includes over 1500 fossil specimens, collected between 1948 and 2004, from the Carboniferous and Mesozoic coastal exposures on the northern shore of the Minas Basin, Bay of Fundy. Approximately 20% of the specimens appear to be of high research and educational importance. The collection includes 150 specimens of fragmentary paleoniscid and acanthodian fish from the local exposures of early Carboniferous Parrsboro, West Bay, and Horton Bluff Formations, including isolated fin spines, scales, well preserved jaws, and cranial material. A well-preserved body fossil of a Carboniferous insect similar to *Stenodictya* and several isolated wing specimens are of high research interest. There are more than 300 trace fossils, including rare Eurypteryid traces, and Carboniferous to Mesozoic footprints, including *Pseudobradypus*, *Batrachichnus*, *Batrachopus*, *Grallator*, and *Otozoum*. The most famous specimen "*the world's smallest dinosaur footprints*" was mentioned in a Time Magazine article in 1986.

Eldon George is an accomplished citizen scientist who carefully maintained notes, examined specimens in detail, and collaborated with international researchers. His collection of fossil and minerals provides an important addition to the Fundy Geological Museum.

Experimental study of development of positive trigons on diamond: conditions of near-surface diamond resorption with application to crystallization conditions of Snap Lake kimberlite, Canada

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Diamond is one of the most well recognized native elements and is in high demand worldwide. Kimberlites are volatile-rich, ultrabasic igneous rocks, which are a primary source rock of diamonds. During ascent of the kimberlite magma to the Earth's surface, as well as after crystallization, its diamonds undergo resorption as a result of oxidation within the kimberlite magma. Diamond resorption near the surface produces surface features on diamond crystal faces (resorption morphology) particularly; trigonal etch pits also known as trigons, and the orientation of these trigons is positive as opposed to negative. The orientation of the trigons is controlled by the temperature and oxygen fugacity in the kimberlite magma. Many studies have been conducted on kimberlite magma composition and crystallization conditions; however, there is a lack of direct near-surface composition constraints and an uncertainty in the first order controlling factors and limits of near-surface diamond resorption. Kimberlitic diamond resorption morphology can be used as a proxy for constraining near-surface crystallization conditions of the host-kimberlite as well as for the controls on the diamond crystal quality. To investigate the diamond-bearing kimberlite near-surface crystallization conditions, this study uses a recent approach of examining the parameters of positive trigons experimentally developed on diamond crystal faces using an atomic force microscope (AFM). Diamond resorption experiments were conducted in the presence of Na_2CO_3-NaCl melts at 0.1 MPa (atmospheric pressure) and 700–

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800°C (relatively low temperatures to reflect near-surface conditions). The experimentally produced positive trigons were measured using the AFM. This study confirms the individual effect of relatively low temperature and melt composition (halogens in the carbonate) on diamond resorption kinetics and morphology, and also shows that the relationship between the diameter and depth of the experimentally produced positive trigons is an important indicator of the volatile composition and temperature in the kimberlite magma interacting with the diamond surface. Application of these results will be used explain the crystallization conditions during emplacement of the Snap Lake kimberlite dyke which shows predominantly positive trigons on its diamonds.

Discovery 360 learning - innovation in the classroom - from 3D printing to drones

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Transferring knowledge today uses creative problem solving and case-based reasoning techniques for different learners. Learn-by-doing allows students to be constructivists and build their knowledge through community experiences and exploration. Community STEM (Science Technology Engineering and Math) events provide the forum for feedback and the context for questions. Students want a place to build ideas and observations at the centre of their learning experience through places called Makerspaces. They can do this in the air with videography, flying instruments, thermal imaging, 360 viewing, and magnetics. Ideation allows students to be responsible for their own learning with teachers guiding students into new discoveries with 3D printing and drones.

Student as constructivists allow them to build 3D models with 3D printing so they can explore and study how their prototypes can impact society. This design process builds confidence and provides better problem solving skills to enhance their observations. Failed experiences mean learner success — students can hypothesize new discussions, ideas, and practical applications for all disciplines. The gathering of data and information, and applying them to senses like smelling, tasting, touching, hearing, and seeing. Our traditional ways of teaching discourages the process on inquiry-based learning. Student learners have different perspectives of the outside world. Today, they can 360 video experience and build portfolios for career development. Drones and 3D models give the students the freedom to advance higher in their education.

Formation-scale, immobile trace element variations in felsic volcanic host rocks of the California Lake Group VMS deposits in the Bathurst Mining Camp, New Brunswick, Canada

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The Bathurst Mining Camp (BMC) is a world class Zn-Pb-Cu mining district, containing forty-six VMS deposits. These deposits are hosted by Cambrian-Ordovician bimodal volcanic and intercalated sedimentary rocks that were deposited in the Tetagouche-Exploits backarc basin. The host sequence was dismembered and subjected to polyphase deformation and mid- to upper-greenschist grade metamorphism during incorporation in the Brunswick subduction complex. This study focuses on the northernmost thrust-nappe (California Lake Group) which is divided into three coeval volcano-sedimentary formations (i.e., Mt. Brittain, Spruce Lake, and Canoe Landing Lake formations) that are all conformably overlain by Boucher Brook Formation. Traditionally, formation-scale exploration in felsic volcanic sequences relies on textural criteria to locate the proximal volcanic facies. However, due to pervasive alteration and subsequent deformation, textures can be destroyed or are highly cryptic. The purpose of this study is to determine if immobile trace element compositions of felsic volcanic host rocks within a single formation can be used to develop exploration targeting tools. Host rocks from the hanging wall and footwall of eleven VMS deposits were sampled from drill core and analyzed using fusion ICP-MS/OES. Zr, Nb, Y, La, Yb, and Ti were considered immobile elements and normalized to Al to correct for mass change effects. Compared to the least-altered averages, deposit associated host rocks are enriched in Zr and La, and depleted in Y and Yb with the footwall units having larger degrees of enrichment and depletion. The Spruce Lake Formation deposit host rocks are enriched in Ti and depleted in Nb, whereas the Mt. Brittain Formation deposit host rocks have the opposite characteristics. The immobile trace element signatures of these host rocks are primarily due to magmatic fractionation processes in shallow level intrusions, and are well-documented among VMS districts globally, but have not been used within a single volcanic sequence. Multivariate statistical analysis of deposit host rocks in the Spruce Lake Formation found that overall grade and tonnage of deposits is positively correlated with Zr, Nb, and La, and negatively

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correlated with Y and Yb. Additionally, Cu grade correlates positively with Zr, La, and Ti, whereas Zn and Pb grades positively correlate with Y and Yb. The felsic volcanic rocks in these formations consist of a thick sequence of stacked rhyodacitic cryptodomes, and the geochemical analyses suggest that immobile trace element signatures can be used to locate the more prospective proximal volcanic facies without the need for detailed textural interpretation.

Petrographic and chemical analysis of metasedimentary rocks and iron formations to investigate gold mineralization in the New Quebec orogen, Canada

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The Labrador Trough is an early Proterozoic fold and thrust belt system that extends from Schefferville to the Kuujjuaq area of northern Quebec. It is part of the New Quebec orogen and represents the foreland of this Paleoproterozoic orogenic belt. The Labrador Trough (or Kaniapiskau Supergroup) consists primarily of metasedimentary rocks. It has been heavily deformed, and preserves tight fold structures that exhibit a range of dilatant structures that are suitable for hydrothermal gold deposition. This project addresses the possible sources for gold in the Labrador Trough, and will relate mineralization styles to the structural evolution of the area. Quantitative contents of gold and other metals in the metasedimentary rocks and iron formations will be determined through a series of analytical methods. The goal is to assess the potential of these units as sources or hosts for gold and other precious metals. This analysis will be based on whole rock geochemical analysis using Instrumental Neutron Activation Analysis (INAA). Mineral and textural data from both microscopy and micro X-Ray Fluorescence (μ-XRF) will include sulphide maps and mosaics that will add data regarding the spatial distribution of metals to the mineralogical data. The Scanning Electron Microscope (SEM) analyses will be used for identifying micro-textures and inclusions within the sulphide minerals. At present, geochemical analysis, μ-XRF mapping and SEM analysis are in progress. Detailed microscopy determined that gold is present in varying abundances in samples of greenschist-facies metasedimentary rocks, siliceous-carbonate iron formations, and greenstone-hosted carbonate vein systems. Polished thin section examination of the metasedimentary samples showed a variability in concentrations of pyrite (4–7%), galena (up to 5%), sphalerite (2–3%), arsenopyrite (up to 10%) and gold (<2%). Gold found in the metasedimentary samples was typically replacing, or in contact with, arsenopyrite grains near carbonate vein structures. The iron formation samples had an abundance of sulphides present; however less gold was found, due to either a lower concentration within the sample and/or gold grains not being visible using microscopy methods. Further work will include completion of Laser Ablation Ion Coupled Plasma Mass Spectrometry (LA-ICP-MS) analysis to determine quantitative precious metals and trace element abundances. It is anticipated that this research will be of interest to exploration companies operating in the area because while the occurrence of gold has been documented in the Kuujjuaq area, there has been little work completed on the sources and sinks for metals in the region.

Reservoir siltation and Quaternary stratigraphy beneath the Mactaquac headpond, New Brunswick, Canada, as revealed by acoustic and ground penetrating radar sub-bottom imaging

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The 660 MW Mactaquac Hydroelectric Generating Station is located on the Saint John River approximately 20 km upriver of Fredericton, New Brunswick, Canada. As part of an aquatic ecosystem study designed to support a decision on the future of the station, sediment in the headpond, extending 80 km upriver, is being examined. The focus of this sub-study lies in (1) mapping the thickness of sediments that have accumulated since inundation in 1968, and (2) imaging the deeper glacial and post-glacial stratigraphy.

Acoustic sub-bottom profiling surveys were completed during 2014 and 2015. An initial 3.5 kHz chirp sonar survey proved ineffective, lacking in both resolution and depth of penetration. A follow-up survey employing a boomer-based "Seistec" sediment profiler provided better results, resolving sediment layers as thin as 12 cm, and yielding coherent reflections from the deeper Quaternary sediments.

Post-inundation sediments in the lowermost 25 km of the headpond, between the dam and Bear Island, are

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interpreted to average 26 cm in thickness with the thickest deposits (up to 65 cm) in deep water areas overlying the pre-inundation riverbed adjacent to Snowshoe and Bear islands (both now submerged). A recent coring program confirmed the presence of silty sediment and showed good correlation with Seistec thickness estimates. In the ~15 km stretch upriver of Bear Island to Nackawic, the presence of gas in the uppermost sediments prevented sub-bottom penetration and acoustic estimates of sediment thicknesses. Profiles acquired in the uppermost ~40 km reach of the headpond, extending to Woodstock, showed a strong, positive water bottom reflection and little to no sub-bottom penetration, indicating the absence of soft post-inundation sediment.

Deeper reflections observed within 5 km of the dam revealed a buried channel cut into glacial till, extending up to 20 m below the water bottom. Channel fill includes a finely laminated unit interpreted to be glaciolacustrine clay-silt covering a possible esker – similar to stratigraphy downriver at Fredericton.

A waterborne GPR survey, using 100 MHz antennas, was conducted near Nackawic in August, 2016 to evaluate its suitability as an alternative to acoustic profiling in areas of gas-charged sediment. This proved to be an effective solution to the "acoustic blanking" problem, revealing bottom sediment layers with estimated thicknesses of less than 1 m. This approach was limited to water depths of ~15 m due to signal absorption, as a consequence of the moderate electrical conductivity (~120 uS/cm) of the water.

Developing an earth science collections strategy for Atlantic Canada

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Collections hold the foundations of our science. For several decades they have been removed from the security they once enjoyed and many collections are threatened with neglect and inevitable destruction. This is not a local problem but is seen throughout collecting institutions worldwide, including museums, government departments, and universities. Some of the most frequently encountered explanations for this phenomenon include lack of curatorial expertise, space, or funding to maintain collections, but as a wider systemic problem can be attributed to a fundamental misunderstanding of the role of scientific collections, and a disregard for the responsibility of scientists to maintain collections as part of the scientific process.

The Atlantic Geoscience Society has undertaken to develop and administer a survey of earth science collections throughout the Atlantic Provinces to determine the exact state of these collections. This will provide an accurate picture of the types of collections held, the state of such collections, how they are managed, and the threats they face. When completed, a regional collections strategy will be developed and circulated to appropriate decision makers. It is hoped that this work will encourage institutions and individuals within them to develop a regional strategy for the management and preservation of collections that will enable them to be used and appreciated by researchers now and in the future.

Examination of geological gradients as a driver of stream biological communities in south-central New Brunswick, Canada

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The New Brunswick Energy Institute (NBEI) sought research to support better understanding of the potential impacts of intensive shale-gas development on surface waters in south-central New Brunswick. A two-year research program was designed to characterize baseline chemical, physical, and biological conditions in surface waters pre-development; and support the ability of provincial and federal regulators to assess and detect changes of concern during or post-development. The overall research program was split into five distinct sub-projects, or components, including; assessment of groundwater inflows and stream temperature, characterization of water quality and biological community structure, characterization of sediment geochemistry, development of a method to assess dissolved methane in streams, and development of an online data portal for publicly accessible data. Water quality analysis revealed a distinct separation among stations that was driven by a strong gradient in ions, nutrients, and metals. There was a clear pattern of higher levels of ions, nutrients, and metals at

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stations located in areas of glacial veneer surficial geology, and lower levels at stations located on undifferentiated bedrock, indicating a natural geology-driven gradient in water chemistry among the study sites. Assessment of physical habitat and GIS data supported the importance of geology in the study area, with both surficial geology and bedrock geology playing a dominant role in distinguishing among stations. Both benthic macroinvertebrate communities and fish communities were distinguished on the basis of underlying surficial geology at the largest scale, with benthic macroinvertebrates appearing to be more directly driven by differences in water chemistry, and fish appeared to respond most strongly to physical habitat variables and temperature at the site-scale. Underlying geology was expected to explain a large proportion of variation in stream and river water quality, however the strength of the association between the geology and the benthic invertebrate and fish communities was an interesting result and will lead to more directed data analysis and research to explore these relationships.

Honouring Don Reid ONS (1922–2016) and his foundational collection at the Joggins Fossil Institute

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The Joggins Fossil Cliffs UNESCO World Heritage Site is a Carboniferous coastal section within the Bay of Fundy. The cliffs represent the World's finest example of the terrestrial tropical environment and ecosystems of the Pennsylvanian (Late Carboniferous). Local resident, Don Reid (also known as "The Keeper of the Cliffs"), diligently amassed a large collection of educationally and scientifically important fossils from the site that represent a broad range of specimens, including micro- and macrofossils; invertebrates and vertebrates; plant material; and trace fossils. In 1989, he and his family opened a fossil museum in Joggins that highlighted their finds.

The UNESCO World Heritage designation and the opening of the newly constructed Joggins Fossil Institute (JFI) in 2008, prompted Don and his family to donate his collection of Joggins fossils to JFI/the Province of Nova Scotia. While JFI's collection continues to grow, Don's specimens still form the foundation of the Institute's collection and his fossils remain exceptionally useful for educational and scientific research, indeed, many specimens have been featured in publications.

Individuals like Don Reid, who are particularly gifted and passionate, should be recognized as champions of our natural heritage. In 2016, Don was awarded the province's highest honour: the Order of Nova Scotia.

Discovery of a possible Zn-Pb-Ag SEDEX basin, Bathurst Mining Camp, New Brunswick, Canada

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SEDEX deposits host greater than 50% of the world's Zn and Pb resources with combined grades and tonnages that are an order of magnitude greater than VMS deposits. Mineral exploration in polydeformed rocks of the California Lake and Sormany groups in the northern part of the Bathurst Mining Camp has focused on a sedimentary sequence and base-metal occurrences that are collectively interpreted as possible evidence of SEDEX-type mineralization. A road cut on the property exposes a sequence of steeply inclined rocks of the Canoe Landing Lake Formation, including pyritic, quartz-veined, silicified, and chloritized mafic volcanic rocks, and overlying limestone/dolomite, pyritic argillite, cherty argillite, chert, and rare 1–2 cm beds of semi-massive to massive pyrite. The sequence is interpreted as part of a sea-floor hydrothermal vent complex complete with a footwall feeder system and associated exhalites. Along strike 1.5 km to the southwest, a 0.36m-wide massive sulphide unit is hosted by or, alternatively, partially replaces a unit of dolomite.

Twelve clusters of angular bedded/banded Zn-Pb-Ag-Cu-Au massive sulphide boulders have been discovered on the property, primarily in Holocene rivers and streams. These clusters are spatially related to pyritic, graphitic argillite/mudstone, Zn-Pb-Ag-Cu-Au massive sulphides, immature clastic sedimentary rocks, pyritic cherty exhalite, pyritic felsic tuffs, and limestone/dolomite in the Millstream, Boucher Brook, and Canoe Landing Lake formations. Deposition of carbonates is interpreted to have developed in a third-order sedimentary basin, the "Millstream Basin". The Rocky Brook-Millstream Fault bounding the northern margin of the basin, and the "66 Fault" bounding the western margin are, respectively, proximal to massive sulphide zones and boulder clusters. Skarn, hornfels, silica, carbonate, sericite, and Mn alteration zones are present, and pronounced Mn alteration of dolomite is observed near several clusters of massive sulphide boulders. Assays from one boulder cluster yielded an average of 0.77% Zn, 1.73% Pb, 0.81% Cu, 124 ppm Ag, and 1.1 ppm Au; 600 m to the east, assays from a second cluster averaged 16.87% Zn, 5.09% Pb, 0.41% Cu, 217 g/t Ag, and 0.90 g/t Au. Sulphide boulders returned Sn values up to 3400 ppm.

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Predicting zones and potential sampling methods for elevated metal concentrations in urban soils, Halifax, Nova Scotia, Canada

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Canada lacks a uniform method for sampling metals in soils, posing challenges for comparing studies and hindering the recognition of trends. Although problematic, the absence of a standard methodology is not unfounded. Soil properties are extensively variable, making it difficult to evaluate a given area. This is particularly the case for urban precincts, where soils have been disturbed and soil horizons are not well developed. Developing a standard methodology holds substantial significance, both for urban soil sampling and for society, as this allows studies to be compared and may add to the effectiveness of environmental and health risk assessments. This study focuses on developing a protocol for urban soil sampling within the city of Halifax in Nova Scotia. One aspect of the study aims to predict where high metal concentrations may arise in a city, by identifying past land use activities that are strongly associated with a particular metal(s). A key prediction method includes the creation of Geographic Information System (GIS) map, illustrating potential zones of high metal concentration and type of metals present in these locations over historic time. A second aspect of the study involves evaluating the variability of metal concentrations with sample depth (0–5 and 0–15 cm sample depths) and particle size (un-sieved, <2 mm and <0.5 mm). Through the use of X-ray fluorescence (XRF), a total of 100 samples from Dalhousie University campus were analyzed, for metals with federal and provincial guidelines: Be, Ba, V, Fe, Co, Ni, Cu, Cr, Zn, Mo, Ag, Cd, Th, Sn, Pb, As, Sb, Se. Samples collected away from obvious point source contamination showed values consistently below Canadian Council of Ministers of the Environment (CCME) or Nova Scotia residential guidelines for Ba, V, Cu, Cr, Ni, Se, Mo, Ag, and Sn. Samples taken proximal to older buildings showed values below and above guidelines for Ba, V, Fe, Cu, Cr, Ni, Se, Zn, Mo, Ag, Th, Sn, Pb, As, and Sb. In some locations, metal concentrations for Fe, Th, Pb, As, and Sb were above both guidelines. Overall, a general trend was identified, with higher metal concentrations typically found within 0-15 cm sample depths. Preliminary conclusions contribute to establishing a possible background range for soils in the city of Halifax. Determining urban background will aid in the assessment of a standard protocol for the evaluation of metal content in city soils. Additional conclusions drawn from soil analysis may provide preliminary recommendations for policy makers.

The influence of regional fault systems in the evolution of the Maritimes Basin complex of New Brunswick, Canada, and adjacent offshore areas: Belleisle and Kennebecasis faults

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Centred beneath the Gulf of St. Lawrence, the late Devonian to early Permian Maritimes Basin complex is a successor basin to the Paleozoic Appalachian orogenic collage in eastern Canada, and has been the subject of exploration for hydrocarbons since the mid-19th century. The evolution of the Maritimes Basin complex is largely controlled by major orogen-parallel strike-slip faults through the Mississippian, followed by more general subsidence during the Pennsylvanian. 'Basin' and 'subbasin' are terms that have been employed in southeastern New Brunswick without formal definition. Here they are used as follows: a 'basin' has all or most of the geometric elements of a depocentre aside from just a thick sedimentary rock sequence preserved, while 'subbasin' contains a thick sedimentary rock sequence bounded not by features characteristic of a depocentre margin, but the abrupt truncation associated with a major fault. Where there is ambiguity, as under the Gulf of St. Lawrence, with limited borehole control, 'basin' is the default term.

In New Brunswick, to the southeast of the main Maritimes Basin, these strike-slip faults and several late Devonian – Pennsylvanian subbasins are exposed from pre-Carboniferous basement in the southwest, continuously into late Pennsylvanian cover sequences along the eastern coast of New Brunswick and eastward beneath Prince Edward Island and the Gulf of St. Lawrence toward the Magdalen Islands. Recently acquired and reprocessed industry seismic reflection profiles have provided, for the first time, well-resolved third dimensional views of the central and eastern part of this area, permitting a more detailed analysis of the interaction of major faults with the upper Paleozoic cover. Two major fault zones, the Belleisle and Kennebecasis fault zones, can be traced from southwestern New Brunswick to Prince Edward Island, and their interaction with subbasin formation and evolution is the subject of this contribution.

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The influence of regional fault systems in the evolution of the Maritimes Basin complex of New Brunswick, Canada, and adjacent offshore areas: Belleisle and Kennebecasis faults

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A low diversity ichnofaunal assemblage at the base of Romer's Gap: Mid-Paleozoic Kennebecasis Formation, Kennebecasis Island, New Brunswick, Canada

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Recent geological mapping of the westernmost Moncton subbasin on Kennebecasis Island has uncovered a low diversity invertebrate ichnofaunal assemblage preserved from limited outcrop. The name Kennebecasis Formation has previously been employed for red beds that clearly occupy different stratigraphic positions within the Mississippian sequence of southern of New Brunswick, but is currently accepted as being stratigraphically the lowest formation in the Moncton subbasin. Fossils are rare within the Kennebecasis Formation due to the red conglomerate-dominated sedimentary rocks, but a porolepiform fish (*Holoptychius*) described by others suggests a latest Devonian age for at least part of the Kennebecasis Formation. The recently discovered invertebrate traces are the first ichnofossils described from the formation and the oldest continental ichnofossils described from the base of 'Romer's Gap'. Traces of *Protichnites*, *Diplichnites*, *Gordia*, *Heminthoidichnites*, and *Gyrophyllites* are preserved within sediments interpreted as alluvial overbank deposits and floodplain deposits from two stratigraphically distinct sites. Newly discovered limestones within the Kennebecasis Formation contain recrystallized (calcite-spar) 'tubes' that likely represent either bioturbation (?*Planolites* or ?*Chondrites*) or algal sheaths preserved within continental evaporite deposits.

New palynology samples have been analyzed from the upper fine-grained strata of the Kennebecasis Formation, and the overlying conformable grey beds previously included in the Kennebecasis Formation. Lithologically, the uppermost grey bed unit resembles the Albert Formation and contains *Lepidodendropsis* sp. stems and *Aneimites* ferns; however, this unit has also yielded spores indicative of Tournaisian Zones 3–5, not latest Devonian – earliest Mississippian age as for the type area of the Kennebecasis Formation, suggesting either a younger, late Tournaisian Sussex Group age or a cryptic geological contact (unconformity, fault

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contact), is present.

The trace fossil assemblage is comparable to that described from the slightly older Devonian-aged Catskill Formation of New York State and to other ichnofossil assemblages observed in the Horton Group. The seemingly unaffected continental ichnofaunal assemblages on either side of the end-Devonian extinction event may suggest that continental biodiversity did not change dramatically across the extinction boundary into Romer's Gap, further suggesting the gap may be an artifact of sampling and taphonomy.

Rutile and zircon LA-ICP-MS U-Pb geochronology of a corundum-bearing skarn deposit, Frenchvale, Cape Breton Island, Canada

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The Bras d'Or terrane of Cape Breton Island contains Neoproterozoic metamorphic and igneous rocks and Cambrian to Ordovician volcanic and sedimentary units, all unconformably overlain by Devonian to Carboniferous volcanic and sedimentary rocks. This study is focused on the Neoproterozoic rocks of the Boisdale Hills area, specifically the mixed carbonate-siliciclastic metamorphic rocks of the Frenchvale Road metamorphic suite, for which the age of metamorphism is poorly constrained. The Frenchvale Road metamorphic suite represents the Precambrian basement into which the Neoproterozoic Shunacadie and Boisdale Hills plutons intruded. These plutons make up the largest igneous units in the Boisdale Hills. New LA-ICP-MS zircon dating shows that they are distinct units, with the Boisdale Hills pluton dated at ca. 540 Ma, slightly younger than the previously determined ca. 560 Ma age for the Shunacadie pluton. The Frenchvale Road metamorphic suite hosts several commercial marble quarries. The Frenchvale quarry that is the main subject of this study contains metasedimentary rocks including marble and calc-silicate units which are intruded by medium-grained granodiorite that is unmetamorphosed. The calc-silicate units have several distinct layers that contain large, purple to pink corundum crystals (1–5 cm), locally known as "Cape Breton rubies", in a matrix consisting of wollastonite, calcite, dolomite, and quartz with disseminated sulphide minerals. These corundum crystals have been documented in the literature but no detailed petrographic, geochemical, or geochronological work have been done on them.

Rutile is present in several different zones within the samples, with crystals found in the wollastonite-calcite matrix, within coronas of micas around the corundum crystals, and within the outer zones of larger corundum crystals. U-Pb geochronology on the rutile grains will determine whether they formed during one episode of metamorphism, or whether the rutile crystals in different mineralogical contexts represent different generations of growth. The primary igneous rutile and titanite crystals occurring within the granodiorite that intrudes the calc-silicate rocks will also be compared to the metamorphic ones. U-Pb (zircon) ages from granodiorite in the quarry indicate that it was emplaced at ca. 560 Ma, and therefore is interpreted to be part of the Shunacadie pluton. Preliminary rutile ages from reconnaissance analyses indicate that some of the rutile crystals are ca. 560 Ma, representing either new mineral growth during contact metamorphism, or resetting of the ages of older rutile grains during contact metamorphism. Further geochronology work and trace element analysis by LA-ICP-MS will be undertaken to distinguish between these two hypotheses.

Stonehammer UNESCO Global Geopark "Sparking curiosity about the Earth"

Wanda Hughes

Stonehammer UNESCO Global Geopark, New Brunswick Museum Archives, 277 Douglas Avenue, Saint John, New Brunswick E2K 1E5, Canada

Our lives are shaped by geology. Where we settle, the landscape, the crops we grow, natural hazards, water resources, climate, what we mine, and the energy we use are all linked to geology. With a landscape created by the collision of continents, the closing and opening of oceans, volcanoes, earthquakes, ice ages, and climate change, Stonehammer UNESCO Global Geopark includes geological stories from late Precambrian time, a billion years ago, to the most recent Ice Age, and almost everything in between.

Stonehammer's 2500 km^2 area recognized by UNESCO Global Geoparks has exceptional geological heritage. This simply means that the area has a natural landscape that is good for education, has a significant scientific value, is particularly rare or it is simply beautiful to look at. Stonehammer is about geology, but it is also about the people, society and culture. Geoparks take in sites with interesting archaeology, wildlife and habitats, history, folklore, and culture, all of which are intricately linked with the underlying geology. What makes a Geopark different from designations such as World Heritage sites is that they

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have a commitment to benefit the local economy. This is done by bringing visitors into the region, creating jobs and increasing the need for new businesses, all of which help create an awareness and understanding of such a wonderful natural resource. Sparking Curiosity every step of the way!

Stonehammer was the first Geopark in North America and is one of 7 world-wide that has recently formed an international partnership with Northern Periphery and the Arctic Geoparks with a "Drifting Apart" project. This will leverage the geopark on the international stage through partnerships and best practice sharing. The geology of the Northern Periphery and Arctic provides a common link between diverse regions. Millions of years of moving continents, mountain building, volcanic activity, changing climates and sea levels, erosion, and deposition have shaped our landscape. Not only does the resultant geodiversity help us understand the history of our Earth but it also profoundly shapes the world around us. Drifting Apart will support the development of new and aspiring Global Geoparks, the promotion of innovative products and services for social and economic prosperity and to continue to build a strong network of Geoparks in the Northern Periphery and Arctic Region and develop a model for sustainable management of the geological areas designated as UNESCO geoparks.

Nature of the hydrothermal alteration in the Lesbos (Greece) petrified forest and its host pyroclastic rocks

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An early Miocene petrified forest is preserved in the Sigri Pyroclastic Formation of western Lesbos. The purpose of this research is to identify the origin of silica-iron-manganese mineralization of the fossilized trees and their host rocks. The approach used is to identify mineral assemblages present in petrified wood, the altered Jithra ignimbrite, the altered fine-grained sedimentary rocks underlying the ignimbrite, and a nodule as well as yellow veins from a fault cutting tuffs. These minerals were compared with published work in other areas with similar minerals to determine their possible geological origin. A Scanning Electron Microscope and EDS chemical analyses were used to identify the minerals. The petrified wood shows cells filled with amorphous silica, followed by replacement of cell walls by silica, then a silica + Fe-oxide mixture, and finally Fe-oxide, in some cases with minor As and Zn, which are bioessential elements that may indicate microbial mediation. The fault zone nodule is mineralogically zoned. The inner zone is entirely microcrystalline or amorphous silica. The middle zone comprises a silica + Fe-oxide mixture with Mn-oxide aggregrates. The outer zone consists of host tuff partly replaced and cemented by Fe-oxides/hydroxides and the silica + Fe-oxide mixture. As the nodule was found in an altered fault zone, it may have been a pathway for hydrothermal solutions that first altered the country rocks in the outer zone and finished with the final filling by yellow silica veins. The altered ignimbrite and underlying fine-grained sedimentary rocks exhibit more extreme alteration. Mineral assemblages in the altered ignimbrite are: (1) K-feldspar + silica? + illite + minor apatite, zircon, TiO_2 minerals; (2) jarosite + hematite + amorphous silica; and (3) Mn-oxides. Hydrothermal K-feldspar appears to have formed by replacement of volcanic glass, hornblende, and plagioclase crystals. Jarosite replaced hornblende already partly replaced by amorphous silica. Assemblages from the altered fine-grained sedimentary rocks are predominantly smectite + silica + TiO_2 minerals ± hematite ± monazite. Smectite was seen to replace crystals of biotite, plagioclase, and glass fragments. Among possible analogues in the literature, the epithermal system of the Taupo volcanic zone in New Zealand has a very similar setting to the Sigri Pyroclastics. The types of alteration produced by different circulating waters can be compared. However, the distinctive amorphous silica + Fe-oxides are chemically and mineralogically comparable with jaspers found in marine exhalative systems (e.g., Bathurst, Ireland). This observation is interesting because there is no evidence for nearby marine conditions in the Sigri Pyroclastics.

How do large hot orogens work? Lessons from the middle crust

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Large hot orogens are characterized by their broad areal extent, crustal thicknesses exceeding ca. 60 km, central plateaux bounded by external thrust wedges, and internal temperatures high enough to promote widespread partial melting in the middle and lower crust. In these systems, melt-weakened middle crust can flow in response to a pressure gradient and/or underthrusting by a strong indentor, leading to lateral transport of ductile middle crust (infrastructure) relative to both cooler upper crust (superstructure) and stronger lower crust and upper mantle. The resulting

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dynamic behaviour and geological characteristics of large hot orogens are therefore fundamentally different from those of typical fold-and-thrust belts. The Mesoproterozoic Grenville orogen of Ontario presents a superb opportunity to investigate the mid-crustal level of a large, hot, convergent orogenic system. Over the past 30 years, field, structural, petrological, and geochronological studies along the well-exposed Georgian Bay transect have illuminated the fundamental tectonic characteristics of the western end of the orogen. It was assembled by northwest-directed ductile thrusting towards the Archean foreland between ca. 1100–1040 Ma, and reworked by ductile extension and flattening between 1040–1000 Ma. Widespread upper amphibolite- to granulite-facies assemblages record P-T conditions of 10-14 kb at 700–900°C. Protoliths were largely pre-1200 Ma Laurentian crust with some peri-Laurentian accreted terranes. 2D thermal-mechanical numerical models were used to investigate the geodynamic behaviour of the system. The results suggest that lateral flow of migmatite in the orogenic core was triggered by transport of strong lower crust beneath melt-weakened middle crust. Post-convergent flow was accompanied by ductile thinning and extension in the orogenic core and coeval thrusting on its flanks. While there is good first-order agreement between model predictions and observations, further testing against geological data is required. Comparison of model results with observations from the Grenville orogen and similar systems suggests that significant volumes of Proterozoic orogenic crust may have been reworked by ductile lateral flow of middle crust.

Sulphur solubility of carbonatites, with implications for mass transfer in Earth's mantle*

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Carbonatites are rare, mantle-derived igneous rocks with >50 wt.% carbon, compared to more typical SiO_2-rich compositions. Whereas the solubility of sulphur for mafic silicate melts has been extensively studied, equivalent data for carbonate-rich compositions has not been obtained. This research looks to determine sulphur solubility in molten carbonate to assess the potential for such melts as a mass transfer agent for sulphur, along with precious metals, in the mantle. The goal is to determine the importance of carbonatite metasomatism to establish precious-metal-rich source regions for magmatic ore deposits. The concentration of sulphur at sulphide saturation (SCSS) in molten carbonate will be measured as a function of several variables, including melt composition and pressure, to assess the sulphur solubility mechanism. Experiments are done using piston cylinder apparatus at the Dalhousie Laboratory for High Pressure Geological Research. Run products are analyzed using the electron microprobe analyzer using wavelength dispersive spectroscopy. A synthetic carbonate melt determined to be in equilibrium with a mantle peridotite assemblage is used. This material is mixed with a similar mass of FeS, doped with 1 wt.% each of Ni and Cu and additional Fe_2O_3, and then loaded, along with ~ 5 wt.% H_2O, into a graphite-lined Pt capsule. Capsules are placed into a pressure cell comprised of crushable MgO, with an outer graphite furnace, pyrex sleeve, and NaCl sleeve. Run-products consist of a crystalline pyrrhotite or quenched sulphide liquid, coexisting with quenched carbonate melt, as represented by a fine-grained intergrowth of carbonate phases. An initial experiment at 1 GPa, 1100°C, FeO <1%, done for 24 hours yields a SCSS of ~700 ppm. Results thus far suggest similar solubilities for carbonate versus silicate melts. Experiments done with up to 30 wt.% added Fe_2O_3 contain ~ 4 wt.% FeO in the carbonate melt, as well as excess Fe-oxide crystals, suggesting primary carbonate melts will be FeO-poor, with limited formation of dissolved FeS complexes, in contrast to silicate melt. Additional experiments to test the effect of pressure and runs doped with platinum group elements in order to measure carbonatite-sulphide partitioning of precious metals are in progress. Further results from this study will provide a better understanding of sulphur solubility mechanisms, and the role of molten carbonate to dissolve and transport sulphur, as well as precious metals, which is currently unknown.

Winner of the AGS Rupert MacNeill Award for best undergraduate student oral presentation

Experimental investigation of the effect of contamination on chromite crystallization in the Ring of Fire deposit, Ontario, Canada

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Economically significant chromitite deposits are rare, despite chromite being a common accessory mineral in primitive mafic rocks. There were no known significant chromitite deposits in Canada until 2007, when it was discovered that the Ring of Fire Complex (ROF), located in the James Bay lowlands of northern Ontario, contains massive chromitite accumulations potentially

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worth billions of dollars. The processes responsible for ore-grade accumulation of chromite can be simplified into two hypotheses: chromite deposits form (1) due to fluid dynamic processes involving crystal sorting from komatiite melts in large conduits, or (2) due to komatiitic magma interacting with contaminants during its transit to the surface. This thesis project aims to test the second hypothesis. Experiments are underway in which komatiitic magma, similar in composition to that parental to the ROF deposit, is mixed with contaminants resembling the local country rocks. Temperature and oxygen fugacity are controlled by using vertical tube gas-mixing furnaces. The resultant changes in chromite solubility and composition will be measured using electron microprobe analysis. The composition and relative timing of crystallization of experimentally-produced chromite will be compared to ROF samples to assess the validity of the contamination hypothesis. A refined understanding of the controls on chromite crystallization processes is important for effective strategizing when discovering new deposits, as focusing exploration efforts to locations with magmatic systems having the most potential for forming ore-grade chromite deposits may decrease the cost of exploration programs.

The ichnogenus *Kouphichnium* and related xiphosuran traces from the Pennsylvanian Steven C. Minkin Paleozoic footprint site (Union Chapel Mine), Alabama, USA: ichnotaxonomic and paleoenvironmental implications

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Since its discovery, the Steven Minkin fossil site at the Union Chapel Mine (UCM) in Walker County, Alabama, USA, has become one of the most productive continental ichnofossil sites from the Pennsylvanian Period. This exceptional trace-fossil Lagerstätte is preserved in deposits of a tidally influenced estuary that are a thin stratigraphic interval of the Lower Pennsylvanian Pottsville Formation. Best known for its vertebrate trackways, the invertebrate trace fossil record at UCM is also extensive. The ichnogenus *Kouphichnium* and many associated ichnotaxa have been attributed to xiphosuran activity at this and many other sites. The ichnospecies *K. aspodon* has been re-examined from numerous samples collected from the UCM. The large sample size offers a unique opportunity to study the variation in some *Kouphichnium* ichnospecies from Pennsylvanian-age strata with broader implications for other localities where *Kouphichnium* is common (i.e., Joggins, Nova Scotia). The morphological variability resulting from the taphonomic, ethological, and underprint fallout in relation to *Kouphichnium* traces from UCM have been documented. Four morphotypes have been segregated from those specimens that previously were liberally assigned to *K. aspodon*. Ichnospecies of *Kouphichnium* identified at the UCM site are: *K. lithographicum*, *K. aspodon* and two morphotypes that conform to the ichnogenus concept of *Kouphichnium* (*K.* isp. A and *K.* isp. B). Additionally, *Kouphichnium*-like locomotion traces that are associated with "jumper" traces are here re-examined and are identified to have been previously misinterpreted as *Kouphichnium* and *Selenichnites*, respectively. Instead, these are the traces of new ichnotaxa and were not produced by limulids. The holotype of *K. aspodon* (*Bipedes aspodon* Aldrich), which is also from Pennsylvanian strata in Alabama, is redescribed in order to better define the ichnospecies. New tracemakers for some *Kouphichnium* ichnospecies are hypothesized and compared to the traditional xiphosuran attribution. Their role in this Carboniferous ecosystem is also examined, and that may have implications for the interpretation of the invertebrate community present at other Carboniferous ichnofossil localities.

Ichnology of the Devonian (Emsian) Campbellton Formation, New Brunswick, Canada

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The Campbellton Formation is exposed along the banks of the Restigouche River-Bay of Chaleur, New Brunswick. The formation has long been known to yield a fossil assemblage of Devonian (Emsian) fish and eurypterids at its westernmost exposure near Campbellton and Atholville, and a well-described flora and early land animal fauna toward its easternmost exposure near Dalhousie Junction. Although the paleobotany, vertebrate and invertebrate paleontology, paleoecology, and paleoenvironment have been extensively studied, ichnofossils are rare and have not been described as a component of the fossil assemblage. Fossils from

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the vertebrate and eurypterid-bearing “Atholville Beds” contain a low diversity ichnofossil assemblage represented by three ichnotaxa: *Monomorphichnus*, ?*Taenidium*, and *Helminthoidichnites*. The trace fossils *Helminthoidichnites* and ?*Taenidium* are thought to be produced by shallow subsurface invertebrate fauna. *Monomorphichnus* has classically been interpreted as a trilobite surface trace produced by the trilobite appendages being dragged across the sediment. Trilobites are not known from the Campbellton Formation, and the paleoenvironment has been interpreted by others to be deposited in a non-marine setting, alternating mouthbar-delta front-prodelta environments, thus excluding marine fauna. Alternate tracemakers are here inferred.

Monomorphichnus is proposed as being produced by the activity of the eurypterid *Pterygotus anglicus*, the only organism known from the fauna that might be considered the tracemaker. Little evidence exists for the diet and feeding strategy of pterygotid eurypterids, however based on body morphology they are typically considered to have been active swimmers and top predators, probably feeding on fish. *Pterygotus anglicus* may have had alternate feeding strategies during its life cycle, preying on soft-bodied slow moving animals. *P. anglicus* may have raked the sediment using the chelicerae to dislodge annelids responsible for ?*Taenidium* and *Helminthoidichnites*.

A tale of two fluids in the Sandwich Point intrusion-related gold setting, South Mountain Batholith, Nova Scotia, Canada

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The chemical discrimination of fluids in intrusion-related gold deposit settings is generally limited to data for the bulk chemistry of fluid inclusions, which implicates a low-salinity (i.e., about 5–10 wt.% eq. NaCl) H_2O-CO_2 ± CH_4 type fluid with X_{CO2} = 0.05–0.15 that may, at times, unmix into other fluid types. Although additional chemical data may be reported, such as the traditional stable isotopes (O, D, C, S), there is a lack of quantitative data for the solute chemistry, such as that generated using evaporate mound SEM-EDS or LA ICP-MS analysis of fluid inclusions. Herein the chemistry of fluids related to the formation of a mineralized (Au-As-Bi-Sb; to 0.5 g/t Au) zone at the eastern contact of the Halifax Pluton, part of the ca. 376 Ma South Mountain Batholith, is presented. At Sandwich Point, sheeted quartz ± arsenopyrite veins and extensive zones of F-rich muscovite greisen are centred on a pegmatite body near its contact with calcareous and sulphidic metasedimentary rocks of the Goldenville and Halifax groups. Locally, these wall rocks record hornfelsing, skarn development, and formation of quartz-tourmaline-carbonate-arsenopyrite veins. Fluid inclusion studies indicate mixing occurred between a high T (600°C), low-salinity (3 wt.% eq. NaCl) fluid (type 1) with minor CO_2 (X_{CO2} ≤0.03), and a lower T (400°C) but higher salinity (20–25 wt.% NaCl-$CaCl_2$) fluid (type 2). The fluids are further characterized with $\delta^{18}O$ of vein quartz and evaporate mound and in situ LA ICP-MS analysis for fluid inclusions. These data indicate the $\delta^{18}OH_2O$ for type 1 and 2 fluids are + 11‰ and < + 20‰, respectively. In addition, whereas type 1 fluid shows relative enrichment in B and As, type 2 fluid is dominated by Ca, Mn, Fe, Mg, Ba, Sr, F, and Pb, but also with elevated Li, Rb, and Cs. These data are interpreted to reflect generation of two fluids from very different processes: type 1 reflects the exsolution of a low-salinity magmatic fluid, perhaps related to the pegmatitic zone, whereas type 2 fluid relates to wall rock devolitization due to the intrusion. However, some features of the type 2 fluids, such as enrichment in F, Li, Rb, and Cs, suggest mixing between type 1 fluid with wall rock derived type 2 fluid. This study highlights the need to more fully characterize the chemistry of fluids in ore deposit settings to better understand the interplay of different fluid reservoirs present in such settings.

Petrogenesis of gold-bearing sulphides within the Lake George polymetallic system, southwestern New Brunswick, Canada: results from LA ICP-MS analyses and in situ sulphur isotopes

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Approximately 40 km to the southwest of Fredericton, New Brunswick is the Late Silurian-Early Devonian Lake George Granodiorite stock and the contact-metamorphic aureole that surrounds it contains known tungsten, molybdenum, antimony, and gold mineralization. A number of publications systematically describe the tungsten-molybdenum mineralization and the antimony mineralization for which the deposit was mined on and off all through the 20th century. The gold mineralization was only identified in the late 1980s due to the “invisible” nature

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of the gold, the very fine-grained nature of the sulphides, and narrow and discontinuous nature of the vein(lets). The cross-cutting relationships of each of the various magmatic-hydrothermal events were identified by previous researchers. All hydrothermal activity in the area post-dates peak contact metamorphic conditions. The gold-bearing veins and veinlets cross-cut the tungsten-molybdenum mineralization and are cross-cut by the antimony veins the deposit was mined for.

LA ICP-MS spot analyses and trace element mapping were used to identify the hosts for gold mineralization and to characterize their trace element compositions. The gold-bearing phases present include arsenopyrite and arsenian pyrite. This revealed a positive correlation between gold concentrations and As, Cu, Bi, and Sb that all occur in solid solution within the cores of arsenic-rich pyrite. Concentrations of gold within the cores of arsenic-rich pyrite reach up to 225 ppm. The results of the trace element mapping show the pyrite has zonation features indicative of coupled dissolution-reprecipitation reactions, which record dynamic changes in the physio-chemical conditions of the ore-forming fluids.

As a way to understand the source of the mineralizing fluids, in situ sulphur isotope analyses were conducted using SHRIMP II. Sulphur isotopic signatures were gathered on pyrite from three different generations; gold-bearing arsenian pyrite, and pyrite from the granodiorite, and pyrite within contact metamorphosed sedimentary rocks. The S isotopic signatures of the gold-bearing arsenian pyrite had a range in $\delta^{34}S$ from -4.90 ± 0.08‰ to -8.55 ± 0.04‰. This slightly negative signature suggests a significant sulphur contribution from a reduced sulphur source. The pyrite from the Lake George Granodiorite had a range in $\delta^{34}S$ from 0.05 ± 0.05‰ to 2.30 ± 0.05‰, which is generally in agreement with other magmatic sulphide $\delta^{34}S$ signatures. The pyrite from the contact metamorphosed sedimentary rocks had a range in $\delta^{34}S$ from -3.31 ± 0.08‰ to -8.51 ± 0.06‰.

Tracing changes in High Arctic environments using microfossils and other biogenic proxies preserved in marine sedimentary archives: the case study of the Wandel Sea shelf

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The extent and consequences of the ongoing melting of the Arctic sea ice is one of the most important uncertainties for predicting the evolution of the future climate. Obtaining detailed information on its natural variability and impacts on the ocean circulation and primary production is crucial to the development of more accurate climate models.

Present-day sea ice and hydrographic data are linked to the modern distribution of 11 biogenic proxies (resting cysts of dinoflagellates, benthic and planktic foraminifera, diatoms, IP_{25}, HBI III, biogenic silica, and the elemental and isotopic composition of organic matter) preserved in surface sediments from the remote High Arctic Wandel Sea shelf (eastern North Greenland). The objective is to establish a reference dataset for recent conditions that can help in assessing past changes in primary production and environmental conditions in High Arctic fjord systems.

Results from this work provide important insights into the distribution of the cysts of dinoflagellates *Polarella glacialis* and cf. *Biecheleria* sp., which have the potential to represent useful proxies for reconstructing past seasonal sea

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ice. Furthermore, the results reveal a close match between the benthic foraminiferal distribution and the major bottom water masses, underlining their relevance for tracing past changes in the Arctic inflow in relation with changes in the Arctic sea-ice cover.

A baseline assessment of dissolved methane in private wells from regions of potential shale gas development in New Brunswick, Canada

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The occurrence of dissolved methane in private well water was investigated in regions of southeastern New Brunswick that had been identified as potential targets for unconventional oil and natural gas development. In total, 434 private wells were sampled across four areas – the Central, Kent, Shediac, and Sussex study areas. Additionally, a subset of 15 wells was sampled monthly for 1 year (time-series sampling). Analyses included testing for inorganic parameters, dissolved gases and isotopes of water, and methane.

Dissolved methane was detected in 55% of the wells sampled. The median concentration for wells with detectable methane was 0.006 mg/L and the maximum was 29 mg/L. Methane concentrations were high enough, >0.1 mg/L, to determine δ^2H and δ^{13}C in methane in 9% of the wells. Biogenic and thermogenic methane were identified in the wells. The Kent study area had the highest frequency of detectable methane, 67%, while Sussex had the highest frequency of samples with methane concentrations >1 mg/L, 9%, and was the only area with methane concentrations >10 mg/L. Ethane and propane were also detected more frequently in the Sussex study area. The bedrock geology of the Central, Kent, and Shediac study areas is relatively uniform; the wells sampled were mainly completed in Pictou Group bedrock, part of the Maritimes Basin. The majority of the wells in the Sussex study area were also completed in bedrock of the Maritimes Basin; however, the geology is more complex due to faulting and folding. The majority of the higher methane concentrations, and most of the ethane/propane detections, were from wells located where Horton Group bedrock is inferred to be present relatively close to the ground surface. The Horton Group hosts the Albert Formation, a known host for oil and natural gas reserves.

The methane concentrations from the monthly sampling of 6 wells in the Kent area indicate little variability in time, with rsd values ranging from 0 to 20%. The methane concentrations in the 9 Sussex area time-series wells had rsd values between 18 and 133%. For all of the Kent time-series wells, drillers reported only one dominant water-bearing zone. The wells in the Sussex area with consistent water quality also had only one reported major water-bearing zone, while the wells with multiple water-bearing zones had variable water chemistry. This is consistent with the expectation that different inflow zones could have different water chemistries and that their relative contribution to the well could vary over time.

Early Paleozoic intra-plate reactivation of the Ottawa graben and links to the onset of the Taconic orogeny: insights from stratigraphy, detrital zircon provenance, and paleoflow of the Cambrian-Ordovician Potsdam Group

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The Ottawa graben is a Neoproterozoic intracratonic rift in northeastern North America that was reactivated throughout the Phanerozoic and persists as a modern seismically active zone of lithospheric weakness with extant topography. Using U-Pb geochronology of detrital zircons combined with paleoflow and stratigraphic data from the Potsdam Group provides evidence for three episodes of reactivation of the Ottawa graben on the Cambrian to Early Ordovician Laurentian craton. The earliest episode was during the late Early to Middle Cambrian and coincided with localized rifting and the opening of fault-bounded mini-basins that were filled with arkose derived from local rift shoulders consisting mainly of ca. 1176 Ma Grenville sources of the Frontenac terrane. Additionally, the local presence of ca. 1442 Ma zircons suggests more extensive opening of the Ottawa graben along the trace of the modern Ottawa River Valley, which provided a localized conduit for the transport of sediment derived from parts of the Central Gneiss Belt, ~350–400 km to the west. The second episode of reactivation occurred during the Middle to early Late Cambrian and resulted in the topographic inversion of parts of the southern Ottawa graben; notably, with the

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onset of uplift of the adjacent Adirondack Dome, and radial dispersal of sediment and introduction of ~1000–1060 Ma detrital zircons throughout the Ottawa graben. The third and final episode of reactivation occurred during the Earliest Ordovician and coincided with a second phase of topographic inversion, but this time marked by subsidence of the Adirondack Dome and uplift of parts of the northern Ottawa graben. This resulted in southeastward paleoflow and the re-introduction of ca. 1442 Ma zircons from reworked older Potsdam strata and/or direct sourcing from parts of the Central Gneiss Belt to the west.

Each of the three episodes of reactivation coincided with regional plate tectonic events in and around ancestral eastern North America which in turn hypothetically perturbed the Laurentian intraplate stress field, triggering reactivation of the Ottawa graben. The earliest episode of reactivation coincides with a poorly constrained period of Cambrian rifting and syn-rift sedimentation in paleo-southern Laurentia that most likely coincident with a late-stage episode of Laurentian lithospheric extension preceding the initiation of Taconic orogenesis. The latter two episodes of reactivation are linked to Peri-Laurentian Taconic orogenic events, including Late Cambrian obduction of the Iapetus Ocean over peri-Laurentian terranes and Early Ordovician initiation of Humber Seaway subduction.

Electric and magnetic signatures of reducing springs at the Tablelands Ophiolite, Newfoundland, Canada

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Winter House Canyon is incised into the ultramafic Tablelands Ophiolite massif in western Newfoundland. The canyon contains springs with unusual reducing chemistry, characteristic of the serpentinization of peridotite. The chemical reactions involve strong electrical potentials and result in the production of magnetite. Therefore, electrical ('self potential' or SP) and magnetic geophysical survey techniques were selected with the aims of characterizing the geophysical signatures of a known spring and locating additional springs. A preliminary study into the effectiveness of SP and magnetics in this environment, conducted in 2011, was hampered by instrument limitations (noisy electrodes and slow magnetic data acquisition). As part of this project, new low-noise SP electrodes were built. A 100 m x 30 m region next to a known spring was surveyed by SP, and a fast, GPS-enabled Overhauser magnetometer was used to survey an area of 1500 m x 200 m along the canyon.

The new geophysical data reveals that the known spring site produces strong, coherent magnetic and SP responses. In the survey down the canyon, a new spring was discovered at the site of a magnetic high, and future exploration targets corresponding to possible new spring sites were found. Furthermore, structural elements of the massif, not visible on the outcrop, were identified. Serpentinization – and hence underground spring water flow – appears to follow long faults roughly perpendicular to the axis of the canyon, at right angles to previously assumed faulting.

New field mapping, U-Pb zircon geochronology, and geochemistry from the Cobequid Highlands, Nova Scotia, Canada: insights into the Late Neoproterozoic magmatic history of Avalonia

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The Cobequid Highlands of central mainland Nova Scotia form part of Avalonia, a lithotectonic terrane of the northeastern Appalachian orogen situated inboard of Meguma and outboard of Ganderia. New field mapping, U-Pb zircon geochronology, and geochemical data obtained with the highlands indicate that it contains a significant and in part unique record of Late Neoproterozoic magmatism. Currently three distinct Late Neoproterozoic magmatic events are recognized. The oldest, >750 Ma, is comprised of mafic volcanic and volcaniclastic rocks interbedded with orthoquartzite and iron formation. This assemblage is interpreted to have formed on the continental margin of Rodinia via decompression melting of upwelling heterogeneous mantle. Intruding this platformal assemblage is a suite of calc-alkaline intrusive rocks ranging in composition from gabbro to granite. This suite was emplaced between ca. 735–765 Ma and is interpreted to represent the root of a continental margin volcanic arc, perhaps recording the initiation of subduction along the margin of Rodinia related to its eventual breakup. Until recently, this crust was only well-documented within the southeastern highlands. A new ca. 740 Ma U-Pb zircon age for a sub-volcanic porphyry within the central highlands indicates that this crust is significantly more widespread and voluminous than originally thought and that the supracrustal equivalents ca. 735–765 Ma intrusive suite are probably also preserved within the highlands. The youngest and most voluminous Late Neoproterozoic magmatic event is well-represented in terms of both its intrusive and volcanic and volcaniclastic rock record, spanning the period between ca. 590–640 Ma. These rocks range in composition from gabbro-granite

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(basalt-rhyolite) and most samples (but not all) possess geochemical characteristics consistent with generation within a continental margin volcanic arc setting. This younger magmatic event is well-recognized in other parts of Avalonia within the northeastern Appalachians, the earlier two are not. The potential for discovery of a fourth Late Neoproterozoic volcanic assemblage within the Cobequid Highlands is suggested from the locally significant ca. 650–680 Ma inheritance in ca. 590–640 Ma volcanic and plutonic rocks. Some yet undated (zircon-poor) volcanic rocks in the central highlands (proximal to the most inheritance-rich rocks) possess geochemical similarities to some of the volcanic rocks of the ca. 680 Ma Stirling belt of southeast Cape Breton Island. Abundant Meso- to Latest Paleoproterozoic zircon found within ca. 590–600 Ma volcaniclastic/epiclastic rocks and >750 Ma orthoquartzite may be remnants of the Avalonian basement.

Apatite for reduction: a potential new oxybarometer for felsic magmatic systems

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Currently, there is a lack of good oxybarometer for use in felsic magmatic systems. Existing oxygen barometer relies on either Fe-Ti oxides or zircon being present in the system. The study involves investigating a potential oxygen barometer using the partitioning behaviour of arsenic and antimony between apatite and melt. Apatite [$Ca_5(PO_4)_3F$] reaches saturation early in felsic magmas and having a range of oxidation states, is known to substitute for phosphorus. Pentavalent arsenic (As^{5+}) is more compatible then trivalent arsenic (As^{3+}) in the apatite structure; therefore, partitioning should increase with an increasing concentration of As^{5+}. Antimony also substitutes into apatite although there is some debate as to what it replaces.

Using the thermodynamic data available along with the Blundy and Wood strain lattice model an As-Sb apatite/melt partitioning model was developed to guide the calibration experiments. This model does not account for changes in speciation due to changing pressure and is sensitive to the thermodynamic data selected (which are extrapolated above normal species temperatures). As well, several key parameters in the strain lattice model could only be estimated.

Owing to an increase in the proportion of more compatible As^{5+}, the model predicts a 100-fold increase in arsenic partitioning over the interval ΔFMQ +2 to ΔFMQ +7. No significant variation in D_{Sb} is expected with fO_2, according to the model. The model predicts D_{As} increasing with increasing melt silica content and decreasing with increasing temperature. Increasing fH_2O shifts the stability of As^{5+} to lower fO2 and thus D_{As} increases. Sulphur fugacity has the opposite effect, destabilizing the presence of As^{5+} in the system.

To date several experiments have been performed; however experimental issues have prevented the acquisition of quantitative data. Semi-quantitate data from two of the experiments indicate D_{As} <0.183 at the CCO buffer and D_{As} is between 0.68 and 2.16 at the Ru-RuO buffer (ΔFMQ +7). These observations concur with the models arsenic trend. Additional experiments are currently being prepared and results will be presented.

Re-examination of the Gautreau Formation and its stratigraphic position, Weldon, New Brunswick, Canada

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At its type location in the Weldon area south of Moncton, the Gautreau Formation is a Lower Carboniferous (Tournaisian) evaporite deposit. The evaporites occur within boreholes in the fault-bounded, westerly-dipping Weldon syncline, where the enveloping strata range from the Albert Formation of the Horton Group to the Hopewell Cape Formation of the Mabou Group. Presumably coeval surface exposures of dominantly grey shale with and without minor evaporites have been mapped by previous workers at several nearby locations.

When first identified by Norman in the 1920s, the Gautreau Formation was interpreted as a salt-dominated Horton Group unit. The definition was subsequently expanded to include the overlying evaporite-bearing (glauberite; $Na_2Ca(SO_4)_2$) and non-evaporite-bearing grey shales beneath red beds of the Weldon Formation. In recent published literature, the stratigraphic position of the broadened Gautreau Formation was reassigned to the

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younger Sussex Group that unconformably overlies the Horton Group in the Moncton subbasin. This refinement was based on palynology constraints (Spore Zone 5) identified in the Stilesville and Peck Creek areas from surface outcrops of shales presumed to be Gautreau Formation equivalent, but without evaporites present.

The Gautreau Formation is herein examined from 90 well logs and conventional core within the Weldon syncline. Surface outcrops and cliff sections along the Petitcodiac River and adjacent tributaries have been remapped. New palynology samples have been studied in conjunction with reprocessed seismic. As a result, the stratigraphic position and definition of the Gautreau Formation are reinterpreted. On the north flank of the Weldon syncline, the Stoney Creek Fault is truncated by overlying sedimentary rocks, suggesting a subtle disconformity exists at the contact or within the overlying red beds of the Weldon Formation. Palynomorphs collected directly from the salt of the Gautreau Formation suggest a Lower Tournaisian age (Spore Zone 2; typical of the Horton Group) and the same for laterally equivalent and overlying evaporite-bearing grey shales. Younger spore zones typical of the overlying Sussex Group (Zones 4 and 5) do not occur consistently until the overlying Weldon Formation, implying assignment of the current Gautreau Formation and its lateral equivalents to the Sussex Group is not justified in the type area, and it should instead remain within the Horton Group as suggested by some prior workers. Bed-scale and longer-term fluctuations between halite, glauberite, gypsum, anhydrite, and other minerals (e.g., thenardite Na_2SO_4) represent the evolution of the evaporite basin from subaqueous halite to eventually sabkha-like nodular gypsum/anhydrite deposition near the end of evaporite deposition.

Subsolidus processes in arfvedsonite granite and associated felsic veins, and the relation to HFSE-mineralization in the eastern Cobequid Highlands, Nova Scotia, Canada

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The Late Devonian-Early Carboniferous arfvedsonite-bearing granite from the Hart Lake-Byers Lake Pluton in the eastern Cobequid Highlands, Nova Scotia, represents the late stages of crystallization of an evolved felsic melt enriched in alkalis and iron. Hypersolvus alkali feldspar, quartz, and arfvedsonite comprise the main mineral phases of the granite. Petrographic observations reveal the subsolidus transformation of the original homogeneous alkali feldspar to perthitic K-feldspar and albite, and the gradual breakdown of the sodic amphiboles to produce predominantly Fe-oxides and quartz. Electron microprobe analyses of selected samples show that silicates and oxides enriched in high field strength elements (HFSE) often accompany the Fe-oxides and quartz as replacement products, forming veinlets that crosscut the arfvedsonite crystals and/or aggregates in close proximity to the sodic amphiboles. Felsic veins of granitic composition that incorporate HFSE-enriched minerals have also been documented in the Eastern Cobequid Highlands, and are interpreted to have been genetically related to the arfvedsonite granite of the Hart Lake-Byers Lake Pluton. In the veins, the HFSE-enriched minerals are spatially associated with Fe-oxides, zircon, and fluorite. This mineral assemblage is often surrounded by remnants of sodic amphiboles, where the orientation of the Fe-oxides appears to follow the cleavage planes of the replaced arfvedsonite crystals.

The enhanced solubility of water and HFSE in iron- and alkali-rich melts postponed the formation of HFSE-enriched minerals until the late stages of crystallization. Petrographic evidence suggests that a hydrothermal fluid was involved in the remobilization of HFSE in the felsic veins. The spatial distribution of the HFSE-enriched granitic veins and their crosscutting relationships with the plutonic and volcanic lithologies in the area suggest that they originated from an evolved silicate liquid characterized by low viscosity and increased mobility. It is plausible that this liquid was internally derived and genetically related to the last melt fraction that generated the arfvedsonite-bearing granite.

Lithospheric flexural controls on landscape evolution of the western Canadian Arctic during incision of the Northwest Passages, Canada

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Lithospheric flexure in response to changing surface loads is an important control on surface topography and processes. The Northwest Passages, a series of waterways in the Canadian Arctic, consist of channels with depths of ~500 m in some areas, some of which are bounded by fault-line scarps. These passages were deepened by recent glacial,

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and partially fluvial, incision through Cenozoic sediments. What is the effect of this incision on the adjacent Arctic Islands?

The Beaufort Formation is a Pliocene coastal plain deposit interpreted on the basis of paleoflow directions and upper and lower contacts to have stretched from the Northwest Territories to Ellesmere Island along the western Canadian Arctic before the incision of the passages. Despite having been deposited in a short period between 3.8 and 2.7 Ma these fluvial sediments and marine equivalents thicken toward the Canada Basin to as much as 3 km. While large straits may have existed previously among the islands, they were evidently sediment-filled during the Pliocene. A key question is whether the incised ribbon-like distribution of the Beaufort Formation and Arctic Islands' current topography can be explained by flexure of the Arctic lithosphere in response to: (1) post-Miocene sediment loading of the Arctic continental margin; and (2) Pleistocene incision of the passages. Elastic flexural sediment backstripping using gFlex is applied to Pleistocene and Pliocene strata offshore to estimate initial bathymetry and coastal topography at the Miocene-Pliocene transition. This allows the converse forward calculation of flexure owing to the sediment deposition. Model flexural downwarping by offshore sediment loading is sufficient to accommodate Beaufort Formation sediments, thereby explaining the ribbon-like distribution of the unit parallel to the coast. The effect of erosional flexural rebound by channel incision is then incorporated by iteratively removing sediment from the channels and replacing it with water until the current bathymetry is achieved. Model results indicate a 60 km lithospheric flexural thickness is suitable, but island uplift, of ~100s metres, is insufficient to match modern topography suggesting more incision in the channels and/or greater paleotopography than assumed in the model. The model results reinforce the interpreted need for a recent ice sheet over the Arctic Islands that was sufficiently thick to excavate the submarine channels without which there would be no navigable Northwest Passage in the western Canadian Arctic.

Deposition, metamorphism, exhumation: the geodynamic evolution of metasedimentary rocks in the western Cape Breton Highlands, Nova Scotia, Canada

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The Jumping Brook Metamorphic Suite (JBMS) of the western Cape Breton Highlands forms an inverted metamorphic sequence that underwent Barrovian-style metamorphism in the Late Silurian-Early Devonian. Although the age of magmatism in the Aspy terrane is fairly well constrained and basic pressure (P)-temperature (T) estimates are available for the JBMS, little is known about: (1) the depositional age of the JBMS and/or the relationship between the JBMS and adjacent plutons; (2) the conditions and style of prograde P-T paths; and (3) the timing of prograde/retrograde metamorphism. To address these lingering questions, U-Pb detrital zircon and metamorphic monazite and apatite datasets were integrated with model P-T paths determined from major element zoning in garnet. Detrital zircons in a metaquartzite from Corney Brook suggest that the JBMS was largely derived from the adjacent Bras d'Or terrane, further supporting the close spatial link between the Aspy and Bras d'Or terranes in the Cambrian and Ordovician. The maximum age of deposition is constrained to ~540 Ma by the youngest concordant zircon population. Reconnaissance dating of monazite in the medium- and high-grade portions of the JBMS yielded ages of 388 ± 2 Ma and 401 ± 1 Ma respectively. These ages are interpreted to reflect monazite growth during prograde metamorphism, and constrain metamorphism in the JBMS to the Early Devonian. Although diachroneity is observed in monazite across the metamorphic field gradient, apatite, regardless of metamorphic grade, yield overlapping U-Pb ages. When regressed together on a semi-total Pb/U isochron (n = 98), a lower intercept age of 370 ± 4 Ma (MSWD = 1.19) is determined. This age is interpreted to reflect rapid cooling of the JBMS through ~400–500°C. Using the THERIA_G software, P-T paths of metamorphism were determined for the garnet- and staurolite-zones of the JBMS. Model results indicate that metamorphism occurred along tight, clockwise P-T paths and that the style of P-T path was similar in both the garnet and staurolite zones. Peak conditions of metamorphism in the garnet and staurolite zones were ~560°C and 7.4 kbars, and ~580°C and 8.2 kbars respectively. For each model P-T path, the peak P and T are attained simultaneously. This observation along with monazite ages, which increase with metamorphic grade, apatite ages, which are the same regardless of metamorphic grade, and

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the presence of inverted isograds, suggests that the JBMS underwent a period of rapid tectonic cooling, exhumation, and isograd inversion following peak metamorphism.

Coupled in situ galena trace-element and Pb isotope mapping: discriminating trace metal sources in VMS settings

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A method to acquire simultaneous trace-elements (Ag, Cd, Sb, Sn, Tl, etc.) and Pb isotope ratios in galena has been recently developed and tested by using a novel laser ablation quadrupole-ICP-MS methodology. Under optimized collection conditions, 20 replicate analyses on the same galena grain using an 80μm diameter crater yield a weighted mean 2σ precision of 0.1%. This level of precision is appropriate for identifying the source of Pb incorporated into galena relative to different Pb isotope reservoirs and deposit-scale isotopic arrays. Importantly, variations in trace-metal concentrations and metal ratios can be directly related to these Pb reservoirs or to mixing models between isotopic endmembers. The method can also be adopted to utilize loose fragments of galena, further enhancing the cost-effectiveness of campaign-style regional investigations.

This talk will: (1) demonstrate the general methodological considerations related to this method; (2) explore some of the results obtained for well-studied VMS, vein-style, SEDEX, and MVT deposits; and (3) lead to a discussion of potential applications of this methodology to unravelling the significance of galena Pb-Pb arrays documented for several deposits in the Bathurst Mining Camp (BMC). Specifically, careful sampling to isolate relict galena in stockwork zones followed by trace-element mapping by LA-ICP-MS to reveal patterns of volatile-element zoning (e.g., Se, Tl, Cd, Sb). Complex primary zoning is well documented in pyrite in the BMC such that galena shielded from the effects of dynamic recrystallization may also preserve growth zoning. Zones of diagnostic metal abundances can then be targeted for in-situ Pb isotope measurements, allowing us to uniquely connect key metal associations with Pb reservoirs. Although significant deviation of isotope ratios for Pb sourced from magmatic versus volcano-sedimentary reservoirs may be small, it may still be possible to examine systematic shifts in Pb sources as a function of trace-element characteristics. Some deposits (Restigouche) have a higher proportion of Pb sourced from an older granulitic low-μ Avalonian basement. By comparison, upper crustal volcano-sedimentary successions have a more radiogenic time-integrated Pb isotope signature. Distinguishing the two endmembers is only possible using an in-situ approach using isotope and trace-element discrimination trends.

ICP-OES and unique mineral and elemental separation capabilities at the Dalhousie University, Cosmogenic Isotope Lab, Halifax, Nova Scotia, Canada

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The goals of the Cosmogenic Isotope Lab are to: (1) train students and visitors in isotope geochemistry, cosmogenic nuclide exposure geochronology, and related analytical methods; (2) provide geochronology and erosion rate results; (3) improve geochronology methods; and (4) complete other fee for service work. The cosmogenic isotope lab prepares ^{10}Be, ^{26}Al, ^{36}Cl targets using combinations of ion chromatography (different volumes and types of anion and cation exchange resins) and pH-controlled precipitations, and soon ^{14}C from quartz, for analysis by accelerator mass spectrometry, with partner labs uOttawa, Lawrence Livermore National Laboratory, PRIME Lab, ETH-Zurich. A large range of mineral separation expertise and Inductively Coupled Plasma Optical Emissions Spectroscopy services are available.

Mineral separation includes physical processing such as cleaning, crushing, grinding, sieving, and routine methods using Wilfley table, frantz magnetic (all shared instruments), and heavy liquid separation. Unique to at least the Atlantic region are the following mineral separation strategies: (1) air abraders capable of 30 g aliquot mineral separation on the basis of mineral hardness; (2) froth flotation using lauryl amine surfactant and compressed CO_2 frothing to separate minerals with different surface electrostatic properties; (3) hexafluorosilicic acid and high-T pyrophosphoric acid methods to remove or digest aluminosilicates from quartz; and (4) selective digestion of silicates in 25-gallon ultrasonic tanks. The isotope lab has a Questron Vulcan automated digestion system which uses recessed heat blocks, syringes, and a combination of acids to digest, transfer, and dilute up to 25 ml samples to test tubes.

The Teledyne-Leeman Lab PRODIGY ICP-OES is capable of measuring a wide range of major, minor, and trace elements as low as 0.1 ug/ml. The ICP-OES can accept solutions containing hydrofluoric acid and is able to analyse halogens.

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Hydrothermal alteration in the Clarke Head Fault Zone, Nova Scotia, Canada

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At Clarke Head on the north coast of Minas Basin, Upper Devonian–Lower Carboniferous igneous and sedimentary rocks outcrop in a fault zone megabreccia. The hydrothermal alteration at Clarke Head is compared with that elsewhere in the Cobequid Highlands in order to better understand its origin and age. The Cobequid Shear Zone was a group of faults active during the latest Devonian–early Carboniferous. It was then reactivated in the middle Carboniferous, as part of the Minas Fault Zone, which led to brittle deformation that is displayed at Clarke Head. At Clarke Head, distinctive types of hydrothermal alteration occur in both sedimentary and igneous rocks. Hydrothermal veins and alteration were documented in the field and the petrography of igneous and hydrothermal samples was studied by SEM and electron microprobe. Rocks lithologically similar to the lower Horton Group are cut by veins of albite ± quartz ± chlorite. Younger rocks of the Windsor Group and West Bay Formation are cut by veins with the following sequence of minerals: quartz + chlorite → calcite + ankerite → Fe-oxides + TiO_2 → barite + xenotime. Sodic alteration occurs elsewhere in the western Cobequid Highlands in granite plutons and the lower Horton Group, where it is dated at ~355 Ma. The assemblage of ankerite, Fe and Ti oxides, barite, and xenotime is characteristic of mineralization along the Minas Fault Zone with an age of ~ 327–310 Ma. The igneous rocks of Clarke Head include blocks of gabbro granulite, which has been previously investigated and is not included in this study. The gabbro consists of hornblende, K-feldspar, ilmenite, and Fe-oxides, with secondary epidote, and small patches of analcime, scapolite, and albite. The diorite consists of K-feldspar, amphibole, and Fe-oxides, with secondary scapolite, analcime, and quartz, and has an igneous contact with Horton Group siltstone. The syenite consists of magmatic K-feldspar, albite, titanite, rutile, and a small amount of quartz, but is highly altered. Scapolite almost fully replaces K-feldspar, analcime occurs in multiple generations replacing perthitic albite and possibly occurring interstitially, and titanite and rutile occur as both primary and secondary phases. Potassium released during this alteration may be represented by widespread biotitization in some Cobequid fault zones around ~345 Ma. Clarke Head thus demonstrates the full extent of hydrothermal alteration in the Cobequid Highlands, in sedimentary rocks and igneous rocks.

Geology collectors in Nova Scotia, Canada, and the provincial museum from 1839–1939: an historic overview

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Additions to the modern geology collection of the Nova Scotia Museum (NSM) consist primarily of specimens acquired from private donors, amateur collectors, and researchers. However, the foundation of the NSM was originally comprised of collections from the Halifax Mechanics' Institute and World Expositions, and submissions of mineral samples from the Nova Scotia Department of Mines. While notable geologists such as Lyell, Dawson, Gesner, and others collected specimens in their quest to better understand geology in general and the geology of Nova Scotia, few of their specimens have been retained in the province, instead ending up in other institutions. Surprisingly, some of the longest lasting contributions to the early NSM geology collection were left, not by famous geologists, but by relatively lesser known curators, Rev. David Honeyman and Harry Piers, who established a tradition of actively collecting and receiving specimens for the promotion of Nova Scotia, the preservation of scientific knowledge, and the education of the public.

Progress on the low-background cosmogenic ^{14}C extraction line at Dalhousie University, Halifax, Nova Scotia, Canada

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Applications of cosmogenic ^{14}C produced in minerals or ice on Earth are providing a new frontier in exposure dating and landscape erosion rate studies. However, technological challenges have limited the applications of the method, owing to the relatively high abundance of ^{14}C in the

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atmosphere and the ~0.04% abundance of CO_2 in lab air.

A new stainless steel UHV ^{14}C extraction line was assembled in 2014 and initial cleaning and final leaks were resolved by January 2017. It is one of only six cosmogenic ^{14}C extraction lines in the world and only the second to be developed using stainless steel in lieu of glass components. The predicted benefit of using stainless steel is in providing a better vacuum and lower and more uniform background, an important consideration as only ~10^6 atoms of ^{14}C are expected to be collected from a 5 g sample of quartz. After removal of meteoric CO_2 from the boat, flux, and quartz at low temperature (500ºC), ultrapure O_2 is flowed over the melting quartz aliquot (~5.000 g) at 1300ºC to convert the in situ produced ^{14}C to $^{14}CO_2$. The $^{14}CO_2$ is then purified, using temperature-specific Liquid Nitrogen-slush traps to remove SO_x, NO_x, and other condensable gases, and a high temperature Ag-Cu mesh oxidation. Additionally, low-level CO_2 –samples can be spiked with ^{14}C-dead well gas. Once collected, the purified CO_2 will be analyzed for $^{14}C/^{12}C$ against standards on the MICADAS gas-source accelerator at ETH Zurich or the future gas-source A.E. Lalonde AMS lab at uOttawa, eliminating a need to graphitize the CO_2.

Preliminary volumetric measurements indicate that a plateau at <4 nmol CO_2 can be achieved as the nominal line background within 6 days after the line is open (e.g. sample exchange). It is hoped this time can be reduced in order to measure more samples in a year, but considering it is low, it may not be necessary, depending on the $^{14}C/^{12}C$ of the residual CO_2. Assuming that most of this carbon is ^{12}C from degassing of the steel and other line parts, the background yields 8 ◊ 10^{14} atoms ^{12}C, yielding a $^{14}C/^{12}C$ of 7 x 10^{-9}, i.e., that the number of ^{12}C atoms is three orders of magnitude lower than what will be expected when CO_2 is extracted from the quartz. Testing with CRONUS international inter-laboratory samples is planned for February 2017.

Petrogenesis of the Archean Prestige leucogranite and associated pegmatites, Northwest Territories, Canada: insights from muscovite geochemistry and apatite U-Pb geochronology*

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The Yellowknife pegmatite field is host to LCT-family rare-element pegmatites that are associated with Late Archean granitic magmatism. Studies of pegmatites in the district have documented occurrences of beryl, spodumene, columbite-tantalite, petalite, cassiterite, and rare microlite. The large Prosperous Suite, a plutonic assemblage composed of 14 muscovite-biotite S-type leucogranites, lies in the southwest quadrant of the pegmatite field. Although the geology in this domain is the most thoroughly documented in the Slave Province, the ages of the major plutonic suites are poorly constrained. Only two plutons of the Prosperous Suite have previously been reliably dated at 2596 ± 2 Ma and 2606 ± 2 Ma using U-Pb monazite.

The Prestige pluton is a small pluton in the Prosperous Suite that has previously been described with particular reference to its high Li contents. The pluton contains significantly higher Li concentrations (mean of 700 ppm) compared to other plutons in the area. Apatite U-Pb was used as a geochronometer and provides a concordant age of 2605.3 ± 6.4 Ma for the Prestige pluton, confirming that it is coeval with the plutons within the Prosperous suite. An upper intercept age of 2588.3 ± 6.3 Ma was determined for the pegmatites interior to the pluton, while an age of 2592.6 ± 6.2 Ma was found for the exterior pegmatites. The pegmatites associated with the Prestige pluton are enriched in incompatible elements, with averages of 22 ppm Sn, 9.5 ppm Ta, 19.6 ppm Nb, 21.0 ppm Cs, and 453 ppm Rb. Muscovite trace-element compositions, determined by LA-ICP-MS analysis, report elevated levels of Rb, Cs, and Sn within the granite and pegmatites. Whole-rock and muscovite geochemistry suggests increasing fractionation trends, shown by decreases in ratios of K/Rb, K/Cs, and Sr/Rb, from the pluton to the pegmatites. In general, there are slight increases in Li, Cs, Sn, Nb, and Ta in the rims of muscovite crystals that can be attributed to normal fractionation processes. Pegmatites interior and exterior to the pluton show similar trace-element concentrations; however, the Li content for the interior pegmatites is significantly greater (mean 270 ppm) than in the exterior pegmatites (mean 30 ppm). The geochronology coupled with the geochemical data indicate that pegmatite emplacement is unrelated to the Prestige granite. This observation applies to pegmatites both proximal to and cutting the pluton. Muscovite has proven to be a powerful fractionation indicator that may be used as an exploration vectoring tool in other applications.

Winner of the AGS Graham Williams Award for best graduate student poster

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Middle to Late Carboniferous movement on the Fredericton Fault, central New Brunswick, Canada

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The Fredericton Fault transects New Brunswick from SW to NE, running below the Pennsylvanian cover of the New Brunswick Platform in the Fredericton area, NE of which its expression is geophysical. Major strike-slip movement is pre-Carboniferous (and probably pre-Devonian), but smaller scale movement controlled small depositional basins during the Visean and late Tournaisian up to the late Visean eruptive episode represented by the Royal Road and Hardwood Ridge basalts and the Cumberland Hill rhyolite/trachyte. The fault trace between Smithfield and Durham Bridge to the SW and NE of Fredericton reveals a complex history of movement affecting Carboniferous strata from Visean to late Pennsylvanian in age. A single fault is not evident and deformation is spread across a broader 'fault zone' in the Carboniferous cover rocks, and Silurian basement. The oldest Carboniferous unit is a red-brown conglomerate/breccia of unknown age, overlain by the upward-fining conglomerate-siltstone/mudstone Shin Formation of late Visean age. The volcanic rocks that top the Shin sequence are only dated in the Cumberland Hill area, and appear to be time-equivalent of the Windsor Group in the Moncton subbasin (ca. 334 Ma: Asbian-Brigantian). Deformation episodes are evidently pre-Shin Formation, and post-Shin Formation/pre-Pennsylvanian.

The mid-Pennsylvanian Minto Formation (Bolsovian) drapes much of the New Brunswick Platform, showing only minor offset along faults that expose the Shin Formation and volcanic rocks as inliers NW of Minto and along the Nashwaak valley. Southwest of Fredericton there is evidence for pre-Bolsovian Pennsylvanian rocks below the Minto Formation – possible Boss Point Formation equivalents (Langsettian) preserved along the line of the Fredericton Fault. The relationship of these rocks with the Minto Formation may be an angular unconformity. This is evidence for movement during early Pennsylvanian time (Duckmantian). Again, displacement occurs over a broad 'fault zone' rather than along a single 'Fredericton Fault'.

Deformation affecting Visean and older rocks and pre-dating the Pennsylvanian formations is consistent with right-lateral strike-slip movement, similar to that noted on the major faults to the southeast. The Pennsylvanian history is more complex. No good kinematic indicators are seen in the pre-Minto Formation units, though this deformation is contemporary with the right-lateral strike-slip history observed on Cape Maringouin. All this history appears to be a reactivation of the Fredericton Fault as a broader movement zone. Post-Minto Formation movement shows no overall trend but seems to be a far-field effect related to the Alleghenian front seen south of Saint John along the coast.

Chronology and origin of cross-cutting vein systems: complex hydrothermal history of the Cobequid Fault Zone, Nova Scotia, Canada

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Intra-continental shear zones developed during continental collision are commonly sites of prolonged magmatism and mineralization. The Cobequid Fault Zone formed part of a NE–SW-trending orogen-parallel shear system in the late Devonian–early Carboniferous, where syn-tectonic granite-gabbro plutons were progressively deformed. In late Carboniferous to Permian, Alleghanian collision of Africa with Laurentia formed the E–W trending Minas Fault Zone, reactivating the Cobequid Fault Zone. The 50 Ma history of hydrothermal mineralization after pluton emplacement was investigated from cross-cutting relationships of veins in the Horton Group in the field and SEM and EMP study of thin sections. The general paragenesis is: albite ± quartz ± chlorite ± monazite → biotite → calcite, allanite, pyrite → Fe-carbonates, Fe-oxides, minor sulphides, calcite, and synchysite. Chronology was determined from literature reports and new U-Pb LA-ICPMS dating of monazite and allanite in veins. Monazite in quartz-chlorite veins cutting the Horton Group at West Advocate was dated 338.9 ± 4.1 Ma, a little older than ~334 Ma subvolcanic lamprophyre northeast of Parrsboro that includes magmatic allanite, calcite, and sulphides. Similar minerals, including monazite, are found in nearby veins. This monazite has two age modes: ~334 Ma and ~312 Ma, with a composite Concordia age of 320.2 ± 6.7 Ma. Allanite from veins in the same area yielded an intercept of 312 ± 6 Ma, but showed scatter reflecting its metamict character. Widespread veins of Fe-carbonates, magnetite, and sulphides (Fe, Cu, Zn) cross-cut the monazite-bearing veins in both areas. Hydrothermal

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REE minerals in sedimentary host rocks are different from those in adjacent granite plutons, suggesting the importance of local derivation of REE and the role of fluorine in REE mobility.

The new data constrain timing of deformation and clarify palinspastic reconstruction of the fault system. Nd isotope determinations on Horton Group rocks constrain Meguma vs. Avalon sources of sediment. Vein mineralization occurred during basin inversion and shows less relationship with timing of magmatism. The sequence of mineralization, from ~355 Ma riebeckite and albite veins, through ~345 Ma potassic alteration, ~334 Ma calcite, monazite, and allanite, to ~327–305 Ma siderite-magnetite and sulphide mineralization, resembles iron-oxide–copper–gold (IOCG) systems in the literature. The system studied here resulted from volatiles derived from a deeply subducted slab with little terrigenous sediment, availability of mantle heat to melt the overlying metasomatized mantle, and strike-slip faulting that facilitated the rise of magmas, resulting in high heat flow driving an active hydrothermal system.

A case study of chromite and associated minerals as indicators of diamonds in the Botswanan Orapa kimberlite cluster

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Kimberlites are deep mantle magmas and the primary source of diamonds. Ilmenite, perovskite, rutile, titanite, and spinel group minerals are commonly found in matrices of kimberlites. Prior research shows that changes in temperature, volatile content, oxygen fugacity, and degrees of country rock assimilation influence what minerals are formed and the textures which are created. Similarly, these processes influence diamond preservation. Therefore, understanding the stability and reactions occurring in these minerals has implications on the features of diamond populations in kimberlites.

Two kimberlite bodies positioned in the Botswanan Orapa kimberlite cluster were examined. The first consists of a single coherent kimberlite pipe, AK-15. BK-1, the second and more complex body is composed of two coherent facies, CK-A and CK-B, and the volcanoclastic MVK facies. Sixty-seven samples, made up of the 4 kimberlite facies, were investigated using optical microscopy to observe the textures, zoning, and phases present in each sample. Twelve thin sections, three from each facies, were examined using a scanning electron microscope (SEM) with Back Scatter Electron imaging, X-ray mapping, and Energy Dispersive Spectroscopic analysis to confirm the presence and relationship between the minerals of interest. CK-A showed altered ilmenite with exsolution textures and reaction products made up of Ti-magnetite, rutile, and titanite indicating high fluid content which fluctuated during crystallization. Minor chromite was present which also showed exsolution textures and was rimmed by titanite. Perovskite was not observed, implying high silica activity. CK-B contained ilmenite displaying exsolution lamella and was rimmed by perovskite and Ti-magnetite. Titanite was often found rimmed by perovskite. Abundant perovskite in the groundmass indicates much lower silica activity than in CK-A as well as a much lower fluid content. In MVK ilmenite showed exsolution textures and was rimmed by intergrown Ti-magnetite, rutile and titanite. Minor amounts of chromite was found, altered and rimmed by titanite. This indicates volatile exsolution and high silica activity possibly due to assimilation of crustal material. AK-15 contained ilmenite typically rimmed by titanite and Ti-magnetite. Chromite was found throughout with alteration textures and Ti-magnetite intergrowths. Rutile, perovskite, and titanite were also found throughout. The observed difference in groundmass mineralogy between the four studied kimberlite lithologies could be a result of differences in assimilation of crustal material, which would rise silica activity and trigger CO_2 degassing with exsolution of fluid. Absence of fluid in CK-B would explain the corrosive surface features and high degree of kimberlitic resorption on CK-B diamonds.

The importance of magmatism in the genesis of the Wolverine volcanogenic massive sulphide (VMS) deposit, Yukon, Canada: constraints from lithogeochemical, Nd-Hf isotope, and in situ U-Pb-Hf isotope data

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The Wolverine volcanogenic massive sulphide (VMS) deposit, Yukon, is a unique natural laboratory to study the interrelationships of magma evolution and tectonics in the genesis of VMS deposits in volcanic- and sediment-rich extensional basins. The deposit is spatially and stratigraphically associated with high-level rhyolite porphyritic intrusions. Pre-VMS (~352 Ma) quartz-feldspar porphyries (QFP) have continental crust-like Nb/Ta ~12, εNd_t = -7.1 to -11.5 (average = -10.6), and εHf_t = -12.2 to -20.8 (average = -16.5). The syn-VMS (~347 Ma) feldspar porphyries have higher high field strength element (HFSE)

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and rare earth element (REE) concentration, and higher Nb/Ta (~17), εNd_t = -7.8 to -8.1 (average = -8.0), and εHf_t = -13.6 to -18.0 (average = -14.8). Both suites have Proterozoic (to Archean) depleted mantle model ages (1.59–2.58 Ga). In situ U-Pb on zircons illustrate that while some ages are close to previously reported concordant TIMS ages, most samples have evidence of inheritance with ages ranging from 348–381.7 Ma for the QFP suite and 368.9–370.5 Ma for the FP suite. In situ εHf_t values for the zircons range from -11.5 to -21.0 (average -15.3) and -11.6 to -26.0 (average = -18.7) for the QFP and FP, respectively. The chemical and isotopic shifts from the QFP to younger FP suite reflects the varying contributions from evolved continental crust versus juvenile basaltic melts, and can be accommodated within an evolving continental back-arc basin in which there was a progressive increase in mantle input as a result of upwelling of juvenile basaltic material beneath the back-arc basin as it opened. Notably, the upwelling of mafic magmatism and greater mantle components in the syn-VMS FP suite also coincided with higher temperature felsic magmatism and VMS deposit genesis.

The presence of high temperature magmatism and extensional geodynamics, coupled with a H_2S-rich shale-dominated near-vent environment were critical for generating the Wolverine hydrothermal system and the resultant deposition of mineralization. Identification of similar tectonic environments with similar geological and geochemical features is critical for finding new resources along evolving continental margins.

Styles and setting of volcanogenic massive sulphide (VMS) mineralization in the Victoria Lake supergroup, Newfoundland Appalachians

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The Victoria Lake supergroup (VLSG), Newfoundland Appalachians, hosts numerous volcanogenic massive sulphide (VMS) deposits with varying stratigraphic settings, styles, ages, and emplacement mechanisms. The oldest VMS deposits are bimodal felsic deposits hosted within the ~513–509 Ma Tally Pond group, and includes the past-producing Cu-Zn-rich Boundary and Duck Pond deposits, and the Zn-Pb-Ag-Au-Ba-rich Lemarchant deposit. All deposits are hosted predominantly in rhyolite flows and volcaniclastic rocks and range from replacement-style mineralization (Boundary, Duck Pond) to that deposited by exhalation in shallow water (i.e., <1500 m water depth); the latter being associated with precious metal enrichment (e.g. Lemarchant). New U-Pb ages (~514–506 Ma) illustrate that the Long Lake group is coeval with the Tally Pond group, and the group contains Zn-Pb-Ba(Cu) mineralization hosted predominantly by an older (~514 Ma) package of felsic volcanic and volcaniclastic rocks (e.g. Long Lake deposit). Younger VMS mineralization in the VLSG, occurring within the westerly Tulks belt, is much more diverse in style and is hosted predominantly in the 498–488 Ma rocks of the Tulks and Pats Pond groups. In the southwestern portion of the Tulks Group, the Boomerang cluster of Zn-Pb-(Cu-Ag-Au) deposits are hosted in a felsic volcaniclastic and shale-rich sequence with local mafic and felsic intrusive rocks, and is interpreted to have formed via subseafloor replacement and exhalation. Towards the central portion of the Tulks belt, both exhalative and replacement-style Zn-Cu mineralization occur hosted in felsic volcaniclastic rocks and lesser sedimentary rocks (e.g., Tulks Hill, Tulks East). In the northern portion of the Tulks belt, deposits are hosted in felsic flows and fragmental rocks with lesser volcaniclastic rocks. These deposits exhibit evidence for deposition in shallow water and (like Lemarchant) show hybrid features between VMS deposits and epithermal Au-Ag deposits (i.e., magmatic fluid input; Bobby's Pond and Daniel's Pond).

Volcanogenic massive sulphide deposits in the VLSG are the product of episodic arc rifting along the Cambrian margin of Ganderia, with the local style, geometry, and metal budgets of mineralization ultimately controlled by host stratigraphy lithofacies, fluid temperatures and their fluctuations, seawater depth, and the presence or absence of magmatic fluids.

When was your last glacial maximum?

David J.W. Piper

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The Last Glacial Maximum (LGM) at ~21.5 ka (18 ka radiocarbon years) was the time of maximum global terrestrial ice volume and hence lowest sea level during the last ~100 ka glacial cycle. A new compilation of ice-margin ages on the eastern Canadian continental margin shows that the timing of maximum ice extent varies geographically and that ice margins fluctuated over the period 40–15 ka. The maximum grounding line is identified from seismic reflection profiles and multibeam bathymetry. Glaciogenic

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debris flows and/or broad erosional channels are further evidence for shelf-crossing ice. Chronology is provided by seismic correlation into cores with radiocarbon dates and dated Heinrich (H) beds.

On the Scotian Slope, seaward of Western Bank, two maximum advances grounded to 540 m depth are dated at 24.5 ka and 28.1 ka. The maximum grounding line in the Laurentian Channel at 685 m is dated at 19.3 ka. On St Pierre Slope, two till tongues are dated 18.1 ka (540 m) and 33.9 ka (560 m). The Halibut Channel limit on the slope is undated, but in the channel at 150 m published work shows two till tongues overlie glaciomarine sediments dated at 17.8 ka and 22.5 ka, that disconformably overlie glaciomarine sediments partially remoulded during glacial advance probably correlative with the older St Pierre Slope till tongue. A ~45 ka shell date in the remoulded unit suggests an MIS 4 age for the basal till. Elsewhere around Newfoundland there is equivocal evidence for MIS 4 tills, more extensive than during the LGM. Northeast of Newfoundland, several ice advances are recorded seaward of Trinity Trough by well-dated glaciogenic debris flows (GDFs) at 28.5 ka, 27 ka (the largest and most prolonged), and then lesser advances at 24, 23, and 21 ka. Off Hawke Saddle, similar GDF deposition terminated at 25.5 ka. Farther north on the Labrador margin off Hopedale Saddle and Hudson Strait, GDFs correspond to H3 (30 ka), whereas off Nain Bank the shallowest GDF corresponds approximately to H2 (24 ka).

Thus the local last glacial maximum rarely corresponds to the classic 21.5 ka LGM. These observations on ice limits can be integrated with evidence for interstadial ice retreat on major ice streams such as those in the Laurentian Channel, Notre Dame Channel and Hudson Strait to demonstrate the dynamic variability and asynchroneity of ice growth and decay in eastern Canada.

Multi-scale analysis of structures and textures and their relationship to mineral growth across the New Quebec orogen, Canada

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The New Quebec orogen (NQO) is a Paleoproterozoic orogenic belt located in the southeastern Churchill Province of Quebec, separating the Superior Craton from the Core Zone. The NQO has been divided into a western foreland referred to as the Kaniapiskau Supergroup, and an eastern hinterland made up of the Rachel-Laporte Zone and the Kuujjuaq Zone, with the latter representing remobilized Archean basement. Deformation events associated with the NQO include two compressional phases related to the initial collision responsible for the general NNW-SSE trend of the area and a late oblique compressional event that resulted in dextral transverse movement along pre-existing thrust faults.

Structural data and petrographic samples were collected across a 40 km transect documenting the foreland-hinterland transition of the northern NQO. In greenschist facies samples original bedding, S_0, is well preserved. S_1 foliation is commonly formed by chlorite, muscovite, biotite, and elongated quartz. A strong S_2 crenulation cleavage (related to D_2) is identified in some samples which folds S_1 minerals and is responsible for new chlorite growth. Several samples display C-S fabrics related to D_3. Chlorite pseudomorphs after biotite are parallel to S_1, indicating biotite growth was syn-kinematic with D_1. Amphibolite facies samples typically contain a biotite-muscovite-quartz matrix with biotite, garnet, and rare staurolite porphyroblasts. In these samples, inclusion trails and rotated porphyroblasts are common with garnet porphyroblasts displaying up to 90° dextral rotation (based on S_i perpendicular to S_e). Garnet growth is interpreted as inter-kinematic with D_1 and D_3. In general, three deformation events are observed with D_1 forming the dominant NNW-SSE foliation observed across the transect, D_2 forming an E-W crenulation cleavage best observed in the western greenschist facies portion of the transect, and D_3 resulting in evidence of dextral shearing in C-S fabrics in finer-grained greenschist samples and rotated porphyroblasts in the eastern amphibolite samples. Peak metamorphic conditions were syn-kinematic with D_1 in greenschist facies samples, and late syn- to early post-kinematic with D_1 in amphibolite facies samples. Evidence of retrograde metamorphism is observed in the presence of chlorite pseudomorphs of biotite, syn-kinematic with D_3. The continent-wide, composite Trans-Hudson orogen is responsible for three phases of deformation experienced by the NQO, as the supercontinent Nuna was being assembled. The foreland experienced peak greenschist facies metamorphism during the initial collision while the hinterland attained peak amphibolite facies metamorphism slightly later. Retrograde greenschist facies metamorphism was experienced by the entire orogen until at least the third phase of deformation.

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Teaching earth science using big ideas

Toon Pronk

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Teaching earth science with all its multi-disciplinary processes and classifications can be an intimidating endeavor for many teachers. At the same time, people's natural curiosity about their natural surroundings makes earth science a perfect entry point into the sciences. The principle that rocks and minerals have to obey rules of physics and chemistry allows you to introduce some of the science concepts at a very early age. Children's innate desire to understand will take over from there. A 5-year old quoted in Jay Griffiths "A Country Called Childhood" says that "Stones are the most interesting things in the world". If we can hook into that curiosity and passion, we may not only spur some young people into becoming (earth) scientists, but we will foster 'earth science literacy' in the population at large. People may recognize the interconnectedness of the rocks and soils we walk on and how we could live sustainably on planet Earth. Using the Big Ideas in Earth Sciences concepts developed by the Earth Science Literacy Initiative (funded by NSF), you can use large concepts to draw your students in and then zoom in on closer-to-home processes, events, and features. There are many ways to do this: with proven concepts such as 'Cosmic View - The Universe in 40 Jumps', or using thought-provoking questions like 'how many earth movements can you think of?' and 'what are the causes and the consequences of each of these movements?' For ideas you can visit the Big Ideas website for guidelines, videos, etc., or draw on your own experiences or those of colleagues. Once you draw attention to the links between geology and processes that happen at the earth's surface and endeavors such as land use and city planning, people in general become interested in the underlying principles that govern these links. Finally, you can view our natural environment as a big, wide-open outdoor classroom. As earth scientists we have a responsibility to share our knowledge with the general public, teachers, and students of all ages.

Direct observation of melting and crystallization in the system $LiAlSi_4O_{10}$–H_2O using the hydrothermal diamond anvil cell: implications for late-stage crystal growth in lithium-rich pegmatites

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A series of hydrothermal diamond anvil cell (HDAC) experiments (n = 41) were conducted in order to investigate melting and crystallization in the system $LiAlSi_4O_{10}$–H_2O. Hydrous lithium aluminosilicate melt was undercooled to various pressures and temperatures below the petalite hydrothermal melting curve. In situ observation of this undercooled melt afforded measurement of crystal growth rates in real time. Crystallization was observed to occur in the silicate melt, the aqueous fluid, or concurrently in both mediums. Crystal growth in the aqueous fluid was complemented by the consumption of silicate melt. Some of the crystals that initially grew in the silicate melt continued to grow beyond the melt–fluid interface by the transfer of melt material in the aqueous fluid. Raman spectroscopic and SEM-EDS analysis of the experimental products indicate that quartz and α-spodumene formed under high pressure conditions, and β-spodumene and virgilite ± lithian mica crystallized at lower pressures. The growth rates of lithium aluminosilicate minerals ranged between 7.52×10^{-8} and 8.52×10^{-6} cm/s and were essentially the same in the melt and aqueous fluid. The results of the HDAC experiments provide insights into crystal growth processes in water-saturated lithium-rich pegmatites. In agreement with previous models of crystal growth in miarolitic pegmatites, these experiments show that aqueous fluid acts as an effective transport medium for the diffusion of residual silicate melt material to the growing crystal faces.

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Stratigraphic and tectonic implications of detrital U-Pb zircon ages from North Islesboro, western Penobscot Bay, Maine, USA

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New U-Pb ages of detrital zircons were determined by laser ablation ICP-MS on three rock samples collected from different parts of North Islesboro, in western Penobscot Bay, Maine. Quartzite from Hutchins Island (44°21.045'N, 68°52.227'W), near deformed marble, minor foliated siliceous schist, and sparse amphibolite, yields abundant detrital zircon U-Pb ages (n = 120) of ca. 2.0 Ga and minor ages of 2.8–2.4 Ga, with a gap at 2.4–2.3 Ga and no grains <1.80 Ga. This age spectrum, unique in the region, permits correlation with the >670 Ma Seven Hundred Acre Island Formation 8–10 km to the south. The quartzite-marble strata are interpreted as a passive-margin sequence. If the depositional age of the quartzite is not appreciably younger than 1.80 Ga, it is a candidate for the oldest rock in the entire Appalachians.

Near Kedears Hill, where deformation is minor (single steep cleavage), the youngest detrital zircon U-Pb age populations in graywacke (44°22.429'N, 68°53.652'W; n = 112) and nearby felsic tuffaceous sedimentary rock (44°22.454'N, 68°53.613'W; n = 70) are Paleozoic. The graywacke is no older than ca. 514 Ma, has abundant Neoproterozoic (683, 626, 577 Ma) and numerous Meso- and Paleoproterozoic grains, and grains of the same ages as in the quartzite. The tuffaceous sedimentary rock is apparently Late Devonian (youngest grains ca. 370 Ma), and has complex zircon rim and core relationships including Ordovician, Silurian, and Cambrian ages as well as a strong Grenvillian (ca. 1160–957 Ma) signal, plus Mesoproterozoic and Archean ages.

In the quartzite, the lack of Mesoproterozoic detrital zircon ages is consistent with sources in both the Amazonian and West African cratons. However, the presence of six zircons having ages of <1.9 Ga argues instead for a West African source, specifically from the Eburnean orogen. Further support for this interpretation comes from the presence of a nearly identical detrital zircon barcode reported for the Taghdout quartzite in the Anti-Atlas Mountains of Morocco. Similar barcodes to that of the quartzite have been documented in fragments of Cadomia, which in the Neoproterozoic were positioned north of the West African craton.

The textural and mineralogical mechanism for induced polarization (IP) effects in gold-bearing rocks from the Herbert-Brent gold showing, Yellowknife Greenstone Belt, Northwest Territories, Canada

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In June 2015, geological mapping discovered significant concentrations of gold now known as the Hebert-Brent (HB) showing, which is situated within an 11 m-wide highly sulphidized sericite-ankerite schist shear zone that is hosted in a 10–15 m-wide, quartz-feldspar porphyry. The HB gold showing is located within the Barney Deformation Corridor of the Yellowknife Greenstone Belt (YGB), Northwest Territories. Two 400 m long IP/resistivity survey lines, with 5/10 m electrode spacing using a multi-gradient array, were completed over TerraX Minerals Inc. As expected the sulphidized mineralization produced an electrical contrast with the surrounding host rocks. In addition, the survey exposed a previously undiscovered anomalous IP source. However, non-economic mineralization can produce an IP response at subsurface, which poses a problem when attempting to interpret newly discovered anomalous IP bodies. It is therefore essential to understand the textural and mineralogical mechanism that gives rise to IP anomalies to avoid non-economic targets. The purpose of this preliminary study is to characterize the mineralogy and texture of variably mineralized rock that is strongly anomalous in resistivity or chargeability.

Detailed textural examination using MicroXRF EDS mapping was performed on 8 variably mineralized samples taken from the HB gold showing. This has been done in order to determine the textural and mineralogical characteristics of anomalous IP zones that are associated with gold mineralization.

MicroXRF EDS mapping on the mineralized samples, has revealed the existence of electrically conductive mineral grains (pyrite, arsenopyrite) in concentrations of (10–15%). The interconnection of sulphide mineralization is good however, segments of interconnected sulphide mineralization is disconnected. No significant non-sulphide IP source has been identified. Continued work will involve examining the dependence of IP effects on sulphide type, concentration, texture, grain shape, and grain size.

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Holocene history of the Labrador Current around the Flemish Cap, Canada

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This study investigated how the Labrador Current and North Atlantic Current have changed over the Holocene on Flemish Cap and Flemish Pass, east of the Grand Banks of Newfoundland. This study is based on push cores that were collected from box cores. As the speed of the currents changes, so does the grain size of hemipelagic sediment. The paths of currents can be identified from their suspended and ice-rafted material and types of microfossils. Grain size data was obtained by sieving and by laser analysis, and used to determine the mean grain size of sortable silt, a proxy for current speed. Chemical data were acquired by portable X-ray fluorescence (pXRF) and mineralogical data by quantitative X-ray diffraction (qXRD). Petrology of granules in the cores was determined using a binocular microscope. Foraminifera samples were collected for C^{14} dating.

Surface sediments show a higher concentration of sand on southeastern Flemish Cap due to the North Atlantic Current. Surface total carbonate content increases towards the open ocean, reflecting different detrital carbonate content of the inner and outer Labrador Current, and higher biogenic carbonate productivity in the North Atlantic Current. Five cores were studied in detail to determine changes in the Labrador Current through the Holocene. Two lithologic units were distinguished. Unit A (0–6.3 ka) consists of olive grey silty mud; unit B is a lighter coloured mud with abundant ice-rafted gravel and sand (6.3–14 ka). Two cores penetrated only the last thousand years; one penetrated all of unit A, and two had a thin unit A over a long unit B. Granule counts showed that the proportion of detrital carbonate grains remained almost constant throughout the Holocene, suggesting that modern ice-rafting is supplied from the lower Paleozoic of northern Greenland. pXRF and qXRD data were used to track the carbonate supply and compare detrital dolomite with total (detrital + biogenic) calcite. The inner Labrador Current transports sediment with a higher dolomite/calcite ratio than the outer Labrador Current and the record in a few cores suggests shifts in those currents through the Holocene. Grain size (sortable silt) shows increase in current strength in the last 1500 years, preceded by a gradual decrease. This record can be compared with other proxy records of the vigour of the Labrador Current in the late Holocene. Such data are important for understanding the impact of future melting of the Greenland Ice Sheet on Atlantic Canada.

Revision of the Windsor Group paleontology: implications for stratigraphic correlation in the Maritimes Basin of Atlantic Canada

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The Windsor Group is an economically important unit in the Maritimes Basin. The macrofaunal zonation of the Windsor Group is a significant aid in understanding the stratigraphy of this unit. A re-evaluation of the paleontology establishes a three part biozone subdivision of the Windsor Group. Based on the paleontological distribution of taxa, the Windsor Group can be divided into: a lower macrofaunal Zone (A subzone/Major Cycle 1); a middle macrofaunal zone (B subzone/Major Cycle 2); and an upper macrofaunal zone (subzones C, D, and E). These biozones also correspond to a stratigraphic division of the Windsor Group into: the Lower Windsor; Middle Windsor; and the Upper Windsor. The Windsor Group lithostratigraphy is complicated due to the plethora of formation and member names applied throughout the Maritimes Basin. The tripartite subdivision of the Windsor Group based on stratigraphy and paleontology simplifies correlation throughout the Maritimes Basin.

Predictive modelling of sandstone reservoirs in the central Scotian Basin, Canada

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The Nova Scotia offshore has been the site of several major hydrocarbon discoveries and continues to be an area of interest for oil and gas exploration, in particular the Early Cretaceous sandstones of the Missisauga and Logan Canyon formations, in which several oil and gas reservoirs have been discovered. Determining the distribution and quality of other potential sandstone reservoirs in Early Cretaceous units elsewhere in the basin is essential in de-risking exploration, particularly in the deep basin. This project uses

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DionisosFlow™, a forward stratigraphic modelling software, to produce a predictive stratigraphic model of the central Scotian Basin and reduce the risks associated with reservoir distribution and quality.

DionisosFlow™ uses a sediment diffusion equation that simulates sediment transport with regards to water discharge, sediment load, and slope for particles with differing grain properties (e.g., grain size and density), which are tracked during the evolution of the basin. This study proposes an integrated multi-disciplinary approach to forward stratigraphic modelling, which implements data from several fields of sedimentary research (e.g., detrital geochronology, geochemical fingerprinting of minerals, and petrological studies) to generate realistic model inputs based on major sources and their catchment areas. This approach accounts for variations in source input, activation, and composition based on geological evidence. Model results are calibrated against well logs, facies, and seismic interpretations of the study area to produce a predictive stratigraphic model. The predicted distribution of sediment classes is used to de-risk reservoir quality by tracking feldspar content throughout the basin to determine its influence on reservoir quality.

During the Early Cretaceous, the central Scotian Basin received sediments from three distinct river systems: the major Banquereau and Sable rivers, and the minor rivers of the Meguma terrane. At this time, salt withdrawal generated major listric faulting, allowing for the deposition of thick clastic successions on the shelf, with sediment transport to the slope and basin floor by a combination of canyon incision, and turbidity current flows. Model results indicate that potential sandstone units are trapped as the result of three main mechanisms: (1) shelf deposition as the result of listric faulting; (2) in mini basins formed by salt withdrawal along the slope; and (3) sediment draping in the deep basin. By combining these results with future interpretations of the influence of feldspar on reservoir quality in the Scotian Basin, this predictive model will be an effective method of de-risking exploration in the central Scotian Basin.

Provenance and diagenesis of the Lower Cretaceous sandstones in the deep well Newburn H-23, Scotian Slope, Canada

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Newburn H-23 is one of seven deep wells drilled on the Scotian Slope. These wells are new and thus in the early stages of research. As such it is important to determine the history of the detrital and diagenetic minerals found in this well and to draw comparisons between them and their shallower age-equivalents on the shelf. Sandy intervals from the Early Cretaceous have been analyzed dominantly using various methods to observe chemical and textural relationships between diagenetic and detrital minerals.

The detrital mineralogy of these sandstone intervals is similar to other wells in the Sable subbasin, suggesting that they are sourced by the Sable River with minor input from Meguma Group metasedimentary rocks and an increased supply of sodic volcanic clasts, probably from Scatarie Bank. The diagenetic history of this well, however, contains several mineralogical occurrences which are have not yet been identified elsewhere in the Scotian Basin, including probable diagenetic zircon and fluorine rich ferroan-calcite. These minerals, along with diagenetic titania minerals suggest: (1) low pH, a high organic content, and a high fluoride content in circulating basinal fluids during mesodiagenesis; and (2) a supply of zirconium, increased salinity in basinal fluids, and higher than expected temperatures during mesodiagenesis. These findings are consistent with evidence from other wells for high salinities and temperatures late in the history of the Scotian Basin.

Comparison of portable X-Ray fluorescence analysis with total digestion of urban soils in Fredericton, New Brunswick, Canada

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Situated on a floodplain between the Saint John River and elevated terrain to the west, the urban centre of Fredericton, New Brunswick, overlies an aquifer that supplies potable water to ~95% of the city. A soil survey completed in 2016 examined 101 sample sites, with a focus on locations overlying the aquifer. Near-surface 'A' samples were collected at a depth of ~10–15 cm and, where possible, underlying 'B' samples were collected at a depth of >30 cm. Subsamples <63 microns were submitted to Activation Laboratories Limited (Actlabs) and analyzed by INAA or TD-ICP to determine elemental concentrations for 50 elements. 'A' group samples collected in the downtown area were found to surpass the Canadian Council of Ministers of the Environment (CCME) soil quality guidelines for As, Ba, Cr, Cu, Ni, Pb, V, and Zn. Anthropological activities, weathering, and elemental mobility were suggested to have contributed to the observed elevated elemental concentrations.

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Building on the previous study, 66 urban centre 'A' sample splits were analyzed by portable X-Ray fluorescence (pXRF) to determine the elemental concentrations of 38 elements. For the majority of samples, pXRF analysis demonstrated lower elemental concentrations than samples analyzed by INAA/TD-ICP, with the exception of Ba, Mo, Pb, and V which exhibited higher concentrations. Similar to the INAA/TD-ICP results, As, Ba, Cr, Cu, Pb, V, and Zn were found to surpass CCME soil quality guidelines for the protection of environmental and human health using pXRF analysis, with Mo and Co also surpassing the guidelines.

In comparison to INAA/TD-ICP, pXRF analysis is advantageous as it requires minimal sample preparation and is a non-destructive method of elemental analysis. While other chemical digestion methods are known to provide more accurate concentration results for certain elements, this study indicates that pXRF can be used in environmental applications as a rapid low-cost first method for determination of anomalous concentrations of selected elements.

Reactive transport of silica-undersaturated alkaline basaltic magma through the lithospheric mantle: a case study from the Rockeskyllerkopf Volcanic Complex, Germany

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Asthenosphere derived magma must pass through lithospheric mantle as it rises but, at low pressures, such magmas are not in equilibrium with peridotite and will react with it. The fact that many magmas reach surface with their high pressure chemical signature intact presents a conundrum. The most likely mechanism for preserving the high pressure signature is that magma moves along high permeability zones which are rapidly modified to a mineral assemblage in equilibrium with the magma and continued flow does not result in further chemical modification.

Peridotite xenoliths in basanites of the Rockeskyllerkopf Volcanic Complex (RVC) in the West Eifel volcanic field comprise two groups: orthopyroxene-bearing (lherzolite/harzburgite) xenoliths and wehrlite xenoliths cross cut by phlogopite/clinopyroxene veins and variably impregnated by these same minerals. Orthopyroxene-bearing xenoliths are characterized by Ti-poor clinopyroxene and phlogopite (and amphibole, though it is now decomposed to glass + clinopyroxene + olivine + spinel) and distinctive LREE enrichment and a strong negative Zr and Hf anomaly in clinopyroxene. The wehrlites are compositionally distinct as they contain Ti-enriched clinopyroxene and phlogopite and contain olivine with lower forsterite content and higher CaO. The clinopyroxene in the wehrlites shows a wide range of intrasample variation in composition that on one end overlaps with that in the lherzolite/harzburgite and extends toward the composition of vein forming clinopyroxene. The wehrlites are the result of reaction between ambient orthopyroxene-bearing lithospheric mantle and infiltrating basanitic melts that penetrated into the lithospheric mantle along high permeability. Reaction resulted in the consumption of orthopyroxene and precipitation of olivine, clinopyroxene, and phlogopite. Modelling with alphaMELTS shows that infiltration of magma similar to that erupted at the RVC into lherzolite/harzburgite results in consumption of orthopyroxene and precipitation of olivine and clinopyroxene. The modelled composition of olivine and spinel are very similar to those observed in the wehrlites, i.e., a decrease in forsterite content in olivine, decreasing XMg and increasing TiO_2 in spinel. Similarly, the alphaMELTS model predicts enrichment of TiO_2 and Al_2O_3 in clinopyroxene and produces a close overlap in the composition of model and wehrlite clinopyroxene for trace elements. The infiltrating melt is also modified; prior to reaching equilibrium it inherits a lower pressure trace element signature. Interestingly the lavas in the RVC show two groups: those with a clear high pressure (garnet in source) signature and those with a lower pressure (garnet and spinel in source) signature.

Diffusion in minerals and melts: a primer for graduate and senior undergraduate students

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Although chemical diffusion is ubiquitous in high temperature geological systems, it is usually not given much time in undergraduate courses since students recoil at the complex mathematical procedures that are needed to analyze diffusion data. Although the equations are sometimes long and have unfamiliar terms, they can be solved quite easily using the SOLVER function in MICROSOFT EXCEL.

Any process in which a chemical potential gradient is generated will result in diffusive mass transfer of chemical components which in turn will result in development of a diffusion profile whose length will vary depending on the time and diffusion coefficient. The chemical diffusion process is divided into three groups, each of which has its

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own set of solutions to the diffusion equations: (1) binary diffusion e.g. Fe-Mg interdiffusion in between two olivine crystals of different composition; (2) ternary diffusion between simple three component melts such as those used in analogue models of magma behaviour e.g. the CaO-Al_2O_3-SiO_2 system; and (3) multicomponent diffusion in natural systems with more than three chemical components.

If we know the diffusion coefficient we can determine the duration of the diffusion process, or, if we control the duration of the diffusion process we can extract the diffusion coefficients. In all cases a detailed chemical profile across the sample starting at the source of the diffusing element and ending in the region unaffected by diffusion is required. With this information in hand we can set up simple models in MICROSOFT EXCEL in which we iteratively change one or more parameters in order to minimize the sum of the squares of the difference between the measured and modelled compositions.

Regardless of the type of diffusion profile being modelled, we need to use a solution to a partial differential equation. Fortunately, there are "cookbooks" available that give every imaginable solution to the diffusion equation. The three scenarios above all use a similar formulation that involves examining the difference between the initial and final composition of the profile points for a fixed diffusion rate over a fixed time. All three use the error function, which is the source of most of the trepidation that students experience when confronted with this kind of problem. A step by step walk-through is provided for the three types of diffusion problem described above so that with practice and some knowledge of EXCEL, students will be able to work with simple diffusion models.

Tied to the Earth: communicating geoscience in an adventurous, aesthetic, and anthropocentric manner

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Members of the general public are often witness to the remnants of geological processes which have shaped our landscape and way of life in Atlantic Canada. However, there is a lack of educational resources aimed at the general public who seek to understand these processes and their implications. The Atlantic Geoscience Society has produced many useful resources, but distribution to the public is sporadic at best. Further, new methods of communicating scientific findings and theories should keep pace with technological advances, enabling geoscientists to remain relevant in an increasing digital world.

Tied to the Earth aims to be such a resource. With a combination of hands on educational experiences, digital products to enable sharing of information, and exposure to the simple aspects of geoscience in general, *Tied to the Earth* will be conveying the rich geological history of the Annapolis Valley, Nova Scotia, as a starting point. This multi-faceted approach involves: (1) adventure geotourism, collaborating with Annapolis Valley Adventures on field trips available to the public and advertised to the waves of tourists who come to the Annapolis Valley, drawn by scenic landscapes, (and occasionally wine); (2) marketing and distribution of handmade stone products, designed to captivate and illuminate the natural beauty of our geological components; and (3) digital companion tools to go along with these tours and products, in the form of QR codes, which will lead to a website that provides educational resources, such as maps and animations of geological processes.

The scope of these experiences is limited to the Neoproterozoic-Phanerozoic history of southern mainland Nova Scotia as a starting point. Field trips include visiting the North Mountain Basalt along the Bay of Fundy, trips to waterfalls within the Meguma Group, kayak trips within the South Mountain Batholith, and fossil viewing excursions to the Carboniferous sedimentary rocks.

Field relations, petrology, and age of mafic rocks in the northwestern Aspy terrane, Cape Breton Island, Nova Scotia, Canada

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Mafic rocks including metabasalt, amphibolite, diorite, and gabbro are major components of the northwestern Aspy terrane. Mapping in 2015–2016 has better defined the distribution of these rocks, and new U-Pb (zircon) dating has clarified their ages. The "George Brook amphibolite" of earlier workers consists of components of at least four different ages and compositions, including: (1) low- to high-grade mafic metavolcanic rocks of the Faribault Brook Formation of the Jumping Brook Metamorphic Suite (JBMS); (2) low-grade metaplutonic bodies, including the newly named Georges Brook metadiorite; (3) gabbroic

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rocks associated and locally mingled with granitic rocks of the Salmon Pool pluton; and (4) amphibolitic sheets in high-grade metamorphic rocks of the Pleasant Bay complex.

The age of the JBMS, for which previous interpretations ranged from Precambrian to Silurian, is now constrained to the Cambrian, based on U-Pb dating of detrital zircon and ca. 490–480 Ma dates from cross-cutting plutons. The metavolcanic rocks are mainly mafic flows and tuffs. The flows locally preserve pillow structures, consistent with the turbiditic character of interbedded and overlying metasedimentary rocks. Metamorphic grade ranges from lower greenschist to amphibolite facies, and some of the latter rocks were previously included in the "George Brook amphibolite". Distinctive Nb and light REE depletion indicates N-MORB affinity, and the JBMS likely formed in a back-arc basin.

The Georges Brook metadiorite intruded mainly metasedimentary rocks in the northern part of the JBMS. In many outcrops the rocks are foliated. Two preliminary U-Pb (zircon) ages indicate emplacement at ca. 475–488 Ma, similar to ages of tonalitic and dioritic plutons to the south. The gabbroic (to dioritic) rocks of the Salmon Pool Pluton are more widespread than previously recognized. In shear zones they are foliated and resemble amphibolite, but elsewhere they are undeformed and mingled with ca. 375 Ma syenogranite. Petrological features indicate that these rocks formed in a within-plate extensional setting, and they may be related to bimodal volcanic rocks of the Fisset Brook Formation.

A major shear zone separates these rocks from high-grade schist, amphibolite, and orthogneiss of the Pleasant Bay Complex to the east. An amphibolite sheet in the Pleasant Bay Complex yielded a preliminary U-Pb (zircon) age of 426 Ma, indicating that it is not directly related to the older amphibolitic rocks to the west.

LA-ICP-MS systematics in sulphides: challenges, developments, and perspectives

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Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) is routinely applied as a reliable and cost-efficient technique in chemical and isotopic research in broad realms of Earth Sciences. LA-ICP-MS has been extensively used and continues to be applied for quantitative measurement of compositional variations within sulphide minerals as well as the recent attempts to develop novel methodologies to measure sulphides' isotopic variations. LA-ICP-MS methodologies in sulphides need to be carefully refined to achieve optimal accuracy and precision. When this optimization is achieved LA-ICP-MS can be used to measure ppb-level concentrations for heavy and precious elements with <50 μm spatial resolution. In addition, the time-resolved analysis of the LA-ICP-MS allows visualization of elements profiles to detect the occurrence of micro-inclusions in the subsurface as a common feature occurring in sulphides.

However, the crystal-chemical composition of sulphide phases presents challenges for LA-ICP-MS analysis. In general, the high weight proportion of metals in sulphides and the presence of high concentrations of first-row transition metals and sulphur, lead to polyatomic interferences at higher masses. Besides, mineral specific characterizations such as bond strengths, melting point, and thermal conductivity of each sulphide mineral demands controlled ablation conditions. Moreover, choices of suitable internal and external standardization protocols, as well as meticulous data reduction strategies, are further required to treat LA-ICP-MS data of sulphides.

Herein, LA-ICP-MS refined methodologies in key sulphides are presented. The modifications in methodology include an assessment of optimized ablation conditions, choice of external and internal standards, and improvement of data reduction strategies. Data acquisition was optimized by adjusting spot size (based on textural criteria and required accuracy and precision), energy density, and ablation times and background intervals. Sulphides such as galena, arsenopyrite, and tetrahedrite are susceptible to melting using high energy density excimer lasers. Scanning electron microscope (SEM) topography images obtained after ablation of individual sulphide minerals show the effect of laser fluence on the formation of melted domains which can be minimized by decreasing the fluence. Therefore, ablation conditions should be adjusted to suit the particular sulphide mineral under investigation. This helps to reduce the effects of melt/condensate droplets in the ablated sites and enhance the system sensitivity and effects of matrix mismatches as well. The LA-ICP-MS systematics in sulphides needs further refinements which in some parts can be achieved by new laser technology and greater cooperation and knowledge transfer among the LA-ICP-MS community.

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Distinguishing between porphyry and volcaniclastic units from the Hebert-Brent gold showing, Yellowknife Greenstone Belt, Northwest Territories, Canada

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The Yellowknife Greenstone Belt (YGB) is located within the western part of the Archean Slave craton, Northwest Territories, Canada. This study is focused on the local geology of the Hebert-Brent gold showing, which is part of the Barney Deformation Corridor. The showing consists of replacement-style gold mineralization hosted in massive to pillowed, bleached mafic volcanic flows that are intruded by variably altered feldspar-quartz and quartz-feldspar porphyries. Due to the complicated metamorphic and deformation history of the YGB, questions remain as to the origin of these units. To shed some light on these porphyries, eight drill core samples were examined petrographically.

Transmitted and reflected light petrography was used in conjunction with micro-X-Ray Fluorescence to characterize the overall mineralogy, alteration and textural variations of each thin section. The original description of the eight porphyry samples had seven identified as feldspar-quartz porphyries and one as a quartz-feldspar porphyry. The overall mineralogy consists of phenocrysts of quartz, minor relict amphibole, and sericitized twinned plagioclase set in a crypto- to microcrystalline groundmass of muscovite, quartz, calcite, pyrite, and Ti-oxides. Samples are variably mineralized with arsenopyrite, chalcopyrite, and sphalerite. The samples were all evaluated for possible plutonic or pyroclastic textures to indicate the origin of the porphyries. Recrystallization textures were most often observed, including muscovite pseudomorphed after prismatic feldspar, quartz subgrain development along quartz grain boundaries, and quartz with undulose extinction. Variably sized (fine to coarse) spherical and amoeboid-shaped quartz grains, typically with embayed and scalloped margins, were found in most samples, as well as broken/dislocated quartz grains. It is possible that these textures represent fragmentation of the quartz grains due to changes in pressure; gases that became trapped during one level of emplacement may have burst during a decompression event. Of particular interest were the spherulites observed in one feldspar-quartz porphyry sample, a devitrification texture that is indicative of volcanic rather than plutonic origin. The microanalytical techniques and textural observations will hopefully clarify the discussion regarding the various porphyries at the Hebert-Brent gold showing. The focus of this study was mineral and textural identification, although limited at this stage due to the microcrystalline nature of the groundmass/matrix. Future work will be aimed at identifying growth patterns in quartz phenocrysts and the identification of the very fine- silicates, sulphides, and oxides that were observed.

On the trail of the Great Stone Chief

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Robert Bell (1841–1917) likely explored more of Canada than any other person. Mostly as an employee of the Geological Survey of Canada, but at times on private ventures, Bell collected details on the geology, natural history, forestry, and ethnography from Newfoundland to the Yukon. He was a charter member of the Royal Society of Canada, and was honoured at home and abroad. Bell's story is being written as a book, based on earlier research by Ian Brookes, to be published to celebrate both the 150th anniversary of Canada and the 175th anniversary of the Geological Survey of Canada. Much of Bell's materials were saved from the debris of a house fire of his daughter in 1962, and are now housed in the National Archives.

The main focus of his mapping was the rivers draining into Hudson Bay, but he also completed comprehensive studies of the Paleozoic of Ontario, gold fields of Nova Scotia, the Appalachian thrust belt of the Gaspé, the Red River Valley of Manitoba, and routes from the Metis heartland in Saskatchewan to Great Bear Lake and the Klondike. Bell was responsible for naming over 3000 geographic features in Canada, and is later explorations resulted in the naming of the Bell River, downstream from Matagami, Quebec, after him. Serving as geologist, naturalist, medical doctor, and linguist, he pioneered canoe-based excursions of all the large rivers entering Hudson Bay and James Bay east from Churchill, and provided both navigational and medical support in three expeditions from St. John's to Hudson Bay through Hudson Strait. He interacted with aboriginal peoples, and was given the title "Great Stone Chief" by the Inuit of the Ungava Peninsula.

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Investigating possible hybridization of the Peggys Cove granite section of the Halifax Pluton, South Mountain Batholith, Nova Scotia, Canada

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An investigation of magmatic growth history of the K-feldspar megacrysts in the Halifax Pluton, a Late Devonian granite intruded into the Meguma strata bedrock, is ongoing. Specifically, the rocks being investigated in this study outcrop along the coast by Peggys Cove, Prospect, and Sambro Head, Nova Scotia. Several outcrops in the latter two areas contain clusters of large mafic enclaves, which differ texturally from country-rock metasedimentary xenoliths, and appear to be of a magmatic origin. The presence of mafic enclaves suggests that a period, or periods, of magma mixing may have occurred. Magma mixing has been documented at Sambro Head, where a mafic intrusion, specifically a dyke, has been injected into the still partially molten granitic host. Similar partial mixing zones have been described in other granitic intrusions of the same age in southwest Nova Scotia. Large K-feldspar phenocrysts (megacrysts) are present in both the granitic rocks and in some mafic enclaves at Prospect. Of note are enclaves which show megacrysts crosscutting their margins, suggesting that both the host granite and enclave were at least partially liquid during megacryst growth. The study area at Peggys Cove differs in that it shows a significant decrease in the volume and size of these mafic enclaves. It also has a much higher temperature gradient than that of the latter two study areas. The granites around Peggys Cove have been much more resorbed, therefore suggesting that there has been much more thorough mixing in this area. This study used field observations, petrography, whole-rock analysis, and detailed electron microprobe analysis to study samples taken from the mafic enclaves, the surrounding host granitic rocks and in particular, the large megacrysts from three separate locations in the Halifax Pluton. Evidence of chemical zoning evident through the patterns of barium and strontium preserved in the granitic feldspar megacrysts, especially where no obvious mafic enclaves occur, suggest that hybridization of this granitic pluton may have been more widespread than previously documented.

Closing Romer's Gap in New Brunswick: a diverse ichnoassemblage from the Lower Carboniferous of southern New Brunswick, Canada

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The landscape of the Late Carboniferous (325–300 Ma) is thought to have been covered in lush, tropical rainforests that were biologically diverse; the iconic image of the "coal-age." Many of the crown groups of tetrapods and invertebrates were well established within such terrestrial ecosystems. The fossil record is known from both abundant skeletal remains as well as abundant trace fossil assemblages (i.e., Joggins, Nova Scotia and Union Chapel Mine, Alabama). Indeed, the Canadian Atlantic provinces are considered a gold standard for late Paleozoic ichnology. The Early Carboniferous (350–325 Ma), however, was until recently thought to be generally barren, with little evidence of terrestrial life, a hiatus known as Romer's Gap. New discoveries from famous fossil sites (Horton Bluff, Nova Scotia; numerous sites in Scotland; and trackways in the Mauch Chunk Formation, Pennsylvania) have shed new light on this mysterious void in the fossil record. Yet, despite the abundance of Early Carboniferous rocks in New Brunswick and their interest to the oil and gas industry for more than 100 years, only plant fossils and fish fossils were previously known with ichnofossils being rare from the Lower Carboniferous of New Brunswick. It was only recently that fossils of terrestrial life were recognized from Early Carboniferous rocks near Norton and Bloomfield, New Brunswick. Although body fossils remain absent, fossil footprints of tetrapods, and invertebrate traces, are now providing new evidence of a diverse terrestrial and marginal lacustrine ecosystem in the middle of Romer's Gap, spanning the entire Tournaisian and Serpukhovian stages. The Kennebecasis, Albert, Bloomfield, Stilesville, Lepreau, and Maringouin formations preserve approximately 40 ichnospecies. This ichnological record in New Brunswick is closely associated with fossil microbial mats and biofilms that seem critical to the taphonomic conditions that allowed trace fossil preservation. This further demonstrates

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the important role that microbial mats play in both the taphonomy of ichnofossils and in paleoecology. Only one other locality worldwide (Horton Bluff) provides such insight into the continental ichnological diversity during Romer's Gap. Strata in New Brunswick offer the opportunity to compare ichnofaunal assemblages, paleogeographically and chronologically. This has allowed for the study of new ecological niches previously unrecognized as inhabited during the Early Carboniferous (upland alluvial fans).

Mantle source of fluids and metals in the Jiaodong gold province, China: evidence from noble gaseous components in ore-related pyrite

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The Jiaodong Peninsula, eastern North China Craton (NCC) is the largest gold district in China and has proven reserves exceeding 3000 t Au. To a first order the deposits were formed in a short time interval (120 ± 10 Ma) and are largely hosted by strike-slip faults in Jurassic-Cretaceous granitoids and Precambrian basement rocks (1.9–2.9 Ga). Up to present, the classification of the Jiaodong gold deposits remains problematic. Some studies classified them as orogenic gold deposits for a unified model in which metals are derived from late-orogenic metamorphic devolatilization. However, others argued that the ore-forming fluids and gold were largely exsolved from coeval deep-sourced magmas with evidence for mantle–crust mixing.

The origin and the interaction history of the ore-forming fluids is a key factor for understanding the formation of the Jiaodong gold deposits. He and Ar isotopes provide powerful tools to constrain the origin of ore-forming fluids. He-Ar isotopes are reported for ore-forming fluids from 20 pyrite samples in the eastern Jiaodong deposits. $^{3}He/^{4}He$ range between 0.42 and 2.39 R_a, $^{40}Ar/^{36}Ar$ are 367 to 2,112, and $^{40}Ar^{*}/^{4}He$ values are 0.26–2.50. The data is a mixture of gas from three sources; a dominant mantle-derived component plus sub-ordinate crustal radiogenic and meteoric components. The mantle end-member has $^{3}He/^{4}He$ (3.3–4.0 R_a) that is lower than most estimates for sub-continental lithospheric mantle (6–7 R_a), implying that it was probably refertilized by subduction-related fluid metasomatism. This is consistent with He-Ar isotopes reported for SCLM xenoliths from basalts in the Shandong Province. Within the mineralization province, mine Au reserves are positively correlated with the proportion of mantle-derived He in the ore-forming fluids. This implies that the fluids, and by inference the gold, was largely derived from mantle degassing during lithospheric extension. Previous work also documented a common magma mixing source and thus a direct genetic link between the coeval mafic magmas that formed the dykes and ore formation in the Jiaodong gold province. This is indicated by several lines of evidence: (1) they both share the same structural features and some dykes themselves were mineralized; (2) they formed at the same time and under a similar extensional tectonic regime; (3) Pb isotopic signatures of the ore sulphides overlap those of the mafic dykes; and (4) metal ratios in magmatic sulphides trapped in minerals from mafic dykes are similar to those of the bulk ore.

The curation of university geology collections: an example from the Quartermain Earth Science Centre, University of New Brunswick, Fredericton, New Brunswick, Canada

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Like many universities, the University of New Brunswick (UNB) collections of geological specimens have been procured over the last 120 years. The fossils, rocks, and minerals are largely the result of research projects of both faculty and students with additional input from other donors and collectors. The Quartermain Earth Science Centre (QESC) was opened in 2011 to display the more unique specimens and to provide educational exhibits and structured programs for students and the public. One of the primary mandates of museums is collections care, which is challenging for many universities due to the lack of financial resources, adequate storage space, personnel, time, and dedication to make specimens accessible to the public.

In 2014, the Earth Sciences department at UNB received support to acquire a part-time curator to manage the QESC and the very large historic collections. Since then, space within the Earth Sciences department has been renewed into the museum storage and preparation room designed for sustainable care of natural specimens. Collections are being meticulously catalogued within a comprehensive searchable digital collections management database, capable of storing high-resolution images, supportive publications,

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and general day-to-day activities. The more exceptional specimens are displayed within the museum or in display cases around the Earth Sciences department, while other, less exotic specimens have been diverted towards outreach activities for visiting students. Although the QESC is managed on a small budget, the interactive programs and extensive collections are proving to be a growing essential resource for education, public outreach, youth employment, volunteer experience, and invaluable research. In the short time since its existence, the QESC at UNB has demonstrated the importance of, and need to preserve, such collections.

Why storytelling is essential to effective communication of the earth sciences: a tribute to Gwen Martin

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Geological issues are increasingly relevant to the everyday lives of individuals and communities around the world, whether it is the risks to water quality, natural hazards (e.g. earthquakes, volcanoes, tsunamis), climate and sea-level change, management of our energy and resources, or the complexities of geological engineering. Yet most earth science professionals, and even educators, find it challenging to communicate geological concepts to the non-geologist. How can we educate the public in basic science, when it is now so skewed by information overload, and, in many cases, by general disinterest?

To help understand how to communicate the science of climate change, Somerville and Hassol suggested: "Try to craft messages that are not only simple but memorable, and repeat them often. Make more effective use of imagery, metaphor, and narrative. In short, be a better storyteller, lead with what you know, and let your passion show." In other words: don't fixate on just the facts…. *tell stories!* Akin to Gwen Martin: one of our most cherished local pioneers who has successfully inspired a generation by making Atlantic Canadian geology accessible through storytelling, activities, and publications.

In her younger years, Gwen was a geologist, prospector, musician, journalist, and geotourism guide. She also jumped freight trains and took flying lessons. In the 1980s she became a professional writer and editor … and hasn't looked back since. Throughout her career, Gwen has contributed to different governmental departments including Energy and Mines, Natural Resources, Natural Resources and Energy (DNRE), and Education. Her passion for the Earth and Earth Science education has resulted in engaging and valuable resources for schools, as well as publications about our earliest geologists, our unique fossils, urban geology, local geo-hotspots….and much more! Her work includes "Gesner's Dream" (published by CIM NB Branch), and "For the Love of Stone" (published by DNRE). She has traveled throughout New Brunswick instructing teachers, inspiring students, and informing the general public.

Gwen's vision for the world now and in the future embraces our innate human need to connect (or re-connect) with our landscape history and our awesome planet. For everyone, just to pick up a rock, break it open, and for the first time, with our own eyes, see a piece of the Earth that has been hidden for a very long time – perhaps a billion years! Through her stories, Gwen Martin reminds us to be in awe of our world, and to unearth new treasures every day.

Sedimentology and oceanography of Early Ordovician ironstone, Bell Island, Newfoundland and Labrador, Canada: ferruginous seawater and upwelling in the Rheic Ocean*

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Early Ordovician ironstones of the Bell Island and Wabana groups, Bell Island, Newfoundland and Labrador provide new information regarding the biogeochemical cycling of Fe and P just prior to the onset of the Great Ordovician Biodiversifiction Event (GOBE; ~485 to 460 Ma). The GOBE is the most important and sustained increase in marine biodiversity in Earth's history. While the Cambrian Explosion produced skeletonized organisms with a range of new body plans, the GOBE records the staggering increase in diversity of these taxa.

The Bell Island and Wabana groups are a ca. 150 m thick succession of both clastic and chemical sedimentary rocks composed of twelve distinct lithofacies that accumulated on the margin of the Rheic Ocean. Lithofacies stacking patterns indicate that deposition occurred during a marine transgression with superimposed small-scale sea-level fluctuations producing six parasequences. Ironstone-dominated parasequences are 10 to 20 m thick and composed

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of hummocky cross-stratified sandstone interbedded with organic-rich mudstone and phosphatic Fe-silicate-bearing siltstone, which is overlain by hematitic granular ironstone capped by an erosive flooding surface.

This lithofacies association suggests deposition of upwelling-related ironstone on a storm-dominated shelf. The close association of Fe-silicates and phosphorite typical of upwelling systems suggests that Fe was delivered from deep, anoxic, nutrient-rich seawater that also stimulated high surface productivities. The result was the precipitation of authigenic sedimentary apatite and Fe-silicates in organic-rich sediments that accumulated near the center of upwelling. As Fe-rich waters advected away from the upwelling front and mixed with oxygenated shelf waters, Fe-oxyhydroxides precipitated that were later reworked by fairweather currents and storms to form hematitic granular ironstone on the lower shoreface. This model challenges longstanding ideas of ironstone formation that rely on a continental source of Fe. It also highlights the potential connection between the delivery of anoxic, ferruginous seawater to the margins of the Rheic Ocean and the Early Ordovician extinctions that punctuate the beginning of the GOBE.

Winner of the AGS Sandra Barr Award for best graduate student oral presentation

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Assessing Holocene deep water formation in the western Nordic seas based on microfossil assemblages

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The Nordic seas are one of the few regions where active deep water formation currently takes place. The study tries to assess millennial-scale variations in convection by evaluating the likeliness of favorable seasonal preconditioning to open ocean convection in the western Nordic seas during the Holocene. This was done by reconstructing surface to subsurface potential density (σ_θ) gradients calculated from dinoflagellate cyst assemblages and planktic foraminiferal (*Neogloboquadrina pachyderma*) stable oxygen isotopes ($\delta^{18}O_c$), at sites close to the present-day convection cells in the Nordic seas. The different calibrations that were used all linked *N. pachyderma* $\delta^{18}O_c$ to σ_θ values between 27.70 and 27.90, occasionally up to 28.00, suggesting a strong isopycnal calcite accretion zone and broadly matching the potential densities of modern Labrador Sea water and Nordic seas overflow waters. The calibrations show that from the early Holocene to ~7–6.5 ka BP relatively light surface waters occupied the western Nordic seas, retaining enough buoyancy to prevent vertical convection, especially in the westernmost area where the fresh water component was higher and persisted slightly longer. After ~6.5 ka BP the surface to subsurface σ_θ gradient decreased and regularly inverted, thus leading to conditions favorable for the development of active overturning cells in the basin, while intermittent eastward spreading of lower density surface waters continued to modulate the area of likely preconditioning. Superimposed on the long-term trend there is a marked local variability, which is more pronounced closer to the fresher and periodically ice-laden East Greenland Current. The timing of the onset of a typical full interglacial climate mode corresponds with the final exhaustion of Northern Hemisphere ice sheet meltwater supplies, while the intermittent eastward spreading of buoyant surface waters might have acted as an on-off switch for overturning cells causing a temporary enhancement or reduction of deep water formation since the mid-Holocene.

Proterozoic to Cambrian zircon geochronology in the Bras d'Or terrane on Cape Breton Island, Nova Scotia, Canada: deciphering the infrastructure of Ganderia

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The relationship of the Bras d'Or terrane to other Ganderian terranes of the northern Appalachian orogen is enigmatic, particularly with respect to its pre-Neoproterozoic history. The southern part of the Bras d'Or terrane consists of Neoproterozoic (or older) metamorphic rocks of lower greenschist- to lower amphibolite-facies with poorly constrained ages, Neoproterozoic plutonic rocks, and Cambrian-Ordovician volcanic, sedimentary, and granitoid rocks. This study is focussed on the Boisdale Hills–Kellys

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Mountain area which contains some of the highest grade metamorphic rocks in Cape Breton Island, with the goal of constraining the Neoproterozoic and older history of these units using U-Pb zircon geochronology.

Kellys Mountain contains primarily paragneiss, in some areas containing cordierite indicating high-temperature metamorphism in a low-pressure environment. One sample of paragneiss from Kellys Mountain (KM10-04) contains zircon grains with an almost continuous range of ages between 2.4 and 1.3 Ga with major peaks at 1.8 Ga, 1.6 Ga, and 1.3 Ga, and minor populations at 1.2 Ga and 0.8–0.6 Ga. The youngest grains in the sample indicate that the depositional age is <620 Ma. In contrast, another sample from the topographic "top" of the Kellys Mountain paragneiss contains zircon grains with minor populations at 1.6–1.5 Ga and 1.3–1.2 Ga, with the main population of grains between 0.7–0.6 Ga. The youngest grains indicate that the maximum depositional age is 600 Ma. Although the youngest ages in both samples are similar, no Paleoproterozoic zircons occur in the latter sample, and the Mesoproterozoic populations are much less prominent, perhaps an indication that the primary sources of detrital material changed during the depositional history.

The Frenchvale Road metamorphic suite (FRMS) represents the highest grade of metamorphism in the Boisdale Hills area, and contains primarily quartzite, amphibolite, marble, and calc-silicate rocks. Two quartzite samples (BH036Q and BH017) from the southwestern and northeastern areas of the FRMS, respectively, have detrital zircon populations with ages ranging from 3.2 Ga to ca. 1 Ga, but in different proportions. BH017 has a near-continuous range of Mesoproterozoic ages, whereas BH036Q contains a large range of ages spanning the Neoarchean to Paleoproterozoic. Both rocks are younger than ca. 1.05 Ga but their lower age limits are not well constrained. Neither sample contains zircon grains in the Neoproterozoic ranges present in the samples from Kellys Mountain. The detrital signatures in these Boisdale samples suggest Gondwanan provenance, and are distinctly different from those in the Kellys Mountain samples.

New geochronological constraints on the timing of emplacement of Ediacaran to Devonian granitoid rocks in the Bras d'Or and Aspy terranes of Cape Breton Island, Nova Scotia, Canada

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Granitoid plutons form more than half of the area of pre-Carboniferous rocks in the Bras D'Or and Aspy terranes of Cape Breton Island, Nova Scotia. Relatively few have well constrained ages, and those ages display a wide range from Ediacaran (ca. 640 Ma) to Devonian (ca. 370 Ma). The ages of many other plutons are uncertain, with existing estimates based mainly on petrological features, and in many cases their relationships to one another are obscure. Better constraints on the age for these plutons are an essential step toward constructing an integrated understanding of their tectonic significance and mineralization potential. As part of the Targeted Geoscience Initiative (TGI-5) in Nova Scotia, samples were selected for dating to include plutons with no age or poorly constrained ages. Selected samples were processed using electro-pulse disaggregation and zircon grains were separated at Overburden Drilling Management in Ottawa, Ontario. Grains for dating were then picked, mounted, and analyzed using laser ablation ICP-MS at the University of New Brunswick.

A major target in the study was the Margaree Pluton, the granitic pluton in the Aspy terrane. It straddles the prominent Aspy Fault, and also appears to "stitch" the Red River and Wilkie Brook shear zones that separate the Grenville-age Blair River terrane from the rest of the highlands. The sample yielded a preliminary concordia age of 363.1 ± 1.6 Ma, interpreted as the main age of crystallization. This age is the youngest plutonic date yet reported from the highlands.

Another significant area of age uncertainty is the southern highlands, where none of the extensive plutons of the former "Leonard MacLeod Brook Complex" had been dated. A Silurian concordia age from the Gillis Brook diorite of 436.4 ± 1.5 Ma combined with recently published similar ages from farther west and north show the presence of a major dioritic event in the Aspy terrane. As more ages are obtained, enhanced understanding of the tectonic history and mineralization potential will emerge, combined with improved correlations with other Ganderian terranes in the northern Appalachian orogen.

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Ganderia: what, where and when

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Ganderia was introduced in the 1990s as a terrane in the northern Appalachians encompassing the former Gander zone and parts of the Dunnage and Avalon zones. It is now widely accepted as an independent Gondwana-derived microcontinent, different and separated from the other Gondwana-derived terranes (Avalonia and Meguma). Ganderia was the first of the Gondwana-derived terranes to arrive at the progressively growing Iapetan margin of Laurentia and hence, was subjected to a complex, polyphase Paleozoic orogenic history that was superimposed on an already existing complicated Proterozoic to Cambrian tectonic imprint acquired during the various tectonic processes responsible for the assembly of Gondwana. The concept of Ganderia as one coherent microcontinent is not straightforward, because it comprises several belts that potentially preserve different geological evolutions. Most of the existing geological differences can be explained by strike-slip shuffling of the various Ganderian belts during its complicated and long-lived tectonic history near plate margins.

Various lines of geological and tectonic evidence link the various constituents of Ganderia together, as well its provenance. Ganderia can be defined by its predominantly Early Paleozoic siliciclastic sedimentary rocks that largely cover the underlying Precambrian basement. However, this sedimentary facies extends into the Cyrogenian and represents development of a long-lived passive margin that was interrupted periodically by periods of ensialic supra-subduction magmatism between 630 and 420 Ma. Detrital zircon studies of the various sedimentary rocks are consistent with a common hinterland, although subtle changes in age-peaks suggest that the various belts may have occupied different geographic positions before final juxtaposition during the Middle-Late Paleozoic. A predominance of quartz arenite in the older and more eastern parts of Ganderia versus siltstone and dark shale in the more western segments indicates that the Gander margin was facing an open oceanic basin to the west in present coordinates during the Cambrian to Silurian; the paleogeographic facing of the Gander margin during the Neoproterozoic is poorly known. Rifting of Ganderia from its continental hinterland, commonly assumed to be Amazonia, which transformed it into a microcontinent during the Middle Cambrian, opened the Rheic Ocean along its trailing edge, making the Gander margin two-sided. However, most of the post-Early Ordovician sedimentary cover that should have been deposited along the trailing Rheic margin is not preserved, suggesting the outboard segments of this margin were largely buried and/or removed by tectonic mechanisms associated with closure of the Rheic Ocean and related seaways.

Diachronous Paleozoic accretion of peri-Gondwanan terranes in the Caledonides and northern Appalachians

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Reconstructions of the Caledonides and northern Appalachians go back 50 years to the original "Wilson Cycle". Subsequently published reconstructions differ in the positioning of the North American and European components and in the correlation of major sutures between these components. Using gravity data, it is possible to restore Mesozoic stretching of the Atlantic margins; the resulting reconstruction places Ireland significantly closer to Newfoundland than has been previously proposed.

In the original Wilson Cycle, the northern Appalachian - Caledonide orogen resulted from the collision of two continental masses separated by a single ocean. One of these continental masses corresponds to the modern concept of Laurentia, but the colliding continent to the east has been variously subdivided into many smaller terranes and domains, including Ganderia, Avalonia, and Megumia. Using published stratigraphic evidence and detrital zircon provenance data from units of known depositional age, the timing of arrival of these units at the Laurentian margin between the Early Ordovician and Early Devonian can be constrained. Several of the accreted terranes do not extend over the entire length of the orogen, with the result that the lines separating them change character along strike from terrane-bounding sutures to simple accretionary thrust

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faults. The domain Ganderia consists of at least four separate terranes that share a common origin on the continental margin of Gondwana, but were separated by back-arc oceanic crust as they crossed the Iapetus Ocean and collided diachronously with the Laurentian margin.

Strike-slip and salt tectonics in the development of the Cumberland and Sackville subbasins, Nova Scotia and New Brunswick, Canada

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A compilation of industry subsurface data permits correlation of major stratigraphic surfaces, in three dimensions, across the Late Paleozoic Cumberland subbasin and adjacent subbasins of the Maritimes Basin in northern Nova Scotia and adjacent New Brunswick. The boundaries of major groups: Pictou, Cumberland, Mabou, Windsor, Sackville and Horton - show increasing deformation down section, indicating that the Maritimes Basin was tectonically active throughout much of its development.

The Horton Group is only clearly resolved in subsurface data in the Sackville subbasin of southern New Brunswick, where it is cut by faults that show variations in their sense of offset within the Horton Group. These repeated inversion events are most reasonably interpreted as resulting from strike-slip motion, which continued during and after deposition of the Mississippian Sackville and Windsor groups, producing a south-propagating flower structure in southern New Brunswick. In the Cumberland Basin, salt expulsion began in the east, probably during the Middle Mississippian, whereas in western sections the major episode of salt expulsion occurred in the Pennsylvanian, providing accommodation for the rapidly deposited Cumberland Group in the area of the Joggins World Heritage Site. At several places in the Maritimes Basin, explusion of salt during transpression appears to have produced a distinctive geometry involving tectonic wedges described here as a "wilted" positive flower structure. This geometry may be characteristic of tectonic settings where strike-slip motion and salt tectonics are active simultaneously.

Progress report on bedrock mapping of the pre-Devonian volcanic/sedimentary rocks in the Round Mountain area of northern Maine, USA: establishment of the Round Mountain Volcanic Sequence

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The Round Mountain area is located in the middle section of the NE-trending "Munsungan-Winterville Anticlinorium" in northern Maine. The anticlinorium is part of the Ordovician Popelogan arc of northwestern New Brunswick and northern Maine. Bedrock mapping in the area since 2016 has made significant progress towards understanding of the pre-Devonian stratigraphic sequences and structural framework of the slightly metamorphosed and foliated volcanic and sedimentary strata.

The Round Mountain Volcanic Sequence (RMVS) is composed of alternating layers of felsic tuff (fine tuff, course tuff, lapilli tuff, lapilli stone, and tuffaceous breccia) and basalt (dominantly porphyritic basalt). The RMVS conformably overlays the older Chase Brook Formation of dominantly slate on its southeast and forms a NW-dipping homoclinal structure. The RMVS is identified as an independent volcanic sequence from other volcanic sequences, such as the widespread Munsungan Lake Formation (Sequence) of volcanic rocks. The difference is confirmed by discrimination diagrams such as Rb-Sr and Rb-Ba diagrams of the tuffs/cherty rocks sampled from both sequences (the trace elemental analysis was performed by a hand-held XRF analyzer). The RMVS was likely produced in a submarine half-graben, rifting setting.

The multiple "chert" layers within the RMVS that were mined by Paleo-Indians for making lithic tools are actually fine– or very-fined-grained silica-rich tuff. The "unnamed volcanic rocks – Ouv" shown on the current state map do not exist; where Ouv is shown there is a NE-striking and NW-moderately-dipping formation of slightly-foliated conglomerate and slate – named the Rowe Lake Formation in this study. It is mapped into three members, the Lower Slate Member, Conglomerate Member, and Upper Slate Member. The conglomerate is polymictic and made of predominantly pebble-size chert (cherty tuff) and volcanic rocks.

A slice of unnamed, NE-striking, dominantly pillow basalt formation occurs on the northwest side of the Upper Slate Member. Their contact is likely an unconformity. This younger basalt formation is tentatively named the Horseshoe Pond Formation in this study.

The Chase Brook Formation, probably the oldest strata

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(Ganderian) in the area, extends further northeast crossing the Machias River, which implies that the Winterville Formation on the east side of the River should be much narrower than what is shown on the current state map. In addition, a layer of fine vitric tuff and a layer of basalt were identified within the Chase Brook Formation, indicating periodic volcanic eruptions during the deposition of the Ganderian slate formation.

A new geological bedrock compilation map of Cape Breton Island, Nova Scotia, Canada: insights and challenges

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Cape Breton Island contains both the oldest and youngest geological units in Nova Scotia, spread over the remnants of six (or more!) Appalachian geological terranes. This geological complexity has been captured on twenty-five new 1:50 000 scale geological maps compiled by the authors and scheduled to be released in early 2017 by the government of Nova Scotia. Accompanying the maps is a 1:220 000 scale overview map of the entire island and a detailed legend with over 350 units from the member to terrane level. The data have been compiled in ARCGIS, and will ultimately be supported by a searchable digital database including outcrop locations, structural information, samples, and geochemical, geochronological, and magnetic susceptibility data. Both printed and digital maps will include geological units draped over a shaded digital elevation model. Other digital products such as aeromagnetic and radiometric maps will also be included in the ARCGIS database. These map products will be fully digital, easy to update and freely available on the NSDNR website.

These maps are the culmination of decades of field mapping, as well as detailed stratigraphic, petrological, geochemical, and geochronological studies. However, this work has tended to focus on either pre-Carboniferous "basement" rocks or on Carboniferous and younger "cover" sequences, with relatively few studies that focused on the relationships between the two age assemblages. By capturing all the details from both older and younger assemblages, these maps provide new insights about terranes, terrane boundaries, and geological history, and clarify some long-standing controversies about stratigraphic relations and age. They will likely encourage mineral exploration that could have long-term benefits for the province of Nova Scotia and aid in the understanding of the northern Appalachian orogen. However, the maps also reveal challenging problems that need to be addressed by additional studies. Clear disconnects are apparent between stratigraphy and structure in Carboniferous rocks compared to pre-Carboniferous rock units, and some of the geological relations displayed or implied on the maps are improbable or impossible. It is also clear that the number of precise ages for pre-Carboniferous units is small and that the ages of many units remain uncertain. The maps also show that Carboniferous stratigraphic units need to be rationalized across the island.

The Middle Paleozoic in northern New Brunswick, Canada: stratigraphy, deformation, and the Salinic and Acadian orogenic cycles

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Deposition of Upper Ordovician to Lower Devonian rocks of the Matapedia successor basin coincided with polyphase deformation of mainly Middle Ordovician volcanic and sedimentary rocks of the Tetagouche backarc basin, which were amalgamated into the Brunswick subduction complex. Successor basin sedimentation and volcanism, and deformation in the subduction complex, each span the Salinic and Acadian orogenic cycles, and post-date Late Ordovician collision of the Popelogan arc and composite Laurentia, marking the end of the Taconic cycle. $^{40}Ar/^{39}Ar$ dating of white mica in S_1 and S_2 cleavage domains establishes the timeframe for underplating of the various crustal blocks that were sequentially incorporated into the subduction complex (D_1), as well as the D_2 event recording the closure of the Tetagouche backarc basin and collision of the Gander passive margin with composite Laurentia ca. 430 Ma. The progressive D_1 deformation generally has only subtle effects on the successor basin sequence, but includes an early Llandovery unconformity that may coincide with ca. 442 Ma underplating of the California Lake block in the subduction complex. In contrast, D_2 deformation in the

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subduction complex is correlated with a basin-wide mid-Silurian unconformity and local northwest-trending folds lacking axial planar cleavage in the Matapedia cover rocks. Breakoff of the subducted Tetagouche backarc slab ca. 425 Ma resulted in rapid uplift of the Salinic orogen (Brunswick subduction complex) and subsequent gravitational collapse recorded by latest Silurian-earliest Devonian (D_3) vertical shortening. In the successor basin, slab breakoff led to within-plate volcanism beginning ca. 422 Ma; furthermore, local ENE- to ESE-trending folds in Late Silurian rocks suggest a correlation with D_3 in the subduction complex. Precise ID TIMS dating of Silurian-Devonian volcanic rocks demonstrates that within-plate volcanism occurred in two episodes separated by an earliest Devonian disconformity: the first (422–419 Ma) is associated exclusively with slab breakoff, but the second (417–407 Ma) shows the influence of a northwest-propagating Acadian "flat slab" following ca. 422 Ma closure of the Acadian seaway and Avalonia-Laurentia collision. The 419–417 Ma disconformity is coeval with a regressive event represented mainly by deposition of shallow-water red beds. This regression was succeeded by deposition of voluminous Lochkovian turbidites; this regressive-transgressive sequence is interpreted to record a propagating Acadian forebulge and foredeep, immediately preceding northwest migration of the Acadian deformation front, which traversed the successor basin between ca. 415–395 Ma. Complex late Silurian-early Devonian relationships indicate rapid transition involving temporal (but not spatial) overlap of the Salinic and Acadian cycles.

Applied geography, geomatics, and geo-enthusiasm

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Why the geo-enthusiasm? The geomatics sector is in the middle of an accelerated renaissance of new technologies. Using computer gaming technologies, photo 3D rendering, and laser scanning, (and GIS and RTN) the real world can rapidly be digitized and analyzed. We get to fly drones/UAVs; we use laser beams and satellites; we use 3D goggles to walk and fly through the digital worlds; we use our smartphones to capture data and augment our reality; and we help create systems to assist the immerging autonomous vehicles, navigate safely. In addition, telling middle schoolers that they can have a job that uses computer gaming, UAVs, smartphones, and cars that drive themselves, gets their attention. Absolutely, geomatics is cool!

There are many geomatics tools and resources that can be integrated into the classroom. Story maps are becoming a very approachable way to introduce interactive mapping to students. A lesson plan worksheet created by ESRI Canada will be presented - *See Your World, Measure and Mark Your World, Explore Your World, Expand Your World, App the World and Create the World.*

Serendipity, opportunity, and toil: development of the *Lagerstätten* collections at the Manitoba Museum

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Over the past 20 years, the Manitoba Museum has built a large collection of fossils from three Ordovician *Konservat-Lagerstätten*, deposits that preserve soft tissues and soft-bodied organisms. Collecting began purposefully in 1997, with fieldwork in the already-known Cat Head-McBeth Point area on Lake Winnipeg's north basin. There, the Cat Head Member of the Red River Formation (Upper Ordovician, Katian) is known for seaweeds, trilobites, and conulariids.

Collections from the other two *Lagerstätten*, though, developed through a combination of contacts, serendipity, and hunches . . . followed by many days of intense toil. In the 1990s, a geologist in the Grand Rapids Uplands discovered fossils on the reverse sides of flat slabs selected as substrates for artwork. This was brought to the attention of a Manitoba Geological Survey geologist, who passed the information to the Manitoba Museum. Subsequently museum personnel found a eurypterid in this area in 2001, but the bedrock source was not located until 2004. Since then a detailed excavation of this locality has been carried out, now called the William Lake site.

At William Lake in 2005 unusual fossils were collected, including the first specimen of a creature that would later be described as the horseshoe crab *Lunataspis aurora*. Contemplating the lithology, a similar rock 650 km away was investigated at Airport Cove, near Churchill. At the latter site a few weeks later, an area of dolostone blocks having the appropriate appearance was located and additional specimens of *Lunataspis* were quickly discovered. In the past decade, return visits to that site have allowed the Manitoba Museum to amass a substantial collection.

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The William Lake site in the Williston Basin, and Airport Cove site in the Hudson Bay Basin, are both of latest Katian age. They share several elements: horseshoe crabs, lingulid brachiopods, gastropods, and large problematic tubes. Several other groups are unique to William Lake: jellyfish and other gelatinous zooplankton, pycnogonids, and abundant eurypterids. The assemblage at Airport Cove includes other arthropods, beautiful seaweeds, and scolecodont assemblages.

All collected material is at the Manitoba Museum: about 1500 slabs from William Lake and 400 blocks from Airport Cove. These constitute one of the most important fossil collections at the Manitoba Museum. Ordovician *Lagerstätten* are rare, and Manitoba's deposits have enhanced the understanding of global Ordovician biodiversity. Studies of the collection are ongoing, but it has also contributed to exhibits and public knowledge: several of the fossils served as models for animated creatures in *Ancient Seas*, a digital panorama of marine life.

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