

# Atlantic Geoscience Society

## ABSTRACTS

### *44th Colloquium & Annual General Meeting 2018*

---

TRURO, NOVA SCOTIA

---

The 2018 Colloquium & Annual General Meeting was held at the Holiday Inn, Truro, Nova Scotia, on February 2<sup>nd</sup> and 3<sup>rd</sup>. On behalf of the society, we thank Colloquium organizers Robert Raeside and Chris White, as well the numerous student volunteers and judges, for facilitating an excellent meeting with about 100 submitted abstracts. AGS acknowledges support from the corporate sponsors and partners of the meeting: Nova Scotia Department of Natural Resources, Nova Scotia Department of Energy, Atlantic Gold, Nova Scotia Geoscientists, Geological Association of Canada, New Brunswick Department of Energy and Resources, Dexter Construction, and Acadia University.

In the following pages, we are pleased to publish the abstracts of oral and poster presentations from the meeting on a variety of topics. The meeting included several sessions: (1) Rocks, Maps, and Tectonic Models; (2) Advances in Assessing Arctic Geohazards; (3) Records of Environmental Change from the Atlantic Provinces and Beyond; (4) Basin-forming Processes during Supercontinent Assembly: New insights from the Devonian–Permian Record of Atlantic Canada; (5) The Meguma Terrane: its place in the Appalachian Orogen and Beyond; (6) Paleontology and Sedimentology in the Maritimes and Beyond; (7) AGS Outreach Innovations: Past, Present and Future; (8) Methane Emissions from Legacy Fossil Fuel Sites in the Maritimes; (9) Petroleum Geoscience on the Atlantic Margin; (10) Techniques in Earth Science; and a general session (11) on Igneous rocks, Mineralogy and Mineral Deposits.

Also included with the conference were two full-day workshops: (1) Your Career and Public Reporting - A QP short course for students (and others) by Amy Tizzard and sponsored by Geoscientists Nova Scotia and (2) Subsurface Methods - how to use and interpret drill-hole data and other subsurface data for both industry and academia by Robin Adair, outgoing president of the AGS. The guest speaker at Saturday evening's banquet and social was Deanne van Rooyen (Cape Breton University) who gave an entertaining talk entitled "Folds, furs, and flies: adventures in northern research" about her exploits in northern Quebec and Labrador.

THE EDITORS

---

**Magnetics and coring study of a newly discovered  
reducing spring in the Tablelands ophiolite,  
Newfoundland, Canada**

---

STEPHANIE M. ABBOTT AND ALISON LEITCH

*Department of Earth Sciences, Memorial University of  
Newfoundland, St. John's, Newfoundland and Labrador  
A1B 3X5, Canada <sma504@mun.ca>*

Winter House Canyon is located in the Tablelands inside Gros Morne National Park on the Great Northern Peninsula of Newfoundland. Winter House Canyon is unusual in that it contains springs that are strongly reducing, characterized by high pH levels, large negative Eh values and traces of methane. The springs, which surface through ultramafic rocks, are also known to be actively precipitating abiogenic carbonate as their fluids interact with atmospheric carbon dioxide. The pronounced magnetic signatures of these reducing springs suggest that geophysical methods are potentially useful for determining the geometry, location, and structural features of the subsurface fluid conduit that feeds the springs and this has been corroborated by previous research. The high alkalinity of the springs is likely the result of an ongoing alteration of peridotite resulting in the production of methane as well as magnetite as a by-product when occurring at low temperatures. As low temperature serpentinization results in the production of magnetite, one would expect that large magnetic anomalies would correspond with regions of past and present serpentinization. It is therefore reasonable to assume that conducting a magnetic survey over segments of the canyon would be an effective method for locating subsurface abundances of magnetite that may have formed during an alteration process. This would likely provide further insight into the nature and composition of underground streams. Based on these considerations, a detailed magnetic survey over a 200 m x 160 m area centered on a newly discovered spring site dubbed "Blagdon Spring" was conducted using a fast, GPS-enabled Overhauser Magnetometer to gather information about structural features. The objective was to build on a 2017 study that identified magnetic anomalies crossing the canyon which revealed bands of high and low magnetization that could potentially correspond with groundwater pathways that produce reducing springs. In addition, the magnetic survey was accompanied by a small petrographic study. In an effort to correlate magnetic data, six drill core samples were obtained from regions of high and low magnetic signatures near the Blagdon Spring site and taken to Memorial University of Newfoundland for comparative analysis and a preliminary look under the microscope. Given that this was not an in-depth petrographic study, comparative analysis focused primarily on the basic mineralogy and abundance of magnetite grains in high magnetic versus low magnetic regions.

---

**Investigation of legacy methane seepage into freshwater  
food webs using novel applications in Stoney Creek,  
New Brunswick, Canada**

---

IFEDAYO ABEL-ADEGBITE<sup>1</sup>, BRIAN HAYDEN<sup>1</sup>, AND  
MICHELLE A. GRAY<sup>2</sup>

- 1. Department of Biology, University of New Brunswick,  
Fredericton, New Brunswick E3B 5A3, Canada  
<IfedayoAbelAdegbite@unb.ca> ¶*
- 2. Faculty of Forestry and Environmental  
Management, University of New Brunswick, Fredericton,  
New Brunswick E3B 5A3, Canada*

Legacy oil, gas, and coalfields in the Maritime region have emitted methane into the surrounding ecosystem for more than 100 years. Methane escaping from these legacy sites may have effects on the surrounding environment; both terrestrial and aquatic. In order to determine if fugitive methane is entering freshwater streams and being incorporated into the local biological food webs, we investigated whether methane could be detected entering freshwater streams via groundwater inputs in an area with abandoned and active oil and gas wells. Introduction of an unnatural compound, such as fugitive methane, could act as an environmental stressor and, if detrimental, should impact the local food web starting at the lowest trophic level. We predicted that if methane was entering freshwater streams and being incorporated into the food web, we could use stable isotopes as a reliable detection tool. Fugitive methane would have a distinct isotopic carbon signature and could be traced through the various biotic compartments. This project also focused on the novel application of using a small thermal imaging camera to help detect subsurface groundwater inputs into the stream for site selection. Using this temperature sensing technology, we found and selected 5 suspected groundwater sources flowing into the stream channel. We aimed to collect biofilm (e.g., bacteria, algae, diatoms), benthic macroinvertebrate, and fish from both upstream and downstream of each input site, but with small streams low summer water levels, we were unable to adequately sample the fish community. Stable isotope analysis of the biofilm and benthic macroinvertebrates did not show obvious incorporation of fugitive methane into the food web, though some values were suspect. There are still some research questions that could be explored before ruling this application out as a tool to find and measure fugitive methane emissions in the environment. Additionally, we completed a diatom community assessment applying the Eastern Canadian Diatom Index (IDEC) as a measure of the biological integrity of streams and were able to show that our study sites in the Stoney Creek region are currently considered "slightly polluted", with a few select locations bordering on "polluted". These study results raise more questions than they answer but serve as an exploration and application of tools and techniques that have not previously been applied in this context.

---

**Mercury and other toxic metals in organic-rich mudstone  
(oil shale) from the Green River Formation, eastern  
Uinta Basin, Utah, USA**

---

ALEXANDER ANI AND DAVID KEIGHLEY

*Department of Earth Sciences, University of New Brunswick,  
Fredericton, New Brunswick E3B 5C3 Canada <aani@unb.ca>*

The Green River Formation (GRF) of the Uinta Basin contains the world's largest oil shale resource, concentrated in 8 organic-rich mudstone (ORM) intervals (up-section from R1 to R8) that were deposited in a stratified, alkaline, lacustrine environment. Ongoing studies relate to several beds of oil shale sampled from both core and outcrop in the lower R8 zone, ~60 to 130 m above the base of the regional R7 marker unit (Mahogany Oil Shale Zone). Analyses indicate enrichment of lanthanides, actinides, and toxic heavy metals occurring in phosphate-rich intervals of ORM. Additionally, in one phosphatic ORM bed, sulfide mineralization outside of a mat-like organic structure is predominantly FeS<sub>2</sub>, with limited occurrence of other phases e.g., ZnS and HgS. The FeS<sub>2</sub> shows evidence of post-depositional, pre-compaction diagenetic growth, with highly localized fabric disruptions and cross-cutting relationships with ORM laminae. Heavy and toxic-metals, including Tl, W, and Po, are found associated with [1.70 µm] euhedral HgS enclosed alongside dolomite within blocky carbonate-fluorapatite (CFA) cement inside the preserved organic structure. Organic geochemical analyses of isoprenoid/n-alkane ratios vary between phosphatic and non-phosphatic intervals in the upper GRF, and maturity indices such as CPI indicate differences in the respective organic matter populations. Some contribution to the differences in trace-element geochemistry might be ascribed to variations in the nature and type of preserved organic matter. As HgS is observed only within CFA inside the mat structure, its formation and/or preservation are likely related to the phosphatization process. Polonium is only observed only in HgS, which suggests that the sequestration of toxic metals is linked to biogeochemical processes. Local [paleo]pore-water chemistry is not precisely understood but might have played a role in the differences observed in the long-chain alkane profiles of analyzed samples. Organic matter may have interacted with local pore-water to alter microbial organic matter, helping to sequester toxic metals, and establish conditions favourable to the precipitation of less common sulfide phases.

---

**Post-accretionary uplift of the Meguma terrane relative to  
the Avalon terrane in the Canadian Appalachians**

---

DONNELLY B. ARCHIBALD<sup>1,2</sup>, J. BRENDAN MURPHY<sup>1</sup>, STEVEN  
M. REDDY<sup>3</sup>, FRED JOURDAN<sup>3</sup>, JACK GILLESPIE<sup>2</sup>, AND STIJN  
GLORIE<sup>2</sup>

1. *Department of Earth Sciences, St. Francis Xavier University,  
Antigonish, Nova Scotia B2G 2W5, Canada  
<darchiba@stfx.ca> ¶*
2. *Centre for Tectonics, Resources and Exploration (TRaX),  
Department of Earth Sciences, The University of Adelaide,  
Adelaide, South Australia 5005, Australia ¶*
3. *School of Earth and Planetary Sciences, Curtin University,  
Perth, Western Australia 6102, Australia*

The Avalon and Meguma terranes were accreted to the Laurentian margin as the Iapetus Ocean closed. The Minas Fault Zone delineates the boundary between these terranes. Exposures of the fault zone include the West River St. Marys Fault, to the south of which lies the Meguma terrane. To the north of the fault lies the St. Marys Basin, which comprises Late Devonian–Early Carboniferous clastic rocks (Horton Group), containing abundant clasts of Meguma terrane lithologies. An elongate and foliated granite intrusion (Kelly Brook pluton) exposed along the West River St. Mary's Fault intruded into Meguma Supergroup metasedimentary rocks. The pluton contains well-developed C-S fabrics with muscovite aligned in the S fabric, and a shallowly (~10°) westerly plunging stretching lineation. New U–Pb (zircon, LA-ICP-MS) geochronological data yield a crystallization age of 375.0 ± 4.6 Ma for the Kelly Brook pluton that is indistinguishable from other Late Devonian intrusive rocks in the Meguma terrane. Petrographic data for muscovite indicate that it grew prior to deformation. A 100% plateau <sup>40</sup>Ar/<sup>39</sup>Ar age of 369.0 ± 1.2 Ma on a single muscovite grain constrains the time of cooling of the granite to approximately 420 to 450°C. Apatite grains also demonstrate pre- to syn- deformational fabrics and yielded a U–Pb (LA-ICP-MS) age of 361.2 ± 5.6 Ma indicating the granite was still above 350°C at this time. Earliest Tournaisian fossils and abundant granite clasts in the unconformably overlying Horton Group strata indicate that the granite was exposed by ca. 359 Ma. Taken together, these new data document the rapid uplift (0.12–1.14 cm yr<sup>-1</sup>) of the Kelly Brook pluton and the Meguma terrane from approximately 9.5–11 km depth during the late Devonian. An apatite fission-track age of 215 ± 14 Ma indicates Mesozoic reburial and reheating of the granite prior to opening of the Atlantic Ocean.

---

**Lithofacies analysis and diagenesis of strata  
in a salt-withdrawal mini-basin: Bashkirian  
Grand Anse Formation, Maringouin Peninsula,  
southeast New Brunswick, and Minudie Point,  
northern Nova Scotia, Canada**

---

FADEL BAHR AND DAVE KEIGHLEY

*Department of Earth Sciences, University of New Brunswick,  
Fredericton, New Brunswick E3B 9P3, Canada <fbahr@unb.ca>*

The Lower Pennsylvanian Grande Anse Formation crops out in three coastal sections adjacent to the New Brunswick - Nova Scotia border. Sedimentological analysis of the >250 m-thick sections has identified 13 lithofacies in erosive, sharp, intercalated and/or transitional contact with each other. These lithofacies are grouped into four facies associations: (FA1) Braided channel deposits, (FA2) debris flow deposits, (FA3) sheet flood deposits, and (FA4) floodplain deposits, which accumulated in a mini basin initiated by salt tectonics in the underlying Windsor Group. This basin appears to have been isolated from the coeval rocks of the Cumberland Basin in the nearby Joggins area as the Minudie salt wall developed.

Petrographic and SEM investigations indicate these Bashkirian strata have undergone minor clay infiltration and various diagenetic alterations. Alterations include: (i) eodiagenetic iron oxide cements that occur in the form of red coating around detrital quartz and feldspar grains and filling pores between detrital grains. A later stage iron oxide associates with dissolved carbonate cement and feldspar grains, which imparted the red colour to many coarse- and fine-grained lithofacies in the lower part of the outcrops (~250m). (ii) Eodiagenetic replacement of feldspar and muscovite by kaolinite in [FA1, 2, and 3] sandstone; interpreted to be related to the influx of meteoric waters and alteration of these unstable detrital grains under conditions of slight acidity (pH ~5). The formation of kaolinite is associated with the creation of intragranular porosity, and thus porosity enhancement. (iii) Eodiagenetic quartz that occurs mainly as syntaxial overgrowths which partly to completely cover detrital quartz grains, fill either partially and/or wholly the adjacent intergranular pores (FA1, 2, and 3) and reduce porosity. Several samples also show later compound zones of quartz overgrowth, chertification, and multiple intergrowths. High silicification in various forms suggests feldspar dissolution and chemical compaction as a main source of silica in early and deep burial diagenesis, and uplifted telodiagenesis. (iv) Near-pure calcite is an eodiagenetic alteration but is followed by mesodiagenetic neocrystallization of high Mn- and Fe- calcite and variably Fe-rich dolomite in conglomerate and sandstone lithofacies (FA1, 2, and 3) that may enclose blocky silica and quartz

overgrowths. (v) Barite is also present within sandstone lithofacies but diagenetic relationships remain uncertain. The suggested source of the barium and sulfate ions is likely from dissolution of limestone and evaporitic rocks of the Windsor Group.

---

**EdGEO across Canada: a proven recipe for  
geoscience workshops**

---

JENNIFER L BATES

*Geological Survey of Canada (Atlantic), Bedford Institute of  
Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada  
<jennifer.bates@canada.ca>*

The National EdGEO Program was initiated in the early 1970s to support workshops about earth science for Canadian teachers. The program is co-ordinated by the Canadian Geoscience Education Network (CGEN) of the Canadian Federation of Earth Sciences (CFES). Financially supported workshops are expected to provide P-12 educators with knowledge, teaching resources, and increased confidence to help them present earth science to students. More often than not, the workshops are organized by geoscientists but teachers are encouraged to do so and are often part of the local organizing committees. For the Nova Scotia EdGEO Workshop Committee, the 1992 Geological Association of Canada – Mineralogical Association of Canada conference in Wolfville, Nova Scotia, marked a moment in time. Following a presentation on the National EdGEO Program, the author who was sat next to the then-Chair of the Atlantic Geoscience Society Education Committee (Graham Williams) remarked, “we should do that here”. This innocent remark led to the formation of the Nova Scotia EdGEO Workshop Committee, which has now organized and run teachers’ workshops for twenty-four years. The original concept for the Nova Scotia EdGEO workshop program was six workshops in as many years in six locations – Halifax, Sydney, Wolfville, Bridgewater, Truro and Parrsboro. However, because of the persistent positive and encouraging attendee feedback, the dedicated committee members worked with volunteer field trip leaders to organize annual two-day workshops until 2012. A change was needed and came with a purposeful shift to run a one-day workshop as part of the Nova Scotia Association of Science Teachers conference. Attendance remained steady and feedback positive. But after almost 25 years, one needs to ask what has been the impact of these workshops? Haven’t we heard that in recent years there been a decline in the number of geology classes offered in Nova Scotia schools? With the environment being such a hot topic why aren’t education administrators desperate to ensure students

understand geological processes? Have we been barking up the wrong tree for 25 years? What does the future have in store for education outreach of the earth sciences? And how can the Nova Scotia EdGEO Committee play a productive role?

---

### The fate of intact polar lipids in hydrothermally altered sediments and their short road to oil formation

---

JEREMY BENTLEY<sup>1</sup>, CARL PETERS<sup>1</sup>, TODD VENTURA<sup>1</sup>,  
AND STEFAN SIEVERT<sup>2</sup>

1. *Department of Geology, St. Mary's University, Halifax, Nova Scotia B3H 3C3, Canada <jeremy.bentley@smu.ca> ¶*
2. *Woods Hole Oceanographic Institution, Woods Hole, USA*

Although hydrocarbon generation has been heavily studied in conventional petroleum-forming basins, the primary mechanisms responsible for converting the initial inputs of sedimentary organic matter into petroleum-forming hydrocarbons is still not fully understood. Intact polar lipids (IPLs) are a fundamental component of sedimentary organic matter. IPLs are composed of a core lipid chemically bonded to a polar head group. These lipids are constituents of cellular membranes. Consequently, IPLs are biomarkers for living and/or very recently deceased organisms due to their labile headgroup, which gets hydrolyzed quickly after cell death. IPLs can also be taxonomically distinct and useful for reconstruction of organic matter source inputs. The polar headgroups of IPLs quickly degrade after the death of a cell and the remaining core lipid may become biodegraded. However, a portion of the altered products will likely become bound to kerogen or assimilated as inherited bitumen where it may later crack to release petroleum. This break down and assimilation may occur at depth over tens to thousands of years depending on the geochemical and sedimentological conditions of the depositional environment. However, this process occurs naturally and at an accelerated rate in very shallow buried sediments within organic-rich, sedimented hydrothermal vent systems. This study will identify and quantify the IPLs recovered from a push core transect running from the interior to exterior of the Cathedral Hill hydrothermal vent site in the Guaymas Basin, Gulf of California. IPLs will be extracted from sediments using a modified Bligh & Dryer protocol and analyzed with an UHPLC-qToF-MS to identify the diversity and quantity of living and recently deceased organisms in relation to their exposure to high temperature vent fluids (up to 142°C). This study will explore whether the IPLs can (1) provide insight into thermal-chemical limits in which IPL structures can be preserved and (2) enable the precise sequence of reactions to be monitored that results

in their conversion into hydrocarbons. This study will also document the reaction pathways leading to the conversion of these lipids into petroleum forming hydrocarbons, which may be used as a proxy for the reaction mechanism that likely occur in conventional petroleum forming basins.

---

### The northern Appalachian tin metallotect: what conditions led to formation of Canada's only past primary tin producer, the East Kemptville Sn-Cu-Zn-Ag-In deposit?

---

LUKE BICKERTON<sup>1</sup>, DANIEL KONTAK<sup>1</sup>, IAIN SAMSON<sup>2</sup>,  
BRENDAN MURPHY<sup>3</sup>, DAWN KELLET<sup>4</sup>, AND ROB CREASER<sup>5</sup>

1. *Harquail School of Earth Sciences, Laurentian University, Sudbury, Ontario P3E 2C6, Canada <lbickerton@laurentian.ca> ¶*
2. *Department of Earth and Environmental Sciences, University of Windsor, Windsor, Ontario N9B 3P4, Canada ¶*
3. *Department of Earth Sciences, St. Francis Xavier University, Antigonish, Nova Scotia B2G 2W5, Canada ¶*
4. *Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada ¶*
5. *Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada*

Globally magmatic-hydrothermal tin deposits share several common features: (1) mineralization associated with highly fractionated, peraluminous, felsic intrusions and subvolcanic rocks enriched in lithophile elements, (2) deposits are typically concentrated into metallogenic districts (distinguishable by a multitude of mineralized centres hosted by voluminous magmatism of similar character), and (3) shallow crustal levels for mineralization (typically 3–4 km to <0.5–2 km). Outstanding issues in tin deposit models are with the factors that control tin enrichment in the metallotects, i.e., a source for Sn in the magmatic-hydrothermal system may be from crustal melting and assimilation, the mantle, or from the country rock.

The northern Appalachians is one such tin metallotect, as there are widespread lithophile element deposits hosted by Early Devonian to Carboniferous metaluminous to peraluminous igneous rocks. In contrast to typical tin districts (e.g., Cornwall, England; Bolivian tin belt), the peraluminous magmatism in this district is hosted by various tectonic terranes at different paleo-depths and economic tin mineralization is rare. The past-producing East Kemptville (EK) Sn-Cu-Zn-Ag(-In) deposit in the Meguma terrane of Nova Scotia is the most significant of the Sn-mineralized centres. The deposit is hosted in a highly-fractionated, F-rich, leucocratic, peraluminous phase (i.e., EK topaz-muscovite granite (EKG)) of the  $372.8 \pm 3.0$  Ma Davis Lake

pluton (DLP) that intruded, at 3.5 kbars, the Ediacaran–Cambrian metasandstone-dominated Goldenville Group during the waning stages of the Neocadian orogeny. The EKG was emplaced along a NE-trending structural corridor that delineates Sn–Cu–Zn–Ag mineralization in southwestern Nova Scotia, some of which records a later mineralizing event at ca. 360 Ma (e.g., Clayton Hill Pluton). Multiple hydrothermal events in the region are recognized at East Kemptonville, where molybdenite has been dated (Re–Os) at ca. 376,  $354.9 \pm 2.0$ , and  $343.7 \pm 1.7$  Ma across the deposit.

The DLP is one of several differentiated granites that make up the large ca. 375 Ma South Mountain Batholith (SMB). Despite hosting significant Sn mineralization at EK, the rest of the SMB is relatively unmineralized, as are other peraluminous granites in the Meguma terrane. This study addresses factors that led to Sn-enrichment at EK, and why no appreciable enrichment has been recognized elsewhere in the Meguma terrane. Several factors influence lithophile element enrichment; they include timing of emplacement and evolution of the batholith (e.g., multiple discrete plutons versus one protracted event), the redox and PT conditions throughout melt evolution, and the hydrothermal evolution that resulted in mineralization.

---

**Life in the Iapetus Ocean: insights from Paleozoic drill cores and thin sections, southeastern Baffin Island shelf, Canada**

---

NIKOLE BINGHAM-KOSLOWSKI

*Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada*  
<Nikole.bingham-koslowski@canada.ca>

The pre-Mesozoic rift bedrock geology in the Davis Strait–Baffin Bay region is poorly constrained due to the paucity of subsurface samples. Six Paleozoic, seabed drill cores were recovered from the Southeastern Baffin Island Shelf during Geological Survey of Canada led research cruises in the 1970s (expeditions 75009-Phase 5 and 77027). These drill cores and their associated thin sections provide unique insights on the depositional environments that existed in the Iapetus Ocean during the Lower to Middle Ordovician. Fossils identified in drill core and thin sections represent a diverse, normal marine community and include bivalves, trilobites, crinoids, sponge spicules, gastropods, brachiopods, corals, cephalopods, dasycladacean green algae, ostracods, bryozoans, and radiolarians, as well as possible foraminifera, calcispheres, and tentaculites. Undifferentiated echinoderm and shell fragments are also common throughout the strata. The matrix is predominantly composed of fine-grained

lime mud with bioturbation observed in four of the six drill cores. The drill cores exhibit absent to preferential to pervasive degrees of dolomitization, with the drill core from 75009-PHASE5 Old Station 4 displaying the greatest degree of alteration. Disseminated pyrite is found throughout the majority of the drill cores and thin sections, and the cores from 75009-PHASE5 Old Stations 8A and 8B contain finely macerated organic matter dispersed in the matrix. Based on observations from the drill cores and thin sections, the preliminary depositional milieus are interpreted to range from shallow, photic zone environments to deeper, open marine settings.

---

**Investigation of a Holocene marine sedimentary record from Pond Inlet, Nunavut, Canada**

---

LAURA ANN BROOM<sup>1</sup>, CALVIN CAMPBELL<sup>2</sup>, JOHN C. GOSSE<sup>1</sup>,  
AND KIMBERLEY A. JENNER<sup>2</sup>

1. *Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada* <laura.broom@dal.ca> ✉
2. *Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada*

Fjords often have high sedimentation rates which gives them the potential to preserve a high resolution sedimentary record of the local and regional environment. Newly acquired sediment cores and geophysical data from Pond Inlet, a fjord in northwestern Baffin Bay, provide the first opportunity for a thorough investigation of the Holocene marine sedimentary record in this region. The dataset includes high resolution multibeam bathymetric data, 3.5 kHz sub-bottom profiler data, and five piston cores. Baffin Bay is within a seismically active zone and experienced the largest measured earthquake ( $M_w = 7.3$ ) north of the Arctic Circle in 1933. Earthquakes and other processes in the region have the potential to trigger tsunamis either directly or indirectly with slope failures. A detailed analysis of the marine sedimentary record is necessary to establish if mass movement events are preserved in Pond Inlet and to begin to evaluate their frequency and locations along Baffin Island. Seabed mapping, analysis of core physical properties, shallow lithologic and acoustic stratigraphy, and geochronology are underway.

Initial results indicate that a record of mass transport deposits (MTDs) and turbidites are preserved within the fjord which represent periods of local instability. While the seabed reveals little evidence of slope failures, sub-bottom profiler data reveal that the basal sediments are composed of hemipelagic sediments interrupted by multiple acoustically chaotic sediments—representing MTDs—along with high amplitude reflectors interpreted as turbidites. The

piston cores show evidence of deformed mud and mudclast conglomerate deposits up to 5 m-thick interpreted as mass transport deposits, as well as centimetre thick sandy-silty turbidites. Our first radiocarbon dates ( $n = 6$ ) from mixed foraminifera assemblages and benthic colus shell fragments indicate that over the last 3 ka at least four mass movement events have been recorded in the fjord and that basal sedimentation rates are approximately 1.8 mm/yr. This is the first opportunity to establish an MTD chronology in northern Baffin Bay which will help improve the assessment of the geological hazards in the region and their potential impact on northern communities on Baffin Island.

---

### *Island at the Centre of the World: why PEI needed a popular book on their geology*

---

JOHN CALDER

*John Calder Earth Works, Boutiliers Point, Nova Scotia B3Z 1W8, Canada <calder.earthworks@gmail.com>*

Prince Edward Island is the only province or territory in Canada with no geological survey, no university geology department, and no natural history museum. And most geologists think of the Island's geology as monotonous at best or having no story to tell at the worst. While diversity is not PEI's strength, it has much to offer: excellent exposure; the best record of early Permian terrestrial life in Canada, including type specimens that help to define the Permian worldwide; a story of sea-level rise and landscape change that was witnessed by its First People, the Mi'kmaq; and a virtual showcase of linkage between geological ages in the recycled, glacially derived soils and younger beaches and dunes. In exploring the book, a serendipitous development was having the opportunity to tell the stories of citizen scientists who secured for us important paleontological specimens, without aid or support other than their own sense of wonder and perhaps societal responsibility. Another was the acceptance by the Mi'kmaq of Epetwitk, and the opportunity to learn of the significance that the island, its birth, and geological character have for its indigenous people. Geological colleagues from far and wide shared their experiences of discovery and personal anecdotes, bringing the human element to standardized accounts recorded in journal articles. The book, supported generously by the Canadian Geological Foundation and by AGS, is modelled on the design of *Coal Age Galápagos*, and will be published in 2018 by PEI's Acorn Press.

---

### **Recent mapping and interpretation of the enigmatic Clarke Head area, northern Nova Scotia, Canada**

---

JOHN CALDER<sup>1</sup>, JOHN W.F. WALDRON<sup>2</sup>, TREVOR MACHATTIE<sup>1</sup>, AND ALISON K. THOMAS<sup>2</sup>

1. *Nova Scotia Department of Natural Resources, Halifax, Nova Scotia B3J 2T9, Canada <John.H.Calder@novascotia.ca>* ¶
2. *Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada*

The Clarke Head coastal section is an oft-visited, visually stunning, and challenging geological site. Mapping of this complex section was facilitated by aerial drone photography that provided detailed rectified photomosaics of the intertidal zone in map view and of the higher, largely inaccessible cliff face. We use the term Clarke Head fault zone (CHFZ) to refer to a nominally 500 m-wide section of deformed Carboniferous sedimentary strata and older igneous rocks that occur south of a narrow but regionally persistent graben involving the late Triassic Blomidon Formation, earliest Jurassic North Mountain Formation, and early Jurassic McCoy Brook Formation. The CHFZ involves coherent but brittlely deformed blocks of 10–100 m-scale sedimentary Carboniferous strata, 10 m-scale subrounded megaclasts, 1–10 m-scale exotic igneous and metamorphosed igneous rocks, and a fine matrix of centimetre-scale and finer sedimentary clasts. Mapping indicates that coherent 100 m-scale sections of Windsor Group (Gigantoproductid-bearing limestone) and Mabou Group (West Bay formation) 'float' within this matrix and that the entire section south of the bounding fault with the Mesozoic strata can rightly be described as *mélange*. Although we are still at the stage of characterizing the geometry of the fault zone, our mapping indicate that *mélange* clasts involve strata older than the West Bay formation of the Mabou Group' (late Viséan–early Namurian). Parrsboro Formation (Langsettian) of Cumberland Group affinity is highly involved at fault margins of the *mélange* proper. These preliminary observations constrain *mélange* formation to the early Namurian–early Langsettian, with further involvement of the basin fill subsequent to the early Pennsylvanian. This time interval correlates with the Mississippian–Pennsylvanian unconformity of eastern North America and implicates late stage assembly of Pangea, later deformation being consistent with timing of salt removal in the Cumberland Basin north of the Cobequids. Involvement of mafic clasts within mylonitized gypsum suggests that Windsor evaporites acted as a flux during transpression along a deeply rooted fault system that was reactivated, incorporating garnet-bearing granulite and mafic elements. The large (decametre-scale) rounded megaclasts that typify the Clarke Head section are also consistent with movement within an evaporite flux, pointing to a possibly joint tectonic–diapiric cause of *mélange* formation.

---

**A geophysical, petrological, and reservoir potential study of the Glass Sand marker unit and associated sandstones in the Upper Horton Bluff Formation, Horton Group, Windsor Basin, Nova Scotia, Canada**

---

REID CAMERON<sup>1</sup>, IAN SPOONER<sup>1</sup>, D. FRASER KEPPIE<sup>2</sup>, AND PEIR PUFAHL<sup>1</sup>

1. Department of Earth and Environmental Science,  
Acadia University, Wolfville, Nova Scotia B4P 2R6, Canada  
<131026c@acadiau.ca> ¶

2. Nova Scotia Department of Energy, Halifax, Nova Scotia B3J  
3J9, Canada

A geological evaluation of sandstones in the upper Horton Bluff Formation (uHBF) was undertaken to determine the reservoir potential with emphasis on the Glass Sand marker unit (GSmu). Multiple wells have been drilled in the Windsor Basin, Nova Scotia, targeting quartz arenite sandstones in the uHBF, yet there has been no production to date. This project was initiated to identify whether these sandstones have the ability to conventionally store and transmit hydrocarbon in economic quantities.

Wireline logs of the uHBF from 6 wells show multiple clean sand units that have API readings between 35 and 45. Based on an interpretation of gamma ray returns, these units typically coarsen upwards and may represent marine parasequences. A basin-wide mature quartz arenite bed conforming to strip log and outcrop descriptions by earlier workers, is identifiable in only two of these cores, which indicates that the facies consistent with the GSmu is not a basin-wide phenomenon. Strip logs describe multiple occurrences of well indurated, texturally mature quartz arenite commonly interbedded with black carbonaceous shales; petroliferous odours and signs of degassing were common and noted in well reports. The quartz arenite beds within the uHBF are characterized by hummocky cross-stratification and ichnofacies consistent with a shallow marine setting and represent the uppermost portion of a marine parasequence. Thin section analysis and liquid porosity and permeability testing were performed on both core and outcrop samples within this sequence at a variety of locations and have yielded porosities averaging 11% with permeability readings <1 mD. Thin section analyses indicate that these sands are compositionally and texturally mature and that burial diagenesis is common. Preservation of mica and feldspar minerals in core samples was evident and also contributes to diminished porosity and permeability at depth.

The Glass Sand marker unit does not appear to be a reliable basin-wide marker unit and we recommend that this designation be discontinued. As well, the mature sands within uHBF do not appear to have conventional

reservoir potential, although their proximity to thick and brittle carbonaceous shales facilitate development by unconventional processes.

---

**New insights into a brackish Carboniferous ecosystem through the coprolites of the Joggins Formation, Nova Scotia, Canada\***

---

M. CHIPMAN<sup>1</sup>, M. GREY<sup>2</sup>, AND P. PUFAHL<sup>1</sup>

1. Department of Earth and Environmental Science,  
Acadia University, Wolfville Nova Scotia B4P 2R6,  
Canada <120988c@acadiau.ca> ¶

2. Joggins Fossil Institute, 100 Main Street, Joggins,  
Nova Scotia B0L 1A0, Canada

The cliffs at the UNESCO World Heritage Site in Joggins (Nova Scotia) hold a wealth of fossils, both terrestrial and aquatic, from the Late Carboniferous Period. Fossils from the aquatic realm have historically been understudied and the ecosystem they represent is poorly understood at Joggins. Examination of fish coprolites that are abundant in the limestones of the Joggins Formation has broadened our understanding of the aquatic ecology, specifically the food web. Coprolites preserve undigested material that give us a window into the diets of these fish and provide important information on species interactions within the ecosystem. The coprolites (N = 74) have been studied in thin section and hand sample, as well as cathodoluminescence to determine the contents. We found that specimens could be divided into six categories based on size and shape: cigar/cylindrical shaped; cone shaped; small/equant; spiral; irregular; and massive (samples greater than 5 cm in length). The small coprolites are the most abundant and the massive coprolites are the rarest. They range in size from <1 cm to >10 cm and are 2–3 cm on average. The mineralogy of the coprolites is high calcium phosphate, similar to the composition of bone. This suggests that the fish producing these coprolites were carnivorous and that there is a lack of vertebrate herbivores present, supporting previous findings of possible soft bodied invertebrates as the dominant herbivores. Bone fragments have been found in almost all samples, however specific species identification has thus far been impossible. This research provides both a foundation for further studies on coprolites and similar fossils and a deeper understanding of aquatic ecosystems as fish diversified further into fresh water in the Palaeozoic. Future work will include species specific identification of undigested bone material, strata specific coprolite analysis and possibly dissolution of the coprolites to study the undigested material directly.

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



---

## Characterizing the variation of kimberlitic apatite within kimberlite bodies

---

RICHARD CHOW AND YANA FEDORTCHOUK

*Department of Earth Sciences, Dalhousie University, Halifax,  
Nova Scotia B3H 4R2, Canada <richard.chow@dal.ca>*

Kimberlites are well known for being the primary source of diamonds, although they are poorly understood when it comes to the processes involved in their formation due to their highly complex nature. Kimberlites are volatile-rich magmas which in combination with their diverse composition, volatile loss during emplacement, alteration, and composition of volatiles – does not allow for them to be well constrained in terms of their formation. The mineral apatite is highly sensitive to the behaviour of trace elements and volatiles due to its crystal structure. It can therefore be indicative of the processes and conditions involved in the stages of evolution of a kimberlite body. While apatite is known to vary between different kimberlite bodies, little is known about the variation that occurs within any one kimberlite body. This study examines variations in the presence, textures, and composition of apatite with depth in kimberlite pipes filled with both magmatic and volcanoclastic kimberlite lithologies.

Samples have been collected from boreholes in Boa and Leslie kimberlites (Ekati Mine, Canada) and BK1 and AK15 kimberlites from Orapa cluster (Botswana). We examined 23.7–234.6 m-depth range in magmatic (coherent) Leslie kimberlite, 30–84.8 m depth range in Kimberly-type pyroclastic and magmatic facies from Boa pipe, 56.16–151.7 m-depth range in magmatic (coherent) AK15 intrusion, and in three drill holes (2 of which have known depth ranges, 36.7–54.33 m and 8.64–124.41m) in two coherent and one Kimberly-type pyroclastic facies from BK1 kimberlite pipe. We observed notable variation in groundmass apatite textures forming irregular and radially aggregates composed of fine apatite crystals. Discrete euhedral to subhedral crystals are also observed with zoning. Poikilitic texture is common with inclusion within both clusters and discrete apatite crystals. Electron microprobe and LA-ICPMS analytical methods are used to characterize the chemical variations.

The features of kimberlitic apatite will help to constrain the behavior of volatiles through the erupting kimberlite column and shed more light on the eruption mechanism of kimberlite magma and the origin of different facies within the same pipe. This study aims to correlate apatite and its implications for the history of kimberlite evolution.

---

## Ichnology and sedimentology of Cretaceous and Paleogene strata on Bylot Island, Nunavut, Canada: development of a rift-basin succession in Baffin Bay

---

LYNN T. DAFOE<sup>1</sup> AND JIM HAGGART<sup>2</sup>

1. *Geological Survey of Canada-Atlantic,  
Bedford Institute of Oceanography, Dartmouth, Nova Scotia  
B2Y 4A2, Canada <lynn.dafoe@canada.ca>* ¶  
2. *Geological Survey of Canada-Pacific, Vancouver, British  
Columbia V6B 5J3, Canada*

The Labrador-Baffin Seaway formed during rifting and separation of Greenland from the North American plate. Rifting began in the Early Cretaceous, with seafloor spreading starting in the Maastrichtian and ending in late Eocene. As a result, Early Cretaceous syn-rift strata accumulated in grabens, followed by late rift and post-rift deposition. Bylot Island, at the northwestern end of Baffin Bay, preserves a record of this rift history, providing a vital analogue for understanding the adjacent offshore succession. Cretaceous and Paleocene strata are preserved today on north Bylot Island at Maud Bight (North Bylot Trough) and on southwest Bylot Island and nearby areas of Baffin Island (Eclipse Trough). Our detailed analysis of the ichnology and sedimentology of 14 measured stratigraphic sections from these areas provides new insights into the depositional paleoenvironments of these strata. Lower Cretaceous syn-rift strata of Eclipse Trough are well preserved along Salmon River on Baffin Island. Basal deposits reflect alternating aquatic conditions and subaerial exposure, including wave, interference, and adhesion ripples, mud crack casts, and plane-bed lineations. Surface trails, arthropod trackways, and *Diplocraterion* comprise a *Scoyenia* Ichnofacies and with the sedimentology suggest deposition within a lake-margin or floodplain setting. The uppermost of these strata are fluvial, with shallow channels, coals, and overbank mudstones. Overlying these beds in both Eclipse and North Bylot Troughs, an Upper Cretaceous transgressive shale is characteristically dominated by *Phycosiphon*, forming an assemblage of the *Zoophycos* Ichnofacies and interpreted as representing outer shelf (or more distal) deposits. Higher Upper Cretaceous sandstones in Eclipse Trough record progradational cycles of storm-dominated, inner shelf through foreshore deposits, with cross-stratified beds alternating with bioturbated fair-weather beds containing diverse and abundant archetypal *Cruziana* Ichnofacies suites. At Maud Bight, probable Upper Cretaceous sandstones also reflect storm-dominated, lower shoreface to upper shoreface, hummocky to tabular cross-stratified beds alternating with fair-weather beds, characteristically bioturbated by *Macaronichnus*. Similar storm-dominated shoreface strata are seen in Paleocene sandstones from

Eclipse Trough; however, more thickly bedded sandstones there show evidence of high sedimentation rates, suggesting deltaic deposition. In Maud Bight, probable Paleocene sandstones and conglomerates reflect delta-front deposition, in addition to fine-grained, grey, *Macaronichnus*-dominated shoreface to foreshore sandstones. Overlying the Paleocene sandstones in Maud Bight, interbedded shales, siltstones, and sandstones reflect shallow, brackish deposition within an estuarine or prodeltaic setting. The overall succession is predominantly marine with common storm-dominance and similar depositional paleoenvironments seen between the two structurally isolated areas of Bylot Island.

---

### Searching for a deep biosphere, hydrocarbon fingerprint in hydrothermal vent sediments at Guaymas Basin, Gulf of California, USA

---

\*C.J. DALZELL<sup>1</sup>, G.T. VENTURA<sup>1</sup>, R.K. NELSON<sup>2</sup>, C.M. REDDY<sup>2</sup>, AND S.M. SIEVERT<sup>2</sup>

1. Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada <connor.dalzell@smu.ca> ¶

2. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543-1050, USA

Conventional petroleum-producing systems often involve multiple sources of sedimentary organic matter. As such, it is difficult to resolve how each input contributes to the characteristics of the resulting oil. To elucidate these differences, we are examining the accelerated petroleum production that naturally occurs in sedimented, deep-sea hydrothermal vent sites, at Cathedral Hill hydrothermal vent site in Guaymas Basin, Gulf of California. In this area, high temperature vent fluids (up to 350°C) rapidly pyrolyze organic-rich sediments on the ocean floor. This produces hydrothermal petroleum at accelerated rates of thousands to tens of thousands of years as opposed to the millions of years required for generation in conventional oil producing basins. We propose that these hydrothermally accelerated petroleum-producing pathways and associated products are comparable to those in conventional systems. Therefore, this project explores how mixed-sources of organic matter are differentially transformed into petroleum forming hydrocarbons by holistically tracking all of the gas chromatographically amenable compounds in a push-core transect from at Cathedral Hill. This site is an active complex of white smokers that receives high inputs of organic matter from overlying surface waters and via runoff from the surrounding continent. Collectively, this results in a rapid sedimentation rate, which produces near uniform compositions of sedimentary organic matter. This study is examining the petroleum forming processes and the factors

controlling the molecular compositions of hydrothermally generated oils. The results may provide insight into the role that water and inorganic minerals play as reactants/catalysts during hydrothermal petroleum generation. Furthermore, this study may aid in the characterization of hydrocarbon fingerprints associated with microbial activity in shallow sediments and may lead to the discovery of novel biomarkers useful in petroleum exploration by improving oil fingerprinting and paleoenvironmental reconstruction techniques.

---

### Application of the paleolimnological method in the environmental assessment of estuarine sediments in a pulp effluent receiving pond: an example from northern Nova Scotia, Canada

---

KIRKLYN DAVIDSON<sup>1</sup>, BAILLIE HOLMES<sup>1</sup>, IAN SPOONER<sup>1</sup>, TONY WALKER<sup>2</sup>, CRAIG LAKE<sup>3</sup>, AND D. DUNNINGTON<sup>3</sup>

1. Department of Earth and Environmental Science, Acadia University, Wolfville, Nova Scotia B4P 2R6, Canada <124859d@acadiau.ca> ¶

2. School for Resource and Environmental Studies, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada ¶

3. Department of Civil and Resource Engineering, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada

Paleolimnological research at an effluent receiving pond in Pictou County, NS has focussed on understanding the spatiotemporal distribution of metals within pre- and post-disturbance sediments. The site was dammed in 1972, effectively converting an estuary into a shallow receiving pond (140 ha, 4 m max. depth). The sediment in the receiving pond reflects both estuarine and fresh water environments and can be broadly characterised as grey marine silt (~ 50% water content) which is sharply overlain by black, organic-rich sediment (~ 90% water content) that has been impacted by the effluent. To determine if contaminant overprinting has occurred, 18 cores of the grey sediment were analysed both at and below the contact for the distribution of As, Cd, Cr, Cu, Pb, Ti, Zn, Mo, and Ni. Total C, total N,  $\delta^{13}\text{C}$ , and  $\delta^{15}\text{N}$  analyses provided clarity on organic matter composition. The samples were collected using a gravity corer, were analysed for metal concentrations using pXRF and ICP-MS techniques, and data was evaluated using R and plotted using QGIS.

Total C, N, and isotope analyses indicate a brackish to marine origin for the grey sediment. Concentrations of As, Cr, Cu, Zn, and Pb in the sediment at the receiving pond are similar to or slightly higher than at reference sites; at both sites concentrations meet or exceed Interim Sediment Quality Guidelines. There is little stratigraphic

variability at each core site, indicating that overprinting of contaminants from the effluent-influenced sediment is unlikely. Considerable variation is evident spatially for all elements, though no distinct patterns were observed. These data demonstrate a geogenic source for many of the elements that have been attributed to the effluent. Our study shows that geogenic contributions must be accounted for when establishing remediation baseline conditions and assessing the effectiveness of site remediation.

---

**Improved spatio-temporal polycyclic aromatic hydrocarbon (PAH) characterization and assessment in small craft harbour sediments in Nova Scotia, Canada**

---

EMILY DAVIS<sup>1</sup>, TONY R. WALKER<sup>1</sup>, MICHELLE ADAMS<sup>1</sup>, AND ROB WILLIS<sup>2</sup>

*1. School for Resource and Environmental Studies,  
Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada  
<e.davis@dal.ca> ¶*

*2. Dillon Consulting Limited, 137 Chain Lake Drive, Suite 100,  
Halifax, Nova Scotia B3S 1B3, Canada*

Small craft harbours (SCHs) are crucial for the fishing industry which is vitally important for the Canadian culture and economy. Nearly 90% of all fishing landings in Canada (worth \$1.6 B CAD), occur at SCHs. Sediments in these SCHs regularly require maintenance dredging for navigation but are commonly contaminated from various anthropogenic activities. In terms of pollutant inputs, polycyclic aromatic hydrocarbons (PAHs) represent one class of contaminants commonly found in marine environments. PAH compounds can accumulate in both aqueous and sediment fractions of harbour systems, creating “hot spots” for sediment contamination. Anthropogenic PAH inputs are produced from various sources, including petrogenic sources associated with petroleum inputs and pyrogenic sources from the combustion of wood, coal, and other organic substances. PAH sources are important to consider as they differ in their ecological impacts in the marine environment. Current assessment of PAHs in SCHs (sediment sampling), relies heavily on bulk sediment PAH concentrations to determine their inherent risk to organisms, water, or sediment quality, with source apportionment often neglected. Source apportionment may provide useful background information for SCH decision makers with respect to source control and remedial options for harbour systems. This research aimed to understand the temporal and spatial variation of PAH concentrations in 31 SCHs across Nova Scotia over a seventeen-year period (2001–2017), while also considering source apportionment to help determine PAH sources. Preliminary results indicate

that the three regions of Nova Scotia (Gulf, Eastern and Southwest) differ in the extent and magnitude of PAH contamination among harbours, with certain harbours demonstrating extremely high PAH concentrations that exceed federal sediment quality guidelines. In terms of sourcing, an overwhelming combustion signature has been identified among all three regions, suggesting that the majority of PAH inputs are from pyrogenic sources and likely from both localized activities and potential long-range transport processes.

---

**Submarine slope failures in inner Frobisher Bay, Canada: morphology, geography, and chronology**

---

ROBERT DEERING<sup>1</sup>, TREVOR BELL<sup>1</sup>, DONALD L. FORBES<sup>1,2</sup>, CALVIN CAMPBELL<sup>2</sup>, AND EVAN EDINGER<sup>1</sup>

*1. Department of Geography, Memorial University of  
Newfoundland, St. John's Newfoundland and Labrador  
A1B 3X5, Canada <robert.deering@mun.ca> ¶*

*2. Geological Survey of Canada-Atlantic, Bedford Institute of  
Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada*

Inner Frobisher Bay hosts an abundance of marine geohazard features (iceberg scours, methane seep pockmarks, and submarine slope failures), raising the question of what threat these processes pose to Iqaluit, the hub of transportation, government, and commerce in the eastern Canadian Arctic. Essential municipal, commercial, and subsistence infrastructure and important cultural resources are located along the urban waterfront at levels vulnerable to flooding. Additionally, new seabed and coastal infrastructure projects may be vulnerable to geohazards in the bay. Submarine slope failures (SSFs), if still actively occurring, have the potential for local seabed and widespread onshore effects. Comprehensive multibeam echosounding (MBES) mapping, covering approximately 75% of inner Frobisher Bay, has revealed 246 SSF features in the basin, a greater density than known anywhere else in Arctic Canada (~1 per 4 km<sup>2</sup>). SSFs can cause destruction directly through their rapid displacement of seafloor and indirectly through the generation of tsunami waves. A preliminary morphometric analysis of these features revealed most to be small (<0.09 km<sup>2</sup>) localized events, incapable of generating a tsunami. However, a few larger events (>1 km<sup>2</sup>) may pose a localized tsunami risk in a partially enclosed basin. Further analysis focusing on three key aspects (morphology, distribution, and chronology) can better establish whether these SSF events pose a hazard in the region. Using a high resolution MBES dataset, SSF features in inner Frobisher Bay were mapped and key morphometric parameters were measured, allowing for further assessment

of their magnitude and tsunamigenic potential. Analysis of SSF distribution enables the study of these features in relation to basin geometry which may focus their energy and impacts. Furthermore, highlighting areas of greater feature abundance can inform planning of developments in the region. The establishment of a chronology of events determines whether SSFs are ongoing processes or if the SSF signatures are simply indicative of mechanisms that have become inactive. The seabed expression of SSF features in inner Frobisher Bay ranges from very fresh-looking to subdued, the latter presumably because of sediment accumulation since the event, suggesting that the SSFs have a wide range of ages. Preliminary results from radiocarbon ages from marine sediment cores indicate ages ranging from 4 to 7 ka. This study has demonstrated that SSF events large enough to pose a hazard to seabed and coastal infrastructure have occurred in inner Frobisher Bay, but it remains unclear what triggered the failures and whether this is an ongoing risk today.

---

#### Experimental imaging of a vertical vein using controlled-source seismic interferometry

---

KRISSELLE DIAS AND CHARLES HURICH

*Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador A1B 3X5, Canada <kdias@mun.ca>*

Seismic methods are desirably implemented in the imaging of economically viable hard rock mineral deposits, due to the technique's intrinsic higher resolution in comparison to traditionally used geophysical methods. Traditional surface seismic methods are inadequate in the imaging of steeply dipping targets, due to unfavourable geometrical relationships between the surface sources, surface receivers, and the target. There is poor recovery of data when geological features have a dip greater than approximately 65°, as the reflected wave propagates at an angle that reaches the surface outside the aperture of the receiver array or does not reach the surface at all. Steep dips also cause the overall travel path to be much longer than the depth of the target, causing a loss of energy and associated amplitude and high frequency attenuation which results in a low signal to noise ratio and associated processing issues. This study investigates the viability of using vertical seismic profiles (VSP) in combination with seismic interferometry as a new method of imaging thin and nearly vertical veins, and develops techniques for the same, and for which a thin, nearly vertical barite vein at the Collier Point Barite property in eastern Newfoundland serves as a well constrained target for study. Seismic interferometry

is a technique in which, a signal pair is cross-correlated to reproduce a virtual source-receiver pair and reconstruct the associated wavefield. These methods can virtually move a source into a downhole location, which avoids the geometric limitations associated with surface-seismic methods. The parameters of the field experiment are optimized using ray-tracing analysis, finite-difference modelling and a study of the physical properties to ensure reflection detectability. The unprocessed dataset is highly contaminated by tube-waves which are removed using spiking deconvolution and F-K filtering. The pre-processed dataset is then subjected to seismic interferometry methods and is processed using standard CMP processing flows. It is noted that the seismic response to the barite target varies significantly through the profile. A 1-D synthetic seismogram modelling program is used to study the variations in the seismic response of the target, and propose a geological interpretation for the same, which is consistent with descriptions in prior geological reports. The study demonstrates that VSP's in combination with the seismic interferometry procedure has proven to be an appropriate tool towards detecting and imaging vertical to near-vertical subsurface bodies of economic importance which may otherwise not be imaged appropriately using surface-seismic methods.

---

#### Resolving episodes of deformation and hydrothermal quartz precipitation in the Amalgamated Break fault, Abitibi Subprovince, Ontario, Canada, from microstructural and SEM-CL analyses\*

---

TAYLOR A. DUCHARME, DAVID A. SCHNEIDER, AND MARK J. COLEMAN

*Department of Earth and Environmental Sciences, University of Ottawa, Ottawa, Ontario K1N 6N5, Canada <tduch009@uottawa.ca>*

Scanning electron microscopy cathodoluminescence (SEM-CL) imaging of quartz can reveal microstructural relationships implicating deformation and hydrothermal growth that would not otherwise be visible using conventional optical microscopy techniques. These microstructures manifest in contrasts between strong (bright), moderate (grey) and weak (dark) CL responses. Moreover, as part of this physiochemical phenomenon, chemically distinct hydrothermal regimes may be reflected in alteration and vein mineral assemblages. Discrete episodes of hydrothermal alteration may consequently lead to variations in trace element concentrations in vein quartz and can further enhance the discrete contacts between CL-bright and CL-dark quartz in otherwise optically continuous grains. Samples from the ductile-brittle E-W-trending

Amalgamated Break fault zone in the Kirkland Lake region of the Abitibi Subprovince preserve quartz vein sets emplaced during repeated episodes of deformation along the fault. These veins are hosted in subvertical, mylonitized, lower-greenschist facies chlorite-muscovite phyllite. Quartz in pyrite pressure shadows and sigmoidal aggregates of quartz or white mica preserve dominantly north-side-up and sinistral displacement along the fault. This indicates either oblique displacement during the most recent deformation or preservation of two distinct episodes of deformation. Microstructures show quartz accommodated strain by grain boundary bulging (BLG) dynamic recrystallization, suggestive of deformational temperatures between 250°C and 400°C, consistent with  $\delta^{18}\text{O}$ -derived data for fluid temperatures in the region. Quartz CL analysis in these veins highlights growth relationships of progressive generations of hydrothermal quartz. Quartz veins display dominantly CL-dark and CL-grey responses that reveal brecciated CL-dark quartz infilled with CL-grey quartz. Fragmented, euhedral CL-bright quartz crystals with puzzle-like geometry suggest fracturing and subsequent healing through precipitation of CL-dark quartz. Relict detrital quartz grains exhibit a predominantly CL-bright response. These grains are cross-cut by bands of CL-dark quartz <1–20  $\mu\text{m}$  in width. CL-bright quartz geometry in veins may represent deformed detrital grains overgrown by hydrothermal quartz. SEM-CL images integrated with polarized light photomicrographs (with the gypsum plate) reveal that intracrystalline fractures and optical grain boundaries delineate domain borders of CL-bright and CL-dark quartz, or otherwise cross-cut CL-bright domains without imposing any discontinuity in CL response. The textures observed indicate at least two episodes of coeval deformation and fluidization: (i) fracturing of CL-bright, detrital quartz followed by infilling and overgrowth by CL-dark hydrothermal quartz; (ii) brecciation of CL-dark quartz by CL-grey quartz-bearing fluids. Integration of these data can shed light on sequences of deformation and hydrothermal growth in regions with complex tectonic histories.

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

---

### Environmental data for future generations: storage formats for multi-parameter, spatiotemporal data

---

DEWEY W. DUNNINGTON<sup>1</sup> AND IAN S. SPOONER<sup>2</sup>

1. Centre for Water Resources Studies, Department of Civil and Resources Engineering, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <dewey.dunnington@dal.ca> ¶

2. Department of Earth and Environmental Science, Acadia University, Wolfville, Nova Scotia B4P 2R6, Canada

Long-term records of environmental change are made up of complex, multi-parameter data, often collected from many sites; the complexity of these datasets can make the storage, visualization, and manipulation of such data inherently challenging. Metadata documenting the how and why of data collection are commonly omitted or stored separately from the data. Dedicated programs have attempted to ameliorate these problems, but the storage format used can be inflexible and/or proprietary, limiting the future reuse of data. In essence, environmental data are comprised of measurements, each having qualifiers (e.g., location identifier, depth below surface, and measured parameter), a value, and tags (e.g., amount of error, number of replicates, written notes pertaining to the value). When data are stored in a table with one row per measurement, the maximum amount of measurement data is retained; when data are stored in a table with one row per time interval per location (one column per parameter), some information is lost but the data are more amenable to visualization in spreadsheet software. The conversion between these structures is easily accomplished using both interactive (e.g., spreadsheet software) and programmatic (e.g., R and Python) mechanisms. As more advanced statistical treatment of data becomes common in long-term environmental studies, storing data in a way that does not result in data loss is advantageous to enhance the replicability of visualizations and statistical analyses. As datasets are increasingly combined with others and reused in future analyses, formats that store metadata with the data itself are particularly important for data collectors to consider.

---

### Promoting Nova Scotia's culture of geoscience: the past is the key to the future

---

TIM J. FEDAK

Curator of Geology, Nova Scotia Museum, Halifax, Nova Scotia B3H 3A6, Canada <tim.fedak@novascotia.ca>

The coastal geology of *Canada's Ocean Playground* has played a vital role for sustaining our vibrant culture and developing of our global world view. Since the 1800s, geology has been a focal point of international identity for Nova Scotia. From the importance of Nova Scotia's mineral resources displayed at the international world's fairs (1862–1876), to the contributions of Dawson, Logan and Lyell at Joggins, geology has provided Nova Scotia with international recognition and contributed to our modern world view of the planet. From the 1950s to today, Nova Scotia's culture of geoscience has continued to attract global attention with important fossils and geology of the Fundy

rift basin, opening of the Fundy Geological Museum in 1994 and the establishment of the Joggins Fossil Cliffs UNESCO World Heritage Site in 2008. Looking toward the future, Nova Scotia released the Culture Action Plan in 2017 as a comprehensive strategy focused on celebrating and sharing our culture, our creative sector, and our diverse communities. The new Culture Innovation Fund has recently been established to support the Culture Action Plan goals. This year, the Nova Scotia Museum is celebrating 150 years as a provincial museum, having been established in 1868 with early collections of minerals and fossils that have shaped Nova Scotia culture. At this exciting time, it is interesting to consider how the geoscience community can further advance Nova Scotia's international identity and diverse culture. Advancing awareness of Mi'kmaq culture and sites in the Cliffs of Fundy Aspiring Geopark and use of new digital media and innovative technology are two examples of how we can continue to support the culture of geoscience that enriches Nova Scotia society. Geology provides a vital perspective for many of the challenges that confront our society, including coastal erosion, global climate change and ecological adaptation. Nova Scotia's geoscience community and historic geology collections continue to provide an important perspective that will continue to enrich our culture and society in the years to come.

---

### Worth a thousand words: the use of photographs in geoscience outreach

---

ROBERT FENSOME

*Geological Survey of Canada (Atlantic), Natural Resources Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada <rob.fensome@canada.ca>*

In communicating our science to the public, writing in an easily understood and interesting style is vital, and well-designed schematics are essential; but nothing catches the attention more than an attractive photograph. A well-crafted image can indeed be worth a thousand words! From experience in making and selecting images for several prominent outreach projects over the past two decades, I share some thoughts on what makes a good “outreach” geological image or set of images. In our more technical work, the tiniest detail is usually the main focus (pun intended). But in conveying geological ideas to a general audience, the “big picture” is usually more important than details, and setting the geological subject matter in a broader backdrop (for example rocks with a beach or cliff in the background) puts the general viewer more at ease. Technical-looking scales, especially in the centre of an image, are very off-putting for a general audience, for whom

a leaf, or tree or person would give an unobtrusive sense of size. Other aspects of more general photographic appeal — attractive colours, thoughtful composition, interesting contrasts — are also obvious assets for a successful image. I will use examples from outreach products such as *The Last Billion Years*, *Four Billion Years and Counting*, and *Nova Scotia Rocks* to illustrate images that in my view work in an educational context. Also, I will discuss the collaboration between the Atlantic Geoscience Society (AGS) and the Photographic Guild of Nova Scotia since 2001. In conclusion I encourage geologists in the field to consider making images for outreach purposes in addition to those for technical needs: maybe when the AGS website is revamped, it could include a bank of images that members and educators could use for educational purposes, including public engagement exercises.

---

### Advances in Mesozoic–Cenozoic stratigraphy in northern and offshore eastern Canada, with emphasis on palynological event stratigraphy

---

ROBERT FENSOME<sup>1</sup>, JENNIFER GALLOWAY<sup>2</sup>, HENRIK NØHR-HANSEN<sup>3</sup>, AND GRAHAM WILLIAMS<sup>1</sup>

1. *Geological Survey of Canada (Atlantic), Natural Resources Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada <rob.fensome@canada.ca>* ¶
2. *Geological Survey of Canada (Calgary), Natural Resources Canada, Calgary, Alberta T2L 2A7, Canada* ¶
3. *Geological Survey of Denmark and Greenland, GEUS, Øster Voldgade 10, Dk-1350 Copenhagen K, Denmark*

Traditional biostratigraphic work in northern and offshore eastern Canada focussed primarily on the development of zonation schemes. More recently, starting with a Late Cretaceous–Cenozoic scheme for the Scotian Margin, an event stratigraphy approach has been followed. This scheme employed data from palynomorphs (dinoflagellate and other algal cysts, spores and pollen), nannofossils, and foraminifera. This approach was further developed in collaboration with academia and industry for the Play Fairway Analysis (PFA) project funded by the Nova Scotia government. A collaboration with the Geological Survey of Denmark and Greenland (GEUS) led to the formulation of a Cretaceous–Cenozoic event stratigraphy scheme for the Labrador–Baffin Seaway, based primarily on dinocysts, which enabled an improved correlation between offshore Greenland and offshore Canada. Work in northeastern Canada continues through analysis of surface sections on Bylot Island, as well as additional offshore studies as part of the Geoscience for Energy and Minerals (GEM) Baffin “region of interest” project at the Geological Survey of

Canada (GSC). Similar activities are underway in the Mackenzie and Western Arctic GEM regions of interest. Specifically, palynological analyses have been carried out on two middle Cretaceous sections in the Mackenzie Plain area west of Norman Wells, Northwest Territories; and Upper Jurassic to Upper Cretaceous sections at Glacier Fiord on Axel Heiberg Island, Nunavut. The aim is eventually to compile a trans-Arctic event stratigraphy, synthesizing all known events in Time Scale Creator software. In addition to the biostratigraphic work, palynomorphs in the regions studied yield important paleoenvironmental information. For example, dinocyst to miospore ratios and relative abundances of individual dinocyst taxa allow for the identification of non-marine, marginal-marine, inner-shelf, outer-shelf and bathyal paleoenvironments. Climatic trends can be determined using both dinocysts and miospores, such as Early Cretaceous ‘cold snaps’, which provoked terrestrial ecosystem change preserved in pollen and spore records from Arctic Canada. Maastrichtian dinocysts from the Labrador Sea show remarkable similarity to those found in higher latitudes of the Southern Hemisphere. A predominance of the dinocyst *Apectodinium* in one Labrador Shelf well denotes the Paleocene–Eocene Thermal Maximum, when Cenozoic temperatures peaked. Further, statistical analyses of pollen and spore assemblages from the Glacier Fiord section allow for the identification of ecosystem changes that may be correlatable within and between basins correlation. Another important aspect of work at the GSC is to develop atlases of palynomorphs (PalyAtlases) to stabilize taxonomic communication, which is vital for accurate applied studies.

- Montreal, Quebec H3A 2T7 Canada ¶  
 7. Canada-Nunavut Geoscience Office, Iqaluit,  
 Nunavut X0A 0H0 Canada ¶  
 8. Faculty of Computer Science, Dalhousie University,  
 Halifax, B3H 4R2 Canada

*Ulinniq* is an Inuktitut word for rapid inundation of land by seawater. Seismicity- and landslide-triggered tsunamis are arguably the most significant natural hazard for communities in Arctic Canada. Most of the communities and major infrastructure, including airports and hospitals, are less than 60 m above sea level and therefore vulnerable to *ulinni*q.

ULINNIQ is a multidisciplinary research project funded by the National Centre of Excellence MEOPAR to provide a comprehensive seismic and tsunamic risk analysis for Nunavut and Atlantic Canada. Initial goals include (i) deploying ocean-bottom sensors in Baffin Bay east of Pond Inlet, within a moderate-high seismic risk zone, to obtain precise position and timing of all seismicity over at least one year, (ii) interpret marine sediment records in and beyond fjords on eastern Baffin Island to extract a paleoseismology history, if possible, from chronostratigraphies that include mass transport deposits; (iii) establish the recurrence interval and location of past rock avalanches and currently gradually sliding or precarious massive slope blocks, with focus on failures that can trigger large displacement waves (such as the deadly 100 m high tsunami that affected Nuugaatsiaq, western Greenland, on June 17, 2017); (iv) after a process of consultation, obtain oral testimonies regarding *ulinni*qs and earthquakes from Inuit Elders in the hamlets of Pond Inlet and Clyde River; (v) develop a numerical model for Greenland and North America that computes the process of glacial isostatic adjustment and the accompanying lithospheric stress changes that may result in seismicity that could directly or indirectly trigger tsunamis; (vi) improve and use the already comprehensive record of habitational evidence on well-dated raised shorelines in the region to determine the timing and location of pre-historic tsunami where evidence is missing.

These models and data are needed to test hypotheses regarding how the rate and style of deglaciation may induce major earthquakes along otherwise inactive intraplate faults, such as the 1929 M7.2 Grand Banks earthquake, and to provide a robust risk analysis for targeted eastern Arctic and Atlantic Canadian communities.

---

### Arctic ULINNIQ—underwater listening network for novel investigations of quakes

---

JOHN C. GOSSE<sup>1</sup>, MLADEN R. NEDIMOVIĆ<sup>1</sup>, CALVIN CAMPBELL<sup>2</sup>, GEORGE W. WENZELL<sup>3</sup>, BJÖRN LUND<sup>4</sup>, REBEKKA STEFFEN<sup>4</sup>, REGINALD L. HERMANN<sup>5</sup>, JAMES M. SAVELLE<sup>6</sup>, LAURA-ANN BROOM<sup>1</sup>, TOMMY TREMBLAY<sup>7</sup>, AND SAGEEV OORE<sup>8</sup>

1. Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia, B3H 4R2, Canada <john.gosse@dal.ca> ¶
2. Geological Survey of Canada, NRCAN, Dartmouth, Nova Scotia B2Y 4A2, Canada ¶
3. Department of Geography, McGill University, Montreal, Quebec, H3A 0B9, Canada ¶
4. Department of Earth Sciences, Uppsala University 752 36 Uppsala, Sweden ¶
5. Geohazard and Earth Observation, Geological Survey of Norway, 7040 Trondheim, Norway ¶
6. Department of Anthropology, McGill University,

---

### Legacy infrastructure in the Stoney Creek oil field based on well site visits and magnetic surveys

---

MITCH GRACE AND KARL E. BUTLER

*Department of Earth Sciences, University of New Brunswick,  
Fredericton, New Brunswick E3B 5A3, Canada  
<mitch.grace@unb.ca>*

The Stoney Creek oil and gas field lies about 15 km south of Moncton, NB, on the western side of the Petitcodiac River. In 1909 oil and gas were discovered at Stoney Creek and the area rapidly evolved into an operating field, with pipelines in place supplying natural gas to the surrounding Moncton and Hillsborough communities by 1912. Over 100 wells have been drilled in the field, and several wells remain in operation, but over 100 are now classified as abandoned, and were left in various states as regulations changed over the years. Inadequately abandoned oil and gas wells provide potential pathways for methane and other fluids to migrate to the surface, contaminate ground water, and emit to the atmosphere. In 2017 the Stoney Creek Field became the subject of an NRCAN-funded study to assess greenhouse gas emissions from sites of legacy fossil fuel infrastructure in the Maritimes.

Visits to the sites of 39 legacy wells, abandoned prior to 1960, were conducted by UNB researchers in the summer of 2017 in order to document remaining infrastructure – both visually and by magnetic surveying. At 16 sites, casings were not visible at surface, but measurements of the total magnetic field using an Overhauser effect magnetometer (GEM Systems Inc. GSM-19GW) revealed large monopolar anomalies (>3000 nT in amplitude) that were able to pinpoint locations and estimate the depths of buried steel casings in support of a soil gas sampling program by St. Francis Xavier University.

Field observations revealed legacy well site conditions to fall under three categories: (i) grassy clearings with casing and well head still in place above ground (6 sites); (ii) grassy clearings with a casing in place but cut below ground (16 sites); and (iii) heavily wooded sites where no well casings were detected (17 sites). The majority of remaining site infrastructure consisted of scrap metal, steel cables, and remainders of connecting pipelines which were most commonly found near sites which had been reclaimed by coniferous forest.

Results from the magnetic surveys conducted at each site revealed depths to top of buried casings vary anywhere from cut at surface to a maximum of approximately 3 m depth. The lack of evidence for steel casing at many sites is not surprising given notes observed on some drill logs from the early to mid-1900s indicating that casings were occasionally pulled from wells.

---

### Early Devonian magmatism, northeastern Dunnage Zone, Newfoundland, Canada, and the nature of basaltic to granitic additions to large magma chambers

---

BEN GRAHAM, GREG DUNNING, AND ALISON LEITCH

*Department of Earth Sciences, Memorial University of  
Newfoundland, St. John's, Newfoundland and Labrador  
A1B 3X5, Canada <gdunning@mun.ca>*

Early Devonian (ca. 413–406 Ma) intrusions occur along the north coast and islands of Notre Dame Bay. They are coeval with a regional deformation event and are predominantly tonalite to granodiorite. Detailed study of one of these intrusions on Fogo Island documents complicated magma mingling on both a field and mineralogical scale during the emplacement of multiple crystal-rich pulses into a growing magma chamber. Modern theories present magma chambers as short-lived reservoirs that are continuously fed by intermittent magma pulses, and processes that occur within them can be highly dynamic. Field evidence of complex magma mingling features occurs at Wild Cove, along the northeast shoreline of Fogo Island, an area interpreted to represent the roof/wall region of a magma chamber. Microgranitoid enclaves of intermediate composition are contained in host rocks of similar composition and occur in rounded, amoeboid shapes. Dykes are broken up into globules in localized parts of the cove, suggesting one mechanism by which the enclaves could be formed as dykes passed through a strong crystal mush into a more liquid-rich region of the magma chamber. New heat was added at a shallow level by emplacement of major olivine-basaltic sills into these mushes, likely reactivating them.

The irregular but sharp nature of the boundaries between units suggests that all co-existed as “mushy” magmas with variable crystallinities reflecting a wide range in temperature between their respective liquidus and solidus. Textural evidence of complex mingling between mush units includes the intrusion into quartz diorite and granite mushes by tonalite dykes which were later pulled apart and subsequently back-intruded by liquid from the host mush. Magmatic tubes of intermediate magma which migrated through magma of identical composition are observed in localized parts of the cove and likely reflect compaction of underlying mush after intrusion of new pulses of magma into the system.

Mineral textures and chemistry reflect the complexity recognized in the outcrop. Multiple zones reflecting growth-corrosion-growth recorded in pyroxene and plagioclase crystals in tonalite, include compositions that must have crystallized from basalt prior to incorporation in the tonalite. Different generations of mafic enclaves have differing chemistry and reflect multiple inputs of hybridized



magma. Tonalitic mushes had 20 to 40% euhedral plagioclase at time of solidification. The field, petrographic and chemical data combine to demonstrate a very dynamic ‘open’ magmatic system with both mantle and crustal melt input and hybridization.

---

### Investigating the relationship between the Bras d’Or and Aspy terranes in Cape Breton Island, Nova Scotia, Canada: insights from Devonian plutonic rocks

---

CALEB GRANT<sup>1</sup>, DONNELLY B. ARCHIBALD<sup>1</sup>, DAWN A. KELLETT<sup>2</sup>, AND NICOLAS PIETTE-LAUZIÈRE<sup>3</sup>

1. Department of Earth Sciences, St. Francis Xavier University, Antigonish, Nova Scotia B2G 2W5, Canada <x2014ggr@stfx.ca> ¶
2. Geological Survey of Canada, Natural Resources Canada, Dartmouth, Nova Scotia B2Y 4A2, Canada ¶
3. Earth, Environmental and Geographical Sciences, University of British Columbia, Kelowna, British Columbia V1V 1V7, Canada

Located on the eastern margin of North America, Cape Breton Island, Nova Scotia, records a complex geological history that formed during the Palaeozoic Appalachian orogenic events. The Appalachian orogen records the accretion of a series of peri-Gondwanan terranes to the composite Laurentian margin. The four major terranes in Cape Breton Island are the peri-Laurentian Blair River Inlier, and the peri-Gondwanan Aspy, Bras d’Or, and Mira terranes. The Bras d’Or terrane is comprised of Neoproterozoic gneissic and metasedimentary units with associated metavolcanic rocks. The Aspy terrane is dominated by younger Silurian–Devonian back-arc sedimentary and volcanic rocks that were intruded by post-depositional plutonic rocks. The boundary between the Aspy and Bras d’Or terranes is defined as a regional, east over west, sinistral shear zone named the Eastern Highlands Shear Zone (EHSZ). Devonian plutons of the Black Brook Granite Suite (BBGS) that intruded into the EHSZ form the focus of this study. The BBGS is a peraluminous, muscovite-biotite, mainly granitoid plutonic suite that has been interpreted by previous workers to have formed from partial melting of metasedimentary rocks. The purpose of this study is to characterize the petrogenesis of the BBGS and other spatially associated “stitching” granitoid plutons such as the Park Spur pluton that are also located along the EHSZ. The study suggests the timing of the emplacement of the BBGS using U–Pb zircon data to be ca. 399–396 Ma. Whole-rock geochemical and zircon hafnium isotopic signatures will be analyzed to determine whether the petrological protolith can be linked to either the Bras d’Or terrane or the Aspy terrane and to better understand the tectonic setting at the time of pluton emplacement. Results will be used to correlate Devonian magmatism within the peri-Gondwanan terranes

of northeastern Cape Breton Island that are associated with the EHSZ with coeval magmatic rocks in Newfoundland and New Brunswick that have similar ages, lithologies, and geological histories.

---

### Time travel at Arisaig, Nova Scotia, Canada, an Atlantic Geoscience Society video production

---

ROBERT G. GRANTHAM<sup>1</sup>, MARTHA E. GRANTHAM<sup>2</sup>, DAVID FROBEL<sup>3</sup>, ROBERT FENSOME<sup>4</sup>, AND GRAHAM WILLIAMS<sup>4</sup>

1. 26 Rockwell Drive, Stewiacke, Nova Scotia B0N 2J0, Canada <robert@grantham.com> ¶
2. Natural Resources Education Centre, Middle Musquodoboit, Nova Scotia B0N 1X0, Canada ¶
3. 14 Micmac Drive, Dartmouth, Nova Scotia B2X 2H2, Canada
4. Geological Survey of Canada (Atlantic), Natural Resources Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada

The Paleozoic rocks of Nova Scotia tell a fascinating story of moving continents, mainly microcontinents, with a general drift from southern high latitudes to more equatorial climes. The rocks at Arisaig, on the province’s Northumberland Strait shoreline, reveal the story of part of one of the microcontinents involved in this ancient canvas, Avalonia, which split from Protogondwana (modern Africa and South America) about 500 million years ago and drifted across the long-lost Iapetus Ocean, colliding with Laurentia (the core of ancient North America) about 400 million years ago. The Arisaig area has long been known for its exceptional exposures of Ordovician volcanic rocks and Silurian and Devonian storm-dominated, sea-floor sedimentary rocks that formed on Avalonia. The volcanic rocks record a restless tectonic interval during the Ordovician, with a mix of mafic and felsic flows. By the Silurian and Devonian volcanic activity had ceased in the Arisaig area, the geological record from that time being of sedimentary rocks. In fact, the shoreline in the Arisaig area displays the world’s most continuously exposed section of Silurian and Devonian sediments. The older parts of this section have no fossils, suggesting that oxygen was limited on the sea floor at the time. Higher in the section, however, more abundant fossils include *Tentaculites*, a mysterious extinct organism, brachiopods, nautiloids and burrows. In places we see evidence of ancient storms that killed off much of the animal life, creating beds of empty shells and broken fragments. This is the exciting story from deep time that we tell in the video, which is a project of the Atlantic Geoscience Society (AGS) Video Committee, who’s aim is to inform the public about important geological sites in Atlantic Canada. A subcommittee of the AGS Video Committee was struck to carry out the production of the

video. A storyline was developed and shooting took place in June of 2017. The camera and audio system was purchased from funds provided by the AGS Education Committee. Additional funding was received from the Canadian Geological Foundation. Most of the footage was shot in two days. Although some graphics are yet to be completed and added, it is taking shape and ready to be seen in its rough form. Excerpts will be shown in this session.

---

### A high-resolution record of sediment deposition in the Gulf of Aqaba, Red Sea, during the last ~5000 years

---

ARIEL GREENBLAT<sup>1A,B</sup>, MARKUS KIENAST<sup>1B</sup>, STEPHANIE KIENAST<sup>1B</sup>, LACHLAN RIEHL<sup>1B</sup>, ADI TORFSTEIN<sup>2,3</sup>, AND NATALIE CHERNIHOVSKY<sup>3</sup>

1. *Department of Earth Sciences (a), Department of Oceanography (b), Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <ar938468@dal.ca>* ¶
2. *Hebrew University, Jerusalem, Israel 91905* ¶
3. *Joint Interuniversity Institute, Eilat, Israel 88103*

The Gulf of Aqaba is a narrow and deep basin at the northeastern tip of the Red Sea. Sedimentation is dominated by biogenic and aeolian material, as well as by material delivered by various wadis surrounding the Gulf. Here we present paleoenvironmental proxy records from a 108 cm gravity core, recovered at 720 m water depth at the northern end of the Gulf. Radiocarbon dating shows that this core covers the last 5000 years. Bulk sediment elemental composition (determined by ICP-MS), foraminiferal abundances, and nitrogen isotopes will be discussed in the context of environmental and hydrographic variability. The carbonate content ranges between 25–45%, and generally covaries with changes in planktonic foraminiferal abundances (0–50/wet gram of sediment). In contrast, both nitrogen concentrations and sedimentary <sup>15</sup>N are homogeneously low (0.040% ± 0.002 and 5.00% ± 0.27, respectively) throughout the core, possibly suggesting a decoupling of carbonate production and nutrient availability. The most prominent interval within the core is an instantaneous event deposit at 96–87 cm (ca. 5190 ± 35 years BP) containing allochthonous material in a fining upward sequence. This period is tentatively ascribed to a turbidite triggered by an earthquake. Sediment flux directly sampled by co-located sediment traps deployed since 2014 shows that sedimentation is dominated by sporadic, short-lived flux events on the order of days. These events transport large quantities of terrestrial material, manifested by the down core Mg/Ca (and Fe/Al) record, which displays an inverse relationship to the carbonate (%) record. Several stratigraphic periods will be discussed in attempt to reconstruct recent geological and paleoceanographic patterns influencing the Gulf of Aqaba.

---

### Hydrological analysis of municipal source water availability in the Canadian Arctic territory of Nunavut accounting for population growth, infrastructure upgrades, and climate change

---

JENNY HAYWARD, AMY JACKSON, LINDSAY JOHNSTON,  
AND ROB JAMIESON

*Centre for Water Resources Studies, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <jenny.hayward@dal.ca>*

The territory of Nunavut is comprised of 25 small (<10 000 people) communities distributed throughout an area of approximately 1 900 000 km<sup>2</sup>. The entire territory is located in the zone of continuous permafrost and lacks ground-based transportation infrastructure (roads or railways) linking the communities to each other, or to southern regions of Canada. These factors result in challenges in building and operating community water infrastructure. Every community in Nunavut currently relies on surface water sources for potable water supply. Water is either extracted directly from a lake or river for treatment and delivery to residents, or pumped to reservoirs during the ice-free period in the short arctic summer. The reservoirs are sized to store water required for the entire year. Due to the remote location of many of these communities, it would be extremely challenging to respond to a scenario in which the surface water sources provided inadequate quantities of water for a community during a dry year. In light of climate change and recent potable water shortages, this study was conducted to provide a comprehensive assessment of water availability across the territory, which accounted for climate change and population growth. For each community, contributing watershed areas were delineated, and a water budget model was used to predict water availability using historical climate data, and projected future climate data generated from downscaled Global Circulation Model (GCM) output. A water availability index (WAI) was computed for each community for both historical and future climate scenarios, accounting for population growth and varying per capita water usage rates. The 24 communities (excluding Iqaluit) were then ranked according to the WAI to provide guidance for prioritization of water supply upgrades. Based on the watershed characteristics and community use, the results indicated that 7 of the 24 hamlets in Nunavut are at high risk of source water shortages. Results should be used to strategically allocate resources to develop alternative source water supplies in hamlets that have highest risk. This type of hydrological analysis could be applied in other arctic jurisdictions to provide a quantitative method of ranking relative risks of water scarcity.

---

**Geologic characterization and historical context for the Gas Seepage Project (GaSP) study areas in the Maritimes Basin, Canada**

---

FIONA HENDERSON<sup>1,2</sup>, ELLIOT MCCLAUCHLAN<sup>1</sup>, AND GRANT WACH<sup>1</sup>

1. *Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada* ¶

2. *Eosense Inc., 1 Research Dr., Dartmouth, Nova Scotia B2Y 4M9, Canada*

Fossil fuel sites are susceptible to the release of methane, a potent greenhouse gas (GHG), at any stage of the extractive sites lifetime. As a response to recent international climate change agreements, Canada has committed to reducing methane from upstream oil and gas industries by 40–45% from 2012 levels by the year 2025. The Gas Seepage Project's (GaSP) primary goal is to investigate and evaluate potential methane emissions associated with historic (legacy) hydrocarbon extraction sites (oil and natural gas wells, and coal mines) in Atlantic Canada. GaSP is the first multi-phase methane mitigation initiative to be conducted in Atlantic Canada with the aim to use a multidisciplinary, holistic approach to evaluate and provide an inventory of methane emissions from legacy fossil fuel extraction sites.

Geologic characterization and the historical context of the sites are necessary to build a foundation for understanding factors that influence methane gas accumulation, abundance, migration potential, approaches to future site mitigation, as well as the anthropogenic influences upon methane generation and migration. Most of developments within the Maritimes Basin were constructed prior to modern environmental regulations. Coal resources throughout Cape Breton Island and in counties north of the Cobequid-Chedabucto Fault System were mined in Nova Scotia for over two hundred years. The Nova Scotia Department of Natural Resources has recorded more than 1900 abandoned coal mine openings in the province and the total is likely higher. The Cumberland, Stellarton, and Sydney basins host most of the coalfields and were a focus of this study. Site characterization involved compiling geologic maps, infrastructure and historical production data of coal mining, and oil and gas development, incorporated into a geologic report and assembled onto a spatial platform using Arc Geologic Information System (GIS) 10.3 software. Examination of the structure, stratigraphy, coal composition, oil and natural gas occurrences, identified key geologic components controlling methane migration pathways for modelling potential trends and relationships. These are all significant for the other task components of GaSP for the analysis of methane emission trends and the investigation of the magnitude of emission rates to both geologic and

anthropogenic structural influences (i.e., faults, and mine adits), and the resource composition type (i.e., gas and coal types).

---

**Application of the paleolimnological method in the environmental assessment of effluent-influenced freshwater sediment: an example from northern Nova Scotia, Canada**

---

BAILLIE HOLMES<sup>1</sup>, KIRKLYN DAVIDSON<sup>1</sup>, IAN SPOONER<sup>1</sup>, TONY WALKER<sup>3</sup>, CRAIG LAKE<sup>2</sup>, AND DEWEY DUNNINGTON<sup>3</sup>

1. *Department of Earth and Environmental Science, Acadia University, Wolfville, Nova Scotia B4P 2R6, Canada* <124973h@acadiau.ca> ¶

2. *Department of Civil and Resource Engineering, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada* ¶

3. *School for Resource and Environmental Studies, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada*

A former estuary in Pictou County, Nova Scotia, began receiving effluent in 1967 from a pulp mill and, for a brief period, a chlor-alkali facility. In 1972 a dam was installed, and the estuary was transformed into a shallow, freshwater pond (140 ha, 4 m-depth). A paleolimnological approach was applied to the bulk geochemical assessment of the sediment that has accumulated at the site. The sediments in the receiving pond reflect the estuarine and fresh water phases of the waterbody and comprise grey marine-influenced dominantly clastic sediment overlain in sharp contact by dominantly organic freshwater sediment. Both units occur throughout the basin. This study focused on identifying the sources of metals (As, Cd, Cr, Cu, Pb, Ti, Zn, Mo, and Ni) in the freshwater phase that were identified as representative of impact at the site. Samples were obtained by gravity coring, and metal analysis was accomplished primarily with pXRF. Total C, total N,  $\delta^{13}\text{C}$ , and  $\delta^{15}\text{N}$  analyses provided clarity on the provenance of organic matter. Sediments were also obtained from a nearby freshwater lake and parallel analyses provided baseline reference concentrations for all bulk geochemical parameters. Data was analyzed in R and plotted using QGIS. At both the receiving pond and reference site, metal concentrations generally exceeded Interim Sediment Quality Guidelines (ISQGs); a strong local geogenic and atmospheric contribution is inferred. The higher levels of some metals (Cu, Zn, and As) at the receiving pond are directly associated with effluent input. There appeared to be no strong spatial trend that would be indicative of metal concentrations being localized to specific regions of the basin. Metal concentrations were generally highest at the top of the receiving pond sediment. Total C, N and stable isotope data indicate increasing low oxygen conditions and

higher terrestrial organic matter inputs till present. These data suggest that the composition of the receiving pond sediment may strongly influence the retention of metals. The bulk geochemical and organic matter characteristics of the receiving pond are anomalous with respect to the baseline of these parameters. Results of this study demonstrate that geogenic and local atmospheric contribution to metal load at contaminated sites must be determined if site assessment, remediation and rehabilitation techniques are to be effective.

---

### The hydrothermal system of the Miocene volcanic rocks of Western Lesbos, Greece

---

ALEXIS IMPERIAL<sup>1</sup>, GEORGIA PE-PIPER<sup>1</sup>, AND DAVID J.W. PIPER<sup>2</sup>

1. Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada <alexhimperial@gmail.com> ¶
2. Natural Resources Canada, Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Dartmouth, Nova Scotia B3Y 4A2, Canada.

The Sigri Pyroclastic Formation in the western side of the island of Lesbos consists primarily of pumice flows, mud flows, and stream conglomerate. Most of the pyroclastic rocks appear to be derived from a caldera near Vatoussa and shows extensive alteration and mineralization. The purpose of this study is to understand the hydrothermal system and determine the origin of the silica-iron-manganese mineralization. Samples were collected from the Jithra Ignimbrite, layered fine-grained sediments underlying the ignimbrite, a zoned nodule from a fault zone, and silicified wood samples from the Sigri Petrified Forest. Rock mineralogy and chemistry were investigated using a petrographic microscope, scanning electron microscope, electron microprobe, Laser Raman spectroscopy, and X-ray powder diffraction. Hydrothermal alteration minerals and assemblages identified from the altered ignimbrite are: (1) K-feldspar + silica + illite + minor apatite, zircon, TiO<sub>2</sub> minerals; (2) jarosite + hematite + amorphous silica and; (3) Mn-oxide. Three different horizons from the underlying sediments show identical mineral assemblage of smectite + silica + TiO<sub>2</sub> minerals ± monazite, hematite. The presence of hydrothermal quartz and K-feldspar, kaolinite and smectite are closely similar to the alteration assemblages found in the epithermal system of the Taupo volcanic zone which are created by different types of circulating groundwater. The hydrothermal veins and the zoned nodule are predominantly made up of silica + iron + manganese mineralization. The availability of manganese may be related to the decay of organic matter as the study area used to be forested with multiple tree horizons. While the amorphous

silica-iron mineralization is mineralogically and chemically comparable to jaspers found in exhalative marine systems. This observation is interesting because there is no evidence for a nearby marine condition in Western Lesbos.

---

### Using a watershed modeling approach to assess changes in phosphorus loading in the Mattatall Lake watershed, Nova Scotia, Canada

---

LINDSAY JOHNSTON, JENNY HAYWARD, MEGGIE LETMAN, RICHARD SCOTT, AND ROB JAMIESON

Centre for Water Resources Studies, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <Lindsay.Johnston@dal.ca>

Mattatall Lake is small headwater lake located on the boundary of Cumberland and Colchester County, Nova Scotia, which has recently experienced cyanobacteria blooms. Phosphorus (P) is widely considered to be the key nutrient which influences trophic state and cyanobacteria bloom risk within freshwater ecosystems. This study attempted to characterize the primary sources of P within the watershed, and changes in P loading during the last 35 years, through a watershed modeling analysis. An adapted version of the Nova Scotia Phosphorus Loading Model was used to predict average annual Total P (TP) concentrations in the lake as a function of land-use and hydrology. The model was validated against the average annual TP concentrations measured during 2016–2017. Once validated, the model was used to assess how TP concentrations in the lake have changed since 1985, when the watershed was relatively undeveloped. The outputs from the analysis indicated that the cumulative land use change in the watershed during the time period 1985–2017 would have increased mean annual TP concentrations in the lake by 1–2 µg·L<sup>-1</sup>. The largest sources of P within the watershed are runoff export from natural landscapes and atmospheric deposition. Anthropogenic sources of P in the watershed include runoff export from roads and residential lots, increased runoff export from areas of the watershed that have been clearcut, and P loading from septic systems. The average annual TP concentrations were measured to be 9 µg·L<sup>-1</sup>, indicating the lake is just below the boundary between an oligotrophic and mesotrophic ecosystem. However, large releases of soluble reactive P from lake sediments were observed at an 11 m deep station in the headwater basin and it was hypothesized that increasing temperatures in the region may be influencing stratification processes and the potential for internal loading of P and cyanobacteria blooms.

---

**Of heavy metal, microbes, and phosphate: rock of the  
Ypresian Age (Early Eocene Climate Optimum)  
illustrates natural processes of metal sequestration  
from an ancient intermontane lake**

---

DAVE KEIGHLEY<sup>1</sup>, ALEXANDER ANI<sup>1</sup>, SUPORN BOONSUE<sup>2</sup>,  
BRANDON BOUCHER<sup>1</sup>, DOUGLAS HALL<sup>3</sup>, CHRIS  
MCFARLANE<sup>1</sup>, AND MICHAEL VANDEN BERG<sup>4</sup>

1. *Department of Earth Sciences, University of New Brunswick, Fredericton, New Brunswick E3B 5A3 Canada <keig@unb.ca>* ¶
2. *Planetary and Space Science Centre, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada* ¶
3. *Microscopy and Microanalysis Facility, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada* ¶
4. *Utah Geological Survey, Utah Department of Natural Resources, 1594 W. North Temple, Suite 3110, Salt Lake City, Utah 84114, USA*

Organic-rich mudstone (ORM, or 'oil shale') is a fossil fuel that typically contains abundant heavy metals associated with organic matter in fine-grained sediments often deposited in lakes. When burnt it is notorious for producing copious waste that can end up polluting soil and water resources. Detailed investigation of how, when, and in what form the metal accumulated with the organic matter in ancient lakes (to produce oil shale) can provide a better understanding of (1) how industry might mitigate against producing such waste should the ORM be burnt, and (2) how naturally polluted lakes in the geologic record were able to sequester such heavy metals for millions of years, indicating ways modern polluted lakes might be effectively remediated.

The Green River Formation (GRF) of Utah and Colorado, USA, hosts the world's largest oil shale resource, which was deposited in ancient lakes during greenhouse-earth conditions of the Ypresian Age (Early Eocene). Previous analysis of ORM from the upper GRF in the Uinta Basin has recorded, in a few beds only, enrichments of numerous toxic trace metals within phosphatic intervals, including rare-earth elements (REE), W, Hg, Th, and U. In all cases the rock contains microscopic globules of Carbonate Fluor-Apatite (CFA), which can be interpreted as the fossilized remains of substrate microbes. While phosphorus (P) is essential to and present in all life, certain microbes, such as the sulfate-reducing bacteria and sulfur-oxidizing bacteria, respectively are known to utilize W in their metabolism, and store P. Environmental change triggered by earthquakes and slumps, or dropping lake levels, during or following some episodes of ORM deposition, may have resulted in mass mortality of the microbes. Microbial decay would then release P into sediment pore waters potentially to reach supersaturation and precipitate as CFA-cemented horizons in the ORM prior to significant compaction. The CFA may

fossilize the microbes, incorporating any W that was present, and encapsulate other early-formed diagenetic sulfides such as HgS. The CFA crystal lattice also is sufficiently flexible to incorporate substitutions of Ca by REEs, Th, and U that diffused from reducing pore waters into the cemented horizons.

---

**Tectonically driven temporal and spatial controls across  
an accretionary orogen: tectonic setting of post-orogenic,  
polymetallic porphyry-style ores**

---

DAWN A. KELLETT<sup>1</sup>, NICOLAS PIETTE-LAUZIÈRE<sup>2</sup>, KYLE P.  
LARSON<sup>2</sup>, AND NEIL ROGERS<sup>3</sup>

1. *Geological Survey of Canada, Natural Resources Canada, Dartmouth, Nova Scotia B2Y 4A2, Canada <dawn.kellett@canada.ca>* ¶
2. *Earth and Environmental Sciences, University of British Columbia, Okanagan Campus, Kelowna, British Columbia V1V 1V7, Canada* ¶
3. *Geological Survey of Canada, Natural Resources Canada, Ottawa, Ontario K1A 0E8, Canada.*

Post-orogenic polymetallic porphyry-style mineralization occurs in distinctive patterns within space and time in accretionary orogens. These patterns are controlled by the tectonic drivers for crustal melting, the presence or absence of metal sources, and the 4D tectonic architecture of the orogen which provides the pathways and channels for melt and fluids. This Targeted Geoscience Initiative activity of the Geological Survey of Canada focuses on the tectonic setting of the Appalachian orogen as a means to investigate the development and maintenance of melt and fluid pathways within an orogen's architecture. Our working hypothesis is that the evolving tectonic setting is a critical factor in focusing polymetallic porphyry-style mineralization in space and time. Towards this end, this activity focuses on the regional tectonic and local structural history of the Eastern Highlands shear zone (EHSZ) on Cape Breton Island, Nova Scotia. To establish the regional tectonic setting, research will target the magmatic, metamorphic, and cooling history of the Aspy and Bras d'Or terranes which are separated by the EHSZ. The detailed local structural history of the EHSZ is under investigation via a combined structural mapping, micro-structural analysis and geochronological study. Preliminary results confirm that the Aspy terrane experienced a rapid cooling event during the Devonian, likely accommodated by slip along the EHSZ as it was reactivated in response to outboard accretion.

---

**Three-dimensional seismic geomorphology of paralic channel systems, Sable Sub-basin, offshore Nova Scotia, Canada**

---

TREVOR B. KELLY AND GRANT D. WACH

*Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <tbkelly@dal.ca>*

Large fluvial systems drained vast areas of Canada during the Late Jurassic to Late Cretaceous and deposited kilometres of sediment within the Scotian Basin, offshore Nova Scotia. These fluvial systems are prominent within the Logan Canyon Formation and to a lesser extent, the Missisauga Formation and can be imaged in the Sable Sub-basin within the Sable Megamerger 3-D seismic dataset. The key objective of this study is to examine the temporal and spatial fluvial system architecture variations, together with an assessment of the controlling features that are influencing this variability. This will be accomplished by integrating seismic geomorphology and sequence stratigraphy within the 3000 km<sup>2</sup> study area located offshore Nova Scotia. The seismic volume will be flattened on two surfaces, one representing the Logan Canyon Formation and the other representing the Missisauga Formation. The flattening process converts the seismic data into a stack of seismic horizon slices, showing the sedimentary features as they would have been deposited. Seismic attributes will be applied such that the horizon slice images containing the fluvial systems and their associated elements become more distinct. These horizon slices will be paired with quantitative seismic geomorphology to obtain fluvial architecture parameters (channel width (CW), channel thickness (CT), meander-belt width (MBW), radius of curvature (RC), meander wavelength (ML), channel length (CL), channel depth (CD), and sinuosity (SI)). These parameters will be used to help determine the main objective mentioned earlier with respect to the Logan Canyon and Missisauga formations. Core and well logs will 'ground truth' the seismic data. A qualitative analysis of the fluvial systems within the study intervals will include describing the fluvial styles present and the lateral spacing between channels. Characterizing these fluvial systems will help to: (1) understand the possible controlling factors and processes that lead to their creation and evolution, (2) refine the existing knowledge of reservoir heterogeneity within the Sable Sub-basin, (3) discern the relative time for each stratigraphic cycle that can be detected, and (4) construct a database of the geometries and dimensions of the fluvial channel bodies occurring in the study area/time interval for subsequent reservoir modelling.

---

**An experimental investigation of the effect of country rock assimilation on chromite crystallization in the Ring of Fire, James Bay lowlands, Ontario, Canada**

---

ERIN KELTIE<sup>1</sup>, JAMES BRENNAN<sup>1</sup>, JAMES MUNGALL<sup>2</sup>, AND RYAN WESTON<sup>3</sup>

1. *Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <eekeltie@dal.ca> ¶*
2. *Department of Earth Science, Carleton University, Ottawa, Ontario K1S 5B6, Canada ¶*
3. *Noront Resources, 886A Alloy Place, Thunder Bay, Ontario P7B 6E6, Canada*

The Ring of Fire Intrusive Suite (ROFIS) in the James Bay lowlands, Ontario, is emplaced into the 2.734 Ga McFauld's Lake greenstone belt, and hosts the Black Thor, Big Daddy, Blackbird, Black Label, and Black Creek chromite deposits, together comprising ~201.3 million tonnes of measured and indicated chromite resources. The formation process of these and other chromitites worldwide is still debated, with models for their petrogenesis including gravitational settling of liquidus chromite to the base of an evolving magma chamber, mechanical sorting of chromite from an olivine-chromite cotectic assemblage during flow, transient increases in pressure, addition of water to the magma, increase in oxygen fugacity, magma mixing between primitive and evolved magma, and contamination of a primitive magma by surrounding country rock during ascent and emplacement. Although this latter process is likely to widely occur, with evidence for this in the ROFIS context, its effect on chromite crystallization has not been experimentally tested. We have addressed this shortcoming in a series of experiments involving mixtures of synthetic komatiite and country rocks to the ROFIS (Fe-bearing sediment and granodiorite) to measure phase equilibrium, chromite solubility, and chromite composition. Experiments involved equilibrating synthetic komatiite (~2100 ppm Cr) containing 0–10% Cr-free contaminants on Fe-saturated Pt loops at 1200–1450°C and 0.1 MPa at the FMQ oxygen buffer in a vertical tube furnace. In all cases, the addition of the contaminant lowered the chromium content of the melt at chromite saturation (CCCS), with the addition of the iron-bearing compositions having the largest effect. Increased contaminant content also decreased the olivine liquidus, as evidenced by an increase in modal melt content. The Mg# of experimentally-produced chromite (0.54–0.89) is uniformly higher than the Mg# of natural ROFIS chromite (0.12–0.54), whereas the Cr# [Cr/(Cr+Al+Fe<sup>3+</sup>)] of experimentally-produced chromite (0.21–0.60) is lower than the Cr# of natural ROFIS chromite (0.51–0.66). These results, combined with mass balance, suggest that the Cr content of the komatiite in experiments may be too low compared

to values for the ROFIS parental magma, although the shift in Mg# seems consistent with assimilation of a Fe-bearing contaminant. Experiments are now in progress using more Cr-rich compositions to test this hypothesis.

---

**Integrating data sets to enhance the subsurface interpretation of the Carboniferous to Permian rocks of the offshore Sydney Basin, Nova Scotia, Canada**

---

KRISTOPHER L. KENDELL

*Canada-Nova Scotia Offshore Petroleum Board, Halifax, Nova Scotia B3J 3K9, Canada <kkendell@cnsopb.ns.ca>*

Carboniferous strata of the Sydney Basin outcrop onshore Cape Breton Island and extend offshore beneath the Laurentian Channel and Burin Platform. The offshore portion of the basin, between Nova Scotia and Newfoundland, is the predominant focus of this study. Subsurface maps were generated using an extensive suite of 2D seismic surveys that vary significantly in vintage and quality across the basin. Exploration wells intersecting the seismic data are shallow and only provide calibration of the Late Carboniferous seismic stratigraphy for the western and nearshore regions. To enhance interpretation of these variable quality surveys with limited well control, additional data sets were integrated into the workstation environment; including modern topography, surface geology, gravity, magnetism and research seismic.

Many of the seismic surveys were collected in the 1980s or earlier and imaging artefacts such as conventional seafloor and peg-leg multiples present a significant interpretation challenge. A recent seismic survey collected on the eastern side of the basin has substantially improved imaging, providing a higher degree of interpretation confidence that was used to guide interpretation on neighboring poorer-quality surveys. In some areas, shallow, high-resolution research seismic profiles were vectorized and incorporated into the database. These shallow penetrating profiles helped to clearly distinguish higher amplitude flat-lying artefacts on the industry profiles from folded, dipping, and erosionally truncated Carboniferous and/or Permian strata. Significant efforts were also made to ensure that the shallow offshore geological interpretations are consistent with the stratigraphy exposed on Cape Breton Island. Likewise, exposed basement terranes in onshore areas were correlated with a moderate degree of confidence into offshore areas, with interpretations bolstered by the integrated gravity and magnetism data sets.

The integration and analysis of multiple data sets has reduced the many uncertainties that impeded an accurate subsurface interpretation of the Sydney Basin. Despite

the remaining uncertainties, two significant observations can be made. (1) Pre-Carboniferous basement rocks are conceivably much shallower in the northern extent of the basin, consequently the overlying Carboniferous section thins to less than 1 km in some areas. (2) Horton Group rocks, and to a lesser degree the Windsor Group, may be localised and restricted to narrow grabens in the central Sydney Basin, thus occupying a less extensive area than previously interpreted.

---

**From active extension to passive sag basin: how Variscan orogenic events may explain the early Viséan evolution of the Maritimes Basin, Canada**

---

D. FRASER KEPPIE

*Nova Scotia Department of Energy, Halifax, Nova Scotia B3J 3P7, Canada <fraser.keppie@novascotia.ca>*

The evolution of the Maritimes Basin in Atlantic Canada appears to have changed markedly in the early Viséan. Initial basin growth involving active tectonics, continental magmatism, and syn-rift deposition (Fountain Lake, Horton, and Sussex groups) appears to have ended by ca. 345–340 Ma. Subsequent, unconformable basin growth appears to have taken place in a passive sag basin setting with restricted marine deposition at its base (Windsor Group) and continental clastic deposition further up (Cumberland, Morien, and Pictou groups). In the Maritimes Basin, while significant progress has been made unravelling overprinting relationships related to Pennsylvanian and younger (<325 Ma) structural inversions and salt tectonics, mechanisms to explain the early Viséan transition from an active to passive depositional regime remain unclear.

In this study, I use a recent global plate model to reconstruct early Carboniferous kinematics and deduce the following kinematic relationships. First, NW-SE faults controlling the early sub-basin geometries in the Maritimes Basin are sub-parallel to the convergent zone between Laurussia and Armorica and not the transform zone between Laurussia and Gondwana. Second, the Maritimes Basin can be correlated along-strike with the Northwest European Carboniferous Basin to the northwest of a southeast-dipping Variscan suture zone. Third, the transition from active to passive deposition in the Maritimes Basin correlates in time with the closure of an inferred, lower Carboniferous ocean between Laurussia and Armorica. Based on this analysis, I propose that motions of a Variscan lower plate controlled active basin growth in the Maritimes Basin prior to the early Viséan; once this Variscan lower plate subducted and Laurussia and Armorica collided, passive basin growth in the Maritimes Basin became prevalent.

---

### 3D multichannel seismic data analysis of the structure of the Mohorovičić discontinuity (MOHO) at the East Pacific Rise

---

GRAHAM P. KERFORD<sup>1</sup>, MLADEN R. NEDIMOVIC<sup>1</sup>, AND  
MATTHEW H. SALISBURY<sup>2</sup>

1. *Department of Earth Science, Dalhousie University, Halifax,*

*Nova Scotia B3H 1Z2, Canada <Graham.Kerford@dal.ca> ¶*

2. *Geological Survey of Canada, Bedford Institute of  
Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada*

The purpose of this thesis is to provide an improved image of the structure of the Mohorovičić discontinuity (MOHO) at the East Pacific Rise (EPR) using 3D multichannel seismic data collected between 9°37.5'N and 9°57'N. To test the existing models of crustal accretion, the gabbro glacier and sheeted sill models, the MOHO was interpreted throughout the study area to identify its structure in a Mid Ocean Ridge (MOR) environment. Early seismic interpretations of the MOHO at the EPR indicated the MOHO is almost completely impulsive with only the occasional shingled reflectors that have a slight overlap. But interpretation of the 3D multichannel seismic data used in this thesis by Amid Aghaei indicated that shingled and diffusive MOHO reflectors comprised 29% and 17% of the survey area, respectively, with a larger percentage of shingled and diffusive MOHO present in the northern portion of the dataset. The present study shows that the MOHO shingles under the ridge axis are actually ridge-parallel, ridge-symmetric terraces. This thesis will provide a more detailed analysis of the structure of the MOHO, with a focus on the continuity of the MOHO reflectors. By providing a more detailed image of the structure of the MOHO, it is hoped that a better understanding of the accretion of the oceanic crust at MOR will be gained. This thesis will attempt to identify the continuity and structural shape of the MOHO by interpreting each reflector separately, then interpreting them collectively. The primary interpretation is that the MOHO is laterally continuous along the ridge axis between 9°37.5'N and 9°57'N, forming distinct terraces with little overlap. Due to the quantity of diffusive and shingled MOHO interpreted in the dataset and variation between the different types of reflectors in the southern and northern parts of the survey area, it is predicted that there will be a large variability in the structure and number of MOHO reflectors present across the survey area.

---

### A suite of geohazards in the Beaufort Sea, western Canadian Arctic

---

EDWARD (NED) L. KING<sup>1</sup>, GORDON D.M. CAMERON<sup>1</sup>,  
SCOTT DALLIMORE<sup>2</sup>, MICHAEL RIEDEL<sup>3</sup>, CHARLIE PAULL<sup>4</sup>,  
STEVE BLASCO<sup>1</sup>, MICHAEL Z. LI<sup>1</sup>, YONGSHENG WU<sup>5</sup>, KEVIN  
MACKILLOP<sup>1</sup>, MATHIEU DUCHESNE<sup>6</sup>, AND MICHELLE CÔTE<sup>2</sup>

1. *Geological Survey of Canada-Atlantic, Dartmouth,*  
*Nova Scotia B2Y 4A2, Canada <edward.king@canada.ca> ¶*

2. *Geological Survey of Canada-Pacific, Sidney,*  
*British Columbia V8L 4B2, Canada ¶*

3. *GEOMAR-Helmholtz Centre for Ocean Research*  
*Kiel, Wischhofstrasse 3 24148 Kiel, Germany ¶*

4. *Monterey Bay Aquarium Research Institute, Moss*  
*Landing, California 95039, USA ¶*

5. *Fisheries and Oceans Canada, Marine Ecology Science*  
*Division, Dartmouth, Nova Scotia B2Y 4A2, Canada ¶*

6. *Geological Survey of Canada-Quebec, 490,*  
*rue de la Couronne, Quebec, G1K 9A9, Canada*

Safe hydrocarbon development in the Canadian Beaufort Sea will face a broad suite of seabed and shallow sub-surface phenomena that may present concern for operations and infrastructure. We are considering a broad suite of geohazards, some that are unique to glaciated and permafrost-influenced conditions. The Mackenzie Fan has a long history of mass sediment failure, including mega-failures. Post-glacial failures are numerous, followed by two mid-size seafloor failures, named the Ikit and Kugmallit Slide Valley Complexes. Numerous successive, retrogressive events followed large initial failures, possibly tsunamigenic, cutting over 200 m deep. Preliminary age dating shows greatest activity immediately following glaciation, but with continued periodic failure. The latest and largest was less than 1000 yrs ago, possibly much less, yet further corroborative evidence is needed. Fresh porewater influx, apparently from permafrost degradation and/or long-traveled meteoric sources, and high initial sedimentation rates are likely pre-conditions to the failures. Seismic triggering is suspected. Though possibly unrelated, post-glacial normal faulting is recognized on the NE Beaufort margin. Throw at the seabed locally exceed 14 m and fault scarps are traced for 10s of kilometres. Further foundation condition instabilities are recognized in widespread diapir-like hills, dense along the shelf-break, and lying above the zone of degrading buried permafrost. Some are ice-cored and similar to true pingos; others form by gas and/or mud efflux. They are a post-glacial phenomenon but flux and growth remain undetermined. The shelf-break also experiences periodic bottom currents, sufficient to erode. Mapping, oceanographic modelling, age dating and seabed instrumentation approaches contribute to their understanding. Shallow overpressures, a potential



drilling hazard, are manifest on the slope in widespread mud volcanoes, some shown to be actively fluxing gas, and warm, fresh fluids and periodically failing on an annual basis. Overpressures are also indicated in shelf areas by a widespread seismic reflection phase reversal beneath (and within?) paleo-ice stream deposits, 200–400 m buried, apparently capping and directing flow to escape to the seabed along its erosional flanks. Fluids may be from deep formational sources, gas hydrates or degrading permafrost. Bottom-simulating reflectors and high velocity (frozen) sediments are in evidence. Buried shelf-based paleo-permafrost depth, distribution and state of degradation presents recognition challenges, but investigations through seismic processing techniques are promising.

---

### Changes in dinoflagellate cyst production in the North Water (NOW) polynya during the past ca. 3500 years

---

KELSEY KOERNER<sup>1</sup>, AUDREY LIMOGES<sup>1</sup>, AND  
SOFIA RIBEIRO<sup>2</sup>

*Department of Earth Sciences, University of New  
Brunswick, Fredericton, New Brunswick E3B 5A3,  
Canada <kkoerner@unb.ca> ¶*

*2. Glaciology and Climate Department, Geological Survey of  
Denmark and Greenland, Copenhagen, Denmark*

The purpose of this thesis is to provide an improved image of the structure of the Mohorovičić discontinuity (MOHO) at the East Pacific Rise (EPR) using 3D multichannel seismic data collected between 9°37.5'N and 9°57'N. To test the existing models of crustal accretion, the gabbro glacier and sheeted sill models, the MOHO was interpreted throughout the study area to identify its structure in a Mid Ocean Ridge (MOR) environment. Early seismic interpretations of the MOHO at the EPR indicated the MOHO is almost completely impulsive with only the occasional shingled reflectors that have a slight overlap. But interpretation of the 3D multichannel seismic data used in this thesis by Amid Aghaei indicated that shingled and diffusive MOHO reflectors comprised 29% and 17% of the survey area, respectively, with a larger percentage of shingled and diffusive MOHO present in the northern portion of the dataset. The present study shows that the MOHO shingles under the ridge axis are actually ridge-parallel, ridge-symmetric terraces. This thesis will provide a more detailed analysis of the structure of the MOHO, with a focus on the continuity of the MOHO reflectors. By providing a more detailed image of the structure of the MOHO, it is hoped that a better understanding of the accretion of the oceanic crust at MOR will be gained. This thesis will attempt to identify the continuity and structural shape of the MOHO

by interpreting each reflector separately, then interpreting them collectively. The primary interpretation is that the MOHO is laterally continuous along the ridge axis between 9°37.5'N and 9°57'N, forming distinct terraces with little overlap. Due to the quantity of diffusive and shingled MOHO interpreted in the dataset and variation between the different types of reflectors in the southern and northern parts of the survey area, it is predicted that there will be a large variability in the structure and number of MOHO reflectors present across the survey area.

---

### Insights into the gold metallogeny of the Meguma terrane of Nova Scotia, Canada, from LA-ICP-MS arsenopyrite geochemistry

---

DANIEL J. KONTAK<sup>1</sup>, BLANDINE GOURCEROL<sup>1,2</sup>, JOE  
PETRUS<sup>1</sup>, AND PHIL C. THURSTON<sup>1</sup>

*1. Harquail School of Earth Sciences, Laurentian University,  
Sudbury, Ontario P3E 2C6, Canada <dkontak@laurentian.ca> ¶*

*2. Bureau de Recherches Géologiques et Minières (BRGM),  
F-45060, Orléans, France*

The time-space distribution of ore deposits in regards to the evolution of geological terranes is known as metallogeny. In the case of the Phanerozoic Meguma terrane of southern Nova Scotia, the origin of its classic slate-belt hosted orogenic gold systems (i.e., Meguma terrane gold deposits) has been the focus of study for well over a century. Despite considerable effort involving many sub-disciplines (e.g., field studies, structural analysis, litho-geochemistry, geochronology), many unanswered questions remain about these deposits, such as fluid and metal reservoirs, single or multiple ore-forming events, and nature of the mineralization. The advent of in situ LA-ICP-MS analysis has provided the means to assess the geochemical evolution of single minerals using a large elemental database at a spatial resolution (10s µm) not available before. Here we apply a novel approach to processing and interpreting such data generated from mapping arsenopyrite from eight gold deposits across the central and eastern Meguma terrane (i.e., the Ovens to Upper Seal Harbour) to further investigate its gold metallogeny. Using this approach, we first establish an elemental paragenesis for the mineralization in each deposit, assess the number of gold events and their nature (i.e., refractory vs non-refractory), characterize elemental associations and elemental abundances through time, and assess elemental reservoirs (e.g., Co, Ni) using a new set of discriminant diagrams. The results document a similar geochemical fingerprint for gold mineralization across the terrane based on a similar elemental paragenesis in deposits, but also indicates several gold events. Using Au-Ag

binary plots with false-color coding to highlight elemental associations, the earliest gold event ( $>10$  ppm Au; Au:Ag = 10) is identified by a Co-Ni-Mo-Sb-Se association which equates spatially to primary growth zones in arsenopyrite. In contrast, a second event, characterized by an Al-Ti-V-Mn element association, Au:Ag  $>100$ , and spatially associated with late fractures, is attributed to remobilization and upgrading of earlier refractory gold. A third event, characterized by a Bi-Pb-Cd-In-Ag elemental association, predates the second gold event and is also reflected in archived whole-rock lithochemical data. Collectively these results indicate a protracted history of precious-metal mineralization in all deposits from an early refractory event to subsequent remobilization events, which may be similar or separate temporally. In addition, the Co-Ni data may reflect interaction of ore-forming fluids with mafic rocks at depth. This study demonstrates the applicability of our approach to resolving long-standing problems in gold metallogeny, in the Meguma terrane and elsewhere.

---

#### Seismic and outcrop investigation of fault development in the transtensional Moncton Sub-basin at the McCully gas field, southern New Brunswick, Canada

---

JARED C. KUGLER<sup>1</sup>, JOHN W.F. WALDRON<sup>1</sup>, AND  
PAUL DURLING<sup>2</sup>

1. Department of Earth and Atmospheric Sciences,  
University of Alberta, Edmonton, Alberta T6G2E3,  
Canada <jckugler@ualberta.ca> ¶

2. Geological Survey of Canada – Atlantic, Dartmouth,  
Nova Scotia B2Y 4A2, Canada

Sedimentary basins in strike-slip settings contain complex structures due to concurrent extensional, contractional, and rotational deformation, making it challenging to understand early basin configurations and depositional patterns. The kinematic history of such basins can be unraveled by measuring the heaves and orientation of fault arrays to quantify deformation.

In the Moncton Sub-basin in southern New Brunswick, Canada, data from the McCully gas field reveal a complex structural geometry. Three-dimensional seismic reflection data tied to 46 wellbores show extensional faults, contractional faults, and folds within the unconformity-bounded, Late Devonian to Early Mississippian Horton Group. A conjugate set of extensional faults is identified with typical east-west strike, along with contractional faults of various orientations. The strike-lengths of these faults range from less than 200 m to more than 4500 m, with dip-slip offsets up to 250 ms of two-way travel time ( $\sim 500$  m). Gentle folds trend NE. Analogous faults are found in highway

outcrops, located approximately 15 km SW of the sub-surface data. Here, siltstone and sandstone of the Horton Group are offset by 136 observed extensional and contractional faults. Again, conjugate sets of extensional faults are observed, with average NNW-SSE strike orientations; the thrust faults mainly have NNE strike orientation.

The subsurface heave and orientation measurements indicate an apparent stretch of  $\sim 15\%$  and an apparent, approximately perpendicular shortening of  $\sim 2.5\%$ . The outcrop data yield an additional 2% of sub-seismic apparent stretch. These quantities indicate that during the Late Devonian to Early Mississippian, the Moncton Sub-basin was deformed in a transtensional setting with an angle of divergence (alpha) of  $\sim 43$  degrees from the zone boundary, resulting in horizontal extension roughly 017 degrees clockwise from north. This extension produced faults which divide the reservoir into fault blocks. Understanding the kinematics of strike-slip and transtension is therefore important for resource exploration in such basins.

---

#### Cliffs of Fundy aspiring Global Geopark update

---

MARLEE K. E. LESLIE

*Cliffs of Fundy Aspiring Geopark; 162 Two Islands Road,  
Parrsboro, Nova Scotia B0M 1S0, Canada  
<coordinator@fundygeopark.ca>*

At present, there are one hundred and twenty-seven Global Geoparks in thirty-five countries. Canada has two formally recognized Geoparks and nine aspiring Geoparks, one of which is in our backyard: the Cliffs of Fundy Aspiring Global Geopark, spanning the shore from Apple River to Portapique River. This area includes dozens of sites showcasing globally significant geological history and many vibrant coastal communities, businesses, and geotourism experiences; it is a visually stunning and scientifically rich area that the Aspiring Geopark aims to promote. A Geopark designation is intended to be an empowering community-driven project that attracts the international community to explore globally significant geology. At the same time it functions to promote local communities, culture, and sustainable development. Consultation with Mi'kmaw elders through the Elders Advisory Council, which has endorsed the project, has allowed for the inclusion of a Mi'kmaw interpretation of the geology and landscape. The project is successfully advancing through the steps toward formal admission into the Global Geoparks Network (GGN). The Geopark Steering Committee of the Cumberland Geological Society is currently finalizing the initial application to the Canadian National Committee for Geoparks (CNCG), and this will be followed by a site visit by the CNCG this summer.

The next goal will be to have a formal site evaluation by the GGN/UNESCO in summer 2019 with a decision announced in 2020 for formal admission into the UNESCO Global Geoparks Network. The Aspiring Geopark's boundaries were recently expanded following enthusiastic engagement from the community. Initially the Geopark boundaries comprised the area between Apple River and Economy Point but it was proposed that the boundary be extended to include Bass River on the basis of its significant mining and timbering history and its present cultural sites and businesses. A public meeting held in Bass River in January to assess community interest was embraced with enthusiasm, leading to the proposal of a new eastern boundary that would include an area up to the Portapique River, extending north to include the Portapique River Wilderness area. The community brought forth this suggested boundary given the significance of the area in Bass River's history and its continued importance for outdoor clubs and activities. The Committee continues to work to develop the Cliffs of Fundy Geopark brand, spread the word about the project, and prepare the application.

---

### The occurrence of methane and other hydrocarbon gases in private water supply wells in the vicinity of the Stoney Creek oil and natural gas field, New Brunswick, Canada

---

DIANA LOOMER<sup>1</sup>, KERRY MACQUARRIE<sup>1,2</sup>, AND  
CHRISTINE CHASE<sup>1</sup>

1. *Department of Civil Engineering, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada <dloomer@unb.ca>*

2. *Canadian Rivers Institute, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada*

As part of the Gas Seepage Project, 42 private water supply wells within a 10-km radius of the Stoney Creek oil and natural gas (ONG) field near Moncton, New Brunswick, were sampled. Along with field parameter measurements, water samples were collected for inorganic ions, dissolved hydrocarbon gases, and stable isotopes of water, methane and ethane. The results for dissolved gases will be the focus of this presentation.

Methane was detected in 34 (81%) of the wells, with concentrations ranging from 0.0005 to 36 mg/L. Two wells had methane concentrations above 28 mg/L, while all other sampled wells had methane concentrations <10 mg/L. The median concentration in the water wells around the Stoney Creek ONG field, 0.03 mg/L, is significantly higher ( $p < 0.001$ ) than the median concentration, 0.005 mg/L, in other areas of southeastern New Brunswick that do not have the same history of extensive ONG resource development.

There is no correlation between methane concentration and distance to an ONG well. The two wells with the highest methane concentrations also had detectable ethane and propane, while butane, pentene, pentane and hexane were observed in one of those wells. The two wells are located east of the Petitcodiac River, approximately 2 km from the Stoney Creek ONG field. However, the ONG-bearing Horton Group bedrock of the Maritimes Brunswick Basin approaches the ground surface in the area of those wells.

The methane concentration was >0.1 mg/L in 12 (29%) of the wells and those wells were resampled for the determination of the isotopic composition of methane, and ethane, if possible. The  $\delta^{13}\text{C}$ -methane and  $\delta^2\text{H}$ -methane values are indicative of a range of biogenic, mixed biogenic/thermogenic, or atmospheric signatures, and the molecular ratios ( $\text{C}_1/(\text{C}_2+\text{C}_3)$ ) combined with the  $\delta^{13}\text{C}$ -methane values from samples with detectable ethane or propane point to biogenic or mixed signatures. Three samples had high enough ethane concentrations for isotopic analyses. Comparison between the  $\delta^{13}\text{C}$ -methane and  $\delta^{13}\text{C}$ -ethane values suggest a mix of biogenic and thermogenic methane but not microbial oxidation of the methane. Given the spatial distribution of methane concentrations – considered against both distance to ONG wells and bedrock geology – as well as the isotopic composition of the dissolved gases, we cannot determine definitely if groundwater methane concentrations in the area result from the presence of natural hydrocarbon-bearing bedrock in the vicinity of the wells or the presence of stray gas related to the ONG field.

---

### Valence state of arsenic and antimony in basalts: an experimental and synchrotron study

---

BRYAN MACIAG, JAMES BRENNAN, AND ERIN KELTIE

*Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <Bmaciag@dal.ca>*

Arsenic (As) and antimony (Sb) are trace elements that have multiple redox states (-III, III, V) in geological systems. This variability in valence state grants these elements a diverse geochemical behaviour, which could be exploited as a tracer of magmatic processes, such as crustal assimilation or monitoring redox state. Furthermore, in many magmatic platinum group element (PGE) deposits, platinum and palladium preferentially partitioning into a coexisting arsenide phase over the sulphide phase, which suggests that arsenic may play an important role in PGE sequestration. Unfortunately, there is a lack of information on the redox state of As and Sb in magmas, with conflicting results in some cases for As. These will be the first quantitative measurements for Sb valence state in a magmatic system.

Preliminary thermodynamic calculations predict changes in the valence state of As and Sb over the range of terrestrial oxygen fugacities ( $fO_2$ ), but these calculations require experimental calibration.

To assess the valence state of these elements we synthesized a suite of Sb- and As-bearing basaltic glasses in chromite crucibles encapsulated in vacuum-sealed silica ampoules over a range in  $fO_2$  (FMQ -3.3 to FMQ +5.7) at 0.1 MPa and 1200°C. We measured the oxidation state of As and Sb in the glasses by x-ray absorption near edge structures (XANES) at the Canadian Light Source (CLS) using the HXMA beamline for Sb and the VESPERs beamline for As. Preliminary analysis of the XANES spectra indicates that the trivalent oxidation state of As and Sb is dominant over the range of  $fO_2$  investigated. Additionally, at higher oxygen fugacities pentavalent As and Sb are present in addition to the trivalent form.

---

### The structural evolution of the central basin of the Malawi (Nyasa) Rift, Africa: methodologies, tectonic insights, and stratigraphic implications

---

TANNIS MCCARTNEY

*Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada*  
<tannis.mccartney@canada.ca>

Early-stage continental breakup is best studied in young, active rifts where syn-rift sediments and structures have not yet been removed or overprinted. These studies provide valuable analogues for understanding the continental rift sections preserved on passive margins such as the Atlantic Margin of Canada.

Syn depositional fault analysis using 2D reflection seismic data is used to constrain the structural evolution of the central basin in the Malawi (Nyasa) Rift at the south end of the East African Rift System's Western Branch. The structural methods used in this study can be applied to 2D reflection seismic data in regions where 3D reflection seismic data are not available.

The central basin of Lake Malawi is a single-half graben rift segment with considerable deformation in the hanging wall of the border fault on the western margin of the basin. Analysis shows that intrabasin faults have been continuously active, with no significant lateral tip propagation, for ~8.5 Ma, coincident with border fault activity. The synchronous fault activity created a small (~500 km<sup>2</sup>) structurally confined sub-basin that is the ultimate sink for sediments from two major watersheds which have a combined total area of nearly 27 000 km<sup>2</sup>. Continental rift lakes are not an environment where mud diapirs are typically expected, however the overpressure conditions required for mud

diapirism developed in Lake Malawi in the last 1.3 million years as a result of the high sedimentation rates of fine-grained sediments and the sediment loading associated with coarse-grained sediment deposition in the confined basin.

---

### A paleolimnological approach to understanding metal mobility and retention associated with salt-water inundation at Laytons Lake, Nova Scotia, Canada

---

HEATHER E. MCGUIRE<sup>1</sup>, IAN S. SPOONER<sup>1</sup>, AMANDA L. LODER<sup>2</sup>, MARK L. MALLORY<sup>3</sup>, DEWEY W. DUNNINGTON<sup>4</sup>, AND NIC R. MCLELLAN<sup>5</sup>

1. *Department of Earth and Environmental Science, Acadia University, Wolfville, Nova Scotia B4P 2R6, Canada* <134108m@acadiau.ca> ¶

2. *Department of Geography and Planning, University of Toronto, Toronto, Ontario M5S 3G3, Canada* ¶

3. *Department of Biology, Acadia University, Wolfville, Nova Scotia B4P 2R6, Canada* ¶

4. *Centre for Water Resource Studies, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada* ¶

5. *Ducks Unlimited Canada, Amherst, Nova Scotia B4H 3Z5 Canada*

Sediments in wetlands and lakes have the potential to retain metals that have been mobilized by natural and anthropogenic disturbance. The role of variable water column chemistry and nutrient load on metal retention and mobility in wetland and lake sediments is not well understood. Laytons Lake is a coastal freshwater lake located in the Amherst Point Migratory Bird Sanctuary, a National Wildlife Conservation Area in Nova Scotia, and experienced a series of marine inundations from the Bay of Fundy in the 1940s. In the late 1970s, researchers identified that the lake was density stratified and incompletely mixed (meromictic) resulting in a strong chemocline, and elevated conductivity levels within 3 m of lake bottom sediments. Thus, a detailed paleolimnological assessment was undertaken in 2017 to investigate the geochemical impact of lake bottom sediment geochemistry on meromixis, and the rate of transition from a meromictic to an intermixing state. A geochemical analysis of lake bottom sediments was accomplished using pXRF to measure elemental proxies, and to measure total C, N and stable isotopes ( $\delta^{15}N$ , and  $\delta^{13}C$ ). A total Pb curve was used to temporally date the sediment core.

Our results indicate a considerable but short-lived (~10 year) response in lake bottom sediment geochemistry to marine inundation events, and that the lake is no longer saline and mixes. Proxies of environmental stability (Ti, K) decreased likely as a result of an increase in autochthonous productivity associated with the marine inundation and a subsequent die-off of freshwater species; a sharp decline in

As may be associated with this process. Cu values remained static suggesting that this marine toxicant may not be strongly influenced by changing salinity. Redox sensitive proxies (Fe, Mn) indicate that strongly reducing conditions were established after inundation and recovered slowly to baseline levels prior to the marine inundations until ~1990. The geochemical record indicates that there has been significant variability in the geochemistry of bottom sediments at Laytons Lake from 1990 to present. Collectively our data provides a framework for predicting the impacts of marine inundation on freshwater wetlands, a process that may result when creating freshwater wetlands on coastal farmland, or from marine inundation associated with rising sea levels.

---

### Shortening of southern Tibet

---

SARAH MCLEOD AND DJORDJE GRUJIC

*Department of Earth Sciences, Dalhousie University, Halifax,  
Nova Scotia B3H 4R2, Canada <sarahmcleod@dal.ca>*

The Himalayan orogeny began approximately 50 million years ago with the collision of the Indian and Eurasian plates, which caused deformation and uplift of the Himalayas and Tibetan Plateau. As this deformation propagated it deformed lithotectonic units independently allowing us to study the deformation of a specific time. The Tethyan Himalaya lithotectonic unit is a fold-and-thrust belt in southern Tibet between the crest of the Himalaya and the India-Eurasia suture (the Indus-Tsangpo suture Zone) that developed during the Eocene and Oligocene. We know from seafloor data that the rate of Indian plate movement has always been faster in the east than in the west, and that during the Eocene and Oligocene was faster than during Miocene, however, current shortening estimates across the Tethyan Himalaya do not reflect this. There are two principal objectives of this project. The first is to calculate the amount of shortening of the Tethyan Himalaya. Secondly, we aim to determine the geometry of the basal detachment of the Tethyan Himalaya. The current hypothesis is that the basal detachment of this fold-and-thrust belt was a south-vergent thrust during Eocene and Oligocene, which was reactivated during Miocene as a low-angle normal fault geometry shear zone. This structure out crops in the northern Himalaya as the South Tibetan Detachment. The objectives of this project will be implemented through construction of a series of balanced, retrodeformable cross sections using MOVE® software. The cross sections will be constructed based on published geological maps and field observations. The long-term aim of the project is to determine if there were spatial and temporal changes in the shortening rate of the southern Tibet and the Himalaya.

---

### Factors controlling mineralization in Silurian and Devonian plutons in Cape Breton Island, Nova Scotia, Canada - Ganderia vs Avalonia

---

ALICIA MONING<sup>1</sup>, SANDRA M. BARR<sup>1</sup>, CHRIS E. WHITE<sup>2</sup>,  
AND DEANNE VAN ROOYEN<sup>3</sup>

*1. Department of Earth and Environmental Science,  
Acadia University, Wolfville, Nova Scotia, B4P 2R6,  
Canada <aliciamoning@acadiau.ca> ¶*

*2. Nova Scotia Department of Natural Resources, Halifax,  
Nova Scotia B3J 2T9, Canada ¶*

*3. Department of Mathematics, Physics, and Geology, Cape Breton  
University, Sydney, Nova Scotia B1P 6L2, Canada*

Cape Breton Island, Nova Scotia, is part of the Appalachian orogen and consists of rocks belonging to the Laurentian Blair River Inlier in the north and the Gondwana-derived Aspy, Bras d'Or, and Mira terranes to the south. Aspy and Bras d'Or are part of Ganderia, whereas Mira is part of Avalonia, both microcontinental fragments that extend through the Atlantic provinces and into New England, USA. Granitoid plutons of known and inferred Devonian age are a major component of both Aspy and Mira terranes in Cape Breton Island. The Gillis Mountain pluton in the Avalonian Mira terrane of southern Cape Breton Island hosts porphyry-style copper-molybdenum mineralization. The pluton consists of three main units: quartz monzodiorite, porphyritic granite and fine-grained granite, with minor aplitic, granitic and mafic dykes. It intruded early to middle Cambrian shale and siltstone and has characteristics typical of shallow intrusions. U-Pb (zircon) dating has yielded an age of  $369.7 \pm 2.3$  Ma. Compilation of previous petrological information combined with new data from recent drill core confirmed the calc-alkalic, subduction-related tectonic setting for the pluton, and the presence of elevated metal contents.

In contrast, plutons of similar or assumed similar age in the Leonard MacLeod Brook area of the Ganderian Aspy terrane of northern Cape Breton Island are not known to be mineralized or associated with mineralization, although they contain rock types similar to those of Gillis Mountain and were also emplaced at shallow depths, based in part on close association with volcanic rocks. Mapping during the summer of 2017 resulted in division of the plutonic rocks in the area into the Gillis Brook, Leonard MacLeod Brook, Easach Ban, and Bothan Brook plutons. Only the Bothan Brook pluton is confirmed to be Devonian, and preliminary results of dating in progress indicates that the other plutonic components are Silurian (436 Ma to 419 Ma). All the plutons have characteristics indicative of emplacement in a subduction-related tectonic setting.

Comparison of host rocks, depth of emplacement, mineralogy, and chemical and isotopic composition of

these plutons may provide insight about factors controlling the presence or absence of porphyry-style mineralization, and the nature of the crust under Ganderia compared to Avalonia. Hence this study has broader implications for plutons of similar age in both Newfoundland and New Brunswick, and also for the understanding of mineralizing systems related to granitoid rocks in general.

---

### Paleozoic orogenesis and Pangea amalgamation controlled by mantle circulation changes?

---

J. BRENDAN MURPHY<sup>1,2</sup>, JOHN W.F. WALDRON<sup>3</sup>, CHRISTOPHER J. SPENCER<sup>2</sup>, ZHENG-XIANG LI<sup>2</sup>, WILLIAM J. COLLINS<sup>2</sup>, ROSS N. MITCHELL<sup>2</sup>, AND R. DAMIAN NANCE<sup>4</sup>

1. *Department of Earth Sciences, St. Francis Xavier University, Antigonish, Nova Scotia B2G 2W5, Canada <bmurphy@stfx.ca>* ¶

2. *Earth Dynamics Research Group, The Institute for Geoscience Research, Department of Applied Geology, Curtin University, Perth, Australia* ¶

3. *Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada* ¶

4. *Department of Geological Sciences, Ohio University, Athens, Ohio 45701, USA*

A plethora of studies have documented the evolution of the Appalachian-Caledonide belt from an accretionary orogen during consumption of the Iapetus Ocean in the Cambrian–Ordovician to a collisional orogen as the Rheic Ocean was consumed in the Devonian–Carboniferous. Collectively, these events culminated in the collision of Laurentia, Baltica and Gondwana and the amalgamation of Pangea. To a first order, we know where and when these events occurred, but much less about the driving mechanisms responsible.

Recent advances in the understanding of how mantle convection as supercontinents amalgamate and disperse allow the evolution of this orogenic belt, the subsidence history of major sedimentary basins in the interior of Laurentia, and the amalgamation of Pangea to be understood in a geodynamic as well as a kinematic framework. Numerical modeling indicates that mantle convection patterns have evolved between degree-1 and degree-2 convection patterns during the supercontinent cycle has been suggested. A focused zone of downwelling that facilitated Gondwana amalgamation would have evolved to become a second zone of upwelling and a transition to degree-2 mantle circulation is predicted within 50 m.y. of Gondwana's amalgamation. Its amalgamation near the south magnetic pole around 550 Ma is predicted to have led to the development of a new upwelling zone at about 500 Ma. A concomitant girdle of downwelling would have been developed close to the paleoequator, where Laurentia was situated, and where the

Williston and other prominent intracratonic basins were initiated during this time interval.

The establishment of the downwelling zone and subduction girdle by the end of the Cambrian explains the onset of subduction along the Laurentian margin within the Iapetus Ocean (despite its relative youth) and why subduction continued along that margin after arc-continent collision and ophiolite obduction associated with the Taconic-Grampian orogeny. The associated geoid low would explain (i) the migration of subduction zones and peri-Gondwanan terranes from Gondwana, thereby opening the Rheic Ocean leading to the eventual closure of Iapetus Ocean by the collision of those terranes and Baltica with the Laurentian margin, (ii) the development of cratonic basins on Laurentia in the early Paleozoic, and (iii) the subsequent re-establishment of subduction within the Rheic Ocean along the Laurussian margin which continued until terminal collision and the amalgamation of Pangea.

---

### Sedimentological evidence for Late Triassic (Rhaetian) marine incursion in the Central Atlantic Margin

---

DARRAGH O'CONNOR<sup>1</sup>, RICARDO L. SILVA<sup>2</sup>, AND GRANT WACH<sup>1</sup>

1. *Basin and Reservoir Lab, Department of Earth Sciences, Faculty of Science, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <darragh.oconnor@dal.ca>* ¶

2. *MARE - Marine and Environmental Sciences Center, University of Coimbra, Rua da Matemática, 3004-517 Coimbra, Portugal*

The onset and dynamics of marine incursions into the basins of the Scotian margin are poorly understood. The first unequivocal evidence of marine influenced sedimentation comes from the Early to Middle Jurassic dolostone-dominated Iroquois Formation. However, slightly older Triassic–Jurassic salts are geochemically interpreted to be of marine origin, thus suggesting marine-influenced deposition before the deposition of the Iroquois Formation. This uncertainty leads to two concurrent hypotheses for Late Triassic paleogeographic reconstructions of the Scotian margin: (i) Late Triassic–Earliest Jurassic marine incursions leading to salt deposition; or (ii) Late Triassic–Earliest Jurassic salt generation through evaporation in an endorheic basin, far from marine waters.

Siliciclastic successions of the Upper Triassic Eurydice Formation were cored in two drill holes from the Scotian (Mohican I-100) and Orpheus (Eurydice P-36) basins, offshore Nova Scotia. In our investigation of both cores, sedimentological features were identified to be consistent with deposition by tide-dominated processes and interpreted to have deposited in an estuarine or deltaic environment.

Limitations of the study are recognized by the authors as both studied cores are short (less than 10 m length), and the formation of interest is deeply buried offshore and extends laterally for more than 600 km.

Our interpretation of the Upper Triassic Eurydice Formation in the wells drilled offshore Nova Scotia suggests that the first marine incursions into the Scotian margin occurred during the Late Triassic. It also demonstrates that early rift sedimentation in the Central Atlantic Margins was punctuated by recurring major changes in the depositional environments rather than a linear evolution. These marine incursions into the Scotian margin are interpreted to be contemporaneous with the main Late Triassic transgressive events recorded elsewhere in Western Europe.

---

### Mitigating Gas Seepage – Creating a Road Map

---

MOHAMMAD OYARHOSSEIN<sup>1</sup> AND MAURICE B. DUSSEAULT<sup>2</sup>

1. *Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada*  
<mohammad.oyarhossein@uwaterloo.ca> ¶
2. *Department of Earth and Environmental Sciences, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada*

In this study, the most common pathways for gas migration from the subsurface are briefly covered. Additionally, possible scenarios that might lead to gas leakage from subsurface sources are discussed. It is essential to categorize different troublesome scenarios, including mechanical, geomechanical, operational, etc., because with the process of elimination and regarding the nature of the sources and the escaping gas, one may better diagnose the most probable reason(s) that might be a cause for the leakage. This holistic picture, referred to as a “road map” in phase I, will need more development and modeling in case further investigations and a more detailed methodology are requested. We are accessing the needed materials and methods to perform the necessary functions delineated in a road map and doing a literature review to better understand and summarize the processes involved in induced (i.e., anthropogenic) gas migration from the subsurface.

The framework described above comprises an essential part of a general risk mitigation approach to gas migration. Although we will not at this stage be dealing with technologies (existing or new) to stop or reduce gas migration, understanding the physics and the pathway is essential to choosing and implementing rectification methods.

---

### Canada's first in situ <sup>14</sup>C extraction line is ready for action

---

CODY A. PAIGE<sup>1</sup>, JOHN C. GOSSE<sup>1</sup>, KEITH TAYLOR<sup>1\*</sup>,  
ANNINA MARGRETH<sup>1,2</sup>, LUKAS WACKER<sup>3</sup>, AND  
NATHANIEL LIFTON<sup>4</sup>

1. *Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada* <cody.paige@dal.ca> ¶
2. *Quaternary Geology, Norges geologiske undersøkelse, Trondheim, Norway* ¶
3. *Ion Beam Physics, ETH Zurich, Zurich, Switzerland* ¶
4. *Department of Earth, Atmospheric and Planetary Science, Purdue University, West Lafayette, IN 47907, USA*

Applications of in situ <sup>14</sup>C produced in minerals or ice on Earth are providing a new frontier in exposure dating and landscape erosion rate studies. In particular, the isotope can avoid problems facing longer-lived, lower production rate isotopes. The Dalhousie <sup>14</sup>C Extraction Line Laboratory (DCELL), the first in situ <sup>14</sup>C extraction line in Canada, was finished in January 2017 and the first background and blank tests have been completed. Up to 8 g of quartz is melted using LiBO<sub>2</sub> flux in an alumina boat to extract in situ <sup>14</sup>C. After removal of atmospheric/organic CO<sub>2</sub> from the boat, flux, and quartz at low temperature (500°C), ultrapure O<sub>2</sub> is bled over the melting quartz aliquot at 1050°C to capture the in situ <sup>14</sup>C as <sup>14</sup>CO<sub>2</sub>. The CO<sub>2</sub> is then purified using temperature-specific pentane-slush traps and a high temperature Ag-Cu wool-mesh oxidation to remove SO<sub>x</sub>, NO<sub>x</sub>, and other condensable gases. The purified CO<sub>2</sub> is analysed for <sup>14</sup>C/<sup>12</sup>C on the MICADAS gas-source accelerator at ETH Zurich, eliminating the need to graphitize the CO<sub>2</sub>.

The first blank measurement of 1.96 x10<sup>5</sup> atoms was obtained using operating procedures developed to minimize flux mass and volatility while still achieving complete <sup>14</sup>C extraction. The blank result is comparable to other similarly designed extraction. The inter-laboratory comparison sample, CRONUS-A, was calculated to be 6.88x10<sup>5</sup> atoms/g which is also within the concentration range presented by other <sup>14</sup>C labs. In the upcoming year the DCELL will be used to estimate erosion rates over the past 35 ka on alluvial fans used as strain markers in Panamint Valley, California, by measuring <sup>14</sup>C saturation concentrations in amalgamated sediment samples from just below the soil mixing zone. Those erosion rates are used to constrain cosmogenic <sup>10</sup>Be and <sup>36</sup>Cl depth profiles to improve the precision of the exposure age and slip rates. Furthermore, in situ <sup>14</sup>C measured in quartz sand in till will be used, in concert with <sup>10</sup>Be, to improve our knowledge of the erosional dynamics of ice sheets in the Canadian Arctic where mineral exploration is complicated by their polythermal basal thermal regime. Also in the queue are glacial erratics from cold-based glacier regions on Baffin Island. Besides these experiments, we have

already begun a process to improve the extraction system in order to reduce the blank by an order of magnitude by eliminating the need for flux and alumina sample boats (the primary source of blanks in most labs).

---

### Tectonic emplacement of the Musquash Harbour granite pluton, southern New Brunswick, Canada

---

ADRIAN F. PARK AND STEVEN J. HINDS

*Geological Surveys Branch, Department of Energy and Resource Development, Fredericton, New Brunswick E3B 5H1, Canada  
<Adrian.Park@gnb.ca>*

The Ediacaran Musquash Harbour granite in southwestern New Brunswick has a complex relationship with Carboniferous sedimentary formations. This granite was intruded into the Neoproterozoic Greenhead and Dipper Harbour groups of the Brookville terrane, and intrusive relationships with these units are preserved locally. Most the contacts between the pluton and Carboniferous rocks are tectonic: either vertical strike-slip faults or reverse faults and thrusts. Some unconformities or nonconformities are also preserved, including one with the Visean Parleeville Formation (Windsor Group carbonates), and another with the Pennsylvanian Lancaster Formation. Strike-slip faults and thrust/reverse fault contacts have the geometry of sidewall and frontal ramps in a regional structure considered to be a transpressive flower structure once called the 'Fundy Coastal Zone'. This structure did not include the Musquash Harbour granite itself in the original definition. This study expands the scale of this 'coastal zone' to include all of the Musquash Harbour pluton and the Spruce Lake shear zone to the north, which is a transfer structure linking the 'coastal zone' to the major strike-slip faults such as the Kennebecasis Fault to the north. Rather than being confined to a narrow coastal zone, these late Pennsylvanian transpressive flower structures are an integral part of the late Carboniferous evolution of the basement and Carboniferous basins in the Appalachians of New Brunswick.

---

### Hydrothermal rutile and the history of Clarke Head, Minas fault zone, Nova Scotia, Canada

---

GEORGIA PE-PIPER<sup>1</sup>, DAVID J.W. PIPER<sup>2</sup>, AND JUSTIN NAGLE<sup>1</sup>

1. *Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada <gpiper@smu.ca>*
2. *Natural Resources Canada, Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada*

At Clarke Head in the Minas Fault Zone, several igneous megablocks are present, including a syenite pegmatite that intrudes gabbro, and diorite with siltstone xenoliths, likely from the lower Horton Group. This study investigates the age and hydrothermal alteration of rutile in the syenite and the origin of the scapolite. It contributes to the current debate over the role of rutile in subduction zones and Ti mobility in the presence of halogens. Rutile was studied by SEM and Raman spectroscopy, trace elements were analysed by LA-ICPMS, and age was determined by in-situ U-Pb analysis. Syenite has magmatic K-feldspar, albite, quartz, rutile and late stage analcime. Most feldspar has been replaced by scapolite, which also forms veins in gabbro and diorite. Analcime was remobilised during this and later vein-forming events. Magmatic rutile in the syenite forms millimetric-scale crystals rimmed by magmatic titanite and magnetite and also occurs as smaller interstitial crystals. Application of the Zr in rutile geothermometer yields geologically unreasonably high temperatures. The interstitial rutile shows some Pb loss and suggests an age older than ca. 353 Ma. Later hydrothermal halogen-rich fluids produced the widespread metasomatic Na-rich scapolite (marialite) in the syenite. These fluids leached Ti and other HFSE, together with REE, from fractured large rutile crystals. Declining concentration of halogens resulted in precipitation of Ti and Zr and resetting of the U-Pb system in the altered rutile, at  $337.4 \pm 3.5$  Ma. This age corresponds to the mid-Windsor hiatus following the deposition of thick halite. Oxygen isotopes in the bulk rocks and scapolite-analcime mixtures suggest an important component of magmatic fluids in the metasomatising system. Deformation of halite in the Portapique fault, well south of the basin margin Kirkhill fault zone, supplied Na<sup>+</sup>, Cl<sup>-</sup> and lesser F<sup>-</sup> to the metasomatising system. Otherwise, the rocks at Clarke Head show a sequence of hydrothermal alteration that is similar to that along the Cobequid Fault: sodic alteration (albite, riebeckite) → potassic alteration (biotite, hastingsite) → early carbonate, perhaps synchronous with the scapolite → magnetite and Fe-Mn carbonates → titania, xenotime and barite. The unique features of hydrothermal alteration at Clarke Head relate to availability of deformed halite along the Portapique Fault.



---

### Bacterial and archaeal intact polar lipids in active petroleum systems of the Scotian margin, Canada

---

CARL A. PETERS<sup>1</sup>, G. TODD VENTURA<sup>1</sup>, CASEY HUBERT<sup>2</sup>,  
ADAM MACDONALD<sup>3</sup>, MARTIN G. FOWLER<sup>4</sup>, JULIUS S.  
LIPP<sup>5</sup>, FLORENCE SCHUBOTZ<sup>5</sup>, AND KAI-UWE HINRICH<sup>5</sup>

1. Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada <todd.ventura@smu.ca> ¶
2. Energy Bioengineering and Geomicrobiology Group, University of Calgary, Calgary, Alberta T2N 1N4, Canada ¶
3. Nova Scotia Department of Energy, Halifax, Nova Scotia B3J 3P7, Canada ¶
4. Applied Petroleum Technology Ltd., Calgary, Alberta T2N 1Z6, Canada ¶
5. Organic Geochemistry Group, Department of Geosciences, University of Bremen, Leobener Strasse, 28334 Bremen, Germany

A new Genome Canada funded Genomic Applications Partnership Program (GAPP) project aims to integrate different bioassays and petroleum geochemistry to develop novel indirect hydrocarbon indicators (IHIs), which can better predict the potential of offshore petroleum in order to further reduce front-end exploration risks to oil and gas companies. One bioassay is the study of Intact polar lipids (IPLs), which are parts of the sedimentary organic matter that can provide information about the community composition and metabolic activity of active, near surface and deeper subsurface microbial ecosystems. IPLs consist of a core lipid chemically bonded to one or more polar headgroup. Both the polar headgroup and the core lipid can be structurally distinct and taxonomically diagnostic. Because of this, depending on the preservation state and origin of the detected lipid, these compounds can be further used to assess the present and past environmental conditions of an organism's habitat. IPLs of aerobic and anaerobic hydrocarbon oxidizing bacteria and archaea that use petroleum as a substrate for their metabolism may potentially provide better insights into the dynamics of the subseafloor biosphere, pathways for carbon cycling, and ultimately may lead to novel proxies for the characterization of benthic seep activity. These proxies might then be used as IHIs for de-risking offshore petroleum exploration. To test whether lipid signatures can be used as potential IHIs for the presence of petroliferous hydrocarbons, surface and piston core sediments were collected during recent expeditions (CCGS *Hudson* 2015 and 2016; RV *Coriolis* 2017) from the oil and gas prone Scotian margin, Nova Scotia. IPLs are being extracted using a modified Bligh & Dyer protocol and analyzed with an UHPLC-qToF-MS. So far, total lipid extracts (TLEs) are significantly more variable and enriched from cored sites containing seep hydrocarbons (ranging from ~300 to 800 µg TLE/g sed.) relative to that of a hydrocarbon negative site ( ~200–300 µg TLE/g

sed.). Furthermore, glycosidic saturated and hydroxylated archaeal ether lipids (e.g., 1G-GDGTs, 2G-OH-GDGTs) likely produced by marine benthic archaea, have been found in both hydrocarbon positive and negative piston core sites. Alternatively, only the hydrocarbon positive site contain a series of yet unidentified bacterial IPLs. Additional core samples will be analyzed to determine if these trends are robust and if the bacterial IPLs can be identified and associated with seep hydrocarbons.

---

### Flemish Cap: a unique part of the Canadian continental shelf

---

DAVID J.W. PIPER

*Natural Resources Canada, Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada <david.piper@canada.ca>*

Flemish Cap is a triumph of Canadian diplomacy, being implicitly identified in Article 76 of the UN Convention on the Law of the Sea along with “plateaux, rises, banks and spurs”. It is also quite unusual in its Quaternary geology. Flemish Cap is a horst of Avalonian basement rocks with a thin Mesozoic and Cenozoic cover, separated from the Grand Banks by the 1000 m deep Flemish Pass. The flanks of the Cap are one of the few areas on the eastern Canadian margin to show neotectonic features. Flemish Cap appears to have supported a glacial ice cap during the penultimate glaciation (MIS 6) despite being no shallower than 127 m today. Seismic profiles show features interpreted as grounding line wedges (“till tongues”) and multibeam bathymetry shows upper slope iceberg pits – evidence of indurated substrate. Ice-margin gullies dating from MIS 6 are widespread around Flemish Cap; a few have been reactivated by turbidity current flows off the Cap. Since MIS 6, sediment supply to the Cap has been almost entirely by iceberg rafting. Sands and gravels have been segregated by currents, with sands swept up into large sand ridges, probably at times of lowered sea level. Large muddy sediment drifts have accumulated in deeper waters around Flemish Cap and cores from these drifts preserve a record of sediment supply from the Labrador Current over the last glacial cycle and into the Holocene. Occasional slope failures in these drifts are likely preconditioned by escaping hydrocarbon fluids, resulting in excess pore pressure, and were triggered by rare passive margin earthquakes. The differences between Flemish Cap and other outer shelf areas on the eastern Canadian margin help to unravel the relative importance of different sedimentation processes on a regional scale.

This synthesis draws on collaborative work, some unpublished, with the Nereida program, Cooper Stacey, Lara Miles, Longjiang Mao, Georgia Pe-Piper, Sabrina

Korsmann, Calvin Campbell, Gordon Cameron, Kevin MacKillop and Nicole Rudolph.

---

### The structural and metamorphic evolution of the northern New Quebec Orogen of northern Quebec, Canada

---

CELINE E. PORTER<sup>1</sup>, DEANNE VAN ROOYEN<sup>2</sup>, CHRIS MCFARLANE<sup>1</sup>, AND DAVID CORRIGAN<sup>3</sup>

*1. Department of Earth Sciences, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada <cporter1@unb.ca> ¶*

*2. Department of Mathematics, Physics, and Geology, Cape Breton University, Sydney, Nova Scotia B1P 6L2, Canada ¶*

*3. Geological Survey of Canada, 601 Booth St., Ottawa, Ontario K1A 0E8, Canada*

The New Quebec Orogen (NQO) is a Paleoproterozoic orogenic belt located in the southeastern Churchill Province of northern Quebec. The NQO formed as a result of the collision of the Superior Craton and the Archean Core Zone during the formation of the supercontinent Nuna and is considered an extension of the Trans-Hudson Orogen. The NQO is divided into a western foreland, the Kaniapiskau Supergroup (KS), and an eastern hinterland, consisting of the Rachel-Laporte (RLZ) and Kuujuaq zones. The KS and the RLZ represent metamorphosed and deformed passive margin rocks and are the focus of the current study. Three major episodes of deformation, including two compressional events associated with the initial collision, and one late oblique, dextral, compressional event have been previously identified. These events resulted in the general NNW-SSE structural trend of the orogen. Metamorphic grade increases from sub-greenschist facies in the western KS to upper amphibolite in the eastern RLZ and to granulite facies in the Kuujuaq Zone.

Over 200 samples and 600 orientation measurements were collected across a 40 km transect of the foreland-hinterland transition of the northern NQO. Metapelitic rocks were of most emphasis during sample collection as they best record both deformation and metamorphic history. Structural analyses were conducted through a combination of stereonet, cross-section and thin section analyses of 50 thin sections. Petrographic studies were conducted to determine the number of metamorphic events and the relative temporal relationship between deformation and metamorphism. Garnet-biotite geothermometry of five samples constrain metamorphic temperatures, and pseudosection construction with Theriak-Domino of nine samples constrain pressure and temperature conditions. Finally, precise in-situ U-Pb geochronology was conducted on metamorphic monazite (one sample) and titanite (three samples) to determine ages of metamorphism.

A total of seven distinct sets of structures relating to

deformation events ( $D_1$ - $D_7$ ) were identified and their effects across the orogen described. Three metamorphic events were identified ( $M_1$ - $M_3$ ), occurring syn- $D_1$ , inter- $D_4$  and  $D_5$ , and syn- $D_5$ , with peak metamorphism identified as  $M_2$ . Evidence of peak metamorphism is preserved as garnet porphyroblasts in the central study area, on either side of the KS-RLZ boundary, and as relict sillimanite within biotite porphyroblasts at the eastern boundary of the RLZ. The most recent metamorphic event,  $M_3$ , overprints  $M_2$ , and is characterized by  $S_5$ -aligned biotite wrapping  $M_2$  garnets, as well as staurolite-biotite-muscovite assemblages at the eastern boundary of the RLZ. Metamorphic conditions calculated from geothermometry and Theriak-Domino will be presented along with a timeline of events.

---

### Mobile methane monitoring for energy sector applications

---

DAVID RISK, P. JAMES WILLIAMS, EMMALINE ATHERTON, ELIZABETH O'CONNELL, JENNIFER BAILLIE, KATLYN MACKAY, AND CHELSEA FOUGERE

*Department of Earth Sciences St. Francis Xavier University Antigonish, Nova Scotia B2G 2W5, Canada <www.fluxlab.ca, drisk@stfx.ca>*

Canadian governments have pledged to cut energy sector methane emissions 40–45 per cent below 2012 levels by 2025. Effective methane-reduction policy relies on accurate and spatially extensive emissions data. In this study, we describe a vehicle-based gas monitoring system equipped with Cavity Ring Down Spectroscopy (CRDS) and other instruments to measure and map methane emissions while driving. The system acquires geo-located ppb-level concentration measurements of several gas species at high temporal frequency (>1 Hz) while driving, in addition to several meteorological parameters. A novel multi-stage computational analysis first attributes plumes to source types on the basis of geochemical ratios, followed by back-trajectory analysis to map plumes back to known oil and gas infrastructure. Finally we perform an emissions rate analysis for the source using the EPA AERMOD dispersion model formulation. Using the system, it is possible to screen 100–400 well pads per day for methane emissions, or an order of magnitude faster than conventional industry techniques. The various computational components can in some cases run in real time. In this presentation, we provide an overview of the methodology, and provide field study examples from a national initiative to map methane emissions from more than 10 000 pieces of active and legacy infrastructure across 5 Canadian provinces. The methodology is extensible to methane mapping within and outside the energy sector and can be mounted on vessels of opportunity.

---

### Applied landscape geochemistry and environmental change in Nova Scotia, Canada

---

PETER J. ROGERS<sup>1</sup> AND WILLIAM JONES<sup>2</sup>

1. 10902 Highway 215, South Maitland, Nova Scotia  
B0N 2H0, Canada <chavin\_consulting@yahoo.ca> ¶

2. exp Services Inc., 7071 Bayers Road - Suite 2002, Halifax,  
Nova Scotia B3L 2C2, Canada

Modern man is fast becoming a potent and transformative planetary force. In Nova Scotia data from lakes, streams, soils, bedrock, tills and plants reveals environmental change. Previous studies concerned mostly acidic precipitation, acid drainage, intracoastal pollution with recent attention given to elevated radon, mercury and arsenic levels. Using Landscape Geochemistry modern drainage catchments are considered to act as mass storage devices containing the 'geochemical genetic code' as background levels for input to GIS and other modeling applications.

Several landscape geochemical studies outline significant man-made (anthropogenic) environmental issues. Catchment lithology, chemical mobility, and dispersion and dilution of metals during transport are related to varying pH. Surface water samples from streams in Hants and Halifax counties identified many bedrock factors with the notable presence of elevated N<sub>2</sub> ions in lowland areas when used for agriculture. Since the 1960s, construction activities at the airport and along the Bicentennial Highway have exposed highly fractured, mineralised, and pyritic units of Halifax Group slate. The 1987 runway extension created an acidic leachate runoff with a pH of 2.9, with resultant fish kills and relocation of a municipal water supply at Enfield. The 1990 amelioration by sheet-creting of the exposed runway bedrock increased pH of outlet water by 0.5 pH units. During the 17th century wooden ships brought foreign pollen as ragweed (*Ambrosia* spp.) and *Plantago* spp. This layer provides a baseline from which to estimate anthropogenic inputs. Dramatic increases in baseline metal values of Pb (automobiles), Cu (plumbing), and V (heating oil) are observed in many cores. Post-*Ambrosia* disturbance is noted near smelters in Ontario. At Chocolate Lake a geochemically distinct 'backhoe' horizon is produced by excavation and construction activities about 40 years ago. Elements in lake cores also act as time and spatial or ballistic markers with Ni, Cu, U, Br, As, Sb and Co useful in Ontario and Al and Zn at Soldier Lake. As a corollary to future global warming effects, lake cores record climatic change to a warm, dry maximum at ca. 3500–5500 RYBP, the xenothermal interval. The use of road salt for ice control is noted by increased halophilous diatoms. Since ca. 1750, deforestation changes are seen in tree pollen and diatoms. Prior to 1900 pH in cores is approximately 4.5 but since the 1970s increasing lake water eutrophication due to leaching of domestic waste is noted by near-neutral pH.

---

### Structural evolution and tectonic history of the Glenelg area, Nova Scotia, Canada, and its relationship to correlative rocks of the South Portuguese Zone, Spain

---

COLIN ROSS, JAMES A. BRAID, AND DONNELLY B.  
ARCHIBALD

Department of Earth Sciences, St. Francis Xavier University,  
Antigonish, Nova Scotia B2G 2W5, Canada

The peri-Gondwanan Meguma terrane is the most outboard terrane of the Canadian Appalachian orogen and encompasses an area of 200,000 km<sup>2</sup> extending from the Gulf of Maine to the Grand Banks of Newfoundland. The terrane consists of mainly greenschist to amphibolite facies turbiditic metapelite sedimentary sequences that were intruded by Devonian plutonic rocks during the Neoacadian orogeny, a tectonic event that stitched the Meguma terrane to the Avalon terrane (ca. 380–370 Ma). The Glenelg area is in the northeastern part of the Meguma terrane. This area has a complex geology including lead and gold mineralization that has received limited academic study. The rocks are primarily composed of quartz-rich metasandstone that are characteristic of the Goldenville Group of the Meguma terrane. Preliminary field and petrographic studies indicate a NE-SW trending fold system and amphibolite-facies metamorphism, with the highest metamorphic grade near the center of the fold that has resulted in the growth of large staurolite and garnet porphyroblasts. The area is also of economic interest as it hosts a likely fault-related galena deposit that crops out along strike of the Cochrane Hill gold occurrence. Initial Inductively Coupled Plasma Mass Spectrometry (ICP-MS) assay results show low gold concentrations, but elevated concentrations of lithium. High lithium concentrations appear to be associated with the large staurolite-bearing beds. Previous assays done on the Hirschfield lead prospect in the area also indicate a high concentration of silver associated with the galena deposit. To investigate regional correlations of the Meguma terrane, detrital zircon U–Pb data were compared to data from the South Portuguese Zone of Spain. In Spain the oldest exposed rocks are relatively weakly deformed Late Devonian phyllite and quartzite; however, the recent discovery of exposed polydeformed alternating beds of phyllite and quartzite could represent an older sequence with potential links to the Meguma terrane. U–Pb detrital zircon data collection is ongoing but indicate that the South Portuguese Zone (Iberian Peninsula) may be underlain by Meguma basement. This interpretation is consistent with paleogeographic reconstructions that place Maritime Canada adjacent to autochthonous Iberia in the Late Paleozoic.

---

**Portable X-ray fluorescence analysis of terminal grade in basal till south of the Mount Pleasant deposit, New Brunswick, Canada\***

---

STEVEN L.E. ROSSITER AND BRUCE E. BROSTER

*Department of Earth Sciences, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada <rossite@unb.ca>*

A common practice for drift exploration surveys is to collect the <63  $\mu\text{m}$  grain-size fraction of basal till for chemical analysis by ICP-MS and INAA. Recent technical advances have enabled researchers to employ portable X-ray fluorescence (pXRF) as a rapid and economical method of chemical analysis with certain limitations that are now being widely studied.

For the present preliminary study, 80 samples of basal till were collected within the McDougall Lake area (NTS: 21 G/07), south of Mount Pleasant: a past-producing W mine in southwestern N.B. Other occurrences of mineralization are known also to be present in the area. Much of the study area is underlain by granite, which at many locations has been intensely weathered to sandy, angular “grus” and incorporated into the locally derived till cover. The high proportion of coarse material within the till matrix is a concern for analytical methods which commonly employ acid digestion on the <63  $\mu\text{m}$  grain-size fraction only. Thus, pXRF has been employed to analyze and compare concentrations of selected elements among the <-1  $\Phi$  (very coarse sand, <2 mm), <2  $\Phi$  (fine sand, <0.25 mm) and <4  $\Phi$  (coarse silt and clay, <63  $\mu\text{m}$ ) matrix modes. The analysis of separate matrix modes has enabled assessment of mineral comminution to “terminal grades” and the effect that terminal grades have on drift prospecting efficacy.

For most elements analyzed, the <63  $\mu\text{m}$  matrix mode reported the highest average concentrations. However, regardless of matrix mode analyzed, elements Pb, S, As, Zn, and Ce, in descending magnitude, consistently demonstrated a large separation between the average and peak concentrations, indicating their utility as pathfinder elements for this mineralized area. For Pb, the magnitude between average and peak values in the size fractions analyzed was 11.76 times greater for <-1  $\Phi$ , 12.62 times greater for <2  $\Phi$  and 19.60 times greater for <4  $\Phi$ .

The results suggest that comminution to terminal grade sizes was not fully achieved for several minerals. Although greater geochemical contrast can often be attained by analyzing the <4  $\Phi$  matrix mode, it is proposed that analysis of the <2  $\Phi$  and <-1  $\Phi$  matrix modes could also yield useful information for drift prospecting in areas of grus-rich till.

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

---

**Arctic tsunamis revisited**

---

ALAN RUFFMAN

*Geomarine Associates Ltd., P.O. Box 41, Station M, Halifax, Nova Scotia B3J 2L4, Canada <aruffman@dal.ca>*

In 2006 I presented a joint paper on the “tsunami Hazards in the Arctic Regions of North America, Greenland and the Norwegian Sea” with Tad Murty to the third Tsunami Symposium of the Tsunami Society. Dr. Murty and I had very few known Arctic events that we could cite and were reduced to listing possible hazard areas and waving our arms most wisely. In the past decade and a half at least three new events have been identified and the concern about possible tsunamis related to deglaciation should now be seriously considered. The phenomenon of glacial-calving earthquakes is now demonstrated and the seismic signals from landslides can now be recognised. This paper will use a definition of an Arctic geohazard as one found in areas of deglaciation and generally in the north of North America, Europe and Asia beyond a nominal tree line. Thus the paper includes post-glacial events along the Alaska Panhandle. The tsunamis that may be generated are not just a hazard to local Arctic communities and to temporary coastal accommodations and facilities used for resource extraction projects. The far field effects of an Alaskan subduction earthquake on 1 April, 1946 killed 159 persons in Hilo, Hawaii and triggered the establishment of the Pacific tsunami warning network. A tsunami generated by a post-glacial fault (pgf) off the coast of SE Greenland could affect coastlines from Portugal north to Great Britain and Norway; a pgf off the SW coast of Greenland could affect the Baffin-Labrador coasts south to Newfoundland and by refraction the coasts of Nova Scotia and New England.

Only one large  $M_w = 7.3$  earthquake is known in NW Baffin Bay on 30 November, 1933 – an area that remains seismically active. While no tsunami was seen in 1933 such an event could well trigger an underwater landslide and a tsunami. Felt earthquakes are associated with the mid-ocean Labrador Ridge and these may trigger tsunamis. If post-glacial rebound is rapid it may be non-elastic and coast-subparallel pgfs are well-documented in northern Norway and Sweden over lengths approaching 400 km with throws of as much as 25 m. If, from a single event, the earthquake would be of a magnitude >8. The huge Storegga landslide of ~8000 years ago may possibly have been triggered by a pgf. Canada now has at least three known pgfs (Lac Turquoise in Quebec, the Holy Grail fault in Manitoba and Dr. King’s recently identified submarine feature at the mouth of McLure Strait). The author’s historic seismicity research has identified a modest tsunami of 24 September, 1848, seen from St. John’s to Fishing Ships Harbour, southern Labrador;

is this a record of a pgf off SW Greenland? We have known rockfall events in West Greenland on 21 November, 2000, at Paatuut, a recent Karrat Fjord event on 17 June, 2017 with four deaths and at Taan Fjord, Icy Bay, Alaska a rapidly retreating glacier left a lateral moraine unsupported and a large rockfall into the sea on 17 October, 2015 created an initial tsunami wave ~150 m high. No one saw it, or heard it, and Columbia University seismologists identified the landslide remotely in Palisades, New Jersey.

---

### Application of predictive modeling to the Early Cretaceous sedimentary sequences of the Central Scotian Basin, offshore Canada

---

CHRISTOPHER SANGSTER<sup>1</sup>, NICOLAS HAWIE<sup>2</sup>, GEORGIA PE-PIPER<sup>1</sup>, FRANCKY SAINT-ANGE<sup>2</sup>, DAVID J.W. PIPER<sup>3</sup>, AND EMERSON MARFISI<sup>2</sup>

1. Department of Geology, Saint Mary's University, Halifax, Nova Scotia, B3H 3C3, Canada, <csangster16@gmail.com> ¶
2. Beicip-Franlab, Rueil-Malmaison, Île-de-France, 92500, France ¶
3. Geological Survey of Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, B2Y 4A2, Canada

The distribution and quality of the reservoir sandstone units of the Nova Scotia offshore is poorly understood in the Early Cretaceous, particularly in the deep basin, where few wells have been drilled. Exploration is further complicated by the widespread salt tectonism and the strong influence of diagenesis on reservoir quality. This project uses *DionisosFlow*<sup>TM</sup>, a forward stratigraphic modeling software, and *CougarFlow*<sup>TM</sup>, statistical analysis software, to produce stratigraphic models of the Central Scotian Basin, and test the sensitivity of produced models. These models will test proposed provenance pathways, determine if sands in the Scotian Basin are trapped on the slope or bypass to the deep ocean floor, and attempt to predict the quality and distribution of reservoir sandstone intervals by simulating the distribution of sand and feldspar within the basin.

An integrated multi-disciplinary approach to stratigraphic modeling has been used, in which model inputs are drawn from research conducted in the Central Scotian Basin. Model results are calibrated against well logs, facies, and seismic interpretations of the study area to produce predictive stratigraphic models.

Model results indicate that the style of sand and feldspar deposition changed through time. In the Upper Missisauga Formation, sand was trapped dominantly on the shelf, with lesser deposition in minibasins along the slope and basin and transported into the deep basin along salt corridors. Feldspar concentrations show a similar trend; however, low concentrations are observed in the central shelf and elevated

feldspar concentrations in the eastern and western shelf. In the Naskapi Member, the system became shale dominated, with sands trapped dominantly on the shelf and very limited transport into the basin. Feldspar shows increased overall concentrations with a more evenly distribution on the shelf, and more feldspar being pushed into the deep basin. In the Cree Member sand and feldspar deposition returned to a similar style as the Upper Missisauga Formation, however, the central shelf shows a more even distribution of feldspar.

Sensitivity analysis of the reference case models show that sand and feldspar distribution are most uncertain in the deep basin, and in association with salt bodies. Preliminary results also suggest that subsidence and supply control sand distribution, and the proportion of feldspar in the sources supplying the system controls feldspar distribution. Future work will combine statistical results and model predictions with fault and temperature mapping, to produce risk maps of reservoir quality for the Central Scotian Basin.

---

### Lower Jurassic organic matter preservation events and their record offshore Nova Scotia, Canada

---

RICARDO L. SILVA<sup>1,2</sup>, LUÍS V. DUARTE<sup>2</sup>, JUAN J. GÓMEZ<sup>3</sup>, STEPHEN HESSELBO<sup>4</sup>, JOÃO G. MENDONÇA FILHO<sup>5</sup>, DRISS SADKI<sup>6</sup>, BRUNO RODRIGUES<sup>2</sup>, DARRAGH O'CONNOR<sup>7</sup>, AND GRANT WACH<sup>7</sup>

1. Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <ricardo.silva@dal.ca> ¶
2. MARE, Universidade de Coimbra, Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Largo Marquês de Pombal, 3000-272 Coimbra, Portugal ¶
3. Stratigraphy Department, Geological Science Faculty, University Complutense Madrid, José Antonio Novais, 12, 3ª planta, dp. 14A, 28040 Madrid, Spain ¶
4. Camborne School of Mines and Environment and Sustainability Institute, University of Exeter, Penryn Campus, Penryn, Cornwall TR10 9FE, UK ¶
5. Departamento de Geologia, Instituto de Geociências, Universidade Federal do Rio de Janeiro, Av. Athos da Silveira Ramos, 274 - Cidade Universitária - Ilha do Fundão, Rio de Janeiro - RJ, 21044-020, Brazil ¶
6. Moulay Ismail University, Faculty of Science, BP. 11201 Zitoune, Meknes, Morocco ¶
7. Basin and Reservoir Lab, Department of Earth Sciences, Dalhousie University, 1355 Oxford Street, Life Sciences Centre, Halifax, Nova Scotia B3H 4R2, Canada

Along the central-northern Atlantic margin, Lower Jurassic sedimentary successions include several organic-rich intervals with source rock potential. These units

comprise the Sinemurian to Pliensbachian organic matter preservation intervals (OMPIs) and the Toarcian Oceanic Anoxic Event (T-OAE). The deposition of these organic-rich intervals was modulated by global paleobiological and paleoenvironmental changes and major perturbations of the carbon cycle. However, the local record of these events and production and preservation of organic matter depends on local paleogeography, paleoclimate, and depositional setting.

Currently, there is a need to predict the presence of source rock along the Scotian margin (and effectively, the entire central Atlantic area) and then define the characteristics of those rocks to determine the potential and viability for economic production. Understanding the geologic processes leading to the accumulation of organic matter increases our understanding of the controls on source rock potential and reservoir delivery systems and develops exploration and production models where few exist. The objective of our study is to: (a) construct a detailed and accurate temporal and geographical frame of Lower Jurassic organic-rich facies occurrences and their main characteristics for the Lower Jurassic at a global scale and (b) use this framework to predict the occurrence of these intervals in the offshore Scotian Basin (Atlantic Canada, central Atlantic). To accomplish our goals, we evaluated and reinterpreted most of the existing and available organic geochemistry datasets for the Lower Jurassic and conducted several novel geochemical studies performed on selected locations from Spain, Portugal, and Morocco (outcrops).

From our study, and regarding the Lower Jurassic offshore Nova Scotia, we rank (in a relative way) the Upper Pliensbachian interval with the highest probability to include a significant source rock offshore Nova Scotia. Upper Sinemurian–Lower Pliensbachian successions are considered to have a lower probability (when compared with the Upper Pliensbachian) of having source rocks. The Lower Toarcian has a low potential to hold a vast source rock interval like the ones occurring in the northern European regions. Speculatively, and as suggested for Morocco, local depocenters might have been restricted enough to accumulate organic matter.

---

**Preliminary results of a pilot study on automated quantitative evaluation of minerals (QEM) in the Kimmeridge Clay Formation (Dorset, UK)**

---

RICARDO L. SILVA<sup>1,2</sup>, STEPHEN HESSELBO<sup>3</sup>, AND  
RICARDO CELESTINO<sup>3</sup>

1. Department of Earth Sciences, Faculty of Science,  
Dalhousie University, Halifax, Nova Scotia B3H 4R2,  
Canada <ricardo.silva@dal.ca> ¶

2. MARE - Marine and Environmental Sciences Center,  
University of Coimbra, Rua da Matemática, nº 49,  
3004-517 Coimbra, Portugal ¶

3. Camborne School of Mines and Environment and  
Sustainability Institute, University of Exeter, Penryn  
Campus, Penryn, Cornwall TR10 9FE, UK

Despite decades of research, the palaeoenvironmental and sedimentological controls leading to the unusual organic matter (OM) contents of the Kimmeridgian–Tithonian Kimmeridge Clay Formation (KCF) and contemporaneous successions around the Atlantic margins are still debated. Several studies conducted in the Dorset area, southern England, the type locality of the KCF, demonstrated the connection between OM content, depositional conditions, and astronomical parameters (eccentricity, obliquity, and precession).

The most recent cyclicity studies of the KCF conducted at Dorset use the datasets collected between 1996–2001 by the NERC-funded project *Rapid Global Geological Events* (RGGE). These datasets, coupled with GTS2004 ages are, until today, the basis to investigate astronomical dependent sedimentary cyclicity (including the organic-rich intervals) and to build astronomically based chronologies for the KCF and the Kimmeridgian–Tithonian time interval. New developments in analytical techniques and the recently updated numerical ages for the Kimmeridgian–Tithonian open the opportunity to, 20 years later, revisit the data collected by the RGGE project.

Our first step in this project was to perform a pilot study focusing on automated quantitative evaluation of minerals (QEM) in several mudstone, limestone, and dolostone lithofacies from the KCF outcrop at Kimmeridge Bay (Dorset, UK). QEM uses automated image analysis combining backscatter and energy-dispersive X-ray signals to identify minerals. This method generates a complete mineral identification of the studied sample and a detailed mineralogical dataset for the studied interval, potentially addressing issues such as sedimentary provenance (heavy minerals), diagenesis (chemical variation of mineral species), and climatic variation (clay mineral assemblages).

Our pilot study results in a concise sample-preparation and analysis protocol for the diverse suite of lithologies of the KCF. It also demonstrated the feasibility of using the QEMSCAN® for QEM of different KCF lithologies. Our goal is to generate new datasets to support a new sedimentological and astrochronology study of the KCF, aiming to improve our view of the paleoenvironmental controls that led to the deposition of this peculiar geological interval in the Atlantic margins.

---

## The Margaree pluton, Aspy terrane, Cape Breton Island, Nova Scotia, Canada: evidence for Late Devonian terrane convergence

---

GABRIEL SOMBINI DOS SANTOS<sup>1</sup>, SANDRA M. BARR<sup>1</sup>,  
DEANNE VAN ROOYEN<sup>2</sup>, AND CHRIS E. WHITE<sup>3</sup>

1. Department of Earth and Environmental Science,  
Acadia University, Wolfville, Nova Scotia B4P 2R6, Canada.

<gabriel\_sombini@hotmail.com> ¶

2. Department of Mathematics, Physics, and Geology, Cape  
Breton University, Sydney, Nova Scotia B1P 6L2, Canada. ¶

3. Nova Scotia Department of Natural Resources, Halifax, Nova  
Scotia B3J 2T9, Canada

The Margaree pluton extends for 40 km along the axis of the Ganderian Aspy terrane of northern Cape Breton Island. Generally described as rapakivi-textured megacrystic syenogranite, detailed mapping has shown that the pluton can be subdivided into mappable units of megacrystic biotite ± hornblende syenogranite, medium-grained equigranular biotite syenogranite, and quartz ± orthoclase porphyry, all locally displaying rapakivi texture. The equigranular syenogranite intruded megacrystic syenogranite, and the porphyry occurs as a marginal unit. The units are locally mingled, consistent with similar U–Pb (zircon) ages of 363 ± 1.6 Ma from a megacrystic syenogranite sample, 364.8 ± 1.6 Ma from an equigranular syenogranite sample, and 365.5 ± 3.3 Ma from a quartz - orthoclase porphyry sample. Although the pluton displays wide textural variation, chemical data from 50 samples from throughout the extent of the pluton are similar. SiO<sub>2</sub> is mainly between 68 and 78%. The pluton is calc-alkaline, peraluminous, ferroan and alkalic to calc-alkalic. The rare earth element patterns are virtually identical, with slight enrichment in the LREE (La 20 to 100 times chondritic values), flat HREE, and moderate negative Eu anomalies. The geochemical signature suggests that the pluton is an evolved I-type granite, emplaced in an active continental margin, a surprising result given the Late Devonian age and its location in an area presumed to be experiencing extension and rifting beginning at ca. 375 Ma. Contrary to previous mapping, where most contacts were interpreted as faults, the Margaree pluton intruded all surrounding units, displaying an *en cornue* shape indicative of emplacement preferentially within or at the margins of a major shear or fault zone, in this case the Aspy Fault, a major late structure in the Cape Breton Highlands. The pluton is not cut by the Aspy Fault, thus constraining the last stages of movement to the Late Devonian. The contact relations and age of the Margaree pluton have important implications for the history of the Aspy terrane and its relationship to the now-adjacent Bras d'Or terrane.

---

## Determining the early incision history of the Colorado Plateau using an innovative dating method

---

MAYA A. SOUKUP<sup>1</sup>, ALAN J. HIDY<sup>2</sup>, JOEL L. PEDERSON<sup>3</sup>, AND  
JOHN C. GOSSE<sup>1</sup>

1. Department of Earth Sciences, Dalhousie University, Halifax,  
Nova Scotia B3H 4R2, Canada <Maya.Soukup@Dal.Ca> ¶

2. Center for Accelerator Mass Spectrometry, Lawrence Livermore  
National Laboratory, Livermore, California 94550, USA ¶

3. Department of Geology, Utah State University, Utah 84322, USA

Terrestrial Cosmogenic Nuclide (TCN) exposure and burial dating techniques have been limited to depths of <30 m. Improvements in TCN target chemistry and Accelerator Mass Spectrometry have provided an opportunity to expand this depth in an effort to address previously intractable questions regarding large-scale landscape evolution such as the timing and origin of canyons. The primary objective of this honours thesis is to test the validity and reproducibility of measuring a long-lived TCN (<sup>10</sup>Be, t<sub>1/2</sub> = 1.39 Ma) in quartz-dominated sediments using muon-produced nuclides at great depths. The secondary objective of this thesis involves evaluating the timing of early incision history of the northern Colorado Plateau, a topic which remains highly debated.

We have devised a strategy to test the limits of muogenic TCN production at depths >130 m and to estimate the rate and timing of initial incision of a large valley near the Book Cliffs, Utah. High energy cosmic ray primaries (mostly protons) produce secondary particles (such as fast and negative muons) when they interact with nuclei of atoms in the atmosphere or exposed minerals. Muons are 209 times the mass of an electron, and because of their small mass they interact weakly with matter. Thus, muons can penetrate deeply into the subsurface, and cause further interactions to produce rare TCN such as <sup>10</sup>Be.

Samples of graphite-bearing quartzite were collected >130 m below the valley bottom along a mine stope that stretches from bank to bank approximately perpendicular to the valley axis above. The concentration of muogenic <sup>10</sup>Be produced from oxygen and silicon in the quartz will be proportionate to the flux of cosmic radiation received, which has not varied more than 10%, over the past 8 Ma. We hypothesize that the sub-surface <sup>10</sup>Be concentrations will have a spatial pattern that reflects the cosmic ray shielding by the overlying topography. If the incision occurred recently, the <sup>10</sup>Be concentrations will be greatest under the deepest portion of the valley. Older or slower incision histories will generate other spatial distributions. Currently seven <sup>10</sup>BeO targets and one process blank are being prepared at Dalhousie University and will be tested at the Center for AMS at Lawrence Livermore National Laboratory. With this

project, we hope to first and foremost determine the viability of detecting muogenic isotopes for future applications of the dating method, and to apply the innovation to help constrain the incision history of the Colorado Plateau.

---

### Middle to Upper Ordovician ironstone of the Western Asturian-Leonese Zone, Spain: coastal upwelling, ocean anoxia, and Paleozoic biodiversity

---

ALEXANDRA D. SQUIRES<sup>1</sup>, PEIR K. PUFAHL<sup>1</sup>, J. BRENDAN MURPHY<sup>2</sup>, CECILIO QUESADA<sup>3</sup>, AND JASON HATCH<sup>2</sup>

1. *Department of Earth and Environmental Science, Acadia University, Wolfville, Nova Scotia B4P 2R6, Canada*  
<alex.squires@acadiau.ca> ✉

2. *Department of Earth Sciences, St. Francis Xavier University, Antigonish, Nova Scotia B2G 2W5, Canada* ✉

3. *Instituto Geológico y Minero de España, Madrid 28003, Spain*

Middle to Upper Ordovician ironstone and associated sedimentary rocks of the Western Asturian-Leonese Zone (WALZ), Spain, provide new information regarding the paleoceanography of the Rheic Ocean and the Paleozoic Fe cycle. The Rheic Ocean formed when the peri-Gondwanan terrane Avalonia drifted northward from Gondwana during the Late Cambrian and Early Ordovician. Examination of drill cores and outcrops indicates the southeastern margin of this narrow seaway was a dynamic continental shelf where upwelling of ferruginous seawater and storm currents controlled lithofacies character.

Parasequence composition and stacking relationships suggests the accumulation of ironstone occurred between fairweather and storm wave base as accommodation increased from lowstand conditions. Proximal parasequences consist of interbedded hummocky cross-stratified sandstone and organic-rich siltstone that shallows upwards into swaley cross-stratified sandstone and granular hematitic ironstone. Distal parasequences are composed of variably bioturbated organic-rich siltstone with thin Fe-silicate and phosphorite layers. These lithofacies associations support an emerging model for ironstone deposition that relies on coastal upwelling to deliver and stimulate the precipitation of Fe in shelf sediment.

This notion provides further evidence for the development of persistent anoxic water masses in an Ordovician ocean that was near the threshold of becoming fully ventilated. New data suggests that minor extinction events punctuating the Great Ordovician Biodiversification Event may be traced to these anoxic waters, which in addition to Fe were also enriched in biologically toxic trace elements. Precipitation of upwelling-related ironstone may have helped sequester these redox sensitive elements, providing a negative feedback response to aid post-extinction recovery.

---

### Lithochemical classification of clastic sedimentary rocks using a quartz-feldspar-mica ternary diagram

---

CLIFFORD R. STANLEY

*Department of Earth and Environmental Science,  
Acadia University, Wolfville Nova Scotia B4P 2R6, Canada*  
<cliff.stanley@acadiau.ca>

Clastic sedimentary rocks are traditionally classified using a combination of textural (clast, matrix) and mineralogical (quartz, feldspar, lithic) criteria plotted on Dott's modified 'Toblerone' diagram. Although this has served geoscientists well over the years, a novel, alternative, geochemically based classification derived from lithochemical data can offer complementary information that allows geoscientists to better understand the clastic sedimentary rocks under study.

Classification involves the conversion of major oxide concentrations (SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, FeO+MgO, CaO, Na<sub>2</sub>O, and K<sub>2</sub>O) of clastic sedimentary rocks into a fixed set of mineral proportions (quartz; anorthite, albite, and K-feldspar; muscovite, biotite), and their subsequent plotting on a quartz-feldspar-mica ternary diagram. This is achieved by first dividing the major oxides by their corresponding molecular weights. Then, multiplication of matrix algebra-derived linear combinations by the resulting molar element numbers (quartz: Si-2Ca-3Na-3K, feldspar: -Al/2-Fe/3-Mg/3+2Ca+3Na/2+3K/2, mica: Al/2+Fe/3+Mg/3-Ca-Na/2-K/2) produce molar mineral numbers that can then be standardized for plotting in ternary space.

Data interpretation on the diagram is straightforward, as clastic rocks containing more molar feldspar than clay minerals (referred to as 'geochemical sandstones') plot within the ternary diagram (because their linear combinations plot in the [+ + +] orthant of quartz-feldspar-mica space). In contrast, clastic rocks containing more molar clay minerals (kaolinite, chlorite, smectite, illite) than feldspar (referred to as 'geochemical mudstones') plot outside the ternary diagram to its left (because all clay minerals plot in the [+ - +] orthant). Classifications of rocks containing other minerals (calcite, dolomite, apatite, pyrite, etc.) are tractable because the effects of these minerals can be projected from by subtraction of appropriate components from the linear combinations (e.g., -Al/2-Fe/3-Mg/3+2Ca+3Na/2+3K/2-2CO<sub>2</sub> accurately measures feldspar in the presence of significant calcite), allowing routine investigation of a wide range of clastic sedimentary rocks.

Patterns made by clastic sedimentary rocks on the quartz-feldspar-mica ternary diagram can be related to provenance composition, chemical maturity, depositional environment, and sedimentation, authigenesis, and diagenesis processes, providing information that is not available using Dott's classification. Consequently, a number of clastic sedimentary



rock systems have been examined using the quartz-feldspar-mica diagram (e.g., the Aldridge-Pritchard Formation, Belt-Purcell Supergroup; the Manitou Falls Formation, Athabasca Basin; the Halifax and Goldenville groups, Meguma Supergroup; epiclastic metasedimentary rocks, Flin Flon Greenstone Belt; the Green River Formation, Uinta Basin; and the Castlepoint Formation, New Zealand). Several of these case histories are presented to illustrate the power and advantages of the quartz-feldspar-mica ternary diagram classification approach.

---

### Beaufort Formation chronostratigraphy and Pliocene landscape evolution – new insights into the formation of the Northwest Passages, Canada

---

SYDNEY A. STASHIN<sup>1</sup>, JOHN C. GOSSE<sup>1</sup>, I. ROD SMITH<sup>2</sup>, AND  
ADAM Z. CSANK<sup>3</sup>

1. *Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <sydney.stashin@dal.ca> ¶*
2. *Geological Survey of Canada, Calgary, Alberta, Canada T2L 2A7 ¶*
3. *Department of Geography, University of Nevada, Reno 89557, USA*

The Pliocene Beaufort Formation in the western Canadian Arctic Archipelago is dominated by stream sediments forming a coastal plain and accretionary wedge that thickens westward into the Canada Basin. The Beaufort Formation contains extremely well-preserved peat, wood, and vertebrate fossils (e.g., beaver and camel), supporting paleoenvironmental records indicating a high Arctic boreal forest ecosystem was present during the Pliocene. However, records from various islands indicate environmental and climate variability among the sites; it is unclear if this is simply because the records are varying in age, or if there were actual climate differences between time-equivalent locations owing to, for example, contrasts in continentality.

Currently, the Beaufort Formation deposits are present on islands divided by inter-island channels. However, paleoflow and lithological provenance evidence collected on Prince Patrick Island in 2017 and reported previously by others suggest that the Beaufort Formation once formed a contiguous 1200 km-long coastal plain. Consequently, incision must have occurred in the waning stages or following Beaufort Formation deposition. Determining a depositional history of the Beaufort Formation would further inform the channel incision history. Additionally, the post-Pliocene mechanism of incision has yet to be properly resolved. Are the inter-island channels tectonic grabens that have been active since prior to the Pliocene, or were they opened after the Pliocene by incision by water and glaciers? Assessments of seismic data bounding M'Clure Strait do not

reveal any normal faults that align with the strait's walls. The presence or absence of inter-island channels is important as their development may have affected onshore and offshore temperatures throughout the Archipelago, perhaps a factor influencing the observed climate variability between paleoenvironmental records.

New and revised ages have been determined for the depositional age of the Beaufort Formation on western Canadian Arctic Archipelago islands, within cuttings from petroleum well cores, and on chrono-stratigraphically similar fluvial deposits elsewhere in the Canadian Arctic. The geochronology will improve our ability to correlate the isolated paleoclimate records on different islands and test hypotheses regarding the paleoenvironmental changes and linking them to global and regional paleoclimate and paleoceanographic changes. Additionally, the cosmogenic nuclide concentrations provide paleo-erosion rates in the source areas to the Beaufort Shelf at particular times. Future work includes further refining the geochronology of the Beaufort Formation as well as using newly acquired seismic data to resolve the presence of faulting within the inter-island channels and to locate the paleo shoreline.

---

### A review of *Kinneyia simulans*: an ichnotaxonomic approach to wrinkled microbially induced sedimentary structures from New Brunswick, Canada\*

---

MATTHEW R. STIMSON<sup>1,2</sup>, R. ANDREW MACRAE<sup>2</sup>, RANDELL F. MILLER<sup>1</sup>, STEVE J. HINDS<sup>3</sup>, NICHOLAS J. MINTER<sup>4</sup>, AND  
ZABRINA PRESCOTT<sup>5</sup>

1. *Natural Science Department, New Brunswick Museum, Saint John, New Brunswick E2K 1E5, Canada <mstimson29@gmail.com> ¶*
2. *Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada ¶*
3. *Geological Surveys Branch, Fredericton, New Brunswick E3B 5H1, Canada ¶*
4. *School of Earth and Environmental Sciences, University of Portsmouth, Portsmouth, PO1 3QL, United Kingdom ¶*
5. *Department of Biology, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada*

The discovery of new morphologies of microbially induced sedimentary structures in New Brunswick has prompted a restudy of how we communicate traces of microbial mats in the fossil record. Microbially induced sedimentary structures (MISS) are an important facet of recent paleoichnological work because of their taphonomic implications. MISS are extensively studied in terms of their formation processes, recognition in the ancient record, and their diverse morphologies. Classification and terminology schemes are based on their appearance and mode of formation; however,

the taxonomic treatment of MISS remains debated. Traditionally MISS have been considered sedimentary structures, and arguments have been made that they cannot be treated as trace fossils under the International Code of Zoological Nomenclature due to MISS being formed by communities of microbiota including algae, cyanobacteria, and others, rather than a single trace maker. We have re-examined MISS using an ichnotaxonomic approach and applied ichnologic terminology and binominal names to specimens from both the Saint John Group (Cambrian) and Horton Group (Mississippian). Upon re-examining the holotype of *Kinneyia* Walcott, a genus commonly used to describe some MISS, we argue it cannot be used to correctly describe wrinkle or ripple-like features seen in MISS, and we agree with previous authors that *Kinneyia* is likely not biogenic in origin. A new ichnogenus and ichnospecies, *Rugalichnus matthewii*, have been assigned to ripple-like sedimentary wrinkle marks known as MISS, separating them from the *nomen dubium* genus *Kinneyia*.

A Mississippian (Albert Formation) example of MISS is distinct from the recently named *Rugalichnus matthewii*. Its regular arrangement of interlocking circular whorls is interpreted to be the result of concentric growth of the living mat outwards from its initial establishment from deposited mat rip-up chips. It is interpreted to have formed in a small, abandoned fluvial sandstone channel that debouched into a marginal lacustrine clastic mudflat environment.

Invertebrate ichnofossils assemblages are directly associated with both examples of *Rugalichnus* and show morphological variability related to their proximity to microbial mats. The close association between invertebrate traces and microbial mats in the Mississippian Period may be a relict paleoecological niche from the earlier transition of invertebrates from aquatic freshwater to terrestrial environments and can be inferred to have played an important role in ancient ecosystems as well as playing a major role in the preservation of ichnofossils.

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

---

### Origin and geodynamic significance of fault-hosted sulfide-rich gold deposits from the Jiaodong gold province, China: Rb–Sr dating and H–O–S–Pb isotopic constraints

---

JUN TAN<sup>1</sup> AND DAVID R. LENTZ<sup>2</sup>

1. Faculty of Earth Resources, China University of Geosciences, Wuhan 430074, China <tanjunallan@163.com> ¶
2. Department of Earth Sciences, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada

The Jiaodong region is the largest gold province in China and has proven reserves exceeding 3000 t Au. The gold deposits are traditionally grouped into three main types, namely, the auriferous quartz vein type (Linglong type), the altered rock type (Jiaojia type), and the interstratified breccia type (Pengjiakuang type). More recent exploration (from 2009 to 2014) indicate a minimum of 27 tonnes Au of additional resources in the Guocheng–Liaoshang gold belt, Jiaodong gold province. The ores are hosted in faults/fractures in Paleoproterozoic metamorphic and later granitic rocks and are characterized as sulfide-rich type with sulfides of up to 40 to 95 vol.%. Rb–Sr isotopic dating of mineralized quartz yielded an isochron age of  $116.2 \pm 2.4$  Ma (MSWD = 0.36). The ore-related quartz samples have  $\delta D$  values of  $-86$  to  $-69$ ‰ (mean  $-78$ ‰), with calculated  $\delta^{18}O_{H_2O}$  values of 0.6 to 7.7‰ (average 3.6‰). The  $\delta^{34}S$  values of ore sulfides vary from 8.5 to 12.7‰ with an average of 9.9‰. Lead isotope signatures recorded in sulfides are much less radiogenic ( $^{206}Pb/^{204}Pb = 17.039-17.862$ ) relative to that of Phanerozoic asthenospheric mantle ( $^{206}Pb/^{204}Pb = 18.179-18.384$ ). These results show that the gold mineralization style in this belt is different from the traditionally identified three types of gold deposits in the Jiaodong Peninsula. They also suggest deep-seated, mantle-derived magmatic sources for the ore fluids, most likely mafic dykes, with sulfur and metals in the hydrothermal system, despite the fact that wall rocks might provide some sulfur reflected in the enriched  $^{34}S$  signature. The inferred mantle reservoir was probably formed by subduction-related fluid metasomatism during the assembly of the Paleoproterozoic (ca. 1.85 Ga) Jiao-Liao-Ji mobile belt (suture within Columbia supercontinent). Extensional tectonic inversion during the early Cretaceous, caused by subduction of the Kula–Pacific plate rather than post-collisional process of the Qinling–Dabie–Sulu orogen, triggered partial melting of this mantle domain, subsequent magma mixing and emplacement with final exsolution of ore-forming fluids.

---

### Origin and down-flow behavior of turbidity currents in Halibut Canyon, eastern Canadian margin

---

MENG TANG<sup>1,2</sup> AND DAVID J.W. PIPER<sup>2</sup>

1. Department of Coastal Ocean Sciences, School of Geography and Oceanography, Nanjing University, Nanjing, China ¶
2. Geological Survey of Canada Atlantic, Natural Resources Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada

The origin and behavior of turbidity currents through submarine canyons on eastern Canadian margins is poorly understood. Four piston cores from East Halibut canyon

(off southern Newfoundland) have been studied in detail. Cores 18 and 19 are about 180–200 m above the talweg and 20 km from the shelf break. Cores 32 and 33 are 90–155 m above the talweg and 30 km from the shelf break. The cores consist principally of mud with thin sand beds in the lower part of the cores. Correlation of the cores is based on grain size analysis,  $a^*$  (red = hematite) color values and bulk density measurements. Chronology is provided by two radiocarbon dates in cores 18 and 33. The Younger Dryas period (YD) has been identified as an important marker for correlation. In the probable YD interval, more sand beds are present in the upper transect (9 in core 18; 11 in core 19) than in the lower transect (5 in core 32; none in core 33). Turbidity currents thus decrease in their ability to transport sand down-system. Thickness of sand beds also decreases down-system, from 0.5–3 cm in core 18, 0.5–6 cm in core 19, whereas in core 32 beds are 0.5–2 cm thick. There is no evidence in the YD for enhanced sediment supply to the shelf edge in Halibut Channel, which was distant from any ice margins. The frequency of sand beds suggests that earthquake-triggered landslides are unlikely to have formed the turbidity currents. Modern dense water flows do not transport significant amounts of sediment. Suspension of shelf sediment by storms and advection of that sediment to canyon heads by ebb tidal currents is a possible mechanism for initiating the turbidity currents. Greenland ice core data suggest that the Younger Dryas period was particularly stormy and the volume of sands deposited in a single event are comparable to likely storm erosion around Halibut Channel. Similar conditions are likely in other submarine canyons along the eastern Canadian margin.

---

**Paleogeography, sea-level rise, and the peopling  
of southwestern Nova Scotia, Canada:  
an archaeological perspective**

---

AARON TAYLOR

*Interdisciplinary PhD Program, Dalhousie University, Halifax,  
Nova Scotia B3H 4R2, Canada <aaronche@hotmail.com>*

Pre-contact societies in the Maritime region are poorly understood owing to the small number of sites located and studied. Predicting the location of sites has always been difficult. Is there a way to refine or create search methods that would give greater success rate in locating undisturbed sites? An examination of local sea-level rise may provide a tool for interpreting pre-contact settlement patterns. In the Bay of Fundy, the main area in this study, sea-level rise has caused the submergence of shorelines and the movement of 'head of tide' up the Annapolis River.

Approximately eleven thousand years ago as the glaciers

retreated, humans following caribou herds entered the Maritime region and settled at Debert, Nova Scotia. The environment that the Paleoindians encountered was dynamic. The tundra landscape turned to a forested one and became inhospitable for caribou herds. The majority of the caribou either perished or left the region and for the past half century the fate of Paleoindians has been debated. Some believe that the Paleoindians left the region with the caribou and have labeled this period as the "Great Hiatus" because for almost four thousand years there is no evidence of habitation. In the 1980s this hypothesis was countered with a "drowned landscape" one, and hence evidence that some Paleoindians remained but turned to a marine economy, is now at the bottom of the sea.

Rivers flowing into the sea are sensitive to sea level changes. Sea level height determines where the river meets the sea and also the point inland where tidal effects are no longer felt. This point, which is the farthest inland reached by tidal water, is called the 'head of tide'. It is the farthest point up river where incoming seawater meets outgoing fresh water and is a place where large anadromous fish congregate. As sea levels rise the head of tide moves inland. This means that river fishing activity should move inland as well. Sites excavated near present-day head-of-tide locations should show evidence of recent use. Since in the Bay of Fundy sea level has been rising for the last few thousand years it is expected that sites nearer the river mouth will show evidence of earlier use.

If people lived on the seashore, then clearly when the sea level rose the evidence would be under water. If they continued to live on the shore then there should be a continuous record from the present shore out to wherever the shore was 10 000 BP.

---

**Sources of groundwater methane in proximity to legacy  
coal extraction sites in Nova Scotia, Canada**

---

KIMBERLEY A. TAYLOR<sup>1</sup>, DAVE RISK<sup>2</sup>, AND  
OWEN SHERWOOD<sup>2</sup>

1. *Department of Earth Science, St. Francis Xavier University, Antigonish, Nova Scotia B2G 2W5, Canada <ktaylor@stfx.ca>*
2. *Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia, B3H 4R2, Canada*

Recent studies have recorded elevated concentrations of dissolved methane in groundwater in proximity to hydrocarbon developments. High methane concentrations in groundwater pose a number of health and safety concerns such as the deterioration of water quality and explosive hazards. Methane may also be exacerbated by oil, gas and coal developments, which can lead to the migration

of stray gas that can contaminate aquifers and escape to the atmosphere, contributing to poor water quality and greenhouse gas emissions.

Currently, there are limited data on groundwater methane concentrations in Nova Scotia. A previous study identified areas with elevated methane concentrations in groundwater near coal formations. However, the specific sources and local distribution of methane in those areas remain unknown. With a lack of baseline data and an abundance of coal, and historic mines, Nova Scotia is an excellent location to study the spatial relationship between methane concentrations in groundwater and legacy coal-extraction sites.

In this study, we sampled 96 wells across the Cumberland, Stellarton and Sydney basins. Preliminary results on a subset of the wells are presented here. In the Cumberland Basin, 5 domestic wells had CH<sub>4</sub> concentrations less than the 10 mg/L hazard threshold. Carbon ( $\delta^{13}\text{C}$ ) and hydrogen ( $\delta^2\text{H}$ ) isotopic analysis of methane, along with non-detectable ethane or propane, indicate a microbial origin of the gas. In the Stellarton Basin, 46 domestic water wells were sampled with methane concentrations in 18 wells <1 mg/L, 16 wells in the 1 mg/L–10 mg/L range, 10 wells in the 10 mg/L–28 mg/L range and 2 wells exceeded the 28 mg/L hazard mitigation threshold. Isotopic measurements of  $\delta^{13}\text{C}$  and  $\delta^2\text{H}$  of methane and ethane indicate a thermogenic-biogenic mixed origin of the gas. In the Sydney Basin, 3 domestic water wells sampled contained very low methane <1 mg/L. In contrast, 42 mine water monitoring wells in the Sydney Basin sampled as part of an ongoing environmental remediation program show evidence of thermogenic gas origin, at least from preliminary isotopic analysis on a small subset of these samples.

The findings from this groundwater methane investigation will help to better understand methane sources, migration pathways, and risks in Nova Scotia. The data acquired in this study may be used to monitor and assess groundwater quality should hydrocarbon exploration operations advance in the future.

---

**Multidisciplinary investigation of primary and secondary salt welds in the late Paleozoic Antigonish sub-basin of Nova Scotia, Canada**

---

ALISON K. THOMAS AND JOHN W.F. WALDRON

*Department of Earth and Atmospheric Sciences,  
University of Alberta, Edmonton Alberta T6G 2E3,  
Canada <akthomas@ualberta.ca>*

The Antigonish sub-basin, one of many within the late Paleozoic Maritimes Basin, stretches from the Nova Scotian Antigonish Highlands into western Cape Breton

Island. The sub-basin is structural in origin and is bounded by interpreted strike-slip faults that developed late in the history of the Appalachian orogen. The late Devonian to late Carboniferous basin-fill consists primarily of clastic sedimentary rocks with the exception of a marine succession of carbonate and evaporite rocks, the Visean Windsor Group. Previous workers identified a discordant surface extending through much of the sub-basin, initially named the Antigonish Thrust. Later work reinterpreted this surface as a low-angle extensional fault, the Ainslie Detachment. Salt walls, previously identified on seismic lines through St. Georges Bay, and a salt diapir in a coastal outcrop, suggest that these structures may be related to salt expulsion.

The origin of the discordant surface was investigated during fieldwork at locations around Antigonish and western Cape Breton Island. Critical outcrops were surveyed with a drone and modelled in photogrammetric software. Outcrops beneath a potential primary weld at Lakevale show folds suggesting that during deformation brittle limestone layers were encased in ductile evaporites which were then removed by solution after deformation. Core from a drillhole through an equivalent surface shows foliated halite breccia. Potential secondary welds at Little Judique Harbour and Port Hood Island display central breccia zones flanked by steeply dipping younger strata with opposing younging directions. Strata to the west show along-strike thickness changes suggesting synsedimentary tilting.

From a modern salt tectonics perspective, the discordant surface matches the predicted characteristics of a salt expulsion surface. The surface first known as the Antigonish Thrust and then as the Ainslie Detachment is reinterpreted as an evaporite weld produced by salt expulsion. Other discordant shallowly dipping surfaces in salt-containing sub-basins of the Maritimes Basin should be evaluated as potential primary salt welds. Likewise, steeply dipping surfaces previously interpreted as faults may be secondary salt welds. Further research may show that salt movement had a greater impact on the geometries of the Maritimes Basin than has previously been realized.

---

**Investigating fluid exchange between host granitic magma, enclaves and dykes in the South Mountain Batholith, Nova Scotia, Canada**

---

DANA K. THOMSEN AND RICHARD A. COX

*Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <danathomsen@dal.ca>*

Recent studies have suggested that mafic enclaves within the (Late Devonian) South Mountain Batholith are mela-granitic restites formed in part from the melting of

metasedimentary rocks. Detailed textural studies conducted in the Sambro Head area have revealed clear evidence of magma mixing between the host granite and a mafic dyke intrusion. Textural and micro-analytical studies also show resorption textures and Ba zoning in K-feldspar megacrysts, indicating significant temperature changes, supporting the hypothesis that hybridization has occurred. However, hybridization and fluid-alteration of the dyke makes determining the original composition extremely difficult. This study aims to investigate the fluid exchange reactions between the host granitic rock and the Sambro Head dyke using whole rock relationships as well as analyses of fluid-bearing phases. Whole-rock samples from the dyke, the mixing zone, and the adjacent peraluminous granites have been collected and analyzed. Whole-rock samples were prepared by grinding portions of each specific dyke section into a fine powder, followed by a fusion at ~1500°C for 50 minutes, creating small glasses. Preliminary whole rock Electron Probe Micro-Analyzer (EPMA) results show a strong decrease in Al<sub>2</sub>O<sub>3</sub> and a general decrease in metal oxides when transitioning from the mixing zone of the dyke towards its center. The dyke's mineral assemblage consists of plagioclase + quartz + biotite + oxides, along with secondary chlorite + muscovite and a significant amount of apatite, much of which appears to be primary. The extensive chlorite + muscovite replacement of biotite indicates continued fluid exchange reactions prior to final crystallization of the dyke. EPMA maps and thin section data show that this replacement is fairly consistent in all samples from within the dyke, with slightly higher replacement of biotite occurring near the edges of the dyke. The biotite selvage adjacent to the mixing zone also suggests evidence of disequilibrium and fluid exchange between the dyke and the granitic host. Small groups of cordierite can be found in similar places, along the edge of the dyke. Results will be used to create a temperature profile using existing biotite, chlorite and apatite geothermometry methods. This investigation also aims to construct a petrochemical classification of the minerals that have remained unaltered throughout the various fluid-assisted reactions in the Sambro Head dyke and thus, define primary versus secondary textures. This will in turn help define which textures can be used to determine the origin of these dykes and mafic enclaves.

---

**Sulphide mineralization and hydrothermal alteration of the Captain deposit, Bathurst Mining Camp, New Brunswick, Canada**

---

SEAN A. TIMPA<sup>1</sup>, JARED E. HANSEN<sup>1,2</sup>, AND  
DAVID R. LENTZ<sup>2</sup>

1. *New Brunswick Department of Energy and Resource Development, South Tetagouche, New Brunswick E2A 7B8, Canada <sean.timpa@gnb.ca>*

2. *Department of Earth Sciences, University of New Brunswick, Fredericton, New Brunswick E3B 3A3, Canada*

The Captain deposit is a copper-cobalt-silver deposit located approximately 40 km south-southwest of Bathurst. The deposit is hosted by the Nepisiguit Falls Formation and consists of stringers, veins, semi-massive, and massive sulphides within a broad zone of chlorite-altered rhyodacite. The mineralized zone is a roughly tabular body dipping 70 to 80 degrees to the west with a strike length of approximately 150 m, thickness of 25 m, and a down-dip extent of at least 400 m. The mineralized zone does not exhibit any systematic metal zoning but does contain a number of small anastomosing copper-rich and cobalt-rich zones. An NI 43-101 compliant mineral resource estimate for the deposit has defined 1.97 million tonnes of ore grading of 0.84 wt% Cu and 0.045 wt% Co.

The Captain deposit is surrounded by a broad zone of chlorite alteration, with complete replacement of feldspar extending out to 100 m. Chlorite is enriched in iron near the center of the deposit ( $Fe/(Mg+Fe) = 82$ ), reflecting higher temperatures and iron-rich fluids. In more distal areas relic feldspars are recognizable and the iron content of chlorite is lower ( $Fe/(Mg+Fe) = 64$ ). Chlorite compositions typical of unaltered Nepisiguit Falls rhyodacite were not intersected within the limits of drilling.

Pyrite is the dominant sulphide phase at the Captain deposit and commonly consists of large, subhedral crystals. Complex oscillatory zoning of trace elements along with the high abundance of impurities in the crystal lattice suggests that the pyrite is not porphyroblastic but grew from a compositionally fluctuating vent fluid. Cobalt enriched zones within the pyrite may reach 4 wt% Co substituting for Fe. Zones of arsenian pyrite are also common with up to 5 wt% As. Bismuth occurs as cryptocrystalline inclusions in pyrite and as discrete grains of bismuthinite and native bismuth. Chalcopyrite is a later phase, replacing pyrite along grain boundaries, fractures, and growth planes.

The Captain deposit is interpreted to be the stringer zone of a volcanic-hosted massive sulphide system on the basis of: (1) high Cu, Co, and Bi and low Zn and Pb sulphide assemblages, (2) the absence of stratiform exhalative facies, (3) discordant relationship with stratigraphy, and (4) symmetrical styles, intensities and extent of alteration in both the structural footwall and hanging wall. The size of the stringer zone and the extent and intensity of the surrounding alteration implies a large hydrothermal vent system. Younging indicators suggest that the deposit is overturned, in which case a large exhalative volcanic-hosted massive sulphide deposit may exist at depth.

---

**A multi-proxy approach to characterizing calcite fracture-filling processes, and the implications for geothermal energy**

---

JACOB VANDERWAL<sup>1</sup>, JOHN MACDONALD<sup>2</sup>, AND OWEN SHERWOOD<sup>1</sup>

1. *Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <jacobtvanderwal@dal.ca> ¶*

2. *School of Geographic and Earth Sciences, University of Glasgow, Glasgow G12 8QQ UK*

Geothermal energy has emerged as a reliable, cost-effective, and sustainable energy resource in areas of tectonic activity where hot sub-surface fluid circulation is common. Precipitation of carbonates within fractures that act as fluid conduits can act to modify and reduce flow, acting as a limiting factor to geothermal energy production. It is therefore important to understand the relationship between mineral precipitation, fluid source, and precipitation temperatures when assessing the economic potential of a geothermal locality. Here we present cathodoluminescence (CL) petrography,  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  stable isotope data, and minor element analyses for six carbonate veins collected from a 'fossil' analogue (easily accessible) basalt-hosted geothermal system in Lunan Bay Scotland, in order to determine the timing and conditions of fracture filling with regards to active geothermal circulation. Carbonate veins, predominantly composed of calcite with minor dolomite and quartz co-precipitates, range from a few mm to tens of cm in width. Carbonate growths are observed as stretched and bladed crystals likely formed during active fracturing, and blocky, altered crystals indicative of post-fracture precipitation. CL signatures, suggestive of changes in Fe/Mn, exhibit relatively constant signatures across smaller veins (<1 cm) and gradual unidirectional variation across larger veins (>1 cm). However, minor element (FeO, MnO, MgO, Na<sub>2</sub>O, and K<sub>2</sub>O) transects across the larger veins suggest more erratic fluctuation, decoupled from trends expected based upon the CL signatures. The  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  (VPBD) values also fluctuate in comparison to CL, with end values varying from -9.9 to -1.9 ‰ and -13.2 to -1.4 ‰ respectively. Several reasons for these variations will be discussed, including changing fluid sources, degrees of fluid-host rock interaction, as well as changes in carbonate crystallization temperature. Furthering our understanding of fracture filling conditions using these methods will help to recognize and avoid systems that may be prone to fracture filling, thereby determining the economic potential of a geothermal locale.

---

**Continental fragments between cratons during supercontinent assembly; new views on the interactions of the Core Zone with the Saglek and Hopedale blocks during the Trans-Hudson orogeny, Quebec, Canada**

---

DEANNE VAN ROOYEN<sup>1</sup> AND DAVID CORRIGAN<sup>2</sup>

1. *Department of Mathematics, Physics, and Geology, Cape Breton University, Sydney, Nova Scotia B1P 6L2, Canada <deanne\_vanrooyen@cbu.ca> ¶*

2. *Geological Survey of Canada, Ottawa, Ontario K1A 0E8, Canada*

The southeastern Churchill Province of the Canadian Shield preserves interactions between the Archean Superior craton, the North Atlantic craton (containing the Archean Saglek and Hopedale blocks), and a composite continental fragment known as the Core Zone. The Torngat Orogen formed primarily between ca. 1.87–1.86 Ga as a result of orthogonal collision between the Core Zone and the North Atlantic Craton and contains granulite facies rocks representing an accretionary prism (Tasiuyak gneiss) and a crustal root of an arc terrane (Lac Lomier Complex). Subsequently, between ca. 1.83 and 1.79 Ga, the Core Zone/North Atlantic Craton collage collided with the Superior Craton and its marginal supracrustal sequences (Labrador Trough) in an early westward thrusting event followed by dextral transpression, forming the New Quebec Orogen. The boundary between the Core Zone and the North Atlantic craton are in part obscured by the Mesoproterozoic Nain Plutonic Suite, but new work suggests that the large-scale Abloviak shear zone between them also represents the original suture during the Paleoproterozoic. New work will focus on documenting the extent of the Trans-Hudson thermal and deformational overprint in the North Atlantic craton to better constrain the kinematics of their original juxtaposition. The Core Zone has only recently been recognized as a composite terrane, containing Archean to earliest Paleoproterozoic crustal fragments that are distinctly different from one another. These fragments are now juxtaposed along broadly NNW-SSE trending anastomosing shear zones. The inter-shear crustal lenses, up to 100 km wide and hundreds of km long, show progressively less exhumation towards the south. The northern area adjacent to Ungava Bay contains granulite facies assemblages, whereas the central Core Zone contains lower-amphibolite facies assemblages, to greenschist facies in the far south. The ages of metamorphism also change systematically; the high-grade northern domains have a consistent 1.8 Ga Trans-Hudson-age metamorphic overprint, while the low-grade southern domains preserve metamorphism of 2.3 Ga. Here we present a model based on targeted field observations, large geophysical and structural datasets, together with

the metamorphic analysis above, that suggests that oblique convergence between the NAC and Superior cratons resulted in the southerly (present-day coordinates) extrusion of the Core Zone through a network of anastomosing crustal-scale ductile shear zones that may also represent original sutures. Furthermore, the southerly-decreasing P-T conditions recorded in the inter-shear crustal blocks suggest a bulk component of top-down extensional shear to the south in a tectonic setting where the southern margin was open.

---

**Correlation among four drill holes in the Faribault Brook Formation near the Road 2 showing, western Cape Breton Highlands, Nova Scotia, Canada: implications for stratigraphy, structure, and economic mineralization**

---

BRENDAN J. VIBERT<sup>1</sup>, CHRIS E. WHITE<sup>2</sup>, AND SANDRA M. BARR<sup>1</sup>

1. *Department of Earth and Environmental Science, Acadia University, Wolfville, Nova Scotia B4P 2R6, Canada <124767v@acadiau.ca>*

2. *Nova Scotia Department of Natural Resources, Halifax, Nova Scotia B3J 2T9, Canada*

The Faribault Brook Formation in the Cape Breton Highlands east of Cheticamp has been a focus of mineral exploration since the 1890s and at least 15 occurrences of sphalerite, chalcopyrite, galena, arsenopyrite, and/or native gold have been reported. The formation consists of interlayered metasedimentary and mafic and felsic metavolcanic rocks, but stratigraphy and age are poorly constrained, as is the mineralization style. Previous studies have suggested that the metavolcanic rocks may be sea-floor basalts and that the mineral occurrences are exhalative massive sulphide deposits, although at least some of the latter are in association with rhyolite. This study is the first to examine the lithological and geochemical characteristics of the formation in a small area to better define the component units and investigate whether or not their interlayering is stratigraphic or tectonic. The study focuses on core from four vertical holes, each 50-m deep, drilled 50 m apart along a north-south transect in the Faribault Brook Formation by Globex Mining Enterprises Limited. These holes were drilled in the area referred as the Road 2 showing where previous studies showed anomalously high base metal samples. Although mainly logged as volcanic rocks, more than half of the core consists of metasedimentary rocks, including metapelite, metapsammite, and calc-silicate rocks, and the other half are metabasaltic tuff and flows. One hole contains about 2.7 m of flow-banded rhyolitic tuff and ash. Altered very fine-grained to glassy amygdaloidal dykes/sills up to 3 m wide are present in all

holes and are highly magnetic. Younging directions evident in the rhyolitic tuff and ash and some sandy layers in the metasedimentary units indicate that the rocks are right way up, but subhorizontal recumbent folds are evident in some places in the metasedimentary units, indicating that stratigraphic relations are not straight-forward, and direct correlation between holes may not be possible. Preliminary chemical data obtained using a portable XRF instrument indicated that most of the elevated Zn values are associated with the calc-silicate and metapelite layers with a few anomalous values greater than 12 000 ppm. Associated Cu and Pb are generally below the detection limits of about 5 ppm; however, a few samples have elevated Cu and Pb up to 1500 ppm and 800 ppm, respectively.

---

**Assessing methane emissions from legacy fossil resource development and methane mitigation potential in Atlantic Canada Nova Scotia (GaSP- Gas Seepage Project)**

---

GRANT WACH<sup>1</sup>, DAVID RISK<sup>2</sup>, MICHELLE GRAY<sup>3</sup>, OWEN SHERWOOD<sup>1</sup>, KERRY MACQUARRIE<sup>4</sup>, KARL BUTLER<sup>5</sup>, AND MAURICE DUSSEAU<sup>6</sup>

1. *Department of Earth Sciences, Faculty of Science, Dalhousie University, 1355 Oxford Street, Life Sciences Centre, Halifax, Nova Scotia B3H 4R2, Canada*

2. *Department of Earth Sciences, St. Francis Xavier University, Antigonish, Nova Scotia B2G 2W5, Canada*

3. *Faculty of Forestry and Environmental Management, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada*

4. *Department of Civil Engineering, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada*

5. *Department of Earth Science, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada*

6. *Department of Earth and Environmental Sciences, Centre for Environmental and Information Technology (EIT), Waterloo, Ontario N2L 3G1, Canada*

The Atlantic Provinces have been extracting onshore energy resources, such as natural gas, oil and coal, for more than 200 years. Most of these developments are considered legacy (historic) fossil fuel sites that predate modern environmental and structural regulations. A number of these sites have been emitting methane gas continuously since abandonment and may be a significant contributor to greenhouse gas (GHG) emissions. Canada hopes to reduce methane emissions by 40–45% from the oil and gas sector below 2012 levels by 2025. Legacy sites in the Maritimes could be excellent targets for permanent mitigation.

In New Brunswick, 85% of 302 total drilled onshore wells sit in a suspended or abandoned state, and 60% were abandoned over 70 years ago. In both provinces, most wells

were decommissioned before proper well abandonment procedures were developed and enforced. Improperly sealed wells can lead to well bore leakage and gas migration, a process which involves the uncontrolled migration of thermogenic gas and oil to the surface and into shallow groundwater, soils, and atmosphere. For coal mining, the Nova Scotia government has documented approximately 7000 historic mine openings, including 1922 pits, shafts, adits, and slopes. Methane liberation declines after mining activity ceases, but abandoned mines can emit methane at a near-steady rate for an extended period although, if flooded, only for a few years.

The Gas Seepage Project (GaSP) is the first of a multi-phase methane mitigation initiative to be conducted in Atlantic Canada, with a focus on legacy fossil resource extraction sites. This includes evaluating methane gas release from legacy coal mines in Nova Scotia, and from oil and gas fields in New Brunswick. The results of this collaborative project include an atmospheric methane emission inventory estimate for legacy fossil resource extraction sites in Nova Scotia and New Brunswick; a techno-economic assessment of methane mitigation potential; development of new technologies and methodologies from local industry, and provide them with valuable corroborating data to assist in product validation. This project is important for methane management and policy formation in Atlantic Canada, and will provide benefits to Canadians via improvements in methane management technology and methodology, as a new regulatory framework is developed in Canada.

---

### Salt tectonics in the Maritimes Basin, Canada

---

JOHN W.F. WALDRON

*Department of Earth and Atmospheric Sciences,  
University of Alberta, Edmonton, Alberta T6G 2E3, Canada  
<john.waldron@ualberta.ca>*

The Visean Windsor Group of Maritime Canada and the correlative Codroy Group of Newfoundland contain substantial evaporite rocks, including gypsum and anhydrite, halite, and potash. The role of rising evaporite diapirs in the tectonics of the Maritimes Basin has long been recognized. However, recent advances in salt tectonics in extensional passive margin environments have focussed on the expulsion of the salt from intervening areas, between diapirs, which undergo corresponding subsidence. The sedimentary record of these “minibasins” thus contains critical information on the halokinesis. These advances add new perspectives to the study of evaporite tectonics in Atlantic Canada, where substantial strike-slip and convergent tectonic movements, due to the latest stages of

Pangea assembly, are superimposed on extension, and add complexity to the history of halokinesis.

In the Cumberland sub-basin, seismic reflection data allow the timing of salt expulsion to be resolved. In the west, the Athol syncline contains the famous Joggins succession, which was rapidly deposited in accommodation space created by salt expulsion, showing that Windsor Group salt remained in place until the late Bashkirian before rapidly moving into diapiric salt walls. In contrast, in the eastern Cumberland sub-basin, relationships in the Tatamagouche syncline show that evaporite expulsion was already controlling sedimentation during late Visean to Serpukhovian deposition of the Mabou Group, and probably during deposition of the underlying Windsor Group.

Field relations in other parts of the Maritimes Basin, where the Mabou and upper parts of the Windsor Groups show striking thickness variations, suggest that this history of early evaporite expulsion is more usual, despite the stratigraphic continuity and regularity of limestone-evaporite-clastic cycles in the Windsor Group. At first sight the regularity of these cycles suggests that halokinesis did not begin until after the end of Windsor Group deposition. However, an alternative explanation is that minibasins already active during deposition of the middle and upper Windsor Group were simultaneously flooded by eustatic sea-level rises, related to glacial cycles on Gondwana.

The Maritimes Basin has not figured prominently in global assessments of evaporite volumes through time. This is partly because the least mobile, and therefore best preserved, evaporite sections are relatively thin. Relationships in the Cumberland basin suggest that the initial thickness of lower Windsor evaporites was comparable to those in better known evaporite successions in the Gulf of Mexico, early Atlantic Ocean, and Mediterranean Sea. The global significance of Maritimes Basin evaporites may thus have been underestimated.

---

### Correlation chart for Late Devonian to Permian stratified rocks of the Maritimes Basin, Atlantic Canada

---

JOHN W.F. WALDRON<sup>1</sup>, PETER S. GILES<sup>2</sup>, AND  
ALISON K. THOMAS<sup>1</sup>

*1. Department of Earth and Atmospheric Sciences,  
University of Alberta, Edmonton, Alberta T6G2E3  
<john.waldron@ualberta.ca> ¶*

*2. Geological Survey of Canada (Atlantic), Natural Resources  
Canada, Dartmouth, Nova Scotia B2Y 4A2, Canada*

A new stratigraphic chart of the Maritimes Basin has been prepared in connection with an atlas of onshore sedimentary basins in Nova Scotia. The chart has been



extended into Newfoundland (NL), New Brunswick (NB), and Prince Edward Island (PEI), where Nova Scotian units have close regional correlatives. The available stratigraphic information is simplified into 22 representative columns.

Correlation in the Maritimes Basin is challenging, both because of a lack of isotopically datable rocks and because biostratigraphically useful fossil groups tend to lack key species, due to unusual environments. Based on a review of recent International Commission on Stratigraphy timescales, together with more recent published isotopic ages, we have developed a working numerical timescale, tied to chronostratigraphy. Then, we have adopted a standard correlation of biostratigraphic zones to this chronostratigraphic scale.

The stratigraphic chart shows well-known major subdivisions, including the volcanic-dominated Fountain Lake and Piskahegan groups in the Late Devonian, and Late Devonian through Early Mississippian mainly clastic successions of the Horton and (in NB) Sussex groups. Some rocks assigned to the Horton Group in NS (and the equivalent Anguille Group in NL) are time-equivalent to the Sussex Group in NB. In addition, the age of organic-rich shales in the Horton Group varies from place to place. Overlying rocks of the Visean Windsor Group include carbonates, evaporites, and clastic sedimentary rocks. Four competing options for the age of the basal Windsor Group are presented. Estimates of the duration of the time-gap at the base-Windsor unconformity range from ~3–11 Myr. Overlying Mabou Group is dominated by clastic rocks but also includes significant evaporites. Its boundary with the Windsor is strongly diachronous where higher Windsor Group marine bands reach their depositional limits. Correlative rocks of the Barachois Group in Newfoundland contain significant coal seams.

A major unconformity separates the Mabou from overlying Cumberland Group, representing a gap of 3–4 Myr straddling the Mississippian–Pennsylvanian boundary. The Joggins section appears highly condensed when plotted against geologic time. An unconformity in the Duckmantian is widespread but represents a shorter break in sedimentation than previously inferred. Post-Duckmantian coal-bearing units in the Pennsylvanian are assigned to the Morien Group in Cape Breton Island, although this designation has been inconsistently applied. The highest, Pictou Group is also strongly diachronous. Its base has been inconsistently correlated by the Nova Scotia and New Brunswick surveys. It is hoped that the new stratigraphic chart will encourage resolution of some of these controversies.

---

**Progress report on bedrock mapping in Munsungun inlier, northern Maine, USA in 2017: new insights into its tectonostratigraphy and basement-cover relation**

---

CHUNZENG WANG<sup>1</sup>, STEPHEN POLLOCK<sup>2</sup>, DAVID PUTNAM<sup>1</sup>,  
ROBERT MARVINNEY<sup>3</sup>, AND CALEB WARD<sup>1</sup>

1. *University of Maine at Presque Isle, Presque Isle, Maine 04769, USA., <chunzeng.wang@maine.edu> ¶*
2. *University of Southern Maine, Gorham, Maine 04038, USA ¶*
3. *Maine Geological Survey, Augusta, Maine 04333, USA*

The Munsungun inlier, or “Munsungun Anticlinorium”, is made of slightly metamorphosed pre-Devonian subaqueous volcanic/sedimentary strata. It is considered an extension of the Ordovician Victoria-Popelogan arc of the northern Appalachians. Bedrock mapping since 2016 has made significant progress towards understanding its tectonostratigraphy and basement-cover relation. Newly obtained geochemical data provide constraints on composition and petrogenesis of the volcanic rocks. (1) The “Anticlinorium” might not be an anticlinorium but a tectonic collage between two accreted terranes – here referred as Chase Brook terrane in the southeast and Blind Brook terrane in the northwest. Both are separated and fault-bounded by a younger, Upper Ordovician black shale-conglomerate formation – the Rowe Lake Formation. Detritus of the Rowe Lake were sourced northwest from the Blind Brook terrane. The black shale might correlate with Popelogan Formation black shale in the Popelogan inlier in New Brunswick, Badger Group black shale in the Victoria arc in Newfoundland, and Partridge Formation black shale in the Bronson Hill arc in New Hampshire. Volcanic rocks within the Chase Brook terrane include Jack Mountain arc calc-alkaline suite of andesite-dacite and Round Mountain-Bartlett Mountain-Norway Bluff non-arc, E-MORB-like tholeiitic suite. The non-arc tholeiitic suite likely formed in an extensional setting as indicated by the Round Mountain half-graben. Volcanic rocks within the Blind Brook terrane include Mule Brook Mountains and Horseshoe Pond tholeiitic basalt and calc-alkaline rhyolite. While their spider and REE patterns indicate arc signatures, they do show differences from the arc suite of the Chase Brook, suggesting both terranes might be associated with two isolated arcs. If the latter is the Ganderian Popelogan arc, could the Blind Brook be a Laurentia arc? Does a suture (the Red Indian Line?) exist between these terranes? (2) Several pieces of basalt and vitric tuff within the Chase Brook terrane might be Penobscotian arc products. For example, the vitric tuff shows remarkable arc signature but distinct spider and REE patterns from other volcanics. (3) An angular unconformity exists between the “Anticlinorium” and its Devonian Seboomook cover, as evidenced by newly-discovered basal conglomerate of the Seboomook Formation on both sides of the “Anticlinorium”. This discovery suggests that the “Anticlinorium” remained to be erosional prior to initial northwestward transgressive deposition of the Seboomook in the early Devonian and after the last Taconic stage. The last Taconic stage likely saw accretion of both arcs/terranes.

The accretion likely caused large-scale thrusting but weak metamorphism and foliation because the prevailing regional foliation and lower-greenschist metamorphism in the Munsungun inlier were Acadian.

---

### Nelly Koziel: you took the time

---

GRAHAM WILLIAMS

*Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada*  
<graham.williams@canada.ca>

The death last year of Nelly Koziel deprived family and friends of someone who enriched their lives and who set an example of diligence for others to follow. Nelly showed a great commitment to the Atlantic Geoscience Society, in which she played an active role for more than twenty years. How did Nelly become involved in geology? Her initiation began when she came to work for the Geological Survey of Canada in 1983. Ten years later, Jennifer Bates, chair of the nascent AGS EdGEO Workshop Committee, asked Nelly to help with the first Teachers' Workshop at Bedford Institute in 1994. The success of the Workshop convinced Nelly to accept responsibility for compiling resources and handling registration for all subsequent Teachers' Workshops, which have been held annually in various locations in Nova Scotia. It was during one of the workshops that Nelly developed a fondness for the Maple Inn in Parrsboro, where she had a special room on the top floor.

Appreciation of her many talents led to Nelly becoming a member of the AGS Education Committee in 2007 and the Video Committee in 2013, as well as Treasurer of both. In 2013 Nelly became Treasurer of AGS, alternating this role with Financial Secretary until 2017. So she was Treasurer of AGS Council, the Education Committee and the Video Committee all at the same time. Other roles included setting up and staffing the Society's display and handling registration at every AGS Colloquium from 1994 to 2016. These colloquia have always been held in late January or early February, when the weather can be awful. This meant hauling three massive containers in a variety of vehicles to such places as Antigonish, Fredericton, Moncton, Sackville (New Brunswick), Truro, and Wolfville. Another notable task, which she performed flawlessly, was the typing of the several versions of *The Last Billion Years*. Nelly's numerous contributions to the Atlantic Geoscience Society were recognized in 2009, when she received the Laing Ferguson Distinguished Service Award, usually presented annually at the Colloquium for continuing outstanding contributions to the Society.

When Nelly died, we lost a true friend. But her memory lives on, as demonstrated by the Atlantic Geoscience

Society's decision to create a Nelly Koziel Award, which will be presented to a person who has recently made a significant contribution to the promotion of geoscience in the Atlantic Provinces, beyond the call of duty.

---

### Methane emissions from abandoned oil and gas wells at the Stoney Creek oilfield, New Brunswick, Canada

---

JAMES P. WILLIAMS<sup>1</sup>, DAVID RISK<sup>1</sup>, GRANT WACH<sup>2</sup>, MITCH GRACE<sup>3</sup>, AND KARL BUTLER<sup>3</sup>

1. *Department of Earth Sciences, FluxLab, St. Francis Xavier University, Antigonish, Nova Scotia B2G 2W5, Canada* <jpwillia@stfx.ca> ¶

2. *Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada* ¶

3. *Department of Earth Sciences, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada*

Emissions from oil and gas operations are understood to originate from active oil and gas operations, but not much concern is given to abandoned infrastructure. Improperly abandoned wells can provide pathways for hydrocarbon gases like methane (CH<sub>4</sub>) to migrate upwards into groundwaters, and the atmosphere. Atmospheric methane emissions have long been recognized as a significant contributor to the greenhouse effect, with a global warming potential 28–34 times greater than CO<sub>2</sub> on a 100-year horizon. Most atmospheric emissions from oil and gas activity occur in the western provinces, but New Brunswick is home to one of the oldest oilfields in the world. Approximately 168 oil and gas wells have been spudded at the Stoney Creek oil field in New Brunswick since 1909, most of which have since been decommissioned. To identify methane emissions from legacy infrastructure in this field, we sampled atmospheric and shallow soil gases around abandoned well sites in the Stoney Creek oilfield over a period of three weeks in late August to early September 2017. Shallow soil gases were sampled using a static flux chamber methodology, with an array of chambers sampled in triplicate at a total of 12 well-pads and 4 control sites. Additional sampling on individual well-pads was done using a backpack-mounted gas analyzer to identify elevated CH<sub>4</sub> concentrations (if present) and potential release mechanisms. Since we could not visit all historic well sites, we also conducted regional gas surveys using a vehicle-based sampling system to record methane and other gas concentrations at >1Hz while driving. Plumes of thermogenic gases (as indicated by δ<sup>13</sup>C-CH<sub>4</sub> and C<sub>2</sub>H<sub>6</sub> tracers) were subjected to emission rate calculations using an Inverse Gaussian Plume Dispersion model. In general, we did measure elevated methane in the region. Regional surveys indicated that abandoned sites were likely emitting at a frequency near 20% (5 out of 27 sites surveyed), but at

average emission rates of only 2.1 ( $\pm$  1.7) kg of CH<sub>4</sub> per day. At only 1 of the 12 legacy well-sites we visited did we record soil CH<sub>4</sub> gas migration fluxes in excess of control sites, but emissions were very small and averaged only 25 ( $\pm$  32) g of CH<sub>4</sub> per day. This study represents the first of its kind in regards to CH<sub>4</sub> emission detection from abandoned oil and gas wells in the Atlantic provinces, and provides valuable information to help understand methane emission risks associated with onshore oil and gas activity.

---

### Petroleum system modelling of potential Lower Jurassic source rocks along the Scotian Margin, Canada

---

J. CARLOS WONG<sup>1</sup>, XIN YUE HU<sup>1</sup>, RICARDO L. SILVA<sup>2,3</sup>, AND GRANT WACH<sup>1</sup>

1. Basin and Reservoir Lab, Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <carlos.wong@dal.ca> ¶

2. Department of Earth Sciences, Faculty of Science, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada ¶

3. MARE - Marine and Environmental Sciences Center, University of Coimbra, Rua da Matemática, nº 49, 3004-517 Coimbra, Portugal

Several organic-rich intervals have been identified along the Mesozoic conjugate margins of the Central and North Atlantic. The similarity of the depositional environments and paleogeography of the Scotian margin with the conjugate Western European and African domains, which contain proven Lower Jurassic source rock successions, suggest the presence of a similar interval in the offshore Scotian margin. If present, there is uncertainty regarding their characteristics (quantity, quality, and maturity) as a source rock. With petroleum exploration offshore Nova Scotia, resolving these uncertainties is needed to reduce the risks.

In this study, PetroMod (Schlumberger) was used to construct several 2D maturity models for these potential source rocks on the Scotian Margin using dip lines of the ION NovaSpan geophysical dataset (NVR1-1100, NVR1-1400A, NVR1-1600, NVR1-2000). In each model, different source rock variables (Hydrogen Index and Total Organic Carbon) were used and based on data from offshore Morocco and the onshore High and Middle Atlas Basins (Morocco). Our results suggest that the hypothesised Lower Jurassic source rocks in the Scotian Basin are within the oil maturity window in the south, transitioning to the gas maturity window northwards. We observe that the Lower Jurassic interval has a range of maturity and generation of hydrocarbons. Data limitations are recognized with four 2D seismic lines used to map the maturity of the Scotian Basin (600 x 200 km).

---

### An experimental study of the effect of water on chromite saturation in komatiite

---

KATE G. WOODS AND JAMES M. BRENAN

Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2 <woodskate@dal.ca>

Chromite (FeCr<sub>2</sub>O<sub>4</sub>) is an oxide mineral and common accessory phase in ultramafic rocks. More unusually, chromite occurs in concentrated strata or lenses within layered mafic intrusions. The komatiite-hosted Blackbird Chromite deposit, located near McFaulds Lake in the James Bay Lowlands, Ontario, is one of five known chromite deposits within the Ring of Fire intrusive complex, and is the subject of this study. Chromite is the only chromium ore, and such deposits have great economic importance. Despite this, the conditions of formation of large chromite deposits are poorly constrained. The purpose of this investigation is to characterize the influence of magmatic water on the mineral phase relationships in komatiitic magmas. Water is hypothesized to promote chromite crystallization by suppressing the growth of silicate phases that might otherwise compete for chromium in the melt. It is known from studies of more felsic melt compositions that, while magmatic water inhibits crystallization of most silicate phases, it has a relatively lesser impact on oxide stability. Orthopyroxene, an important constituent in komatiites, readily accepts chromium into its structure, such that early-crystallizing pyroxene can prevent chromite from precipitating. Preliminary data from this study suggest that olivine may be a heretofore overlooked competitor for chromium. Experiments using synthetic komatiite (~2100 ppm Cr) with up to 4 wt% added H<sub>2</sub>O have been equilibrated at temperatures ranging from 1350–1450°C. To accommodate water, experimental charges are sealed in graphite-lined platinum capsules and pressurized to 1 GPa in a piston-cylinder apparatus. In addition to phase characterization by electron microprobe analysis, we will analyse for chromium and trace element partitioning between mineral phases and melt using laser-ablation inductively coupled plasma mass spectrometry. If trace element partitioning is sensitive to water content, and water content affects the chromite formation capacity of a melt, then such a fingerprint may have applications in characterization of natural komatiites with respect to their economic potential. Experiments are underway to measure the chromite liquidus in magmas of different water contents, as well as to verify the liquidus phase assemblages.

---

### A characterization of properties of the eutectic mixture of zirconium tetrafluoride and potassium fluoride for a molten salt nuclear reactor

---

REGAN WORDEN, CHRISTOPHER MCFARLANE, AND  
WILLY COOK

*Department of Earth Sciences, University of New  
Brunswick, Fredericton, New Brunswick E3B 3A3,  
Canada <regan.worden@unb.ca>*

Transitioning to a non-carbon emitting energy source is one of the major challenges that the world currently faces as the impacts of a changing climate becomes more imminent. One of the main suggested sources during our transition to a new energy future will come from nuclear energy. In past decades, the use of uranium fuel rods has been used to generate heat to drive a turbine. There are current undertakings for the proposals of safer alternatives which have higher efficiency and electrical output. Terrestrial Energy is a company based out of Ontario that is developing a pilot plan that uses a eutectic  $ZrF_4$ -KF mixture to be used in a molten salt nuclear reactor. The physical-chemical properties of a eutectic mix of potassium fluoride and zirconium tetrafluoride have been previously untested in a laboratory, but will be the integral mix that will be used in the cooling system in the second loop of the proposed molten salt nuclear reactor. The predictable behavior of the eutectic mix is crucial for the stability and efficiency of such a proposed project. As such, the homogeneity of the mixture, purity and subsequent trace impurities of transition metals, and water moisture content within the crystal lattice will be measured. This has been accomplished by examination through laser ablation ionically coupled plasma mass spectrometry (LA ICP-MS), x-ray fluorescence (XRF), Arizona Instruments Computrac Vapour Pro XL for water moisture analysis, and a scanning electron microscope (SEM). Various standards are used to determine any impurities that could be within the lithium meta-/tetraborate mixture, which is used to melt and fuse the eutectic mixture. Before samples can be measured, they are internally spiked with indium oxide ( $In_2O_3$ ) as a secondary standard for measurement to refine measurements from the singular primary standards. Using this method, it was identified that calcium, aluminum, sodium, copper, and silicon are the largest contributors to trace impurities within the eutectic mix. The individual components of the mixture have a range of water content trapped within the crystal lattices from 0.8 wt% to 14 wt%. All of the data that has been, and will be collected in the future, will be submitted to the Nuclear Energy Board of Canada for future projects that would involve this compound.

---

### Deep drilling 1978 into oceanic crust in Iceland – revisited

---

MARCOS ZENTILLI<sup>1</sup> AND JÓHANN HELGASON<sup>2</sup>

- 1. Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <zentilli@dal.ca> ¶*
- 2. Geodesy and Geographic Information Division, National Land Survey of Iceland, Stíllholti 16-18, 300 Akranes, Iceland*

Forty years ago, during the developmental years of Plate Tectonics, there was a need to better understand the oceanic crust, generally too deep for conventional drilling. An alternative was to bore into oceanic islands. Members of Dalhousie's Geology Department (James Hall and others) spearheaded the multinational Iceland Research Drilling Project (IRDP). In 1978 a ~2000 m drillhole with 98% recovery was completed by drillers from Quebec, through a tilted (~3 km) section of Neogene basaltic lavas, into a dike swarm at the head of Reydarfjörður, eastern Iceland. This was the best studied section of zeolitized basalts anywhere in the world, the field area of renowned British geologist George P.L. Walker (1926–2005). Many Canadian and international students and faculty benefitted from the experience.

The expectation was that a complete profile of oceanic crustal layers 1 to 3 would be intersected: subaerial flows, then pillow basalts, an increasing proportion of mafic feeder dikes to nearly 100% at depth, then perhaps gabbro and plagiogranite bodies. The core was logged and studied in detail for paleomagnetism, mineralogy of alteration, structure, geochemistry and geochronology. Temperature at the bottom was 80°C and artesian hot water exited the well at ~50°C. Unexpectedly, the proportion of dikes did not increase with depth, but remained constant, the reason being that the dikes at the site are younger than, and thus did not feed, the drilled volcanic pile. Later field work by the second author revealed downward-terminating dikes interpreted to indicate the dike magma flowed laterally from the Breiðdalur central volcano located tens of km to the south. The presence of epidote alteration explained increased seismic velocities at depth.

Numerous theses and publications contributed to make the IRDP drillhole one of the best studied in Iceland. The archival core is presently curated at the geology and heritage museum and research centre in Breiðdalsvík; a section of the institution is dedicated to field and laboratory equipment and documents of the late George P.L. Walker.

A recent visit to the project area revealed that one of the most important social contributions of IRDP, still remembered by the local inhabitants, was the discovery of hot water in what was then considered a “cold” area (too distant from the active zone). To this day, the well provides free heating to an adjoining farm, and deep drillholes like IRDP's now feed 80°C water to an outdoor swimming pool and year-round health/recreation centre in the nearby fishing port of Eskifjörður.