

# Atlantic Geoscience Society

## ABSTRACTS

*39th Annual Colloquium & Annual General Meeting 2013*

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Dartmouth-Halifax, Nova Scotia

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The 2013 Colloquium & Annual General Meeting was held at the Holiday Inn, Dartmouth, Nova Scotia, on February 1 and 2, 2013. On behalf of the society, we thank Colloquium General Chair Bob Ryan, Technical Co-Chairs Elisabeth Kusters and Grant Wach, Nelly Koziel, and the numerous student volunteers for facilitating an excellent meeting. We also wish to acknowledge support of the corporate sponsors: Encana; PotashCorp (New Brunswick); American Association of Petroleum Geologists; Basin & Reservoir Lab, Department of Earth Sciences (Dalhousie University); Erdene Resources Development; Department of Geology (Saint Mary's University); Department of Earth and Environmental Science (Acadia University); Department of Earth Sciences (Dalhousie University); and the Nova Scotia Department of Natural Resources.

In the following pages, we are pleased to publish the abstracts of oral presentations and posters from the Colloquium, which focused on the following themes: New insights in Atlantic Geoscience; Geoheritage; Atlantic Geoscientists in the Arctic; Atlantic Geoscientists Abroad; Petroleum Systems of the Atlantic Margin (a memorial session to honour Al Grant). In addition, a public panel discussion took place on the "Current Regulatory Framework on Unconventional Gas Development in North America". Also included with the conference were workshops on the "Application of Fluid Inclusions to Geology" and "Oil and Gas Exploration Principles in Mature Basins" and a guided tour of the Nova Scotia Gold Exhibit.

**THE EDITORS**

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### The role of geology in the development of the International Appalachian Trail

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The International Appalachian Trail (IAT) was founded on “Earth Day” in the State of Maine in 1994 and currently includes 19 Chapters representing an estimated 12 000 miles of trail along the ancient Appalachian terranes rimming the North Atlantic basin including Maine, Canadian Maritime Provinces, Quebec, Newfoundland and Labrador, Greenland, Iceland, Ireland, British Isles, Scandinavia, Netherlands, France, and Spain. The IAT mission seeks to advance recreation, tourism, education, health and fitness, and support rural economic development.

Throughout human history, the geological foundation of our landscape has determined the location of settlements, trade routes, and human migratory paths, inextricably linking our culture to geology. With advances in communications over the past several decades, an ever-widening international audience has benefited from instantaneous information on geological events and discoveries. Examples include: geologically related disasters such as earthquakes, tsunamis, volcanic eruptions, and landslides; the quest for fossil energy resources and the consequences of their development and use; climate change; significant paleontological discoveries; the quest for fresh water resources; and modern society’s dependence on rare mineral resources. Geological literacy among non-scientists has probably never been greater. From its inception, the founders recognized the geological underpinnings of the IAT and have engaged a cadre of dedicated international earth scientists to help develop the framework of and the advocate for the advancement of this unique recreational, cultural and educational resource.

The development of the IAT continues to be a work in progress as individual Chapters: (1) construct a long-distance walking trail; (2) locate the IAT within areas that have been identified by geologists as having been part of the ancient Appalachian/Caledonian landscape; (3) locate the IAT so that it connects to the bordering Chapters; (4) make available to the public map and trail descriptions of the IAT within its jurisdiction via the IAT web site; and (5) produce educational web site trail guides. The IAT provides an excellent opportunity for earth scientists to participate in this unique recreational/educational project and to engage

the public in a discussion of the geological foundations of modern society.

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### Remote assessment of instantaneous changes in water chemistry after liming in a Nova Scotia catchment

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Southwestern Nova Scotia (SWNS) has some of the most acidic freshwaters in North America due to its location downwind of major emission sources and due to resistant geology with little acid buffering capacity. Because of the poor buffering and regionally high runoff, hydrological events such as snowmelt and rain storms are frequent and can cause sudden changes in water chemistry which can have devastating effects on freshwater biota due to increases in acidity and 13 metals. Here we take advantage of recent advances in equipment to monitor water chemistry in an experimental catchment, and explore the response to catchment liming.

Catchment liming is thought to be the best strategy for mitigating long-term effects of acid deposition in sensitive areas. We limed a segment of the dynamic source zone at a rate of 5 t/ha in a 50 ha catchment in SWNS to examine interactions between application of lime with the geological and climatological conditions of this region. In order to assess changes of episode frequency caused by liming, we established two mobile environmental monitoring platforms in the catchment: a control site located immediately above the limed area, and a treatment site 320 m below the limed area. We monitored pH, DO, water temperature, conductivity, stage height, air temperature, wind speed and direction as well as precipitation every 15 minutes with the data being accessed in real-time. The high frequency measurements were supplemented by chemical analysis of bi-weekly to monthly grab-samples at the site. pH values before treatment were as low as 4.9 and Ca<sup>2+</sup> as low as 0.7 mg•L<sup>-1</sup> demonstrating the need for liming treatment. In this work, we show real-time outputs of pre- and post-treatment stream chemistry and present the short-term effects of liming on this acid sensitive ecosystem.

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**Nalcor Energy: exploration strategy and activity**


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Nalcor Energy Oil and Gas Inc., the crown corporation of the province of Newfoundland and Labrador, was created in 2007 and holds equity stakes in the Hibernia Southern Extension and White Rose Growth Lands offshore oil field developments and in the Hebron Project. The exploration strategy is to improve our understanding of the petroleum systems of the frontier areas to lower exploration risk in these under explored basins. The goal is to enhance exploration activity and to attract new companies to the region.

Nalcor has partnered with oil and gas service providers for regional studies of oil seeps, seabed cores, gravity and magnetics and plate reconstruction. In 2010, Nalcor invested and partnered in a large scale TGS-PGS regional spec seismic survey off Labrador. This survey consisted of 22 000 km of long-offset, broadband GeoStreamer 2D data that extended into the deep water well beyond the slope. Over 70% of the survey area had never been imaged by any seismic data before. In 2011, a further 20 000 km was approved to cover the Orphan Basin, Flemish Pass Basin and areas off the Flemish Cap and Carson Basin. The new data from these studies are transforming our understanding of the frontier regions with new basins and plays emerging from the datasets.

Nalcor will continue to improve our knowledge of our petroleum systems in 2013 with new geopressure and rock physics studies, interpretation and analyses of the new data, and integration and review of existing data, Nalcor will also continue research and development with partners at Memorial University and Dalhousie University and with overseas partners in NAPSA and GEUS. The petroleum resource potential of the frontier regions of Atlantic Canada are looking ever brighter as Nalcor sheds new insight on the petroleum systems with investments and participation in data acquisitions, geoscience studies, and R&D collaboration.

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**Carboniferous volcanic and sedimentary rocks of the Lorneville Group, southern New Brunswick**


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Interbedded volcanic and sedimentary rocks located south of and in faulted contact with Proterozoic and Cambrian rocks in the vicinity of the city of Saint John are termed the Lorneville Group and subdivided into the Taylors Island Formation (West Saint John, Taylors Island, and Lorneville areas) and West Beach Formation (east Saint John, Red Head area, West Beach area, and outliers to the east along the Bay of Fundy coast). Although traditionally termed the Mispék (or Mispék) Series (or Group) and assumed to be Carboniferous, the lack of direct age constraints and uncertain stratigraphic relations led to a wide age range assignment (Neoproterozoic to Carboniferous) on recent maps. A sample from thin rhyolite layers interbedded with basaltic flows at Sheldon Point in West Saint John yielded a U-Pb (zircon) age of 358.9 ± 5.8/-5.2 Ma, and confirms that at least the Taylors Island Formation is Late Devonian-Early Carboniferous. Petrological similarities indicate that all of the basaltic rocks of the Taylors Island and West Beach formations are of similar age and formed in a continental within-plate tectonic setting. In the Lorneville/Coleson Cove area, basalt and sedimentary rocks of the Taylors Island Formation are increasingly deformed and mylonitic to the south, and tectonically interlayered with variably mylonitic granitoid rocks, including aegirine-bearing alkali-feldspar granite with A-type chemical affinity and a Carboniferous U-Pb (zircon) age of 346.4 ± 0.7 Ma. Also present in the area are variably mylonitized and tectonically interlayered metasedimentary rocks and leucotonalite of uncertain age. The latter rocks can be traced through Partridge Island to the Red Head area where together with the West Beach Formation, they occupy a thrust sheet above red conglomerate-sandstone-mudstone of the mid-Carboniferous Balls Lake Formation. Deformation was likely a result of dextral transpression along the Cobequid-Chedabucto Fault Zone during accretion of the Meguma terrane.

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### Seabed geological and geohazard investigations, Canadian Beaufort Sea outer shelf and upper slope

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In 2009, hydrocarbon exploration in the Canadian Beaufort Sea shifted from the inner to outer shelf and upper slope. A collaborative project among the Geological Survey of Canada, ArcticNet and the oil industry was initiated to investigate seabed geohazards in water depths of 70 to 1200 m. The CCGS Amundsen icebreaker, outfitted with hull mounted multibeam and subbottom profilers and box, gravity and piston coring capability, served as the survey platform. GSC research focused on establishing a regional geohazard framework and identifying potential seabed instability conditions that could adversely affect exploration drilling activities using dynamically positioned and/or anchored drilling structures.

Late Wisconsinan glaciogenic deposits consisting of subaqueous outwash overlain by glaciomarine sediments thicken down slope to over 100 m. A thin Holocene veneer of recent mud less than 2 m thick overlies the older deposits. Within these sediments several instability conditions and features have been identified. These include seabed scouring by ice keels, submarine slides, mass transport channels and fans, low strength sediments, subsea permafrost, active mud volcanoes, pockmarks, shallow gas and faults. Continuing research is focused on mapping the spatial distribution of observed geohazards and determining the temporal frequencies of active vs. relict instability features.

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### A preliminary fluid inclusion study of interstitial quartz from pegmatitic gabbro in the East Bull Lake Intrusion, Ontario, Canada

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The East Bull Lake intrusion (EBLI) is a Paleoproterozoic mafic-ultramafic (low-Ti, high-Al tholeiitic) intrusion located roughly 90 km west of Sudbury, Ontario. The intrusion itself consists primarily of massive and layered gabbro and gabbro-norite and is interpreted to be the product of crystallization of partial melts from sublithospheric depleted mantle, a remnant of a ~2.48 Ga large igneous/metallogenic province. The intrusion hosts disseminated-blebby PGE-Cu-Ni sulfide mineralization (0.5–2.5 ppm Pt + Pd + Au; up to ~10s of ppm locally in massive sulphide pods) primarily in its lower zones that are heavily contaminated by

country rock fragments.

Fluid inclusion assemblages (FIAs; groups of coevally trapped inclusions) representing late-stage magmatic-hydrothermal fluids were characterized by microthermometry using patches of interstitial quartz in a mineralized pegmatitic gabbro. The FIAs contain three-phase liquid-rich inclusions with halite daughter phases. Final homogenization in all measured inclusions occurred by halite dissolution at temperatures significantly higher than vapour bubble disappearance.

These preliminary measurements illustrate that suitable FIAs (i.e., not influenced by post-entrapment modification) show minimum trapping pressures from 2.1–3.0 kbars, with final homogenization temperatures ranging from 291 to 367° C, corresponding to bulk salinities of 37.5–44 wt% NaCl equivalent. For comparison, Ti-in-quartz thermometry for fluid inclusion-rich domains in the quartz indicate crystallization and inclusion entrapment between 650° C–750° C. The data suggest that if the inclusions are primary then actual trapping pressures are significantly higher than the minimum values estimated above. The study provides first constraints on the nature of late-stage fluids associated with the EBLI.

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### Fluid and melt inclusions as recorders of the earth's dy- namic history

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Fluid and melt inclusions represent microscopic samples of fluids trapped in minerals either during or after their formation. Using analytical techniques that have been developed and improved during the past few decades, it is now possible to determine both the temperature of formation and the composition of the fluids in these inclusions. In addition, the pressures (or depths) of formation can be estimated by interpreting these results within the framework of PVTX data for the appropriate fluid system. In recent years, major advances in our understanding of processes associated with hydrocarbon generation and migration, mineral deposit formation, evolution of magmatic systems, deep crustal processes and the important role of fluids in subduction zones and in the upper mantle have resulted from studies of fluid and melt inclusions. From a practical point of view, these results can be applied effectively in exploration for mineral and energy resources.

Perhaps the most significant advance in our understanding of ore-forming processes during the past half-century has come from studies to determine the metals content of the ore-forming fluids and how the concentrations evolve during mineralization. These data, integrated with microthermometric and paragenetic information, allow us

to constrain, in many cases, the depositional mechanisms. For example, detailed studies of porphyry copper deposits show clear trends in copper contents with temperature that suggest temperature decrease is the dominant depositional process in these deposits, an interpretation that is supported by both stable isotope and alteration data. As another example, detailed fluid inclusion studies of epithermal precious metals deposits have documented a clear genetic relationship between gold and/or silver deposition and boiling of the hydrothermal fluids in many (but not all) deposits. As such, fluid inclusions provide an effective means to explore for and vector towards hydrothermal systems that have the capability of producing economic mineralization.

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**Integrated structural and petrological observations constraining the Paleoproterozoic polymetamorphic evolution of the Newton Fiord region Hall Peninsula, Baffin Island, Nunavut**

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The Canada-Nunavut Geoscience office completed the first of two field seasons of a regional bedrock and surficial mapping project on Hall Peninsula, eastern Baffin Island, during the summer of 2012. Hall Peninsula is situated within the core of the Himalayan-scale Paleoproterozoic Trans-Hudson Orogen. The Newton Fiord study area on the southwestern coast of Hall Peninsula comprises two regions of contrasting styles of deformation within close proximity (ca. 4 km<sup>2</sup>). The eastern study area lies on the limb of a regional F<sub>2</sub> fold and the western study area lies in the hinge zone of the regional F<sub>2</sub> fold; both consist generally of metasedimentary rocks, primarily pelite, intruded by orthopyroxene monzogranite and late garnet leucogranite.

Linked field observations and microtectonic analysis have revealed two main tectonometamorphic events each of which can be further characterized based on relative chronology of mineral growth and fabric formation. The first event, D<sub>1</sub>/M<sub>1</sub>, is characterized by weakly to strongly aligned fine- to medium-grained sillimanite (M<sub>1a</sub>) only preserved as inclusion trails in garnet and cordierite porphyroblasts, followed by voluminous garnet-cordierite-bearing leucosome formation (M<sub>1b</sub>). Field evidence for D<sub>1</sub> fabric elements is subtle but convincing where S<sub>1</sub> is recorded in the orthopyroxene monzogranite but is cut by the garnet

leucogranite. Within the pelitic rocks, the M<sub>1a</sub> assemblage is preserved in garnet porphyroblasts and consists of garnet + sillimanite + K-feldspar + spinel + ilmenite + quartz ± rutile, whereas the M<sub>1b</sub> melt assemblage is plagioclase + cordierite + K-feldspar + quartz ± sillimanite, ± garnet; both represent equilibration above the biotite dehydration melting reaction. The second event, D<sub>2</sub>/M<sub>2</sub>, consists of moderately to shallowly west-dipping gneissosity (S<sub>2a</sub>) defined by interlayered leucosome and sillimanite-biotite mesosome in the pelites. Progressive D<sub>2</sub> deformation resulted in moderately west-inclined F<sub>2b</sub> folds associated with a strong hinge-parallel lineation defined by biotite and very coarse matrix sillimanite (L<sub>2b</sub>). The M<sub>2</sub> mineral assemblage associated with both phases of D<sub>2</sub> deformation consists of garnet + sillimanite + biotite + ilmenite + K-feldspar + plagioclase + quartz ± melt, indicating equilibration below the biotite dehydration melting reaction and the addition of H<sub>2</sub>O most likely from the breakdown of cordierite and crystallization of melt.

These data suggest a relative chronology of events beginning with the development of a weak S<sub>1</sub> foliation at granulite facies, likely synchronous with orthopyroxene monzogranite emplacement, which led to voluminous partial melting and emplacement of the garnet leucogranite. Progressive D<sub>2</sub> deformation at upper amphibolite to lower granulite facies evolved from the development of a strong flattening fabric into regional-scale, east-vergent folding and eventual shearing of F<sub>2</sub> fold limbs.

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**Pliocene landscape and environmental evolution in the Canadian Arctic: when was the Beaufort Formation incised?**

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It has been hypothesized that the Pliocene Beaufort Formation once formed a contiguous 1200 km-long coastal plain along what is now the western Canadian Arctic Archipelago. Today, the deposit is broken by inter-island straits and fiords. The timing and causes of the deposition and incision of the Beaufort Formation are potential clues to the changes that occurred leading up to the Late Pliocene “climate crash”. The climate crash was preceded by an anomalously warm excursion where global temperatures were similar to the warming that is predicted for the 21st century. Cosmogenic nuclide burial dating will be used to test whether a global sea-level fall, local tectonics, or local ice sheets were responsible for the dramatic incision of the Beaufort Formation (a sea-level fall would result in synchronous incisions, whereas tectonics or ice sheets would cause diachronous incisions). These landscape evolution hypotheses need to be tested before we can begin

to understand the impact of climate change on the Arctic.

Furthermore, the Beaufort Formation is laden with well-preserved peat, wood, and vertebrate fossils (e.g., beaver and camel) which indicate a high Arctic boreal forest ecosystem. However, because the records are poorly dated, it is impossible to distinguish if temporal (e.g., climatic) or spatial (e.g., latitudinal, sea ice distribution) variations are the cause for differences in estimated mean temperatures and seasonality from various deposits. New cosmogenic nuclide burial dating of sands that bracket previously studied peat will improve our ability to correlate the isolated paleoclimate records on different islands and test other hypotheses regarding the feedbacks and links of the paleoenvironmental changes to global and regional paleoclimate, sea ice, and paleoceanographic changes. Additionally, the new geochronology will provide a means to estimate rates of incision and sediment flux to the Beaufort Shelf at particular times.

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**First reported occurrence of *Cochlichnus anguineus*  
Hitchcock traces in sediment at Fredericton,  
New Brunswick**

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Nematode traces identified as *Cochlichnus anguineus* Hitchcock were found in samples from a 42.67 m (140 ft) borehole drilled by the Canadian Water Network at Fredericton New Brunswick (06, 2003). During drilling, A. Daigle collected samples from the cohesive units using 75 mm- and 50 mm-diameter Shelby tubes. The sampling process enabled recovery of a continuous core through a laminated clay-silt unit investigated for engineering, geochemical, and lithological properties. Traces of *Cochlichnus anguineus* nematodes were found along silt partings at depths of 21.20, 18.14, and 12.78 m. Traces occurred within an estuarine unit extending from approximately 24–6 m below surface at 10 m asml. Vertical fluctuations within the unit indicate deposition under glacial marine influences, changing to brackish water conditions during pulses of fresh water associated with high-silt and low chloride concentrations.

This first reported occurrence of nematodes in Late Wisconsinan sediments in New Brunswick and high chloride occurrences suggests that during deposition here, the Saint John River valley was open to the sea. The upper part of this unit is exposed at some locations along the river valley and has been interpreted as deposition in Lake Acadia, an arm of the late glacial DeGeer Sea.

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**The petrogenesis of REE-enriched granite dykes in the  
northeastern Cobequid Highlands, Nova Scotia**

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Granitoid rocks enriched in incompatible elements have been the focus of ongoing exploration for rare earth elements (REEs). High concentrations of REEs were discovered in 2010 at the contact zone between two Late Devonian to Early Carboniferous felsic igneous units in the Debert Lake area, northeastern Cobequid Highlands, Nova Scotia. REE concentrations range from 100–2000 ppm within the REE-mineralized occurrences. The main rock types present in the Debert Lake area include granitic rocks of the Hart Lake-Byers Lake pluton, felsic volcanic and volcanoclastic rocks of the Byers Brook Formation, and late diorite bodies and diabase dykes. REE mineralization is associated with a coarse-grained and pegmatitic arfvedsonite-bearing granitoid that is elevated in incompatible elements compared to the rest of the Hart Lake-Byers Lake pluton. REE mineralization occurs in late granitic dykes that cross cut all other rock types in the area and range from 1–50 cm wide. Less common are 1–25 cm wide segregated pods within the arfvedsonite-bearing granitoid. In order to study the relationship between the Hart Lake-Byers Lake pluton, the REE-enriched granitoids and the REE-mineralized dykes and pods, 22 samples were selected for petrographic study of differences in mineralogy and texture. Appropriate samples are being analyzed using an electron microprobe (EMP) for geochemical trends recorded by amphibole. U-Pb zircon age dating will be conducted to determine the timing of emplacement of the HFSE-REE-enriched dykes compared to the Hart Lake-Byers Lake pluton. Petrographic studies show a change in amphibole composition based on color of pleochroism between each granitoid phase. Amphiboles within the incompatible-enriched granitoids consistently show dark-blue or black to greenish-brown pleochroism, indicative of arfvedsonite, compared to green to yellow pleochroism in the Hart Lake-Byers Lake granite. This evidence is consistent with EMP results on amphiboles which show higher sodium and iron content within the REE-enriched granitoids compared to the Hart Lake-Byers Lake pluton.

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**Potential for lacustrine source rocks in Middle Triassic-  
Early Jurassic synrift basins offshore eastern  
North America**

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Recent discoveries of super-giant pre-salt oil fields in Brazil's offshore basins, and related discoveries in its African conjugates, have highlighted the great importance of synrift / pre-breakup fluvial-lacustrine successions to the success and efficiency of their petroleum systems. Improvements in seismic acquisition and processing technologies were keys in imaging the architecture of the underlying rift basins, and interpreting the basin fill and internal depositional facies later confirmed by drilling.

Middle Triassic to Early Jurassic synrift basins are exposed onshore eastern North America (Newark Supergroup) and extend into adjacent offshore areas, with equivalent basins in Portugal and Morocco northwest Africa. Organic-rich lacustrine successions occur in a number of the onshore USA synrift basins, although no commercial discoveries have been made. The basin-fill model for sedimentary successions in these extensional basins defines four tectonostratigraphic (TS) units: TS I: Unconformity-bounded, fluvial-lacustrine sequence (Late Permian); TS II: Fluvial (and some lacustrine) strata (underfilled, hydrologically open basin); TS-III: Lacustrine sequence (closed basin or one in hydrological equilibrium); and TS IV: Playa / lacustrine (and basal CAMP volcanic rocks) successions.

Seismic profiles in the Fundy/Chignecto (Canada) and Newark (USA) basins reveal high amplitude, laterally continuous reflections adjacent to the boarder faults. They are distal to Middle to Late Triassic TS-II fluvial successions and interpreted to represent deep water lacustrine facies. This architecture infers high levels of tectonically driven extension resulting in the basins being closed from their inception facilitating lake formation. During TS-II deposition (late Anisian to early Carnian), paleomagnetic data places these basins within a north equatorial, tropical humid belt. They are thus in a position favourable for the evolution of lakes with conditions favourable for organic matter creation and preservation. If correct, this interpretation would have a significant impact on the potential for hydrocarbons sourced from lacustrine successions in pre-salt synrift basins offshore Nova Scotia and Morocco.

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**The public's knowledge of earth sciences**

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Formal education can lay important learning foundations but lifelong learning involves a commitment of adults to take advantage of informal learning environments such as geoparks that offer programmes, exhibits, and more. This project examined trends in geological knowledge and specifically compared knowledge of university students and Stonehammer geopark visitors who learned through formal and informal educational opportunities. We developed the 28 question Earth Science Literacy Survey (ESLS) to measure knowledge of concepts central to the nine Big Ideas (BI) outlined by the Earth Science Literacy Initiative, (BI-1 - Earth scientists use repeatable observations and testable ideas to understand and explain our planet; BI-2 - Earth is 4.6 billion years old; BI-3 - Earth is a complex system of interacting rock, water, air, and life; BI-4 - Earth is continuously changing; BI-5 - Earth is the water planet; BI-6 - Life evolves on a dynamic Earth and continuously modifies Earth; BI-7 - Humans depend on Earth for resources; BI-8 - Natural hazards pose risks to humans; and, BI-9 - Humans significantly alter the Earth). Overall, participants (N = 343) who had taken a geology course had higher ESLS scores (Mean YES = 87.4% vs. Mean NO = 84.16%;  $p = 0.013$ ) due to their significantly higher scores on Big Ideas 6 ( $p = 0.015$ ), 8 ( $p = 0.006$ ), and 9 ( $p = 0.039$ ). We also compared the ESLS scores of people with an interest in geology with those who were not interested. Overall, those who were interested in geology had higher ESLS scores than those with no interest (87.16% vs. 83.16%;  $p = 0.001$ ). In this comparison, there were statistically significant differences on Big Ideas 1 ( $p = 0.023$ ), 4 ( $p = 0.005$ ), 7 ( $p = 0.006$ ), 8 ( $p = 0.014$ ), and 9 ( $p = 0.014$ ). Thus, it appears that both formal (had a course) and informal (had an interest) educational opportunities increase awareness of topics central to earth science literacy.

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**Microbially induced sedimentary structures in the Car-  
boniferous Horton Bluff Formation near Hantsport,  
Nova Scotia**

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The Blue Beach Member of the Horton Bluff Formation comprises cyclic tidal deposits of early Mississippian age. Near Hantsport, microbially induced sedimentary structures, formed by the growth of cyanobacterial mats, are unusually well preserved on the bedding surfaces of tidal-flat

sandstones. The structures match those documented from modern sediments at Mellum Island, North Sea, and Archean strata at Barberton, South Africa. The sandstones display wrinkle structures, leveled surfaces and multidirectional ripple marks, in association with wave ripples, planed-off ripples, and desiccation cracks that imply shallow-water and periodically exposed conditions. A single, well exposed surface was mapped in one-metre segments with estimates of the areal percentage of microbial features, descriptions of the main types present, and photographs. The outcrop is ~70 m long and 1 m wide, selected for its high quality and quantity of microbial features. Microbial structures cover ~10% of the surface, with a maximum value per meter of 70% coverage and a minimum of zero. Within small patches < 25 cm<sup>2</sup> in area, wrinkles are sub-parallel or lack preferred orientation, and have 1 mm height and 1–2 mm spacing – much smaller than associated ripple marks. The wrinkled patches occur mostly on ripple crests, especially on flattened, planed-off areas, and are commonly associated with coarse, probably windblown, sand. Some wrinkled patches cover sediment that fills ripple troughs, where mat growth has contributed to levelling of the sediment surface. Examples of multi-directional ripples are present, formed where mats stabilized part of a rippled surface against reworking, allowing a different ripple orientation to be overprinted on unstabilized areas. A bed of domal stromatolites 1 km down the coast has a 15 × 10 cm microbial patch in the same bedset. Similar microbial features are present on many other bedding surfaces, and microbial effects were pervasive during deposition.

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### **Influence of hydrostratigraphy on erosion of drumlin islands in Mahone Bay, Nova Scotia**

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The processes that influence the erosion of drowned drumlins in coastal Atlantic Canada are not particularly well understood. Consequently, management strategies and engineering practices focussed on limiting erosion have had limited success and in some cases have resulted in shoreline modifications that have significant ecological and social impacts. This study focuses on determining the relative importance of the hydrostratigraphic, geomorphological and physical parameters that contribute to headward erosion of seven drowned drumlin islands in Mahone Bay, southwestern Nova Scotia.

The islands studied are palimpsest drumlins formed during Wisconsinan ice advance from 30 ky to 17 ky BP.

Sea level rise following deglaciation and recent and gradual subsidence associated with foreland bulge migration has exposed these islands to marine influence. A historical airphoto survey established long term erosion rates of > 0.46 m/yr. A suite of marine physical parameters (bathymetry, fetch, swell) were studied to constrain energy transfer processes. Site investigation involved documenting the sedimentology and stratigraphy of eroding surfaces as well as the hydrological conditions (water table elevation, permeability) that might contribute to headland instability.

The palimpsest stratigraphy coupled with variable till lithology and permeability contribute to the development of a complex suite of conditions (glide planes, loading) that contribute to failure of exposed surfaces. Exposures of heterogeneous lodgement till that are overlain by coarse grained, permeable ablation till are particularly prone to mass wasting. Rotational and translational failure occurs in response to oversteepening and loading associated with an elevated water table. If the exposed basal till is underconsolidated, erosion is expedited. This research demonstrates that an assessment of vulnerability to external (marine) conditions coupled with an understanding of the mass wasting processes active at each site is required to develop effective erosion management strategies for these islands.

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### **Recognition of geoheritage: a vital bridge between geoscientists and the public**

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The formal recognition of geoheritage, while superficially a ‘feel good’ project, and practically a path to geotourism opportunities, is much, much more. It is the path by which we can bridge the deep chasm that separates the knowledge possessed by geoscientists from the more than 6 billion non-geoscientists on Earth. The spectrum of geoheritage recognition ranges from modest to ambitious, but to reach its full potential, it must be formalized. In Canada, although protection is afforded some geological sites (mostly paleontological), Quebec is the only jurisdiction to have formally recognized geoheritage in its legislation. From Newfoundland to the Northwest Territories, the very use of the term ‘geoheritage’ seems to have the effect of having people reflect on an important message: that we share a common history on Earth, and perhaps most importantly, that we also face a shared and uncertain future that presents humanity with very real challenges. A simple rubric for recognizing geoheritage is being tested in Nova Scotia with the goal of being universally applicable in any jurisdiction or region. The rubric being used can be readily implemented by drawing on the knowledge of regional geoscientists, and

contrasts with onerous systems such as that attempted in Ireland, which have stalled under their own inertia. The list and its logic will be critically evaluated in an open session at the Atlantic Geoscience Society Colloquium.

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### Preliminary assessment of marine geological hazards in Baffin Bay, eastern Canadian Arctic

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Resource assessments of the Baffin Bay region suggest hydrocarbon resource potential similar to or greater than the Beaufort-Mackenzie and Jeanne d'Arc basins. Although currently no exploration plans are proposed for the Canadian portion of the bay, industry interest will likely put pressure on regulators to open this area. Before determining if exploration will proceed, scientific understanding of geological hazards is essential. Recently, the Geological Survey of Canada initiated a study of marine geological hazards in Baffin Bay with the goals of providing a predictive framework for the geological and engineering properties of the seabed, and determining the regional distribution and severity of seabed hazards. This presentation provides some preliminary results from this research.

The most significant hazards in Baffin Bay are seismicity, seabed instability, iceberg scour, and natural fluid (including hydrocarbon) seeps. One of the largest passive margin earthquakes ever recorded occurred in Baffin Bay in 1933 (M 7.3). Sparse data collected in 2008 showed no evidence for slope failure near the 1933 epicentre, but legacy data shows widespread sediment failure on the Baffin Slope. Studies from the late 1980s also identified a large scale bank-edge slip related to deeply penetrating faults. Re-assessment of legacy data has revealed that this instability zone is much more extensive than originally reported, continuing more than 800 km from the slope off Home Bay in the south to the slope off Scott Inlet in the north. Natural hydrocarbon seeps with widespread surface slicks occur along the northern Baffin Shelf. The seeps represent natural hydrocarbon contamination of the environment, but it is not known whether they are episodic or continuous phenomena. As yet, repetitive multibeam bathymetry surveys are insufficient to assess rates of modern iceberg scour on the shelf. It is clear that there are significant knowledge gaps about geological hazards in the area.

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### Fish skeletal assemblages from the famous Joggins Fossil Cliffs of Nova Scotia: systematics, paleoecology and paleoenvironments

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The Joggins Fossil Cliffs, Nova Scotia, Canada, are widely recognised as one of the world's finest Pennsylvanian exposures, and have held UNESCO World Heritage Site status since 2008. The 915.5 m-thick Joggins Formation spans the Langsettian Stage (approx. 313.5–314.4 Ma) and is one of five formations represented in the Cliffs; it contains a very rich fossil assemblage which has proven pivotal for the reconstruction of Pennsylvanian 'coal-age' ecosystems.

Fragmentary fish remains are extremely common at Joggins, but have largely gone unstudied for the last 150 years. A large collection amassed by the Joggins Fossil Institute is currently under investigation; existing collections housed at the Redpath Museum (Montreal) and the Yale Peabody Museum (New Haven, Connecticut) have also been examined. An updated taxonomic list for the formation is presented, accompanied by a discussion of its paleoenvironmental and paleoecological implications, and comments on the taxonomic and nomenclatural confusion that has surrounded (and, in some cases, continues to surround) some of these groups.

Preliminary results suggest that several genera supposedly endemic to Joggins are, in fact, synonymous with other, more cosmopolitan taxa. This is consistent with other considerations indicating a closer association of the site with the paleo-shoreline than previously assumed.

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**Stratigraphy and salt tectonics of Mississippian–Pennsylvanian strata of the northern Cumberland Basin, Maringouin Peninsula, southeastern New Brunswick**

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On the Maringouin Peninsula of southeastern New Brunswick, detailed field work has confirmed a succession of upper Mississippian strata comprising salt and carbonate (Pugwash Mines and Lime-kiln Brook formations), and redbeds (Maringouin, Shepody, and Enragé formations), paraconformably–disconformably overlain by lower Pennsylvanian clastics (Boss Point Formation) that collectively have been tightly folded and faulted by diapirism of Mississippian salt. To the north, these strata are overlain with angular unconformity by very gently dipping redbeds of the Grande Anse Formation. A recently revised palynostratigraphy from the nearby Joggins section assigns Boss Point Formation strata to the *R saetosa* zone (Yeadonian–Langsettian, ~320–319 Ma); the Grande Anse Formation best fits the *R fulva* zone (Langsettian, ~319–318 Ma). This suggests very rapid salt expulsion and deformation that may have been completed by the time of deposition, south of the diapir, of the uppermost Joggins Formation to basal Ragged Reef Formation.

Structurally, the Boss Point Formation succession is characterised by shallowly east-plunging to subhorizontal, open, locally kink-like, north-verging folds. Sporadic faults indicate two generations of fault propagation. Early, steep to subvertical, strike-slip faults are commonly developed as conjugate pairs of E-W-striking dextral faults and N-S-striking sinistral faults. The dextral faults are commonly bedding sub-parallel, have narrow (< 10 cm) damage zones, and occur at the interface between mudstone and coarser-grained sandstone and conglomerate. Later, moderately north- and south-dipping reverse faults and subvertical, E-W-striking normal faults are associated with north-verging, tight to rarely isoclinal fault-bend folds in Pugwash Mines Formation gypsum and are thus related to diapirism. Proximal to the unconformity, joints appear to be radial about an open fold axis. Disturbance of the Grande Anse Formation and the unconformity itself appears to be minimal. This suggests that some strike-slip faults, such as the Harvey-Hopewell and Shepody faults, may run beneath outcrop of the Grande Anse Formation and were not substantially active following halokinesis.

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**Long-term landscape evolution of Hall Peninsula, Baffin Island, Nunavut: insights from low-temperature (U-Th)/He thermochronology**

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The northern coast of Hall Peninsula, Baffin Island, comprises a portion of the eastern Canadian Arctic Rim, an extensive physiographic feature with high relief spanning from southeastern Ellesmere Island to northern Labrador. Much of the high relief (> 1000 m) on Hall Peninsula has been attributed to incision during rift-flank uplift associated with Baffin Island separating from Greenland; however, the mechanisms for maintaining this high relief are poorly understood. In the nearby Torngat Mountains to the south, geophysical and thermochronologic data indicate the presence of a crustal root that induced rapid rift flank uplift. Conversely, thermochronologic data from Cumberland Peninsula to the north does not support the presence of a crustal root, suggesting other mechanisms responsible for the generation of its high relief.

In the summer of 2012, 50 low-temperature thermochronology (e.g., apatite and zircon (U-Th)/He) samples were collected along three strategically positioned transects to determine the regional cooling history of the rocks on Hall Peninsula. Spatial distributions of the cooling ages of samples from two horizontal transects, one oriented parallel and one perpendicular to the Baffin rift-margin, will provide insight to the role (if any) of pre-existing drainage systems in the development of the high relief on eastern Hall Peninsula. Data from a vertical transect will be used to determine the rate of exhumation, if it varied with time, and the total amount of rock exhumed. Furthermore, the results from this study will link together previous thermochronologic studies on Cumberland Peninsula, North-Central Baffin, and Torngat Mountains by testing for thermochronologic evidence of a crustal root below Hall Peninsula, and serve to enhance our understanding of the geomorphic evolution of eastern Canada. Cenozoic sediment fluxes to Baffin Bay and an exhumation history derived from a 3D thermokinematic model (Pecube) will benefit ongoing efforts to evaluate petroleum potential in the region.

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**Linking watershed rainfall and storm surge models to better predict flooding in coastal communities: an example from River Phillip and Oxford, Nova Scotia**

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Traditional flood modelling has focused on either fluvial runoff scenarios or storm surge scenarios. It is often the case that significant weather events result in both storm surge and high rain fall simultaneously. The traditional approaches to flood modelling fail to capture the interactive nature of these events. Flood events due to high rain fall are exacerbated by higher tides, which in effect of restrict the outward flow of the flooding river system. Our study aimed to develop an integrated system for amalgamating land and sea borne high water in order to (i) reproduce real world flood conditions for a given storm events and (ii) project future storm scenarios.

To satisfy the study objectives, flood models were developed and integrated using the MIKE software suite developed by DHI for Oxford, Nova Scotia. The town of Oxford is known to be prone to flooding in response to heavy rainfall and is linked to the Northumberland Strait by the River Phillip. The fluvial response to heavy rainfall was simulated using a rainfall dependent inflow and infiltration model linked to a one-dimensional hydrodynamics model. The marine response to tidal surge was simulated using a two-dimension hydrodynamic model. Model results demonstrated realistic flood extents in response to a historical rainfall event in September of 1999. Flood extents were found to increase when an artificial tidal surge was applied during the same event. The results yield important information on flow bottlenecks, and the timing and severity of flooding in response to rainfall and tidal events.

With current sea level rise at an observable rate of 29 cm per century for the region, it is important that aggravating factors related to estuarine flooding, such as precipitation, be accounted for in the modelling process so future planning practices do not underestimate flood impacts.

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**Linking Mesozoic and Cenozoic tectonic and stratigraphic events in the Orphan Basin, offshore Newfoundland, Canada**

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The formation of Orphan Basin is tied to rifting east of Newfoundland and development of the North Atlantic Ocean from the Triassic to Early Cretaceous. Renewed interest in this frontier basin has stemmed from a petroleum discovery in the adjacent Flemish Pass Basin. Our multidisciplinary approach to understanding the development of Orphan Basin builds on previous detailed seismic studies by incorporating data from well logs, core, cuttings, biostratigraphy, seismic and subsidence history. This approach has resulted in the identification of 7 significant tectonostratigraphic events that define Orphan Basin formation and associated stratigraphic responses to these events, which we describe here. (1) Initial rifting began with shallow marine deposition during the Middle to Late Jurassic or perhaps earlier, followed by deformation. (2) During the Tithonian and Early Cretaceous, rifting propagated westward, and thick deposits accumulated against major growth faults. (3) Termination of rifting was succeeded by the development of the Central Orphan High and deformation of Tithonian and Early Cretaceous deposits approximately coinciding with an Aptian sequence boundary. (4) Thinning of continental crust east of Orphan Knoll and possible contemporaneous development of a major flooding surface within the basin took place in the Albian to Cenomanian interval. (5) During the Santonian, another prominent sequence boundary developed around the same time as crustal faulting in northern Orphan Basin and north of the Charlie-Gibbs Fracture Zone (CGFZ). Just north of Orphan Basin and the CGFZ, possible transitional crust developed at this time, while true oceanic crust formed east of Orphan Basin and south of the CGFZ (Chron 34). These events were followed by major subsidence of the Orphan Basin. (6) During the latest Cretaceous to Early Eocene, magmatism was localized in northern Orphan Basin. (7) Finally, during the Tertiary, basin filling and shelf-slope development continued under eustatic sea-level fluctuations.

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### Tectonic significance of a mafic *mélange* in the Pangean suture zone, southwestern Iberia

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Pangea formed in the Late Paleozoic by the closure of the Rheic Ocean, which resulted in the collision between Gondwana and Laurussia and is expressed by the Appalachian and Variscan orogens. The Pangean suture zone is exposed in southwestern Iberia, where the South Portuguese Zone, a fragment of Laurussia, is spatially juxtaposed against para-autochthonous Gondwana. The suture zone is characterized by fault-bounded units of oceanic metasedimentary rocks, *mélange*, and mafic complexes. Despite the tectono-stratigraphic sequence being well known, a number of key units exist, the origin and evolution of which remain poorly understood, including the Peramora *Mélange* and the Pulo do Lobo Schist, which structurally overlies the *mélange* in a regional antiform.

Detailed geologic mapping of the Peramora *mélange* (exposed in southwestern Spain) reveals a complex pattern of imbricated schist and mafic block-in-matrix *mélanges*. Age constraints are provided by two cross-cutting plutons, recently dated at ca. 339 Ma. Geochemical signatures of the Pulo do Lobo schist (PDL) display a range in TiO<sub>2</sub> and Fe<sub>2</sub>O<sub>3</sub> + MgO, and are consistent with derivation from both mafic and continental sources. Detrital zircon analyses of key PDL samples do not display an exotic origin similar to those of other metasedimentary rocks from the suture zone. The mafic block-in-matrix *mélange* displays normal mid-ocean ridge basalt (N-MORB) geochemical signature and a range of zircon ages similar to those observed in the PDL, suggesting a sedimentary component. Taken together these data suggest a complex tectonic history characterized by erosion of a N-MORB source, *mélange* formation, and imbrication during underplating occurring during the final stages of continent-continent collision. These data help deduce the age, origin, evolution, and provenance of the Peramora *Mélange* and Pulo do Lobo schist within the suture zone and contribute to a better understanding the processes involved in the formation of Pangea.

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### Widespread collapse of the southwestern Scotian margin triggered by the ~51 Ma Montagnais marine bolide impact, offshore Nova Scotia

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The ~51 Ma Montagnais impact crater on the outer Scotian Shelf is well known, but the potential effects from the impact event on the slope and rise seaward of the crater have, until now, remained poorly understood. Through detailed seismic stratigraphic correlation and ties to available wells, we define a three-fold seismic stratigraphic subdivision for Upper Cretaceous to Eocene strata on the shelf and slope, calibrated to the most recent biostratigraphic results. Using this framework, we identify a number of depositional and erosional products that are temporally consistent with a late Ypresian impact event (within the limits of seismic and biostratigraphic resolution). We link a series of prominent failure scarps on the outer shelf and upper slope to a single widespread mass transport deposit (MTD) on the lower continental slope, rise and abyssal plain. Failed material amassed in a large debris field referred to here as the 'Montagnais MTD'. It covers an area of ~93 000 km<sup>2</sup> and travelled up to 580 km from the impact site where its distal termination onlaps the New England Seamounts, making it one of the largest known debris avalanches on Earth. We interpret these deposits, and the associated pattern of erosion landward of them, as products of widespread margin collapse caused by a combination of ground shaking and ensuing tsunamis triggered by the Montagnais impact event. This study provides insight into the potential effects of outer-shelf marine impact events immediately down slope from impact sites, and their diminished effects with increasing distance along the margin.

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### Contrasting salt tectonic styles on the western versus central parts of the Scotian Margin, offshore Nova Scotia

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A major Late Triassic to Early Jurassic(?) synrift salt basin underpins much of the Scotian Margin, and formed as Nova Scotia rifted and ultimately broke apart from its Moroccan conjugate. Observed structural styles on the margin were preconditioned in part by the synrift basement fabric (including transfer zones) and development of rift-related accommodation and prominent basement blocks

that controlled the original thickness and distribution of salt. Using available 2D/3D seismic data-sets, this poster highlights two considerably different salt tectonic styles that dominated the western versus central parts of the margin, reflecting significant first-order differences in post-salt deposition and postrift subsidence. Landward to seaward variations in the amount, rate, and symmetry of postrift subsidence were most important along the western Scotian Margin, where most of the primary salt basin is now located in deepwater after subsiding up to 8 km after continental break-up. Increased subsidence seaward of the margin hinge zone tilted the landward parts of the salt basin, generating a region of gravity gliding and raft tectonics above the autochthonous salt layer, with vertical diapirism and sediment downbuilding dominating seaward areas where shortening also took place. In contrast, much of the primary salt basin on the central parts of the margin occupies a more landward position below the present day shelf. Increased Jurassic and Cretaceous sedimentation here expelled salt into two separate but linked salt canopies referred to as the Sable Shelf Canopy and the Sable Slope Canopy. A common detachment surface connects these canopies in multiple locations as thin-skinned extensional systems in landward areas expelled salt seaward into the Sable Slope Canopy. Recognition of four distinct salt expulsion styles (salt-based detachments, counterregional systems, hybrids and salt stocks) allows for a higher order subdivision of the Sable Canopy Complex.

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### **Structural geology of the Meguma Supergroup and White Rock Formation contact in the Cape St. Marys area, southwestern Nova Scotia**

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The contact between the Halifax Group (HG) slate and White Rock Formation (WRF) at Cape St. Marys (CSM) is deformed at greenschist facies, but the exact nature of the contact is disputed. At the CSM “unconformity” cleavage in the HG and WRF are parallel; and bedding in the WRF is parallel to the steeply SE-dipping contact and cleavage. Bedding in the HG slate is more steeply dipping than the contact and displays asymmetric folds with the orientation of thickened short limb and thinned long limb, consistent with topside-up shear (SE, WRF side). The deformed folds are accompanied by intense cleavage with down-dip stretching lineation (quartz fringes on pyrite). With increased distance across strike NW from the contact the zone of intense cleavage is replaced by a narrow interval of open folding bound by another zone of intense cleavage. In all zones of HG, intersection of bedding and cleavage has subhorizontal to moderately steep plunge, suggesting

heterogeneous deformation. Vertical paired burrows in the intensely cleaved HG slate function as paleo-plumblines with respect to bedding. Burrows are now boudined down-dip parallel to the quartz fringe lineation and lie within the cleavage. The burrows lie approximately 10° to bedding indicating a high degree of shear strain associated with the transposed bedding. The HG slate also contains rigid pyrite crystals that disturbed the stress field and flow pattern around them during deformation. Sides of the pyrites normal to the minimum compression are low strain areas within which quartz strain fringes formed in the direction of the instantaneous stretching axis (ISA). The strain fringes are important not only because they produced the macroscopic down-dip lineation but also recorded part of the progressive deformation history of the host-rock and indicate the degree of non-coaxiality of deformation and the finite strain.

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### **Geoheritage as permanent geoscience outreach**

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Geoheritage, in its broadest context, is a continuation of geoscience outreach but on a more permanent basis. By formally establishing geoheritage locations we increase the exposure of the public to rocks, fossils and geological processes, how geoscientists weave a story of past events and the way predictions for the future may be made. Linking cultural and biological information with geological data at a geoheritage site provides a deeper and more integrated understanding of the site. Outreach activities such as talks to various groups and walking tours of geological sites provide hands on insight into earth history but depend on a continuing group of volunteers to lead, animate and narrate. Designated geoheritage sites may offer a systematic source of information, examples and self-guided study without the continuing need of volunteers. Locations available in Nova Scotia such as the Joggins UNESCO World Heritage Site, Arisaig and Taylor Head provincial parks and Peggys Cove offer a wealth of information about geological history, climate change and the methodology of science. Sites for future development need not be on the scale of Joggins or the Stonehammer Geopark in Saint John, NB; these potential sites need to meet the criteria of the, Friends of Canadian Geoheritage, to be on public land and to be safe. The benefits of good geoheritage sites are clear: (1) a feeling of having constructive, quality time during a visit, (2) increased awareness of geological history and the role of geoscientists, (3) integration of biological and cultural heritage with geological information, (4) construction of knowledge, and (5) skills of observation and analysis that are transferable, for some, to other societal questions.

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**Tectonic evolution of mafic dykes in a suture zone, southern Iberia: Implications for the formation of Pangea**

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Southern Iberia records the Late Paleozoic amalgamation of Pangea and exposes today a fragment of Laurussia (South Portuguese Zone), which is spatially juxtaposed with autochthonous Gondwana (Ossa Morena Zone). Fault-bounded oceanic metasedimentary rocks, mélanges, and ophiolite complexes characterize the suture zone and are in turn crosscut by intrusive granitoid rocks and mafic dykes. The generation and emplacement of these mafic dykes and their relationship to the suture zone are undetermined.

Geochemical analyses (major, trace, REE) reveal that the mafic dykes exhibit a MORB signature and have Zr-Y ratios characteristic of within-plate basalts. Rare earth element profiles reflect derivation from a transitional, spinel lherzolite mantle. Uranium-lead geochronology indicate that the dykes were emplaced at ca. 316 Ma, which supports field evidence that the dykes are the youngest unit in the Pulo do Lobo Suture Zone. Samarium-neodymium isotopes indicate that the dykes were derived from juvenile mantle. A comparison of Sm-Nd isotopes of the dykes and other mafic suites from the Pulo do Lobo Suture Zone, Laurussia and Gondwana suggests that the sub-continental lithospheric mantle was replaced beneath Southern Iberia during the Gondwana-Laurussia collision. We propose that during the final stages of the Rheic Ocean's closure, the lithospheric mantle beneath Southern Iberia delaminated, resulting in the upwelling of juvenile asthenosphere and the formation of a new sub-continental lithospheric mantle beneath the Pulo do Lobo Zone. Taken together, these data provide insight into the processes responsible for the emplacement of syn- and post-collisional igneous rocks in suture zones and their association with the complex tectonic processes at work during the waning stages of continent-continent collision.

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**Abenaki carbonate platform to Sable Island delta transition: in search of modern analogues and towards a seismic-and-well-based model for a major depositional facies change - Late Jurassic, Nova Scotia Shelf, Canada**

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Abenaki carbonate understanding has greatly increased through recent publications by Encana-associated geologists on the Deep Panuke gas field and by the web-published Play Fairway Analysis on regional setting of the Abenaki carbonate platform. These workers offered somewhat different versions for Abenaki sequence stratigraphy and facies model(s) despite both using well cuttings and core descriptions done by Leslie Eliuk. Neither dealt in much detail with changes from thick relatively pure Abenaki carbonates to the Sable deltaic depo-centre with minor carbonates. After a brief survey of previous transition interpretations, the results of a search for possible modern analogues are presented. In the modern as in much of the ancient, thick clean carbonates with both reef framebuilders and oolites next to major deltas are absent to very rare. Curiously the pre-Holocene marine transgression seems to have more widespread oolites than the modern! This may be a clue that the sea chemistry, geometries, and settings during the Late Jurassic were peculiar. Finally, based on newly logged wells and cores but unfortunately still not well constrained dating, an interpretation of this perhaps unique transition will be presented. Examples of shallow-water coral reefs less than a meter thick and major vertical depth/facies changes in reef and mound builders over just 10 m in ramp settings comparable to those over 100s of meters in ramp or kilometre thicknesses in rimmed platform settings plus shelf-margin deltas and reefs are part of this mixed-carbonate-siliciclastic story.

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**Lead accumulation in open water wet ecosystems in the Border Marshes region, Nova Scotia – New Brunswick**

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Open water wet ecosystems (OWWE) in the Border Marshes region (BMR) provide productive avian and invertebrate habitat. In the BMR lead (Pb) is a contaminant

of interest due to potential bio-magnification and subsequent uptake by migratory waterfowl in OWWE. This study focuses on the relationships between constructed OWWE, autochthonous productivity and lead accumulation. Eleven sites were selected to represent the spectrum of the OWWE environments in the BMR. Sites variability was determined by measuring salinity (0%–2.83%), pH (6.6–9.1) and specific physical parameters. Variability at each site was defined through weekly determination of water pH, temperature, dissolved oxygen (DO), salinity and total dissolved solids (TDS). Top-of-core and bottom-of-core sediment samples were collected for each site and analyzed for loss on ignition (LOI), carbon-nitrogen ratios (C:N) and elemental concentrations of Pb and other environmental proxies (Ti, Fe, and Mn) using X-ray fluorescence.

Carbon-nitrogen ratios and  $\delta^{13}\text{C}$  data indicates variable productivity (C:N 6.73–17.62) and that the organic sediment in all environments is dominantly autochthonous. Excavated sites had lower lead concentrations (0–14 ppm) in top-of-core sediment samples than non-excavated sites (> 16 ppm). Bottom-of-core sediment samples exhibited highly variable lead concentrations (5–92 ppm) that reflect either natural lead sources (erosion of till) or the lack of an anthropogenic atmospheric source due to the pre-industrial age of the sediment. The variation in surficial sediment lead concentrations is likely due to a combination of factors including variable shoreline erosion, variable autochthonous productivity and, in some cases point source pollution. There was little evidence to indicate that lead sequestration correlates with salinity or pH. Results to date indicate recently excavated sites have higher autochthonous productivity and lower lead in surface sediments than either older excavated sites or natural OWWE.

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### Bedrock incision and relief generation of the western Hangay Dome, Mongolia

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The origin of relief of the Hangay Mountains in west-central Mongolia is problematic because they are situated far from any plate boundary or major active tectonic structure. Straths, former stream bottoms preserved as bedrock terraces, are useful indicators of rock uplift or foreland basin subsidence. By correlating and dating straths of differing heights preserved along valleys in the western Hangay Dome, it is possible to relate them to the tectonic or isostatic processes that contribute to the relief.

Two approaches are being undertaken. The first

approach is to study the pattern of the paleo-longitudinal profiles of selected streams throughout the study region. The inferred paleostream profiles will be compared with the modern incised rivers to examine the history of stream incision. If uplift has occurred in the dome, the strath surfaces will show faster incision rates at the head of the river, so the paleo-longitudinal profiles will converge downstream. After establishing if the dome rocks are uplifting (or if the basin is subsiding), we can interpret the rates of rock uplift and determine if the rates have varied over time. Preliminary results indicate that the paleo-long profiles converge downstream, supporting the rock uplift hypothesis.

The second approach is to determine the age of the exposed straths, to help confirm our correlation of the strath fragments in Approach 1, and to determine any variability in the rates of incision between periods of strath abandonment. Cosmogenic <sup>10</sup>Be and <sup>36</sup>Cl exposure dating of the strath surfaces (bedrock samples were collected in three valleys) will be used to determine the age of strath abandonment. Given the age of river abandonment, and paleo-stream and modern river elevation, we can approximate stream incision rate.

The temporal variability of incision rate will help test the hypothesis that the uplift is related to a mantle avalanche (rates will be initially rapid in that case). Thus, the analysis, will contribute to our understanding of intra-continental plate dynamics.

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### Mineralogical study of uranium-niobium-rich alteration zone at the Lofdal carbonatite-silicate complex, Namibia

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The Lofdal Farm Area, located in northwestern Namibia is host to a middle Neoproterozoic (ca. 750 Ma) rift-related silicate-carbonatite intrusive suite. The complex consists of nepheline syenite and carbonatite plugs, and diatreme breccias, surrounded by a wide area (200 km<sup>2</sup>) of carbonatite and phonolite dyking accompanied by hydrothermal alteration. The core of the complex, referred to as the “Main Intrusion”, outcrops as a large carapace of nepheline syenite (1.5 km<sup>2</sup> exposure area) intruded by a calciocarbonatite (sovite) plug. Airborne radiometric surveys have identified a large uranium anomaly along the western and NE extremities of the Main Intrusion. A grab sampling program over the main U anomaly has identified enrichment averaging U 500 ppm and Nb 5000 ppm (0.5%). Of interest in this study, are the enrichment processes responsible for anomalous concentrations of uranium. These enrichments appear to be related to a late stage metasomatism of the nepheline syenites, by alkaline fluids released from the crystalizing

carbonatite plug, a processes termed fenitization. This study will utilize petrography and electron microprobe analysis to provide mineralogical and textural descriptions of the metasomatized syenites which can be compared with unaltered samples to describe this process. Preliminary results show the presence of a Nb mineral resembling fersmite, which displays strong zonation and in some samples includes late stage rim growth characterized by increased levels of Na and U, likely attributable to fenitization fluids. A more critical examination of the fenitization process will provide clarification on the source(s) of the uranium, mode of transport, and condition changes responsible for causing its precipitation from solution.

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### Reversing the impact of the Houghton Crater, Devon Island, Canada

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The Miocene cooling age of the Houghton Crater, Devon Island, based on <sup>40</sup>Ar/<sup>39</sup>Ar dating of a single impact-ejected gneiss clast with multiple K-bearing phases (23.4 ± 1.0 Ma) and apatite fission track thermochronology (22.4 ± 1.4 Ma) in similarly impact-melted gneiss clasts among the impact breccia was recently revised to 39 ± 2 Ma using a spot-dating <sup>40</sup>Ar/<sup>39</sup>Ar approach on glass within the gneiss. The former age is consistent with Miocene faunal and floral fossil evidence in lake sediments within the crater. The latter more popularly cited age supports an Eocene multiple impact cluster including the Canadian Wanapitei and Mistastin craters. The possibility that the crater was much older than the fossil-bearing sediments previously could not be precluded, although no earlier fossil assemblages have been found. Using thermochronometers with a lower closure temperature (apatite-He 75°C, and zircon-He 150°C), here we report new ages for the timing of the Houghton Crater impact. (U-Th-Sm)/He ages on apatite and zircon from different partially melted granitic gneiss clasts found on the surface of the impact breccia yield mean ages of 21.4 ± 0.9 Ma and 21.2 ± 0.8 Ma. New paleomagnetic stratigraphy of the lake sediments above the breccia-sediment contact to

near the top of the sequence, suggest that the entire sequence has reversed polarity. This, along with XRD analysis of clays that show no evidence of an early marine incursion into the crater (which was initially at or below sea level) supports the interpretation that the fossil-bearing lake sediments were formed soon after impact and refutes the hypothesis that there was a long delay between impact and fossil record. We conclude that the impact age of the crater is 21.3 ± 0.6 Ma (1SE, n = 16), there was no long hiatus between impact and lake, and this is the maximum-limiting age on the rich fossil record, including the recently discovered land-sea missing-link mammal *Puijulla darwinii*.

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### Hydraulic fracturing in Nova Scotia

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Hydraulic fracturing is a technique used to enhance the recovery of oil and gas from conventional and unconventional resource plays. The extraction of unconventional hydrocarbons has only recently become economically feasible due to technological developments in directional drilling and new applications of hydraulic fracturing. Hydraulic fracturing has become a topic of interest in Nova Scotia because of the geological potential of the province. The Horton, Windsor, and Cumberland groups in Nova Scotia have shown promising shale gas and coalbed methane resources. Although the province has potential onshore hydrocarbons, environmental and human health concerns surrounding hydraulic fracturing have caused controversy with the general public and environmental groups in part due to lack of public awareness and education. To address these concerns, in April 2011 the Nova Scotia Department of Energy and Nova Scotia Environment launched a joint review with the intention of identifying possible effects of hydraulic fracturing, industry best practices, and relevant regulations used in other jurisdictions. With proper environmental mitigation measures the development of the onshore hydrocarbon industry in Nova Scotia shows economic potential and a source for domestic energy supply.

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**A fluid inclusion study of volcano-sedimentary - hosted quartz-carbonate-copper sulfide-gold veins at the Mile Brook occurrence, Broad River Group, New Brunswick**

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Outcrops of quartz-carbonate-copper sulphide-gold bearing veins cutting Neoproterozoic Broad River Group (BRG) metavolcanic (felsic lithic tuffs, interbedded felsic/mafic flows) and metasedimentary rocks occur along the Bay of Fundy coast, ~75 km northeast of Saint John, New Brunswick. The mineralized veins at Mile Brook are characterized by chalcocite-bornite infilling vuggy quartz-carbonate with abundant inclusions of electrum and bismuthinite.

Only two-phase liquid-vapour fluid inclusions were observed in the host quartz. The origin of the inclusions cannot be discerned based on petrographic criteria (i.e., not hosted in growth zones, healed fractures). However, microthermometric data were obtained on ~85 inclusions grouped into multiple assemblages (small groups of adjacent inclusions in patches of optically continuous quartz). Homogenization occurs by vapour bubble disappearance between 150-270°C for all assemblages; individual assemblages show relatively narrow ranges (e.g., assemblage 5A, 173–191°C, n = 22). Bulk salinities from final ice melting range from 4 to 13 wt% NaCl eq. (compared to individual assemblages; e.g., assemblage 5B, 7 to 11 wt% NaCl eq.). No correlation between salinity and Th is observed. Stable isotopes (qtz-carb) constrain the crystallization/final equilibration T of the host quartz to between ~250–270°C; if inclusions are primary, then a maximum P trapping = ~1.5 kbar, based on the lowest T assemblages, is estimated. Stable isotope data for the host quartz and carbonate ( $\delta^{18}\text{O} = 13.7\text{--}15.1\text{‰}$ ;  $\delta^{13}\text{C} = -4.4$  to  $-4.6\text{‰}$ ) and estimated fluid from which the quartz precipitated ( $\delta^{18}\text{O} = 6.1\text{‰}$ ) combined with the microthermometric data rule out unmodified, heated seawater and meteoric water as fluid sources, and suggest either a magmatic source, or more likely, formation water modified through fluid-rock interaction with the host metavolcanic rocks. The data share some similarities to other Cu-Au quartz-carbonate vein systems hosted in volcano-sedimentary sequences (e.g., Keewenawan Peninsula and Mamainse Point, Michigan and Ontario; Lisbon Valley, Utah; SW Scottish Highlands).

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**Tectonic synopsis and petroleum geology of the Peekaboo Corner to Sussex area, southeastern New Brunswick – preliminary results from 2012 field mapping**

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In the Sussex to Peekaboo Corner area of southern New Brunswick, the oil- and gas- bearing members of the Lower Carboniferous Albert Formation (Horton Group) have been affected by multiple episodes of tectonism during the Late Devonian to Late Carboniferous, approximately 383 to 320 million years ago. Recent fieldwork and seismic analysis in the study area have revealed that branches or splays from the Ratter Road Fault cross and offset the older, northeast-trending Kennebecasis Fault in the Peekaboo Corner area. The main trunk of the Ratter Road Fault displaced strata in the Sussex area and extends several kilometres farther northward than previously thought. Field and magnetic data suggest that the Penobsquis fault system in the McCully Field region is a major easterly splay of the Ratter Road Fault, which initiates in the Sussex area. New geological maps and cross sections illustrate the original Horton basin-forming faults and potential structural and stratigraphic traps in the study area.

Several new measured stratigraphic sections and new ichnology and paleontological analysis were completed during the 2012 field season. A preliminary observation is that the depositional environment of the Horton Group may have been subjected to periodic exposure to more marine conditions in the study area.

Approximately 1.3 km southeast of the town of Apohaqui, a newly discovered quarry in the Albert Formation reveals dark organic shales which exhibit oil seeps and burn when exposed to flame. In general, there is direct surface evidence of an active hydrocarbon system in the central study area that extends over a distance of 20 km. Work is continuing on organic geochemical analyses, paleontology, seismic interpretation, and geological compilation to produce revised New Brunswick Department of Natural Resources plates and reports.

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### Miocene-Present shortening in the Himalayan Foreland Belt

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The 2500 km-long Himalayan orogen is characterized by continuity of the principal lithotectonic units. However, there is evidence for different convergence rates between the western and eastern parts of the orogen. Present-day precipitation rates and Late Miocene erosion rates indicate an east to west gradient. This study aims to test whether these differences are reflected in the rates of tectonic activity and shortening along the range. To do so we have constructed balanced cross sections for 11 transects across the Siwalik Group.

The Siwalik Group comprises the deformed part of the Neogene foreland basin along the southern orogen margin. The group consists of synorogenic sediments, which date back to ~18.5 Ma and form the youngest and frontal parts of the Himalayan fold-and-thrust belt. Thrust faults in the Sub Himalaya are branches of a major décollement (the Main Himalayan Thrust), which spans the entire Himalaya thrust belt. Several south-verging thrusts define the deformation and shortening in the Siwalik Group: (1) the Main Boundary Thrust (the backstop), (2) the Main Dun Thrusts (duplexes), and (3) the Main Frontal (the toe).

In the last 11 myr, convergence rates of the Indian plate colliding with the Eurasian plate were constant, but varied laterally from ~34 mm/yr in the northwest to ~44 mm/yr in the northeast of India. The Shillong plateau, a basement pop-up structure in front of the eastern Himalaya, is the only active structure in the Himalayan foreland that could accommodate/partition 4–7 mm/yr of this convergence.

By having internally consistent cross sections, the shortening rates obtained will help determine if there are differences in shortening along the Himalaya. By using these internally consistent cross sections, factors that influence shortening may be examined, such as: sedimentation and/or erosion rates, partitioning of convergence, changes in overthrust vs. underthrust rates, and changes in basal friction.

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### Winds of change: a new benchmark in public perception concerning well control

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In the last quarter century we have seen a significant and somewhat onerous shift in public opinion on well blowouts, largely driven by the media. The search for new sources of oil and gas to feed ever-expanding and more competitive global demand must be carried out with an even higher standard of care relative to the prevention of well control events. We have come a long way in applying new technologies to safe drilling practices. However, in the “post-Deepwater Horizon” era, a paradigm shift in training is already underway to ensure there will be no repeat of that type of scenario.

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### Sedimentology and chemostratigraphy of the Mabou Group from drill-core in the Penobscus area, New Brunswick: evidence of Gussow’s unconformity?

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Post-Windsor Group strata from the Penobscus area, Sussex, New Brunswick, consist of Mabou Group sedimentary rocks that are only informally subdivided due to limited outcrop, the absence of significant marker beds, and poor biostratigraphic recovery. Examination of close to 5 km of drill core from the PotashCorp exploration program in the area has identified a variety of sandstone, gravel, and fine-grained facies. Most are brown, greyish-brown or reddish-brown, poor to moderately sorted, moderately compacted, ferruginous or calcareous, and mainly horizontally laminated or cross-stratified. Broadly, sandstone, siltstone and mudstone at the base of the succession gradually coarsen up into conglomerate, and are considered the result of active alluvial fan progradation across a floodplain/playa from the northeast. Also encountered in several of the cores is an interval of localized, horizontally laminated to cross-stratified bluish grey sandstone, containing carbonaceous plant fragments and siltstone intraclasts. The interval can also be recognized in wireline logs, and possibly by a correlative reflector in seismic.

A total of 185 samples from four boreholes have been analyzed using ICP, ICP-MS, and XRD. Chemostratigraphic analysis of elemental ratios (e.g., Al/Mg, Si/Na, Si/Al, Na/K, Ti/Nb, Rb/Cs, etc.) has revealed two packages bounded by an interval that correlates with the grey sandstone beds and rip-up clasts. Changes in the ratios are interpreted

to mark a broader population of mineral species and diagenetic phases in the upper package. This further implies variation in the provenance and substrate environment of the redbed succession either side of a disconformity that is also represented by rip-up clasts produced by sediment reworking along this boundary. Ongoing studies will attempt to confirm these trends and the validity of an unconformity-based subdivision of the post-Windsor redbeds, first postulated by Gussow nearly 60 years ago.

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### Stratigraphy and structure of the Scotsburn anticline, Pictou County, Nova Scotia

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The Scotsburn anticline is a doubly plunging fold that deformed Devonian-Carboniferous rocks at the eastern end of the Cobequid Highlands in Pictou County, Nova Scotia. New mapping shows that mafic volcanic rocks of the Diamond Brook formation may be a single ca. 30 m-thick basalt flow that roughly follows the Diamond Brook river, but appears multiple times in outcrop as the river cuts up or down through the section. Recognizing this fact allows regional correlations to be revised and simplified. A stratigraphic sequence from bottom to top includes the upper Diamond Brook formation, the Falls Formation, and the Millsville Formation, all of which are folded about both whaleback and dome structures along a single main anticlinal axis. The sequence of Diamond Brook volcanic rocks exposed in the central Cobequid Highlands appear to be older than the basalt exposed in the Scotsburn anticline, but may underlie the nose of the Scotsburn dome and may explain the magnetic anomaly associated with this structure. The Falls Formation and Millsville Formation conglomerates fine to the northeast which suggests that the modern topography, with basement highs exposed to the south and west, resembles the topography that may have existed in the early Carboniferous.

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### Is the Yucatan Block a Laurentian microplate?

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Following the closure of several paleo-oceans, the collision between Laurentia and Gondwana is generally thought to mark the last major amalgamation event in the construction of the Pangean supercontinent. To constrain this process, it is essential to identify the geometry, kinematics, and timing of the Laurentia-Gondwana suture zone. A key area of uncertainty is what happens to the Laurentia-Gondwana suture zone after it passes through Florida and continues to the west. This is because the Yucatan Block lay west of Florida in Pangea (in most reconstructions), yet the provenance of the Yucatan Block is not well-determined. A Gondwanan provenance may be hypothesized for the Yucatan Block if it is assumed that rifting between what is now the United States of America and the Yucatan Block exploited the older Laurentian-Gondwanan suture. However, a Laurentian provenance is proposed here for the Yucatan Block based on a consideration of Nd-isotope data, a potential correlation between Silurian plutons in the Mayan mountains of southeast Yucatan and the Cat Square terrane of the southern Appalachians, and potential geophysical piercing points identified for the Wichita and Reelfoot rifts and Grenville rocks in the southern United States and possible equivalents preserved in the Yucatan basement.

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### Preliminary evaluation of trace hydrocarbon speciation and abundance by bulk GC analysis of fluid inclusion volatiles as an exploration tool for footwall-style sulfide ore associated with the Sudbury Igneous Complex, Ontario, Canada

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The North Range of the Sudbury Igneous Complex (SIC) hosts footwall-style Cu-Ni-platinum group element (PGE)-rich sulfide deposits of predominantly magmatic origin but that have been influenced by multiple syn- and post-magmatic hydrothermal events. The composition of reduced carbonic phases (unsaturated and saturated hydrocarbons, C1 to C6) in fluid inclusions within the matrix of Sudbury breccia, a rock unit that is permeable to circulating volatiles and that commonly hosts footwall-style Cu-Ni-PGE deposits, has been investigated by in-

line rock-crushing gas chromatography. This was done on samples from zones of breccia that are known to contain economic footwall sulfide deposits and zones barren of such deposits. Subtle but strategically significant differences have been found in the composition and abundance of bulk hydrocarbons that are released from mineralized and barren breccias when fluid inclusions are opened. These findings include: (i) statistically higher average abundances of light, saturated hydrocarbons (C1–C4) in mineralized, embayment-associated footwall packages than in breccia from barren environments (maximum difference of approx. half an order of magnitude for propane abundances; mol/g rock); (ii) higher total abundance of hydrocarbons in fluid from mineralized environments ( $8.11 \times 10^{-9} \pm 1.91 \times 10^{-9}$  mol/g) than in barren ones ( $4.93 \times 10^{-9} \pm 1.53 \times 10^{-9}$  mol/g); and (iii) no statistically significant differences in average unsaturated hydrocarbon abundances between the two breccia environments, but differences are present when considering the spatial variations of hydrocarbons within the mineralized breccia package itself relative to massive sulfide mineralization. Additionally, samples of breccia and quartz (from quartz + sulfide assemblages) from PGE-rich environments significantly deviate from expected hydrocarbon signatures and are considerably more enriched in unsaturated hydrocarbons. These findings strongly suggest that fluid hydrocarbon signatures should be taken into consideration when exploring for Cu-Ni-PGE-rich footwall-style ore bodies as a supplemental criterion to traditional visual and geochemical approaches.

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**Fluid inclusion evaporate mound analysis: a rapid, efficient and informative means of determining fluid chemistry in hydrothermal systems**

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The bulk chemistry of fluids implicated in a large range of hydrothermal systems, from high-T magmatic to low-T diagenetic, is generally constrained from the measurement of the ice melting temperature ( $T_{m,ice}$ ) in previously frozen fluid inclusions. Given that Na is often the most common cation in hydrothermal fluids, the NaCl-H<sub>2</sub>O binary is used to infer the concentration of dissolved salts, expressed as equivalent wt. % NaCl, based on  $T_{m,ice}$  and the experimentally determined liquidus surface in this binary. This assumption is known to be an over simplification for natural samples based on fluid inclusion analyses that show: (1) depression of the NaCl-H<sub>2</sub>O eutectic (i.e., <-21.2°C) due to presence of divalent cations (e.g., Ca, Fe, Mg); and (2) a complex solute chemistry from both leachate and in situ LA ICP-MS analyses. In order to address this short coming

in fluid inclusion studies, a rapid and efficient means of semi-quantifying solute chemistry is discussed. The method involves generating evaporate mounds by overheating fluid inclusions which induces decrepitation; the resultant mounds are subsequently analyzed using standard SEM-EDS methods. Application of this method to a wide variety of settings, including magmatic Sn-W, evolved pegmatites, carbonatitic, orogenic- and intrusion-related gold, and carbonate replacement (i.e., MVT) indicates the following: (1) Na is most common cation with others (Ca, K, Fe, Ba, Sr) dependent on setting; (2) Fe and Mn are common in mineral magmatic settings (e.g., Sn-Cu); (3) Ba and Sr are most enriched in carbonatitic samples; (4) solute chemistry is a good monitor of F:R interaction; (5) S is commonly present in most mineralized samples; and (6) F is also common anion which, if considered a proxy for magmatic fluids, implicates some orogenic gold settings as being, in part, of magmatic parentage.

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**Fluid inclusions record a history of melt source, transport and optimum fluid conditions for base-metal mineralization at the Pitarrilla Ag-Zn-Pb deposit, Sierra Madre Occidental, Mexico**

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A fluid inclusion study of the ca. 31.6 Ma mineralized (Ag-Zn-Pb) Pitarrilla felsic volcanic centre was conducted using: (1) quartz megacrysts (QM) from quartz-feldspar phryic synvolcanic dyke rocks, and (2) quartz and sphalerite from the high-grade, base-metal mineralized part of the IM sulphide mineralization. The QM are characterized by deeply embayed textures, abundant melt inclusions (MIs) with decrepitate textures and haloes of aqueous fluid inclusions, and planes of secondary L-V±H±S fluid inclusions. Final homogenization of L-V-H inclusions (88 in 17 fluid inclusion assemblages (FIAs)) occurred two ways (L+H→L, L+V→L) with a large variation in  $T_h$  for phase changes among FIAs (200–500°C), but little variation for changes in FIAs. Using appropriate bulk compositions and projection of the halite liquidus surface in PT space, the data track decompression for the QMs over a 3–4 kbar interval. This conclusion, consistent with geochemical constraints, is supported by the embayed QMs and both decrepitate textures of MIs and inclusion-rich haloes around them. Thermometric measurements (639 inclusions in 93 FIAs) for two phase (L-V) aqueous inclusions in QMs and quartz and sphalerite in the mineralization indicate: (1) trapping of L- and V-rich inclusions (i.e., fluid unmixing) on growth

zones in quartz with  $T_h = 160^\circ$  and  $275^\circ$  to  $300^\circ\text{C}$ ; (2) a continuum of data for FIAs in T-salinity space from 2 wt. % eq. NaCl,  $200^\circ\text{C}$  to 18 wt. % eq. NaCl,  $380^\circ\text{C}$ . A separate group plots at  $140\text{--}170^\circ\text{C}$ , 0 wt.% NaCl; and (3) a narrow range of data for FIAs in sphalerite, measured using an IR camera ( $1100\ \mu\text{m}$ ), with 1.7–8.5 wt. % eq. NaCl and  $200\text{--}300^\circ\text{C}$ . These data indicate two processes: (1) generation and unmixing of a magmatic fluid with 18 wt. % eq. NaCl; and (2) mixing of this fluid with meteoric water. The limited window in T-salinity space for sphalerite-hosted FIAs reflects the optimum physio-chemical conditions for its formation.

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### A model for the Paleoproterozoic metamorphism, crustal residence, and exhumation of the Repulse Bay block, Melville Peninsula, Nunavut

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The Repulse Bay block (RBB), Nunavut, is composed of a 2.9–2.7 Ga TTG magmatic suite, with minor ca. 1.91 Ga metasedimentary slivers, that was subsequently deformed and metamorphosed at upper amphibolite to granulite facies during the Trans-Hudson Orogeny (THO). The block demonstrates features that have not been widely documented in the THO: (1) high pressure kyanite-bearing metasedimentary rocks, (2) lack of steeply dipping shear zones, and (3) prolonged exhumation below  $650^\circ\text{C}$ . Thermobarometry combined with in-situ LA-ICPMS accessory mineral geochronology elucidate almost 400 million years of Paleoproterozoic evolution of the block. The granulite-facies rocks of the RBB underwent HP/HT (9.5 kbar/ $800^\circ\text{C}$ ) metamorphism that originated with zircon recrystallization at ca. 1.88 Ga. Prograde metamorphism in pelitic gneiss is recorded by the growth of garnet at ca. 1858 Ma, muscovite dehydration at ca. 1844 Ma, and the growth of a second generation of garnet at the expense of biotite at ca. 1815 Ma. Propagation of melts from lower crustal pelitic units into the middle crust caused water assisted melting and the development of widespread migmatites, metatexites and diatexites. The final stage of HT-metamorphism is recorded by cordierite-spinel coronas surrounding garnet, indicative of near-isothermal decompression at ca. 1791 Ma. Based on titanite, rutile and apatite geochronology, cooling of the RBB occurs at a rate of  $2^\circ\text{C}/\text{million years}$ .

The results suggest that the RBB was likely buried by an allochthonous package of rocks displaced during the Snowbird Orogeny at ca. 1.88 Ga. Crustal residence was

then prolonged due to the effects of indentation of the Meta Incognita microcraton. Sub-horizontal ductile fabrics preserved in the block are interpreted to have formed during mid-crustal flow between 1840–1810 Ma, causing weakening of the middle crust and juxtaposition of two levels of crust. Following terminal collision of the Superior Province, the RBB was then uplifted by lateral tectonic escape to the west along the Lyon Inlet Boundary Zone.

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### Late Wisconsinan dynamics of the northwest Laurentide Ice Sheet on Banks Island, Northwest Territories

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The paleogeography of the western Canadian Arctic Archipelago during the last Ice Age has remained largely speculative over the last half-century. Despite regional mapping studies aimed at characterizing the Quaternary geology of the islands, chronologies constraining the nature and timing of Late Wisconsinan glaciation remain sparse. The focus of this study is the evolution of the northwest Laurentide Ice Sheet on Banks Island and the adjacent marine channels. Detailed mapping of the glacial geomorphology and a new radiocarbon chronology constrain the maximum extent of Late Wisconsinan glaciation and delineate the pattern and timing of subsequent ice sheet retreat. The results demonstrate that the maximum extent of the northwest Laurentide Ice Sheet lay west of Banks Island on the Beaufort Sea Shelf and that by  $\sim 14\ \text{ka BP}$  the ice margin was situated in the central interior of island. Following this, widespread ice sheet retreat was interrupted by a phase of moraine deposition terminating at  $\sim 12.9\ \text{ka BP}$ , during which the Jesse moraine belt was constructed. High rates of ice sheet retreat characterized the interval  $\sim 12.9\text{--}12.5\ \text{ka BP}$ , which included final ice sheet withdrawal from Banks Island and Amundsen Gulf. This contrasts with the latter two-thirds of the Younger Dryas chronozone,  $\sim 12.5\text{--}11.65\ \text{ka BP}$ , which was characterized by general ice marginal stability. Further, the withdrawal of the northwest Laurentide Ice Sheet across Banks Island included concomitant changes in the position and geometry of local ice divides. The reconstructed dynamical behavior of the northwest Laurentide Ice Sheet provides new insights regarding ice sheet responses to late-glacial climate and relative sea level change, among other variables.

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**The temporal evolution and volcanic plumbing system  
beneath the southeast Lammersdorf Volcanic Center,  
West Eifel Volcanic Field, Germany**

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The West Eifel Volcanic Field, western Germany, comprises ~240 volcanic edifices spread over ~600 km<sup>2</sup>. Magma intruded into Devonian and Triassic meta-sedimentary rocks over the period 940 ka BP to 11 ka BP. Low velocity anomalies indicate the presence of a thermal plume containing 1–2% melt in the asthenosphere below the field. Since there are several large towns in the region and the Eifel is on the flight path for many major airports, any assessment of volcanic hazard must be based on the dynamics of magma emplacement. The Rockeskyllerkopf Volcanic Complex (RVC) first erupted the Southeast Lammersdorf volcanic center at ~474 ka BP with the final eruption of the Rockeskyllerkopf volcanic center, at ~360 ka BP. The deposits of the first eruptive event contain mantle-derived and high pressure cumulate xenoliths that were entrained in rising magma. Numerous studies have shown that the olivine in mantle xenoliths is in disequilibrium with the magma that brought them to surface; this is reflected in the development of Fe-Mg diffusion profiles. Olivine was analyzed in 9 peridotite and 5 clinopyroxenite xenoliths. Fe-Mg diffusion times in peridotites indicate xenoliths took less than one week to reach the surface whereas olivine from fragmented xenoliths of clinopyroxenites records a contact time a week to one year. Variations in forsterite compositions and melt Mg# indicate the presence of more than one magma in the volcanic plumbing system beneath RVC, possible re-equilibration of olivine, and a vein network of magma interacting with lithospheric mantle ~25 years before magma ascent into crust. Additionally, results indicate that magma was present within the crust below the RVC for up to as much as one year prior to the first eruption. As such, precursor activity ought to be expected as much as one year prior to eruption, however, there will be little warning.

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**Sedimentologic and structural studies of the Fredericton  
Trough west of Fredericton, New Brunswick**

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West of Fredericton, New Brunswick, the Fredericton Trough is dominated by the mid-upper Silurian Kingsclear Group (mainly Burtt's Corner Formation). Previous reports of this and other Silurian strata in the Trough have identified grey, argillaceous, fining-upward sandstone beds, occasionally with flute-like marks on their soles, plus extensive grey shale with graptolites and rare crinoid debris. Zonal fossils *Cyrtograptus linarssoni* and *Monograptus nilssoni* place the succession as mid-Wenlock to lower Ludlow. This has led to the interpretation of the strata as being the product of marine deep-water turbidity-current deposition. However, some sandstone beds investigated here do not fine upward, and contain wave ripples and wave-modified current ripples which indicate that at least some of the succession was deposited in shallow water, above storm wave depth, and possibly above low water. This suggests a significant marine regression during the Ludlow Stage, and that the region formed part of a distal shelf, rather than basal continental slope and rise as envisioned in numerous tectonic reconstructions of the region for these times.

Deformation involves two phases of folding and development of related fabrics. A predominantly bedding-parallel foliation ( $S_{0.1}$ ) is related to rare  $F_1$  folds, and these features are refolded by mainly upright, open to tight  $F_2$  folds with a related slaty cleavage ( $S_2$ ). Deformation seems to have been initiated while these sedimentary rocks were only partly dewatered, and isolated examples of non-bedding parallel  $S_1$  are related to loading structures. Form-surface maps of bedding through the area illustrate the large-scale form of the  $F_2$  folds (hinges are strongly curvilinear) and identify zones of stronger deformation where  $F_2$  limbs are overturned,  $F_2$  hinges are broken out, and there is evidence of detachments, probably thrusts. The  $F_2$  folds are cross-cut by lamprophyre dikes of Pridoli age indicating that the entire history, from deposition to dike intrusion, represents less than 5 million years.

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### Preliminary bedrock geology of the eastern Cobequid Highlands, northern mainland Nova Scotia

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The eastern Cobequid Highlands were remapped during the summer of 2012 to provide better understanding of the geology and economic potential of the area. The mapping confirmed early division of the area into two blocks, Bass River and Jeffers, but redefined some of their components. The oldest units in the Bass River block are the < 900 Ma Gamble Brook and Folly River formations of the Bass River Complex. The Gamble Brook Formation occurs along the faulted margins of the block and consists of metasedimentary rocks. The Folly River Formation forms the core of the block and consists of back-arc-related mafic metavolcanic rocks and ironstone and hence has potential for VMS deposits. Both formations are intruded by a suite of Late Neoproterozoic calc-alkaline granite to diorite/gabbro plutons (Debert River, Frog Lake, and McCallum Settlement) and a Devonian suite of alkali-feldspar granite plutons (Guyon Brook and Polson Mountain).

The oldest unit in the Jeffers block is the ca. > 850 Ma paragneissic and orthogneissic Mount Thom Complex which was intruded by the ca. 755–735 Ma calc-alkaline Mount Ephrairn plutonic suite consisting of granite to gabbro, and also by a suite of Ordovician within-plate syenitic and gabbroic rocks. In faulted contact with the older units is the Late Neoproterozoic Dalhousie Mountain Formation which consists of volcanic and sedimentary rocks intruded by dioritic to granitic plutons. Fossiliferous Silurian sedimentary rocks of the Wilson Brook Formation are in faulted contact with the older units. Devonian and Carboniferous sedimentary and volcanic rocks of the Byers Brook, Diamond Brook, and Nuttby formations and related A-type Hart Lake-Byers Lake plutons are in faulted contact with older units in both the Jeffers and Bass River blocks and are hosts to REE and epithermal Au-style mineralization. Numerous IOCG-style mineral occurrences occur along the southern flank of the eastern Cobequid Highlands.

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### Ice keel features in Amundsen Gulf, Canadian Arctic Archipelago: marine evidence for a glacial ice stream

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Studies of multibeam imagery and 3.5 kHz sub-bottom profiles obtained by ArcticNet and the Ocean Mapping Group, University of New Brunswick reveal the presence of ice keel ridge and groove lineations on the seafloor in Coronation Gulf, Dolphin and Union Strait and Amundsen Gulf, which lie in the southwestern part of the Northwest Passage. Drumlins occur locally in western Coronation Gulf and parts of Amundsen Gulf. Trends of the lineations and drumlins and published information delineating glacial ice flow directions and landforms on the adjacent islands and mainland provide a record of late glacial events in this region of the Canadian Arctic. Lineations displayed by the multibeam imagery resemble modern and paleo lineations found by researchers in Antarctica, Svalbard, Greenland, and other Canadian Arctic regions. They have been interpreted to have been emplaced by fast flowing glacial ice streams. These interpretations are supported by results from studies of bedforms formed and being formed beneath active present day Antarctic ice streams. Those bedforms include both lineations and drumlins. On the basis of the seafloor evidence and published terrestrial data within the study area, a glacial ice stream is interpreted to have occupied Amundsen Gulf, Coronation Gulf, Dolphin and Union Strait and parts of the adjacent islands and mainland during the Late Wisconsinan glaciation. Part of the ice stream was diverted through Prince Albert Sound and rejoined the main ice stream in Amundsen Gulf. The coalescent ice stream extended northwestward into the Beaufort Sea.

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### Lake Ontario was at sea level about 12,900 years ago

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A massive, overstepped, sand and gravel barrier beach beneath Holocene mud in western Lake Ontario has been delineated in piston cores, and acoustic and seismic reflection profiles between the communities of Grimsby and Oakville, Ontario. The Grimsby-Oakville barrier crest is about 78 to

80 m below the lake and 3 to 5 m below present sea level. A similar barrier that now encloses Hamilton Harbour has been constructed by westward longshore drift of shoreline sediment across the present end of Lake Ontario. A similar origin for the paleo-barrier is related to a unique interaction of deglaciation, sea level, and differential glacial rebound of the western and eastern ends of the Lake Ontario basin which connects with the upper St. Lawrence River valley. When the lower St. Lawrence valley was deglaciated about 12 900 cal BP, glacial lakes were drained and the rising Atlantic Ocean entered the upper St. Lawrence valley as the Champlain Sea. Analysis of rebound shows that the Grimsby-Oakville barrier and Champlain Sea beaches were then at the same elevation while sills and sea level were both rising, causing a near stillstand in western Lake Ontario before rebound raised the upper St. Lawrence sills above sea level and isolated the lake from the Champlain Sea after a few centuries. Although freshwater supply from northern glacial lakes prevented early Lake Ontario from becoming saline, its water surface was confluent with that of the Champlain Sea, a condition that makes the Grimsby-Oakville barrier a sea-level datum, the farthest west datum in eastern North America at the time between Hudson Strait and Gulf of Mexico.

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#### Stratigraphic revelations regarding Mesozoic salt on the Scotian Margin and implications for early trans-Atlantic basin history

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Mesozoic salt of the Scotian Margin is traditionally assigned to the Argo Formation, and its palynological age to Early Jurassic. On the Grand Banks, two Mesozoic salt formations are recognized: the Late Triassic Osprey Formation and the Early Jurassic Argo Formation. Besides the age distinction, the Osprey Formation is characterised by low Br content in salt (< 20 ppm), whereas the Argo is characterised by higher Br (60 to > 200 ppm).

Recent biostratigraphy as part of the OETRA Play Fairway Analysis identified Late Triassic salt on the southwest Scotian Margin at the Glooscap well. It occurs beneath tholeiitic basalt related to the Central Atlantic Magmatic Province (CAMP), the same relationship to CAMP basalts as observed for Grand Banks Osprey Formation. Hence, is this a Scotian Margin equivalent of the Osprey Formation?

In our study we examined the petrography and geochemistry of the salt at Glooscap and 5 other Scotian

Margin wells, including stratigraphically in-place and diapiric salt. As predicted, the Late Triassic salt at Glooscap is indeed low-Br facies (<1 ppm) and probably represents Osprey Formation equivalent. All other sites with Early Jurassic ages have much higher Br content (50 to 142 ppm), consistent with their continued assignment to Argo Formation.

An earlier, Late Triassic, low-Br salt-dominated evaporite facies followed by CAMP basalts, and then a later, Early Jurassic, high-Br salt is therefore a consistent stratigraphic pattern that extends about 1000 km along the Scotian-Grand Banks margins. Intriguingly, the same stratigraphic pattern occurs on the conjugate Moroccan Margin. This could indicate that a continuous evaporite basin existed during the early phases of Atlantic Ocean opening that evolved from a non-marine salt basin (low Br) to one with direct marine connection (high Br), with the transition occurring almost coincident with eruption of the CAMP basalts. Alternatively, these were isolated basins that evolved in parallel through similar successive phases.

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#### Holocene ice cap dynamics reconstructed from <sup>14</sup>C-dated moss and mammal bones currently emerging along receding ice margins

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Receding cold-based ice caps in the Canadian Arctic steadily uncover fossil fauna and flora that were entombed during ice expansion. The exceptionally warm summer of 2009 on Baffin Island resulted in ice marginal retreat exposing numerous patches of dead vegetation and faunal remains. We collected and microscopically analysed 65 samples and radiocarbon dated 47 of them: 44 plants and 3 caribou bones. A few samples were observed to include green bryophytes or algae and were not submitted because they may contain modern admixtures.

The dated moss and caribou bones reveal several distinct phases of Holocene ice cap expansion. The first expansion started about 4.7 cal ka and continued until 3.2 cal ka. The following hiatus of dates between 3.2–1.9 cal ka indicates a continuous ice cover at these high elevations (> 800 m). Ice caps then receded or completely melted before expanding again between 1.9–1.1 cal ka, followed by a short interval of stability and recession above these elevations before the final phase of expansion starting after 0.75 cal ka.

Steady cooling during the Holocene facilitated the onset of the Neoglaciation at around 4.7 cal ka. The second hiatus (1.1–0.75 cal ka) corresponds to the Medieval Warm Period (1000–700 BP), which supports the hypothesis that the hiatus represent recessions. The last episode of ice cap growth coincides with the Little Ice Age (400–100 BP), which is nowadays visible as decameter-wide lichen-kill zones around ice caps. Future work will analyse the links between ice cap expansion and changes in regional atmospheric and oceanic circulation, solar insolation, and volcanic activity.

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### Late Quaternary variations of the Labrador Current in Flemish Pass

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Sediment drifts of alternating sand and mud on the eastern Canadian margin preserve evidence of Labrador Current strength throughout the last glacial cycle. Drifts formed in Flemish Pass, a narrow, 1000 m deep basin seaward of the Grand Banks of Newfoundland. Previous work in northern Flemish Pass shows that significant grain size variations through time are influenced by the strength of the Labrador Current. A transect of four cores together with seismic profiles were collected across a prominent drift located on the eastern side of southern Flemish Pass during a CCGS Hudson cruise in 2011. Core descriptions, X-radiography, and down-core measurements of colour, grain size, P-wave velocity, bulk density and magnetic susceptibility were used with seismic profiles to correlate the cores. An age model was based on recognizing Heinrich layers previously dated in nearby cores. The grain size variations, down-core and laterally, and changes in sedimentation rates provide evidence for variations in Late Quaternary Labrador Current flow across Flemish Pass. In the past 16 ka, there has been strong sediment partitioning, where sedimentation rates vary across Flemish Pass, with an average of 10 cm/kyr. From 22–16 ka there was blanketing sedimentation and a high average sedimentation rate of 37 cm/kyr, suggesting a weak current. In core 0022, a 0.12 m thick unit of basaltic clasts is found 4 m beneath the seafloor. A comparison study with North Atlantic basaltic ash demonstrates that the basalt was likely from the 23 ka Icelandic eruption, presumably transported by ice, providing additional evidence for ocean circulation in glacial times. Labrador Current variations are a proxy for the North Atlantic Subpolar Gyre strength, which is weakened by freshwater additions from Heinrich events, weakening global ocean circulation and causing climate change.

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### The geological collections of Dr. Abraham Gesner (1797–1864)

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When Abraham Gesner (1797–1864) began his geological survey of New Brunswick in 1838 he became the first government-appointed geologist in a British colony. The survey was supported until 1842, resulting in five reports on the geology of the Province. As the survey came to a close, Gesner opened the doors of his museum in Saint John to the public to display his collection of rocks, minerals, and fossils. On April 5, 1842 ‘Gesner’s Museum’ became one of the first public museums in Canada. *The ‘Synopsis of the Contents of Gesner’s Museum of Natural History’* listed more than 1 200 geological specimens, only part of his reported collection of almost 4 000 specimens. The collection, now at the New Brunswick Museum, was more than a curiosity cabinet. Gesner had systematically organized his museum for scientific study, including his New Brunswick specimens that documented his geological survey of the Province. Localities described in his reports are represented by specimens in his collection, and thus it likely represents the second oldest government geological survey collection in the British Empire. In 1836, prior to his survey appointment in New Brunswick, Gesner self-published *Remarks on the Geology and Mineralogy of Nova Scotia*. References to rock, mineral and fossil localities in the book can be matched to specimens found in Gesner’s collection. His geological reports and book often referenced well-known geological localities in the world, such as the Giant’s Causeway or Mount Etna, sites also represented by specimens in his museum. Gesner’s collection survives today as one of Canada’s oldest geological collections comprised mostly of specimens from his work in New Brunswick and Nova Scotia but also with reference material acquired from the United States of America and Europe.

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### An integrated water quality forecasting model to restrict the harvesting of shellfish following extreme weather events

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Prince Edward Island (PEI) hosts one of Canada's largest shellfish aquaculture industries and a significant portion of its land area is occupied by agriculture. Aquaculture leases located downstream from agricultural land are especially vulnerable to contamination during extreme weather events. Fecal coliforms, principally *Escherichia coli* (*E. coli*), are bacteria that live in the digestive tracts of warm-blooded animals, such as domestic and farm animals. Since fecal coliforms are not normally detected in sea-water in significant concentrations, their presence compromises the safety of a shellfish growing area. There is a need to accurately forecast the spatial distribution of harmful bacteria under a variety of different environmental conditions. Geographical Information System (GIS) possesses a dynamic capability of integrating and analyzing spatial and ancillary data obtained from different sensors and methods. The development of an integrated GIS-based tool which models ideal conditions for *E. coli* growth dependent on hydrological, meteorological and tidal conditions can respond to that need. The tool will be a result of combining a river runoff model and coastal hydrodynamic model. Particle tracking of *E. coli* will be modeled from coastal watersheds with contrasting land use and weather characteristics. Forecast information will provide the predicted spatial extent of potential contamination given certain parameters and will be used to improve the efficiency of regulatory sampling, reduce unnecessary closures and identify major sources of contamination.

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### The Late Neoproterozoic Greendale Complex, Avalon terrane, Nova Scotia: an example of feedback between igneous and tectonic processes

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The ca. 607 Ma Greendale Complex (GC), Antigonish Highlands, Nova Scotia is a local representative of extensive arc-related magmatism in the Avalon Terrane of the Appalachian orogen. The complex is a roughly semi-circular body with a diameter of ca. 5 km and is located

between the Hollow and Greendale Faults, which were active during its emplacement. GC, which displays many of the characteristics typical of appinite suites, is primarily composed of steeply dipping, intrusive sheets of ultramafic, mafic, and felsic composition which define a distinct layering that ranges from centimetres to metres in width. There are also abundant roof pendants and xenoliths of (Georgeville Group) host rock. GC is heterogeneous on all scales with abundant evidence for mixing and mingling. The ultramafic sheets are commonly discontinuous, occurring as boudins derived from early-formed layers. Felsic rocks occur in veins as either conjugate sets or networks and typically terminate in pegmatitic lenses. The mafic or intermediate rocks, which dominate the complex, are composed mainly of amphibole-rich porphyritic gabbros. Structural analysis indicates that the sheets were emplaced during dextral shear on the bounding faults. Each type of intrusive sheet has a geochemical equivalent in the Georgeville Group host rock, implying that active movement along the bounding faults tapped arc-related magmas of diverse compositions thereby facilitating the mixing and mingling of these magmas.

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### Comparing auriferous and barren fluid vein systems at the 007 Zone Gold Deposit, Bissett, Manitoba

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The Rice Lake Greenstone Belt (RLGB) has been producing gold for almost a century and is the most prominent gold district in Manitoba (1.77 million oz produced). Despite the long history of mining in the RLGB, the genesis of these gold deposits is not well understood. The 007 Zone gold deposit is a relatively new discovery in the Archean RLGB and barren and auriferous quartz vein systems are used to characterize the 007 Zone deposit using petrography, stable isotopes and fluid inclusions. Alteration (e.g., sericite and ankerite) associated with barren and auriferous veins are similar, however, the oxygen and sulfur isotopic composition of vein quartz and pyrite are distinct. Quartz from barren veins has an average  $\delta^{18}\text{O}$  value of  $7.7 \pm 1.8$  ‰, whereas quartz from auriferous veins has an average value of  $12.9 \pm 2.8$  ‰. Pyrite from auriferous veins has slightly higher  $\delta^{34}\text{S}$  values ( $1.8 \pm 1.0$  ‰) relative to pyrite from barren veins ( $-1.6 \pm 2.2$  ‰). These sulphur isotopic compositions of pyrite are consistent with a magmatic source for the sulphur. Fluid inclusion petrography identified three main types of inclusions: (1) primary 2-phase aqueous ( $\text{H}_2\text{O}$ -NaCl) inclusions; (2) primary 3-phase aqueous -

carbonic ( $\text{H}_2\text{O}-\text{CO}_2-\text{NaCl}$ ) inclusions; and (3 secondary 2-phase aqueous ( $\text{H}_2\text{O}-\text{NaCl}$ ) inclusions. Primary, saline (17 wt % equivalent NaCl)  $\text{H}_2\text{O}-\text{CO}_2-\text{NaCl}$  inclusions are most abundant in quartz associated with gold and suggest that  $\text{CO}_2$ -immiscibility may have been the dominant mechanism for gold precipitation. Homogenization and stable isotope equilibrium temperatures suggest that barren veins formed at  $370 \pm 50^\circ\text{C}$  and 3.5–4.5 kbars, whereas mineralized veins formed at  $280 \pm 50^\circ\text{C}$  and 1.5–2.5 kbars. Therefore, the 007 Zone gold deposit shares many characteristics with both mesothermal and epithermal gold deposits, and is interpreted to be a shallow, low-temperature mesothermal gold deposit.

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#### Methods for detecting and monitoring seepage at CCS/ $\text{CO}_2$ -EOR sites

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In order to fulfill a role in demonstrating containment, surface monitoring for Carbon Capture and Geologic Storage (CCS) sites must be able to clearly discriminate between natural, and seepage-source  $\text{CO}_2$ . To this end, a number of researchers have begun to compare and contrast monitoring tools that can be used to detect seepage (defined as movement of  $\text{CO}_2$  from the subsurface to the atmosphere) from CCS sites. Here, we present results from the Weyburn injection field using several common ecological gas monitoring tools, including surface flux chambers, subsurface gas wells and stable and radioactive isotopic tracer species. Results from the analysis of these data show the importance of capturing and understanding the natural variability for detecting seepage. Based on our results, and the results of other researchers at Weyburn, we develop a signal to noise ratio (SNR) based approach to evaluate the efficacy of near-surface monitoring techniques for detecting  $\text{CO}_2$  seepage. While it is clear that no one method will detect seepage with absolute certainty, a combination of methods with the highest SNR and a smart sampling plan which accounts for areas of high natural variability is likely to maximize the operators ability to ensure  $\text{CO}_2$  is properly stored.

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#### A 12 000-year record of driftwood delivery to the western Queen Elizabeth Islands, Arctic Canada

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Ninety-five new radiocarbon dates on driftwood collected from the modern and raised beaches of Melville and Eglinton islands (western Canadian High Arctic) are presented alongside the larger driftwood database for the entire Canadian Arctic Archipelago. By documenting the species (provenance) and spatio-temporal distribution of driftwood at various sites across the Arctic, regional characterizations of former sea ice conditions and changes in Arctic Ocean circulation patterns could be deduced. The earliest postglacial invasion of the Canadian Arctic Archipelago by driftwood is recorded on central Melville Island at ~12.0 cal ka BP. Throughout most of the Holocene until ~1.0 cal ka BP, the rate of driftwood delivery to the western Arctic islands was low (~1 stranding event every 200 years) and intermittent, with the longest break in the record occurring between ~3.0 and 5.0 cal ka BP. This 2000-year hiatus is attributed to a period of colder temperatures causing severe sea ice conditions and effectively making the coasts of the western Arctic islands inaccessible to driftwood stranding. After ~1.0 cal ka BP, driftwood incursion increased to maximum Holocene levels (~1 stranding event every 20 years). The species of driftwood delivered at this time indicates that the Trans Polar Drift was dominantly west-shifted, which correlates to a positive Arctic Oscillation mode. The Little Ice Age, which occurred between 1250–1900 AD, appears to have had little impact on driftwood entry within the western Canadian Arctic Archipelago, indeed the general abundance in the latest Holocene may record infrequent landfast sea ice. Sea ice mobility during the Little Ice Age would provide more open water, which is not inconsistent with the high precipitation rates noted for this time in lake sediments in the central Canadian Arctic islands.

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### Production and transport of radon-222 gas through Halifax Regional Municipality's bedrock and till units

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Radon-222 gas is a human health risk, as long-term exposure to high radon concentrations through inhalation is the second leading cause of lung cancer after smoking. Studies from the Halifax Regional Municipality (HRM) area have documented radon gas levels high enough to be classified as a potential health risk (> 200 Bq/m<sup>3</sup>). The objectives of the study were: to create a map for indoor radon potential using indoor radon values, surficial and bedrock geology maps, radiometric maps, and known uranium occurrences; and, to quantify the dominant transport processes through HRM tills. A detailed map of potential radon exposure was developed for the HRM that linked spatially integrated residential radon levels with radon measurements from previous field studies, known uranium deposits and radiometric surveys. The second objective was to examine, in detail, the production and transport through depth of the fine grained leucomonzogranite till facies of the South Mountain Batholith within HRM as it returned the highest radon soil gas values (51.0 kBq/m<sup>3</sup>) and soil radon potential index values (34.5). Using laboratory soil column apparatuses, the dominant transport processes in HRM tills were quantified by measuring the permeability, diffusivity, and radon soil gas profiles through depth. Examining field soils and bedrock in a controlled environment concluded that production and transport of <sup>222</sup>Rn in the till was determined overall to be a more important control on the potentially dangerous indoor radon risk than <sup>238</sup>U production from the HRM bedrock; both permeability and diffusivity were significant controlling parameters.

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### The Orpheus Graben Triassic Eurydice and Chedabucto formations and their relationship to the Fundy Basin Wolfville Formation

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The Orpheus Graben is a fault-bounded basin plunging east from Chedabucto Bay to the Laurentian Channel. The graben shares a tectonic link with the Fundy Basin through oblique-slip movement of the Cobequid-Chedabucto Fault (CCF) during Middle to Late Triassic development of the

North Atlantic Ocean basin.

Sediments of the Orpheus Graben include the Late Triassic Eurydice Formation and presumed Late Triassic Chedabucto Formation. The Eurydice Formation is poorly defined and limited to offshore well penetrations. It is comprised of cyclic red shale with subordinate siltstone and sandstone, interpreted to represent coastal and tidally influenced deposition under arid conditions. The Chedabucto Formation consists of red siltstone and sandstone, with minor conglomerate, interpreted as alluvial and fluvial deposits. The Chedabucto Formation, outcropping along the western edge of the Orpheus Graben, may represent an up-dip equivalent of the Eurydice Formation. The lithofacies, cyclicity, and presumed age of both the Chedabucto and Eurydice formations are similar to that of the Wolfville Formation in the Fundy-Minas Basin. The location of all basin fill proximal to the CCF suggests a continuous belt of tectonically related sedimentation patterns from the Fundy Basin to the Orpheus Graben in the Late Triassic, a concept known as the "Broad Terrane Hypothesis".

The separated basins can be interpreted as fragments of a larger transtensional basin system formed through synchronous movement of the CCF. Later Mesozoic basin inversion and erosion may have caused the separation of the Fundy Basin and Orpheus Graben.

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### Magma mingling in the Avalonian Holyrood Granite, Newfoundland

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Detailed mapping and sample analysis has been carried out on an outcrop of the ca. 620 Ma Holyrood Granite where spectacular magma mingling features are displayed. The ~50 × 10 m<sup>2</sup> outcrop is located on the coast on the east side of Conception Bay, the Avalon Peninsula, Newfoundland, just outside the town of Holyrood. The outcrop corresponds to the upper levels of a granitic magma chamber, as evidenced by sporadic columns of pegmatite, and the main features of interest to this study relate to the intrusion of a more mafic magma into the chamber. Most occurrences of the second, more mafic rock type are in the form of metre-scale, rounded blobs, many of which have been preferentially eroded, but there are also occasional dykes. Though earlier assumed to be basaltic, closer examination of the second rock type proves it to be intermediate in composition, and contacts which appear sharp in the field contain intergrown crystals. No chilled margins were observed and we suspect that the second magma was a crystal-bearing slurry when intruded. The surrounding granite must also have been mushy at the time. A changing rheology with either time or depth in the

chamber is observed across the outcrop. At its northern end, contacts between host and blobs are smooth and unbroken, whereas at the southern end blobs have arcuate spalled rims, where the surrounding granite cracked and the more mafic magma intruded into the cracks. Throughout the outcrop there are faults which cut across blobs, apparently in the later stages of solidification.

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### Amphiboles in A-type granites as indicators of complex magmatic systems: the Wentworth Pluton, Nova Scotia

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The Wentworth Pluton is one of several late Paleozoic A-type granite plutons in the Cobequid Highlands. The Wentworth granite has a bimodal abundance of Mg, and is, regionally, the only granite that contains both primary sodic and calcic amphiboles. This study investigates why the Wentworth granite has more geochemical and mineralogical diversity than other plutons. Microprobe analyses of amphiboles were compared to the modal and whole-rock composition, and Sm-Nd isotopic data, of the granites. Temperature (from zircon and amphibole), pressure (from amphibole), oxygen fugacity (from Fe-Ti oxides), fluorine and water-in-melt contents have been calculated, for the investigation of the magmatic conditions. The amphiboles include primary ferro-edenite, ferro-hornblende, ferro-richterite, and arfvedsonite and secondary ferro-actinolite, ferro-winchite, ferro-eckermannite, and riebeckite. The calcic amphiboles are hosted in granites with higher Mg and Ba concentrations compared to the sodic amphiboles. Furthermore, the granites with sodic amphiboles have higher  $\epsilon_{Nd}$ , zircon-saturation temperatures, and initial F in-melt, compared to the granites with calcic amphiboles. The initial H<sub>2</sub>O in-melt is higher for granites with calcic amphiboles. Sodic-calcic oikocrystic amphiboles are hosted in a fine-grained granite dyke that yielded the lowest pressure but high temperature. These differences between the granites indicate the presence of two magmatic systems in the Wentworth Pluton. A hydrous, Mg-rich magma with lower  $\epsilon_{Nd}$  values and temperatures crystallized calcic amphiboles, whereas a relatively dry magma of higher temperature and  $\epsilon_{Nd}$  crystallized sodic amphiboles. The sample with interstitial development of both sodic-calcic and calcic amphiboles suggests that a hybridized granitic pulse rapidly reached the upper crust. This study shows that

compositional variation in amphiboles of A-type granites can also result from the contribution of more than one magmatic source, not just from differentiation, and that the Wentworth magmatic system is more complex than previously proposed.

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### Feldspar diagenesis and its significance for sandstone reservoirs in the Scotian Basin

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Diagenesis of K-feldspar and plagioclase are among the most significant changes occurring in sandstone during burial diagenesis. Sixteen representative samples at various depths from eight exploratory wells in the Scotian Basin were selected for detailed study of the diagenesis of the detrital feldspars, to evaluate the roles played by sedimentary facies (which influence porosity and permeability), geographic location (controlling the type of detrital supply), burial depth, temperature and salinity as recorded by fluid inclusions, and the structural setting of the sandstones. K-feldspar authigenesis starts at ~1900 m depth as K-feldspar overgrowths on detrital K-feldspar grains, or as cement that fills fractures in fractured K-feldspar, and continues to 3000 m. Albitization of K-feldspar also starts at ~1900 m, with diagenetic albite following weakness paths and at greater depths, K-feldspar disappears through dissolution and/or replacement by ferroan calcite ± ankerite. K-feldspars disappear between 3 800 and 4 500 m. Detrital plagioclase is either oligoclase or albite. Early patches of diagenetic albite in detrital albite grains give way with depth to albite pseudomorphs or partially dissolved albite grains, containing large pores. Albite pseudomorphs predate late ankerite cement. Detrital oligoclase is first replaced at depths > 3 700 m by diagenetic albite as overgrowths or irregular patches with straight crystal outlines. Diagenetic albite is much more abundant in thick sandstone units than in thin sandstone beds with interbedded mudstone, probably because such sandstones were pathways for flux of basal fluids. It is more abundant, in the same facies and depth, in the Thebaud-Glenelg fields, where fluid inclusions in silica and carbonate cements are ~21% NaCl compared with the eastern part of the basin where fluid inclusions are ~10% NaCl and probably a little cooler. Dissolution of K-feldspar seems predominantly controlled by burial depth, but is most severe in permeable thick sandstone units.

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**Monazite (U-Th-Pb) dating of polyphase tectono-metamorphic deformation in the Government Point formation, Jordan Falls, southwestern Nova Scotia**

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The ages of monazite crystals from metapelitic rock samples from the Jordan Falls region of southwestern Nova Scotia have been examined using in-situ dating methods. The rocks are from the Government Point formation of the Goldenville Group which is characterized as an andalusite-staurolite-cordierite granofels. The protoliths are thought to be turbiditic sediments deposited off the passive margin of Gondwana and subsequently deformed during the assembly of Pangaea. The equilibrium mineral assemblage suggests medium- to low-P (amphibolite-facies) metamorphic grade formed under conditions of approximately 550°C and 2.5 kb. These metasedimentary rocks contain an inclusion-rich staurolite poikiloblastic fabric that has been overprinted by inclusion-free staurolite poikiloblasts. These textures are interpreted as evidence of polyphase metamorphism and deformation associated with the early- to mid-Devonian Neocadian orogeny. Monazite, a LREE phosphate, is widely used as a chronometer due to its unique chemical signature and high Th and U contents. Electron microprobe textural and chemical microanalysis has been performed on samples from the region. These data are combined with Laser-Ablation Induced Coupled Plasma Mass Spectrometry (LA-ICPMS) total Th-U-Pb monazite chronology that has been used to constrain the timing of the distinct tectono-metamorphic deformation events recorded by these samples. Compositional mapping of monazite grains in these rocks has identified concentric zonation defined by Y concentration resulting from the breakdown of garnet, staurolite, and xenotime under prograde and retrograde metamorphic conditions. This strongly suggests multiple growth stages of monazite. Chronology of the individual compositional domains within monazite grains yielded distinct ages that represent the main metamorphic events that affected the rocks of southwestern Nova Scotia.

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**Detrital Nd isotopes as an indicator of hinterland tectonics, Jurassic-Cretaceous, Scotian Basin**

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The study of detrital minerals provides good evidence for specific sediment sources and thus transport routes. However, it is difficult to estimate the volumetric proportions of sediment from different sources using mineralogical data, because many source rocks lack abundant diagnostic minerals. We have attempted to use bulk Sm-Nd isotopic determinations to make semiquantitative estimates of the role of different source terranes in provenance studies.

A GIS geological map of Atlantic Canada was assembled from individual provincial maps. Rock units were characterised by proportions of different lithologies. Epsilon Nd data from the literature were assembled and the average  $\epsilon_{Nd}$  of each rock unit was estimated. In this manner, the  $\epsilon_{Nd}$  isotopic composition of detrital sediment from any designated source area could be calculated. Four principal sources to the Scotian Basin are expected from mineralogical studies: the outboard Meguma terrane (present-day epsilon Nd -11 to -14), more inboard Appalachian terranes with more juvenile igneous rock sources (present-day epsilon Nd -6 to -10), the Grenville Province of southern Labrador (present-day epsilon Nd -12 to -16 for juvenile rocks, average -20 including reworked basement), and Mesozoic volcanic rocks (present-day epsilon Nd +3 to -1).

Ninety-two samples from different parts of the Scotian Basin and at different stratigraphic levels were analysed for Nd isotopic composition. In general, adjacent shale and sandstone show similar Sm-Nd isotopic composition and show no evidence of systematic aliasing by REE-rich heavy minerals. Relative proportions of supply from the various sources are partly constrained by mineralogical studies and can be further quantified from Sm-Nd isotopic studies. Volcanic input was most important in the Tithonian, Barremian, and basal Albian. Supply from Labrador was most important in the Albian. No difference in source area was detected from the Barremian Upper Missisauga Member to the Aptian Naskapi Member, despite their quite different depositional environments.

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### Provenance and depositional environment of the Lumsden Dam formation, Wolfville, Nova Scotia

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Recent mapping of the Meguma terrane in the Nova Scotia has led to the identification of several mappable units in the Halifax and Goldenville groups of the Meguma Supergroup. In the Wolfville region the Halifax Group comprises the North Alton, Lumsden Dam, Elderkin Brook, and Hellgate Falls formations. The Lumsden Dam formation is laterally equivalent to the Bluestone and Feltzen formations in the Halifax and Mahone Bay areas. Excellent exposure of the Lumsden Dam formation can be seen in the overflow channel at the type section. The outcrop exhibits low metamorphic grade and is a fossil locality of the graptolite *Rhabdinopora flabelliformis*. This, together with acritarch assemblages, constrains the unit to the early Tremadocian. The Lumsden Dam formation consists mainly of light-grey siltstone and dark-grey mudstone with minor very fine-grained sandstone. Bouma sequence divisions Tb-Te are common in thin to medium graded beds throughout the section. Siltstone and sandstone beds are parallel to cross-laminated, while mudstone layers contain thin parallel silt laminations.

A detrital zircon assemblage from a sandstone bed in the Lumsden Dam formation displays a similar distribution to samples collected in the upper Goldenville Group. It shows a prominent peak in the late Neoproterozoic (common in peri-Gondwanan terranes) and has a significant cluster of grains between 1.9 and 2.1 Ga, consistent with a source in the West African or Amazonian craton. The sample also contains a cluster between 0.9 and 1.1 Ga, possibly derived from Amazonia. Lithological and provenance similarities between the Cambrian successions of the Harlech Dome in North Wales and the Meguma Supergroup have been identified. They both show an increase in detrital zircon age diversity up section; however, the early Tremadocian Dolcyn-afon Formation in North Wales displays an assemblage suggesting derivation from Ganderia, indicating different source regions for the basins by Early Ordovician time.

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### Constructing a 3D-sediment velocity cube and extracting its features in the deep water areas of the Arctic Ocean

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A 3D-sediment seismic velocity cube is constructed using seismic refraction velocity results from 118 sonobuoy stations in the deep water parts of the Canadian margin in the Arctic Ocean. Sediment compaction as well as its spatial variation are modeled and analyzed with sediment supply and tectonostratigraphic evolution. Sediment velocity and its patterns mainly depend on sediment supply, tectonic subsidence, and thermal evolution history, and they follow experimental or theoretical models very well in the deep-water environment characterized by fine-grained sediments. These models have wide-ranging applications in tectonostratigraphic interpretation and natural resource exploration.

In a large study area, such as the Canada Basin and its nearby regions in the Arctic Ocean, velocity data at 118 sonobuoy stations is too sparsely sampled for any currently available interpolation methods for interpolating a 3D velocity cube. Therefore the inverse spatial principal component analysis (isPCA) method has been developed and used in the construction of the 3D velocity cube. Patterns of velocity series are studied by modeling the slowness velocity function (which is based on compaction theory) with observed velocity series. Distinct categories of velocity models are identified based on the spatial features of modeled velocity functions in a GIS environment, such as ArcGIS, and these categories have clear spatial links with the interpreted tectonostratigraphic background of the study area.

In addition, the spatial variations describing the modeled velocity and compaction history manifest a qualitative relationship with the distance to known sediment sources such as the Mackenzie Delta, and depocenters within regions such as the Stefansson and Nautilus basins.

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### Paleoceanographic evidence of climate change in the Canadian Arctic: the past 10 000 years

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The reduction, and ultimately the disappearance, of sea ice enhances the warming response of high latitude oceans through a positive feedback loop related to reduction of the heat reflected from ice. Computer models predict that continued global climate warming may lead to a temperature rise of 7.5°C and ice-free Arctic water by 2100 AD, but these models are deficient in accuracy of sea ice predictability. Paleoceanographic studies of Holocene sediments from the Canadian Arctic use fossil plankton that are tuned to modern sea surface temperatures, salinity and ice cover to reconstruct prehistorical changes for known times of climate conditions that were either warmer or colder than now. The results of these paleoceanographic studies are used to test the validity of the climate models. Data will be presented from research in the western and eastern Canadian Arctic using sediment archives, dinoflagellate cysts, pollen and diatoms to reconstruct changes in arctic temperature and sea ice over the past 1 000 to 10 000 years. The most recent research using quantitative estimates derived from dinoflagellate cysts reveals east-west swings in summer surface water temperature and sea ice records between Beaufort Sea and northern Baffin Bay that may allow refinement of earlier paleoclimate models for the whole Arctic region.

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### Ordovician/Devonian bedrock on Orphan Knoll? Was Alan Grant ahead of his time?

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The Geological Society of America's 'Decade of North America Geology' bedrock geology map of the continent shows Palaeozoic sediments in about 1 500 to 1 800 m of water approximately 450 km northeast of Newfoundland. Alan Grant was almost single-handedly responsible for this small aspect of the 2005 GSA 1:5 000 000 map.

In 1969 the author nominated Orphan Knoll as a drilling site for the Deep Sea Drilling Project. The July 1970 Site 111 of 'Glomar Challenger', Leg 12, proved the continental nature of Orphan Knoll. Traversing the Knoll

'Challenger' ran two airgun profiles. However a full year earlier Alan Grant as Chief Scientist on 'Sackville' had run a profiler line on a cruise "to investigate the geologic structure of the northeastern terminus of the Appalachian System". Our two sets of profiles defined what are now known as the "Enigmatic Mounds" along the northeast margin of Orphan Knoll. Canada never went back to the Knoll for 40 years. In the meantime a 1971 dredge haul near the base of one of the mounds gave an indication of Devonian fauna that were known only from bedrock in the centre of the Arctic Archipelago and which could not have been moved by glacial ice into the Atlantic Ocean at any time in the past ca. 15 000 years. The information got into a footnote in the Leg 12 Initial Report (1972) but was rejected by Nature. Alan Grant, however, picked up on it and flew with it in GSC and CSPG publications (Devonian of the World - a 1988 CSPG Memoir 14). Ruffman and others had put it all in a drawer and almost ignored the samples until their August 1995 special issue of 'Scripta Geologica' firmly put the Palaeozoic origins of Orphan Knoll back on the table. In 2010 the ROPOS ROV on 'Hudson' looked at ahermatypic corals on two of the mounds and attempted to sample bedrock unsuccessfully. The cruise participants have suggested that the Enigmatic Mounds may be tilted blocks of Miocene sediment. The debate on the origin of the 300 to 600 m high mounds continues.

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### Employing contact metamorphism to assess the conditions of pluton emplacement in southwestern Kellys Mountain, Cape Breton Island, Nova Scotia

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At Kellys Mountain, Cape Breton Island, Nova Scotia, the Precambrian meta-quartz wacke of the Glen Tosh formation (a low-grade component of the Barachois River Metamorphic Suite) has been intruded by diorite, granodiorite, and granite plutons, and hosts a narrow metamorphic contact aureole. In the contact aureole metasedimentary rocks are biotite- and cordierite-bearing, and have reached amphibolite-facies metamorphic grade. Minor actinolite-bearing meta-tuff and meta-andesite are also found throughout the unit. Outside the aureole, the metamorphic grade is at lower greenschist facies, but farther to the north the Barachois River Metamorphic Suite increases in grade into the sillimanite zone in the eastern Cape Breton Highlands.

The conditions of metamorphism in the aureole have been determined to result in the development of neofomed

biotite, muscovite, cordierite, ilmenite, garnet, andalusite, and sillimanite in the meta-quartz wacke, a mineral assemblage also found in the Kellys Mountain Gneiss as a result of low-pressure regional metamorphism. The mineral assemblages in the Precambrian meta-quartz wacke are sufficiently developed to determine the depths of intrusion of the plutons, which caused the contact metamorphic aureole. Understanding the level of intrusion allows consideration of questions involving the relationships among the plutons, and comparison of this contact aureole with other metamorphic rocks in the area (e.g., Kellys Mountain Gneiss and northern parts of the Barachois River Metamorphic Suite).

Petrographic and microprobe analysis have been performed in order to determine the temperature and pressure conditions of metamorphism of the meta-quartz wacke in the Glen Tosh formation. Conditions have been determined to be 2.5–5.2 kbar at 365–750°C, implying intrusion at depths of as much as 16 km, although earlier formed andalusite indicates that the rocks may have initially undergone a low-pressure regional metamorphic event prior to the deeper high-pressure contact metamorphic event.

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#### A well-preserved tetrapod skeleton preserved from the Malagash Formation, Nova Scotia, Canada

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Nova Scotia is famous for its Late Carboniferous (e.g., Joggins Fossil Cliffs UNESCO World Heritage Site) and Permian (e.g., Brule) fossil sites. The Joggins Fossil Cliffs preserve large lycopod trees in which the world's oldest known reptiles have been found entombed at their bases. Brule has yielded a rare in situ, standing *Walchia* (primitive conifer) forest and a large array of tetrapod trackways that preserve the oldest evidence of herding behaviour in vertebrates.

A nearly complete skeleton from the Malagash Formation (Late Carboniferous – Early Permian) was recently discovered in the base of an ancient river channel along the Northumberland Shore in Nova Scotia. Much of the skeleton, including a nearly complete skull roof, entire rib cage, vertebral elements including elongated neural spines, scapulae, and humerus was discovered loose on the beach, while the mold was preserved in the cliff-face. Other fossils, such as an exquisitely-preserved partial dragonfly wing, plant fossils (e.g., *Cordaites* leaves), and invertebrate

traces help to elucidate the paleoecology of the area.

A preliminary investigation of the skeleton indicates that it may be a temnospondyl amphibian, possibly a cacopine dissorophid, but further examination and laboratory preparation is required. The Malagash Formation has never before produced any known tetrapod specimens and age-dating of the formation has relied largely upon sparse palynological records. This recent discovery may provide valuable new insights into the geographic distribution and evolutionary history of this important group of terrestrial tetrapods that coexisted with reptiles during this early chapter of terrestrial vertebrate evolution.

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#### Geochemical and fluid inclusion study of a suite of samples from Busang, Kalimantan, Indonesia

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From 1992 to 1997 Bre-X Minerals Ltd. alleged to have found one of the richest gold deposits on earth in central Kalimantan, Indonesia. In 1996 Dalhousie Professor G.C. Milligan was invited to visit Busang and collect samples from the highest grade zones. Initial study of these samples in Halifax failed to detect any gold. In 1997 independent evaluations determined that Busang samples had been systematically salted, unearthing one of the worst mining hoaxes in history.

The suite collected by Dr. Milligan includes 12 samples of drill core from the Busang Southeast Zone. Here they have been re-studied petrographically and analyzed for major and trace elements, and microthermometry of quartz-hosted fluid inclusions has been carried out on mineralized veinlets. Samples are volcanic and subvolcanic andesite-dacite and their geochemistry suggests calc-alkaline magmas generated in continental arcs typical of the host rocks in the Kalimantan Gold Belt. Alteration consists of silicification, calcitization, sericitization, and chloritization. Quartz-calcite ( $\pm$ gypsum/anhydrite) veinlets contain pyrite, sphalerite, galena, tetrahedrite-tennantite, and lesser chalcopyrite, but no discrete Au or Ag minerals are noted. Pyrite is ubiquitous throughout the altered rocks as dendritic veinlets and clots. Rare fluid inclusions in veinlet-hosted quartz are small ( $< 20 \mu\text{m}$ ) and prismatic to irregular and dominantly two-phase (L-V) aqueous with anticipated high temperatures of homogenization based on their L:V ratios. They are unclassified, as they do not occur along temporally constrained features such as growth zones or healed fractures.

In conclusion, the suite represents a moderately mineralized system hosting base metal likely generated by

hydrothermal fluids of probable magmatic origin. As such, it is compatible with location at the fringe of an epithermal precious metal system. However the absence of a significant gold anomaly (8–139 ppb Au) and the lack of textures typical of low-sulfidation epithermal deposits are incompatible with the suite representing a rich ore deposit.

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### Discovery of a new ichnofossil assemblage from the Bloomfield Formation in Bloomfield, New Brunswick

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A new ichnofossil assemblage has been discovered within the Lower Carboniferous, Moncton Subbasin, near Bloomfield, New Brunswick. An array of small-scale invertebrate trackways was identified from six stratigraphic intervals within the Lower Bloomfield Formation. Stratigraphic logs have been produced for the Lower Bloomfield Formation (LBF) and the Upper Bloomfield Formation (UBF). The LBF is exposed as outcrops within the Midway quarry and from adjacent roundcuts. The UBF is exposed along Mitchell Brook. Their assignment is based on palynology and lithostratigraphy. Three sedimentary facies are identified within the LBF: the lower reduced grey-bed facies interpreted as poorly drained-submerged sediments, a middle transitional facies, and an upper oxidized red-bed facies interpreted as well-drained alluvial/fluvial sediments. The UBF contains a forth alluvial/fluvial sedimentary facies of a cobble conglomerate at its base which fines upward into fine-grained red beds. A fluvial grey bed unit sits gradationally at the formation top which contains abundant commuted plant fragments. Trackways are preserved on shaly siltstone beds of the LBF. Ichnofossil assemblages represent both aquatic and terrestrial conditions. Trace fossil assemblage 1 within the lower reduced sedimentary facies contains surface traces of Kouphichnium, Diplichnites, Cruziana, Dendroidichnites, Diplopodichnus, and Rusophycus, all tentatively interpreted to be produced by limulids, tealiocarid shrimp, and branchiopod crustaceans.

Trackway assemblage 2 is dominated by walking traces Paleohelcura, Diplichnites and double tailed Diplichnites that are tentatively interpreted to be produced by scorpions, myriapods, and branchiopods crustaceans respectively. Kouphichnium trackways are evidence of limulid activity in the Maritimes Basin during late Tournasian times. Modern day limulids are marine animals with a high salinity tolerance for brackish and fresh water conditions. The depositional setting for these sediments and traces is

tentatively interpreted to represent a shallow, near shore, low energy embayment, likely under local fresh water conditions. Based on their modern biology, limulid activity reveals a periodic distant marine connection.

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### High resolution sequence stratigraphy of the Banquereau Formation, offshore Nova Scotia

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The Late Cretaceous to Late Neogene/Early Quaternary Banquereau Formation in the Scotian Basin, offshore Nova Scotia, is a stacked series of prograding sequences that downlap onto the Wyandot Formation. The Banquereau Formation unconformably overlies the Wyandot Formation and ranges in depth from 165 to 1355 m below the seafloor, reaching the thickest point of 1500 m in the Sable Subbasin, north of Sable Island. This paper interprets the lithostratigraphy of the Banquereau Formation within a sequence stratigraphic framework and describes the internal geometry of a section of clinoforms within the Banquereau Formation by computing a dense set of correlated 3D stratigraphic surfaces between two mappable seismic horizons. This is done by using a steering cube, which is a continuous measurement of reflection slope and azimuth throughout the seismic volume. Studying the clinoforms of the Banquereau Formation provides an in-depth understanding of the internal structure of the prograding sequences. Interpretation of seismic data demonstrates that clinoforms prograded to the southeast suggesting that the paleoflow direction of the Cenozoic deltaic system was from the northwest to the southeast. Based on analysis of cuttings and wireline logs, lithofacies of the formation show an overall coarsening upward trend from mudstone in the fore- and bottomsets into sandstone in the topsets with minor amounts of conglomerate. Sequence stratigraphic interpretation integrated with micro-paleontological studies allows a relative sea level curve to be developed for the succession. Although this formation does not have hydrocarbon occurrences in the Scotian Shelf, the method is applicable to any region (e.g., Trinidad, Brazil, West Africa) where sequence and parasequence scale stratigraphic characterization contributes to understanding petroleum accumulations.

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### Evaporate analysis of quartz-hosted fluid inclusions by SEM/EDS: evaluation of method

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A cost-effective, relatively simple, and time-efficient alternative to the variety of techniques used to determine the bulk composition of fluid inclusions is the analysis of decrepitate, also evaporate, mounds. This semi-quantitative method determines inclusion compositions by energy-dispersive analysis of precipitates, or mounds, produced by thermally inducing decrepitation of fluid-inclusion wafers (150–200 µm thick). The method is applicable to magmatic-hydrothermal systems where fluid inclusions contain > 95% of total weight (normalized) salt ions (e.g., Na, K, Ca, Cl, F). In order to assess the application of the method for evaluating the hydrothermal evolution and regional metal fertility of the large (7800 km<sup>2</sup>), variably mineralized (e.g., Sn, W, Cu, U, Mo, Ta) South Mountain Batholith (SMB), Nova Scotia, the protocol is being evaluated and the results are reported here. Mounds containing 50, 75, and 95 wt. % NaCl were synthesized and decrepitate mounds analyzed using a LEO 1450VP (SEM) linked to an Oxford X-Max 80 mm-2 SDD detector. Based on decrepitating over a range of temperatures, from 350° to 500°C, it appears that T ≤ 500°C is optimal since it produced large, well-shaped, and readily identifiable mounds amenable to raster analysis. To optimize analysis time and, hence, reduce analytical costs, data were collected with 5-, 10-, and 30-second acquisition times. In situ fractionation of mounds is assessed through comparison of point- and raster-mode analyses, whereas chemical heterogeneity is substantiated with X-ray mapping of large (i.e., > 20 µm) mounds. The number of analyses required to produce a representative result is discussed by comparison of results for 4, 8, 16, 32, 64, and 128 analyses of mounds for individual samples. The results of aforementioned analytical conditions will be presented and discussed in the context of the optimal conditions to be applied in the regional study of the SMB, the first of its kind ever conducted.

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### A paleolimnological record of anthropogenic impact on water quality in First Lake, Lower Sackville, Nova Scotia

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Lakes situated in urban environments are subject to a variety of anthropogenically induced pressures including nutrient loading, erosion, metal and salt inputs, and hypolimnetic anoxia. Since the 1920s, First Lake in Lower Sackville, Nova Scotia has been the focus of watershed development and degradation of lake water quality is an ongoing concern. A time stratigraphic, multi-proxy, geochemical investigation was conducted on a sediment core from First Lake in order to determine pre- and post-development water quality conditions. A year-long study of limnological conditions, local weather conditions, and existing historical data was conducted in 2012. First Lake is 82 ha in size with a maximum depth of 23m. Survey results indicate shallow secchi depths (< 2 m), strong stratification (~6 m) and neutral pH values (6.48–8.67). Oxygen-deprived bottom waters (< 5%) commonly develop as the summer progresses. Water temperature trends indicate continual mixing in the epilimnion.

Atmospheric Pb concentrations found within the sediment core were used to approximate sedimentation rates. Pre-development (pre-1920) data indicates a mesotrophic lake that may have experienced occasional eutrophic conditions. Post-development proxy data indicates higher δ<sup>15</sup>N values and lower C/N ratios indicative of increased primary productivity within the lake as a result of increased nutrient input from early agricultural development during the 1920s. Changes in concentrations of Ti, Cu, K, loss-on-ignition, and magnetic susceptibility values indicate landscape instability and increased sediment and toxin transfer into the lake associated with urbanization in the 1960s. Collectively, these data indicate that though First Lake was a moderately productive lake before development, recent water quality degradation is strongly linked to specific anthropogenic activities in the watershed, an understanding of which is a fundamental factor in developing effective lake management strategies.

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**Suprastructure-infrastructure boundaries in polydeformed metamorphic rocks as moving targets: a case study in the Thor-Odin – Pinnacles area of south-eastern British Columbia, with future applications on Cape Breton Island.**

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The Thor-Odin dome in SE BC is a tectonothermal culmination, structurally overlain by an ~12 km thick south-southwest dipping panel of rocks, and together, these high grade polydeformed metamorphic rocks are exposed in the footwall of the Columbia River and Okanagan Valley-Eagle River extensional fault systems. The panel that overlies the Thor-Odin dome is often interpreted as a single mid-crustal zone representing orogenic infrastructure or a mid-crustal channel during the Late Cretaceous to Eocene. We question this interpretation based on new analyses of the metamorphic and deformation history within this panel.

The rocks in the footwalls of the CRF experienced protracted, but not necessarily continuous metamorphism throughout the Cretaceous to Paleocene, with the ages of metamorphism younging downwards, and increasing in grade downwards throughout the structural section into the dome. This downward younging progression of metamorphism and deformation is best explained by a migrating suprastructure-infrastructure boundary that is located at different structural levels at different times. Cooling paths constructed for different structural levels within the section using U-Pb zircon, monazite and titanite geochronology data in conjunction with new hornblende, biotite and muscovite <sup>40</sup>Ar/<sup>39</sup>Ar data show that the panel has a complex cooling/reheating history. Exhumation in the upper part of the section was ongoing during the last stages of transposition and folding in the dome during northeast-directed transport over a basement ramp in the Eocene at ~56–54 Ma. By ~51Ma, retrograde metamorphic processes were active at all structural levels reflecting crustal scale extension.

We propose that the approach of looking for suprastructure-infrastructure boundaries within packages of apparently undivided metamorphic rocks would be instructive in areas where metamorphic history and linkages to deformation are broadly known, but the details remain elusive. The gneissic units of the Boisdale Hills area on Cape Breton Island offer a possibility to test this prediction.

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**Burning rocks: the history of the petroleum industry in Canada and the Maritimes**

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From Abraham Gesner's discovery of kerosene that marked the demise of the whaling industry, to Encana's new high-tech Deep Panuke gas development off the shores of Nova Scotia, both Canada and the Maritimes have led the world in oil and gas exploration. It was in Petrolia, Ontario where the first oil was pumped in 1865. This led to the development of the Canadian drill rig which was a simple, sturdy, wooden structure that could be dismantled and set-up in two days; they were used all over the world from the United States to Indonesia. At about the same time, Imperial Oil developed oil refining in London, Ontario. This lecture traces the development of oil and gas exploration in Canada and the people who led the way.

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**Evolution of the Iapetus Ocean in the Appalachian-Caledonide orogen: what can we learn from modern continental margins?**

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The Appalachian-Caledonide orogen is divided by the Mesozoic-Cenozoic Atlantic Ocean. Both parts of the orogen have been subdivided in zonal and terrane-based schemes, leading to several proposed correlations between the two segments. One significant source of variability is the Mesozoic fit assumed prior to Atlantic opening. Most reconstructions have been based on a 'loose' fit that does not take into account Mesozoic stretching. A more realistic fit taking into account the thinning of the conjugate margins reduces the reconstructed distance between the reconstructed Paleozoic terranes of Newfoundland and Ireland by as much as 50%.

The margin of Laurentia underwent protracted rifting from ~615 Ma to at least 550 Ma, and perhaps later. A Neoproterozoic 'early' Iapetan rift probably developed east of Dashwoods and other peri-Laurentian microcontinents; this was superseded by a western rift between these microcontinents and the Laurentian margin. Analogies with modern oceans suggest that this rift-drift history

would have substantially separated Dashwoods from the Laurentian margin.

Subduction of the Paleozoic Iapetus Ocean began relatively soon after its opening at ~515–505 Ma. The earliest collisional events are recorded almost simultaneously in Laurentian and peri-Gondwanan elements during the Early Ordovician, 490–480 Ma. This suggests that subduction was not initiated at a mature passive margin, a commonly assumed, but non-actualistic part of the ‘Wilson cycle’. Closure of the ocean between Avalonia and Laurentia was complete by ~425 Ma.

We propose that Iapetus Ocean closure was initiated at a subduction zone migrating from the adjacent external ‘Paleopacific’ in a manner analogous to the Mesozoic-Cenozoic capture of the Caribbean plate in the Atlantic realm. This hypothesis may help to explain: the initiation of subduction and the early closing of the Iapetus; the timing of the earliest collisional events; the isotopic character of Iapetan ophiolites; and the distribution of peri-Gondwanan terranes in the orogen.

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### Vulnerability of Nova Scotia’s transportation link to Canada from coastal climate change impacts

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With sea-level rise (SLR) estimates of 1 to 5 m predicted for the Chignecto Isthmus by 2100, and more intense storms another likely consequence of climate change, Nova Scotia Transportation and Infrastructure Renewal (NSTIR) has concerns for protecting the significant transportation infrastructure in this area. At present, a system of agricultural dykes and the Canadian National Railway (CNR) hold back the sea and protect the Trans-Canada Highway (TCH), and residents of Amherst and Sackville and thousands of hectares of land with public and private assets exceeding \$100 million. The area has flooded many times over the past 300+ years including major flooding events in 1758, 1869 (the Saxby Gale), 1887, 1958, and 1976 (the Groundhog Day Storm). These flooding events led to considerable property damage and loss of lives, and all were associated with storm surges that coincided with very high tides.

Flood modeling using a new high-resolution digital elevation model (Lidar-DEM) of the Isthmus terrain between the upper Bay of Fundy and the Northumberland Strait clearly shows (1) critically-low segments within agricultural dykes in Nova Scotia and New Brunswick,

(2) dyke overtopping at these low areas and flooding of portions of the CNR and TCH during storm surges at high tide (delays in trade with a value of \$50 million per day), (3) extensive flooding of local roads and protected dykelands (~2 200 ha in Nova Scotia), and (4) salt water damage to agricultural lands and the many non-agricultural, public and private assets.

With extreme predictions of SLR, up 4–5 m by 2100, the low lying areas behind the dykes are vulnerable unless the dyke system is considerably upgraded or other adaptation options implemented. While this event is likely a long time off, or a rare occurrence, it is prudent for stakeholders to start planning for the long-term sustainability of the Atlantic Gateway.

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### The Porter Puddle Complex, petrology and geochemistry of the Marmot Formation (Group II), Northern Canadian Cordilleran Miogeocline

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The Porter Puddle Complex (PPC) is located in the southeastern Bonnet Plume map sheet (NTS 106B/SE) in the northern Canadian Cordillera (Northwest Territories). The region, according to published reconnaissance-scale maps, is underlain by Lower Paleozoic Road River Group basinal strata, undivided Silurian-Devonian platformal carbonate rocks, and Middle Devonian Earn Group turbiditic siltstone and sandstone. The Lower Paleozoic strata were deposited in the Misty Creek paleo-embayment, an embayment of the Selwyn Basin thought to have formed by incipient rifting. Ordovician-Silurian volcanic rocks of the Marmot Formation have been identified and their extent is approximately mapped in several areas of southern NTS 106B.

The PPC has previously been interpreted as a submarine volcanic edifice that records shoaling, pertaining to the Marmot Formation. It consists of potassic-ultrapotassic and alkalic volcanic rocks. Previous studies of the geochemistry of these rocks are limited, and were summarized by grouping the rocks according to geographic and not stratigraphic location.

New mapping, carried out as part of the Northwest Territory Geoscience Office (NTGO) Selwyn-Mackenzie Shale Basins project during the 2009–2012 field seasons, has applied the newer stratigraphy to mapped areas, and better delineated the various horizons of the PPC. The purpose of this study is to expand the understanding of the Porter Puddle Complex, through detailed petrological,

mineralogical, and geochemical analyses.

Eleven samples of mafic flows from various parts of the complex were collected for polished-thin section, whole rock major and trace element geochemical analysis. Initial examinations of these mafic rocks reveal euhedral-subhedral seriate to subophitic phenocrysts of olivine, zoned pyroxenes, and biotite or phlogopite set in a pilotaxitic fine-grained altered chloritic matrix. Local carbonate alteration of the groundmass is present, originating from late-stage quartz and calcite veining associated with tectonism, and/or from seawater-sourced fluids close to the time of deposition.

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### Al Grant, an East Coast icon

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Few earth scientists can claim to have left a legacy comparable to that of Alan Grant, whose contributions are being recognized by the dedication of a Special Session at the 2013 Colloquium of the Atlantic Geoscience Society. A foretelling of Al's future success was his education at Pictou Academy, the same institute that produced another famous Nova Scotian geologist, John William Dawson. After graduation from Acadia, Al went to work as a geophysicist in Calgary. He returned to Nova Scotia to further his education and later accepted employment at the Bedford Institute of Oceanography. At BIO, Al focussed on geophysical studies of offshore northeastern Newfoundland, the Labrador Margin, Baffin Bay and Hudson Bay, research that often involved cruises lasting several weeks. Al became a good sailor and a top-notch interpreter of single- and multi-channel seismic data. This inevitably led to the publishing of numerous outstanding reports and ground-breaking maps, showing the offshore bedrock geology, depth to basement, and tectonics. One major milestone is the map *Tectonic Assemblages: Atlantic Canada Region*, which he co-authored with Harold (Hank) Williams.

During his career with the Geological Survey of Canada at Bedford Institute, Al Grant published over 200 scientific papers in addition to his maps. His accomplishments have been recognized multiple times by his peers: he was the recipient of the M.J. Keen Medal for the Marine Geosciences Division of the GAC in 1997, the AGS's Gesner Medal in 2004, the CSPG's Douglas Medal in 2005 and, with Bruce Sanford, the AAPG's I.A. Levorsen Memorial Award for best paper in 1990. Al also received the honorary degree, Doctor of Laws *honoris causa*, from Dalhousie University. By any standards, that's a great legacy for someone who started his education in a one-room school in Pictou County.

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### U-Pb ages and Lu-Hf isotope compositions of magmatic and detrital zircon in the Mira terrane, Cape Breton Island, Nova Scotia, Canada

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Combined laser ablation ICP-MS U-Pb and Lu-Hf isotopic analyses of detrital zircon from Neoproterozoic-Cambrian clastic sedimentary rocks and Neoproterozoic igneous rocks in the Mira terrane provide new insights into Avalonian crustal evolution. Detrital zircon populations younger than 800 Ma were derived from Avalonia, whereas older populations were derived from distal sources in the parent craton. Crustal evolution trends defined by  $\epsilon\text{Hf}(t)$  values varying with age predict two long periods of juvenile magma production in the source continent at 1.2–2.2 Ga and 2.4–3.1 Ga with an “age minimum” between these events. Four periods of mixing juvenile and recycled crustal material in continental magmatic arcs are distinguished at 0.5–0.72 Ga, 1.4–1.7 Ga, 1.8–2.2 Ga, and 2.4–2.7 Ga, as well as a weakly represented period of zircon-forming events at ~0.75–1.2 Ga without any input of juvenile crust. These data provide a distinctive overall Hf isotopic signature for detrital zircon in Avalonia which matches closely with the crustal evolution in the Amazonian protocontinent, supporting the original position of Avalonia at the present northern margin of Amazonia.

Avalonian crustal evolution is detected in the younger detrital zircon grains and in zircon from igneous rocks formed in Avalonian-cycle arcs at ca. 680–550 Ma. Positive  $\epsilon\text{Hf}(t)$  values suggest strong juvenile input from the mantle and variable mixing with older recycled crust. Most negative  $\epsilon\text{Hf}(t)$  values are interpreted to represent recycling of predominantly Mesoproterozoic underlying crust, but likely also some Palaeoproterozoic and Archean crust. Initially in the Late Neoproterozoic – Early Cambrian sediment deposition in the Mira terrane occurred in separated belts. Juxtaposition of these belts likely occurred by strike-slip movement before and during deposition of lower Cambrian clastic sediments in a rift basin over the assembled belts. The youngest detrital zircon population (ca. 517 Ma) is interpreted to represent syn-rift magmatism before separation of Avalonia from Gondwana.

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### Fine grained gold analysis in soil samples: a strategy to avoid the nugget effect

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Pedogeochemical exploration for gold is impeded by the ‘nugget effect’, a sampling error that adds enough variability to data to prevent dispersion pattern recognition. Strategies used by Western geochemists to avoid the ‘nugget effect’ generally involve the analysis of larger samples (> 30 g). Because such samples likely contain numerous coarse gold nuggets, they exhibit reproducible grades and avoid the ‘nugget effect’. ‘Bulk leachable, extractable gold’, and ‘metallic screen analysis’ are proxy methods employing this large sample approach to avoid the ‘nugget effect’.

An alternative method, used mostly in China, involves analyzing small samples (< 5 g). This method’s rationale is that small samples are not likely to contain large nuggets, yet still contain abundant numbers of small nuggets to be reproducible. On the rare occasion that a coarse nugget is present within a small sample, very large grades are obtained, making them easily recognizable. Once identified, these high-grade results are deleted and the samples are re-analyzed. Although this procedure is significantly cheaper than large sample techniques, its gold grades are biased downward and they exhibit less geochemical contrast because coarse nuggets are absent. Consequently, such procedures can only be used in mineral exploration, where only relative concentrations are important, and grade patterns vector toward mineralization.

This research investigates this Eastern gold exploration strategy using 30 auriferous soils from the Fifteen Mile Stream gold deposit, Nova Scotia. Gold grades in 14 size fractions (from 0 to 250 µm) and sixteen 0.3 g sub-sample replicate analyses have been compared to confirm that the small samples do not contain variance-inducing coarse nuggets. Results indicate the small sample strategy can be used to confidently explore for gold in soils at far less cost than conventional methods.

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### New insights into the Gander margin system in northern New Brunswick

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New field and analytical data have shed further light on the evolution of Ganderian elements in northern New Brunswick, including the Middle Ordovician Popelogan arc-forearc system and subsequent Salinic forearc deposits associated with subduction of the Tetagouche–Exploits backarc basin (TEB). Geochronological and lithogeochemical data from a small inlier near Oxford Brook, and from the Elmtree Inlier near Bathurst, highlight close parallels with Ordovician volcanism in northern Maine, and provide evidence for late Darriwilian volcanic arc activity in the TEB. At Oxford Brook, felsic volcanic rocks yielded a U–Pb zircon age of  $467.7 \pm 0.4$  Ma, identical to ages obtained from Ordovician inliers in northern Maine. Furthermore, SHRIMP isotopic analysis demonstrates a zircon inheritance profile very close to that of the Maine rocks, and confirms that the Popelogan arc was constructed on Ganderian basement. In the Elmtree Inlier, felsic tuff beds in the Pointe Verte Formation display volcanic arc signatures, and one such bed has been dated at  $463.2 \pm 2.6$  Ma. The arc-related Pointe Verte Formation is slightly younger than the structurally overlying, ophiolitic crustal rocks of the Devereaux Formation and is structurally underlain by mélangé with large slivers of serpentinized mantle, implying that the former was deposited on oceanic crust and probably records migration of the magmatic axis away from the trench because of shallowing of the subduction zone.

In a separate study, recent mapping in the Bathurst Mining Camp has extended the distribution of the Tomogonops Formation, which overlies Sandbian–Katian black shale and chert at the top of the Bathurst Supergroup. On the eastern limb of the Nine Mile Synform, two belts of sandstone, slate, wacke, and calcilutite that were formerly assigned to the Boucher Brook Formation are reassigned to the Tomogonops Formation. Detrital zircon analysis has shown that the youngest zircons in the Tomogonops Formation are late Katian, implying that the Tomogonops is coeval with lithologically similar, Late Ordovician–Early Silurian rocks deposited in the Matapédia forearc basin farther to the west, during west-directed subduction of the TEB. The implication of this “spillover” of forearc rocks onto the accretionary wedge is that the forearc progressively

expanded towards the southeast between 445 and 435 Ma; this is interpreted to result from accretion of successive TEB terranes and concomitant stepping back of the subduction zone.

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### Timing and conditions of polyphase deformation and plutonism during Paleoproterozoic assembly of northeast Laurentia

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Numerous and sometimes widely varying tectonic evolutionary models have been proposed for the assembly of northeast Laurentia during the Paleoproterozoic Trans-Hudson, Torngat and Nagssugtoquidian Orogenies. This presentation does not offer a new evolutionary model, instead, the timing and distribution of deformation and discrete episodes of plutonism along a transect from southern Baffin Island to northern Quebec and to western Greenland will be presented in order to highlight gaps in understanding. At ca. 2.07–1.92 Ga passive margin sequences, including clastic, carbonate and mafic volcanic units, developed on the margins of disparate cratonic fragments. Beginning at ca. 1.91–1.89 Ga deformation and plutonism likely heralded the onset of accretion along the margins of the Rae craton on Cumberland Peninsula and the Nain craton in western Greenland and eastern Labrador. The margins of the Superior craton to the south and intervening microcontinents were not affected during this time interval. Between ca. 1860 and 1840 Ma the Rae and Nain margins underwent a major phase of progressive deformation likely generating the ca. 1865–1845 Ma Cumberland and Proven Batholiths as the microcontinent Meta Incognita/Core Zone accreted from the south and west. Ca. 1850 to 1835 Ma deformation and magmatism appears to be restricted to the southwestern part of this now composite terrane which has been attributed to accretion of another microcontinent Narsajuaq Arc/Sugluk Block. Between 1820 and 1805 Ma terminal collision with the Superior craton promontory resulted in the main stages of deformation in the Cape Smith belt of northern Quebec whereas the foreland experienced only large wavelength cross folding and discrete zones of shearing likely related to escape tectonics. Late, stitching leucogranite dykes and sills intrude the entire region between 1810 and 1780 Ma. Recent and ongoing mapping projects on Cumberland and Hall Peninsulas, eastern Baffin Island, may shed light on the often controversial time periods and segments of the many evolutionary models for this region.

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### Fission-track re-evaluation of thermal inversion of the Scotian Margin: the need to consider the presence of diagenetic apatite and drilling-mud contamination

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Previous apatite fission track (FT) studies of the Scotian Basin (and onland Nova Scotia) have suggested a thermal event in the Late Cretaceous or Tertiary and subsequent thermal inversion, so that the rocks deep in some wells were hotter in the past than at present. Suggested explanations have included significant post-Eocene erosion (base level changes or fault tectonics), higher mean annual surface paleo-temperatures, local circulation of hot fluids, effects of salt, and analytical artefacts.

Fifteen apatite samples from cuttings and core from 8 wells: Abenaki J-56, Venture B-43, Panuke H-08, Thebaud I-93, Wenonah J-75, Alma F-67 (Shelf) and Crimson F-81 and Balvenie B-79 (Slope), were analyzed by the FT method, using optical track counting and measuring of confined track length and etch-pit size (D-par), combined with LA-ICPMS and EPMA of apatite grains. The latest methodology provides an order of magnitude more length measurements than the previous one, and a wealth of apatite geochemical composition data that allow for discrimination of populations with different provenances. The age, length, and geochemical data were modelled using HeFTy© and a few the AFTINV software. The methodology allows for individual time-temperature modelling of discrete groupings (populations) of apatite, an important improvement over past studies.

Although the results of earlier studies have been validated, the new methodology discovered two complications not considered before: (1) Apatite grains sampled in Scotian Basin wells were always assumed to be detrital. However the innovative modelling utilized shows that some apatite populations cannot be detrital. Some can be best modelled as authigenic apatite, having grown in situ during diagenesis; a mixture of detrital and ( unsuspected) diagenetic apatite modelled together could mimic temperature inversion. (2) Some apatite samples from cuttings include populations that have evaded any heating in the basin, indicating that they are accidental contaminants of the drilling fluids, making their data worthless.

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### Fluid inclusion study of salt-dome related hydrothermal development on Axel Heiberg Island, Canadian Arctic Archipelago

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In several sites, adjacent to evaporite diapiric structures on Axel Heiberg Island, Nunavut, a region with 500 m of permafrost, saline water flows perennially at constant flow rates and temperatures (+6°C), despite a mean annual air temperature of -15°C. These springs were interpreted as Holocene phenomena related to deglaciation; however a network of veins were recently discovered on the steep glacial trough of White Glacier in Expedition Fiord (WG). The host rocks are brecciated limestone and sandstone, anhydrite, and altered basalt, marginal to a large evaporite dome. Acicular, radial aggregates of calcite line fractures and cavities, with textures identical to but coarser than those observed in the active springs. Spar calcite fills the centre of larger cavities. Marcasite, pyrite (rare chalcopyrite) and quartz occur in several veins, and epidote and chlorite where they cut basalt. Thermochronology suggests that rocks now at surface were at temperatures of ~100°C until the Miocene.

Fluid inclusions in calcite (5–10 µm) have salinities that fall into two distinct groups: one very low, ca. 1.5 and another ca. 16 NaCl wt% equivalent. Primary inclusions that occupy growth zones in some of the coarser acicular calcite crystals have Th (L+V→L) ranging from 100°C to 300°C (n = 26) independent of salinity, but restricted range in Th within individual groups of inclusions in different areas of the host carbonate (i.e. variable from assemblage to assemblage). These values are considerably higher than the average temperature of the brines in the active springs. Despite the similarities of the WG site with perennial springs, our data are incompatible with models invoking shallow-circulating fluids related to deglaciation. We propose a model by which deeply-circulating basinal fluids were expelled in recurrent pulses during diapiric rise of salt in the Tertiary and mixed with low-salinity surficial waters, thereby establishing a long-lasting plumbing system as a precursor to active spring discharge.

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### Sediment geochemistry as a provenance indicator: climate change, tectonism, and volcanism in the hinterland of the Scotian Basin, offshore eastern Canada

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This study investigates use of bulk-sediment geochemical analyses to determine sediment provenance in the Upper Jurassic–Lower Cretaceous deltaic sediments in the Scotian Basin. 445 samples of mudstone and sandstone representing the geographic and stratigraphic range of interest have been analysed for 57 elements. The data were first screened to exclude the effect of severe diagenesis and appraised for the influence on element variation of grain size, source-area weathering, hydraulic sorting, polycyclic concentration of heavy minerals, and diagenesis using scatter plots and principal-component analysis (PCA). Diagenetic processes added Ca to many rocks and removed K in rocks buried below 3 km, thus impacting published weathering indices. However, other geochemical evidence for the degree of weathering showed climatically controlled changes in weathering in the Tithonian and Barremian. Lower weathering indices in the Albian Cree Member results not from aridity in the hinterland, but rather from greater supply from higher-grade metamorphic terranes of Labrador. Covariance of elements in heavy minerals demonstrates polycyclic supply and stratigraphic changes in sources, with greater importance of first-cycle minerals than previously interpreted from mineral studies. Geochemical analyses revealed a previously unsuspected Tithonian alkali volcanic sediment source, characterized by very high Nb and Ta, derived from fluvial erosion of ash from the Labrador rift. Mississippi-Valley type hydrothermal mineralization of shales was an unexpected finding of the geochemical analysis. The lack of highly contrasting sources means that geochemistry alone is inadequate to determine sediment provenance. Published discrimination diagrams are of limited value and single indicator elements for particular sources are generally lacking. However, low Cr is supplied by the Meguma terrane, whereas high Cr is supplied from Labrador and the ophiolites of western Newfoundland. Careful consideration of geochemical variability on a case-by-case basis, integrated with detrital mineral studies, provides new insights into paleoclimate, sediment provenance, and hence regional tectonics.

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**Diamond-destroying metasomatism under the central Slave craton: constraints from diamond morphology in Ekati mine, Northwest Territory, Canada**

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Volatiles are important agents of mantle metasomatism, which control geophysical and geochemical properties of the mantle. Volatile-induced resorption features are documented on natural diamonds and produced in experiments. We investigated mantle-derived dissolution morphology on diamonds from kimberlite pipes in the central Slave craton in order to better understand the conditions of diamond-destroying metasomatism under the Slave craton. The study focused on finding a relationship between the diamond resorption morphology and the internal properties of diamond crystals including the internal growth patterns revealed on cathodoluminescence images, carbon isotopic content ( $\delta^{13}\text{C}$ ), N content and aggregation state. The study used 82 octahedral diamonds selected from 603 stones from Grizzly, Misery, Leslie, and Koala kimberlites in Ekati Diamond Property, Canada. Zoning

patterns on cathodoluminescence images helped to distinguish between growth and resorption for step-faced morphologies. Nitrogen content varies from 13 to 2128 ppm, and  $\delta^{13}\text{C}$  values analyzed range from  $-6.4\text{‰}$  to  $-2.3\text{‰}$ , which accounts for  $-5\text{‰}$  of the mantle C isotopic range. Nitrogen contents and aggregation state determined by infrared spectroscopy form two clusters: (1) total nitrogen above  $\sim 400$  ppm and lower state of aggregation; and (2) total nitrogen  $< 1000$  ppm and higher state of aggregation. The limited variability of C isotopic compositions for the diamonds analyzed cannot distinguish mantle derived from recycled crustal carbon or peridotitic from eclogitic diamond reservoirs. Correlations between diamond morphologies and nitrogen aggregation, however, are apparent. Comparison of our results with the existing experimental data on diamond dissolution at high pressure and with the published datasets of diamonds recovered from eclogitic and peridotitic xenoliths shows that, in the Slave craton, metasomatism in peridotite develops complex resorption features (CM-1) perhaps in the presence of  $\text{CO}_2$ - or carbonate rich media and step-faced (SM-2) diamonds in the presence of  $\text{H}_2\text{O}$  fluid; whereas metasomatic fluid in eclogite is likely  $\text{H}_2\text{O}$ -bearing.