

## 2006 Colloquium & Annual General Meeting Abstracts: Greenwich, Nova Scotia: Atlantic Geoscience Society

Volume 42, numéro 1, January 2006

URI : [https://id.erudit.org/iderudit/ageo42\\_1abs01](https://id.erudit.org/iderudit/ageo42_1abs01)

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### Éditeur(s)

Atlantic Geoscience Society

### ISSN

0843-5561 (imprimé)

1718-7885 (numérique)

[Découvrir la revue](#)

### Citer ce document

(2006). 2006 Colloquium & Annual General Meeting: Abstracts: Greenwich, Nova Scotia: Atlantic Geoscience Society. *Atlantic Geology*, 42(1), 69–125.

# Atlantic Geoscience Society

## A B S T R A C T S

### *2006 Colloquium & Annual General Meeting*

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GREENWICH, NOVA SCOTIA

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The 32<sup>nd</sup> Colloquium and Annual General Meeting was held at the Old Orchard Inn, Greenwich, Nova Scotia on February 2 and 4, 2006. On behalf of the society we thank the organizing committee, Liz Kusters, Rob Raeside and Ian Spooner, as well as their supporting staff. We also acknowledge sponsorship from the following companies and organizations: Acadia Gold Corporation, Corridor Resources, Falconbridge, Potash Company of Saskatchewan and the Nova Scotia Department of Natural Resources, Mines and Energy Branch. In the following pages we are pleased to publish the abstracts of oral presentations and posters from the Colloquium.

THE EDITORS

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**Integrating analogue experiments and seismic interpretation for improved understanding of sedimentation and salt dynamics in Mesozoic sub-basins and their deepwater extensions, offshore Nova Scotia**

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Salt-deformation features beneath the shelf and slope of the Scotian Margin manifest complex tectono-stratigraphic relationships with high rates of sedimentation and progradation during the Jurassic and Early Cretaceous. Exploration and seismic interpretation concepts developed in other salt basins (e.g., Gulf of Mexico and South Atlantic basins) are not directly transferable to the Scotian Margin due to differences in palaeographic setting, sediment supply, and primary salt-basin geometry.

We have begun an integrated geoscience study with innovative 4D physical simulations using scaled analogue models and 2D/3D seismic interpretation. Our objective is to investigate the complex interplay between sedimentation and salt deformation in different sub-basins and their deepwater extensions that are characterized by contrasting salt deformation styles ranging from major extension and roho-style detachment to minor extension and vertical salt movement.

Public domain seismic data provide the boundary conditions for the experiments including tectonic setting, geometry of salt basins, and sedimentation pattern and rates. The evolution of the sedimentary basins and the dynamic salt system is simulated in physical experiments that consist of scaled granular-viscous models with syntectonic sedimentation. Model deformation is analysed by time-series of images and 3D displacement data obtained with high-resolution optical image correlation techniques (2D/3D PIV – Particle Imaging Velocimetry).

Structural 3D models are built from model sections with commercial seismic interpretation software to provide insights in the architecture of the linked salt-controlled basins and fault structures. The integration of structural interpretation with time-series of fault strain data allows the reliable 3D fault correlation and the mechanical analysis of complex fault systems. For the first time, this new modelling approach allows us to quantitatively assess: 1) the timing and mechanisms of faulting, folding and salt migration, 2) the role of variable sedimentation patterns and rates, and 3) the coupling between extensional, translational and compressional regimes.

In this experiment series we have investigated the role of basin floor dip, sedimentation pattern and rates on the basin evolution at regional scale. The experiment results show that gravitational collapse and salt mobilization generate complex

3D structures similar to those observed along the Scotian Margin, including crestal grabens, landward-and seaward-dipping roller structures, triangular-shaped reactive and active diapirs, turtle structures, canopies, and allochthonous salt detachments. The tectonic evolution is strongly controlled by sedimentation. Individual sub-basins and their deep-water compressional belts are coupled spatially and temporally and are characterized by lateral and temporal migration and highly variable and localized subsidence patterns. Our results show that a strong relation exists between sedimentation, rate of extension and dominant structural styles.

Integration of 4D physical simulations with 2D/3D structural modelling and seismic interpretation will lead to a new generation of improved interpretation templates for salt-related structures and basins of offshore Atlantic Canada. The project will significantly improve our understanding of the interaction of dynamic salt systems with sedimentation and erosion processes and will aid interpretation of complex structures beneath the Scotian Margin.

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**An ornithischian dinosaur from the Sustut Basin, northern British Columbia, Canada**

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In 1971, dinosaur bones were discovered during uranium exploration in the Sustut Basin in northern British Columbia, Canada, and were donated to Dalhousie University in Nova Scotia in 2004. Although dinosaur bones have been reported from British Columbia previously, this specimen is the earliest recorded discovery of dinosaur bones from the province. The specimen also represents one of the westernmost discoveries of dinosaur bones in Canada. The bones were collected from loose blocks in a talus slope, near the intersection of Birdflatt Creek and Sustut River.

The fossils are encased in a hard siltstone that shares characteristics with both the Early Albian to Late Cenomanian Tango Creek Formation and the Late Campanian to late Early Maastrichtian Brothers Peak Formation, making a more precise age estimate for this specimen difficult. Bones collected include the right humerus, a radius, the distal portion of the right tibia and fibula, several pedal phalanges including two unguals, and several unidentifiable fragments. A small block of matrix removed from the tibia contains additional small bones, but further preparation is not possible at this time.

Comparison of the material with specimens at the Royal Ontario Museum and descriptions in the scientific literature indicates that a relatively small (less than five metres in length), bipedal ornithischian is represented. General features of the tibia and phalanges are consistent with the ornithopod *Thescelosaurus*, but a low deltopectoral crest on the humerus matches closely with *Stegoceras* and other pachycephalosaurs.

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### Distinguishing primary versus hydrothermal alteration assemblages at the Chuquicamata porphyry copper system, Chile

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One of the major problems facing a new geologist at a mine is learning how to distinguish in the workings and in drillcore the various fresh, generally unmineralized rock units, their hydrothermally altered equivalents, and those altered by weathering, which are often intermingled due to complex structural deformation. It is also tricky to distinguish between magmatic biotite and K-feldspar from that formed by potassic alteration. Previous review of previous work is essential, and classical mineralogy and petrographic techniques, such as slabbing and staining of feldspars can help, but often thin section microscopy, x-ray diffraction and other modern mineralogical tools (e.g., electron microprobe) are necessary to unravel the alteration record. At the Chuquicamata porphyry copper deposit, Chile, mineralogical and geochemical evidence suggest a multiphase history of intrusion and alteration/mineralization complicated due to structural complexity. A strike-slip structure, the West Fault, truncates the Chuquicamata Intrusive Complex (CIC), which consists of the calcalkaline granodioritic Este, Oeste, and Banco porphyries. The CIC is overprinted by multiple phases of alteration (e.g., potassic, quartz-sericite, argillic) and mineralization. Inside the open pit and juxtaposed across the West Fault is the relatively unaltered and unmineralized Fortuna Intrusive Complex (FIC). Macroscopically, the fresh and the potassically altered Este Porphyry are nearly identical, making pit and core mapping very difficult. However, a closer examination of the potassically altered rocks reveals a lack of Ca-bearing silicate minerals. The potassic alteration affecting the Este Porphyry is the result of a late hydrous phase of the same magma with high halogen contents that preferentially partitioned Ca into the melt and the escaping fluid phase. The Banco Porphyry is unaffected by the potassic Ca-leaching event giving a firm relative age of intrusion, but altered by the phyllic event which obliterated feldspars and biotite, but introduced sericite and anhydrite. The upper levels of the mine and structurally shattered zones are deeply weathered and dominated by low temperature clay minerals, sulfates and other secondary minerals that make the rocks textures unrecognizable.

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### Analogue models of salt dynamics and sedimentary basin evolution on passive margins: implications for offshore Nova Scotia hydrocarbon exploration

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The high economic risk in hydrocarbon exploration on the Scotian Slope, offshore Nova Scotia, is caused by the complex salt structures, which developed from the Triassic to Cretaceous periods. This study applies physical experiments with optical strain monitoring to develop new concepts for the interpretation of geological and geophysical data, and provides information for the hydrocarbon exploration in this area. The scaled analogue models, which use silica sand and silicone as sediments and salt analogues, simulate gravity-driven syn-sedimentary deformation in passive margin sedimentary wedges overlying a mobile substratum. High-resolution optical strain monitoring techniques (2D/3D Particle Imaging Velocimetry, PIV) enable one to quantify the complete 3D deformation and surface flow in the experiments.

A series of experiments have been conducted to study the effects of varying sedimentation rates and the dip variation of the experimental base on the spatiotemporal deformation pattern. Results show that complex relationships exist between sedimentation pattern, basal dips, salt structures, and fault formation in the overburden. Time-series strain data and structural interpretation of these experiments provides insights in the dynamic evolution of sedimentary basins over a mobile substratum. Our results have the potential to improve the structural and seismic interpretation of the Scotian Slope salt province.

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### Comparison of the spatial and temporal patterns of change in salt marshes of the Avon and Cornwallis river estuaries

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Salt marshes and mudflats are dynamic systems that will respond to even slight changes in their surrounding environment. This would include changes in shoreline topography, main tidal channel position, wave action, water levels, ice and coastal development. These changes can be quantified by analyzing the spatial extent of salt marsh vegetation over time, identifying progradational or erosional sequences. Documenting and analyzing these sequences through a GIS over a decadal temporal scale can be used to evaluate the relative sensitivity and resilience of these systems to change. In addition, it is the first step in isolating the relative significance of variables driving those changes.

Both the Avon River (Windsor) and the Cornwallis River (Kingsport) enter the Minas Basin in an estuarine setting, where tidal action creates, and exposes, the salt marsh environment. These areas are exposed to macrotidal conditions, high suspended sediment concentrations, strong seasonality, and human development which will influence overall marsh evolution. The purpose of the research presented in this poster is to compare the spatial and temporal patterns of change in salt marsh habitat between the Avon and Cornwallis River

estuaries. It forms a component of a larger research project examining the ecomorphodynamics of intertidal ecosystems in the Upper Bay of Fundy.

Historical aerial photographs of the areas (1944 to 2003) were assessed for research suitability based on tidal level (low vs. high tide) and photos taken at high tide (e.g., entire marsh not visible) were excluded from the analysis. Unfortunately this resulted in gaps within the temporal record and even spatial gaps within a particular year. In addition, flight lines often were not flown within the same year in adjoining counties which limited comparison between study areas. The remaining air photos were scanned and rectified against digital 1:10 000 planimetric map sheets using ArcGIS 9.1. Variations in aircraft position were accounted for by using a second-order polynomial transformation in ArcGIS 9.1 during the rectification process. A custom AML for Arc/Info Desktop was used to mosaic the photos, resulting in an image with a ground resolution of one meter. Salt marsh habitats (incorporating both high and low marsh) were outlined using on-screen digitizing procedures in ArcView 9.1 and marsh area calculated. The resultant polygons were compared on a decadal scale, and change quantified using the geoprocessing capabilities within ArcGIS. These data were normalized for each estuary as a percentage of change between each year and over the entire time period. These data are currently being analyzed. By comparing the values gained for each estuary, the system stability can be evaluated, and potential reasons for the spatial and temporal patterns of change can be explored. These data can be used to show what has changed, where these changes have occurred, how much has changed, and examine the relative sensitivity of marshes within the Southern Bight of the Minas Basin. Only after these baselines have been generated can research hypotheses on factors controlling changes in salt marsh habitat be explored in a systematic and non-biased manner.

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### “Schools on Board!” Bridging Arctic sciences and education

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*Schools on Board* was created as an Outreach program to CASES (Canadian Arctic Shelf Exchange Study, and NSERC Strategic Project) and ArcticNet (and NCE, National Centre of Excellence). It is a vehicle for Arctic scientists and graduate students to outreach their research program to the general public. The program is designed to support teachers who are interested in including Arctic Sciences into their science programs by providing resources and opportunities to takes high school students and teachers into the Arctic to participate in

field research. Participants board the CCGS *Amundsen* where they are integrated into the activities of the various science teams.

This adventure into Arctic research exposes students and teachers to the research objectives and methods of numerous science teams representing a number of research disciplines and institutions from across Canada and beyond. Face-to-face interactions with scientists of all levels (graduate students, researchers, CRC chairs), hands-on experiences in the field and in the labs, and access to state-of-the-art scientific instrumentation, combine to create a powerful learning environment. In addition to hands-on research activities the program introduces participants to many aspects of Canada’s North, including local knowledge, culture, history, and politics – within the educational program on the ship and the planned visits to Northern communities.

Building on the success of the 2004 pilot program on-board the CASES project, the 2005 Field Program on board the NGCC *Amundsen*, successfully met its goals of promoting Arctic sciences, increasing awareness of environmental issues related to the Arctic and climate change, and providing new and exciting learning opportunities to this country’s next generation of scientists. In addition to the field expedition, Schools on Board promotes Arctic sciences in the classroom through its Network of educators and scientists and its most recent initiative, the Arctic Climate Change Youth Forum.

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### Machias Seal Island quartz monzodiorite: the southernmost rocks in New Brunswick

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Machias Seal Island is located at the mouth of the Bay of Fundy, about 20 km south of Grand Manan Island and 20 km east of Machias, Maine. The island has an area of about 0.04 km<sup>2</sup>, and is barren except for a lighthouse and dwellings maintained by the government of Canada. It has the last manned lighthouse in the Maritime Provinces, and is well known among bird-watchers as a nesting site for puffins, auks, and other seabirds. Geologically, Machias Seal Island is important because of its location in an area through which it is difficult to trace terranes from the mainland of Nova Scotia and New Brunswick into the New England states. Studies in Grand Manan Island have not entirely resolved the problem, as rocks there most resemble those of the New River terrane of southern New Brunswick, suggesting that the Kingston, Brookville, Cالدonia (Avalon), and Meguma terranes all lie outboard of Grand Manan Island.

Machias Seal Island consists entirely of grey, locally pink, fine- to medium-grained weakly foliated quartz monzodiorite, gradational to granodiorite. Small ovoid metadioritic xeno-

liths, generally less than 20 cm in maximum dimension, are abundant and consist of fine-grained granoblastic plagioclase, orthopyroxene, clinopyroxene, amphibole, and biotite. Two anastomosing mafic dykes, oriented approximately north-south and about 1 m in width, cut across the island. One dyke is alkalic, whereas the other is tholeiitic and may be related to Mesozoic basalt on Grand Manan Island.

Typical Machias Seal Island quartz monzodiorite contains 60% strongly zoned plagioclase, 40% amphibole and biotite, and about 20% interstitial quartz and orthoclase. The amphibole contains relict cores of orthopyroxene. The average chemical composition (6 samples) has 60.6% SiO<sub>2</sub>, with relatively high Al<sub>2</sub>O<sub>3</sub> (over 16%) and low K<sub>2</sub>O (2.8%). Overall, the chemical characteristics, including low Rb, Y, and Nb, are consistent with emplacement in a continental margin subduction zone.

A quartz monzodiorite sample yielded a preliminary U-Pb zircon age of 542.5±1.3 Ma, indicating that the pluton was emplaced close to the Precambrian-Cambrian boundary. Both the age and composition differ from those of the Three Islands Granite, which underlies the rocky shoals 14 km east of Machias Seal Island, and which has yielded a much older age of 611.1 ± 2.4 Ma. Small granitic plutons on Grand Manan Island have yielded ages more similar to the age of Machias Seal Island (ca. 547 Ma and 535 Ma), but they differ in terms of petrography and mode of occurrence. The Machias Seal Island quartz monzodiorite also differs in age from the adjacent granitoid rocks in Maine which are Silurian–Devonian and part of the Coastal Maine magmatic province. Age and compositional similarities strongly suggest correlation of Machias Seal Island quartz monzodiorite with the abundant ca. 550–525 Ma gabbroic to granitic plutons of the Brookville terrane on the mainland of southern New Brunswick.

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### The upper Hazelton Group in northwest British Columbia: an example of an ore-forming arc to rift transition

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In island arcs, the latest stage of subduction-related processes is commonly followed by an extensional tectonic regime. The Stikine terrane of the Canadian Cordillera records one such transition in the rocks of the Early to Middle Jurassic upper Hazelton Group, in northwestern British Columbia. These rocks are host to the world-class Eskay Creek volcanogenic massive sulphide (VMS) deposit. Recent targeted studies of the upper Hazelton Group have documented a number of

characteristics which confirm that the upper Hazelton Group represents a shift from arc building during the Early Jurassic to an extensional environment during the late Early to Middle Jurassic. These characteristics include 1) the presence of original rift bounding faults; 2) unconformities that are associated with rift filling conglomerates, including one that grades into more distal facies argillite; 3) a shift in the geochemical signature of mainly intermediate Early Jurassic calc-alkaline volcanic rocks to Middle Jurassic bimodal rhyolites and tholeiitic basalts; and 4) evidence for a major transcurrent tectonic regime, which opened distinct rift segments that were separated by horsts of older Stikinian units. Although the upper Hazelton Group is composed of separate sub-basins, the lithologies, geochemistry and morphologies of far-separated segments correspond closely to one another. The Willow Ridge Complex (WRC), and the Pillow Basalt Ridge Complex (PBR), which are 100 km apart, each contain a succession of sedimentary and bimodal volcanic rocks between 1000 m thick sequences of mainly pillow basalt. These middle units, in both regions, are very similar to the strata that host the Eskay Creek deposit and may represent a repetition of the conditions that were favourable to mineralization at Eskay Creek.

New whole-rock major oxide and trace element geochemical analyses of 17 samples collected from the WRC agree with previous interpretations that they were deposited in a rift setting. The chemistry of these rocks is similar to those that host the Eskay Creek VMS deposit and other VMS-hosting volcanic rocks world-wide. The WRC is composed of a bimodal suite of mainly basalts and rhyolites. Basalts from the WRC are characterized by: a) a negative correlation of TiO<sub>2</sub> with Mg number in compositionally-similar, TiO<sub>2</sub>-rich tholeiitic MORB; b) a slight enrichment in light REE (La<sub>n</sub>/Sm<sub>n</sub> = 1.83) and flat heavy REE (Gd<sub>n</sub>/Yb<sub>n</sub> = 1.19); c) slight enrichment of strongly incompatible elements and a small negative Nb anomaly in mantle-normalized incompatible-element diagrams. Rhyolites from the WRC have broadly similar characteristics to basalts (La<sub>n</sub>/Sm<sub>n</sub> = 3.01, and Gd<sub>n</sub>/Yb<sub>n</sub> = 0.86) but they have strong negative Ti and weak positive Zr anomalies. The similarity in trace element abundances between rhyolites and basalts rules out derivation of rhyolite from basalt via fractional crystallization. All but the most primitive basalts are interpreted to be derived from sublithospheric mantle, and rhyolites are interpreted to be derived from partial melting of crustal rocks.

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### How a committee earns its keep: current activities of the Atlantic Geoscience Society Education Committee

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Translating 'geo-jargon' into words that can be understood by teachers, students and the general public is a daunting task. But I guess some people are up for the challenge – and, thank goodness, some of these people are members of the

Education Committee of the Atlantic Geoscience Society (AGS). This Committee began its task in the late 1980s and grew to take on a number of what seemed to be formidable projects. The Nova Scotia EdGEO Workshop Program started in 1994 with last year marking the presentation of the twelfth in the continuing saga. EarthNet (earthnet-geonet.ca) was also one of the Committee's early projects. Development continues as it strives to become a true national resource for teachers. The popular geology book *The Last Billion Years*, published in 2001, is probably the group's most notable accomplishment. Please note that other excellent education products have been developed by sister committees of AGS; they are the geological highway maps of the Maritime Provinces and the "The Geology of Atlantic Canada" video series (plus teaching guides).

Today, the AGS Education Committee is thriving. Members include geologists and educators. Representatives from local museums, science centres and like-minded education groups also sit on the Committee. All this generates a natural setting for good discussion and collaboration. Recent activities include production of the "Nova Scotia Rocks", a pamphlet for those at the first-level entry to Nova Scotia geology; a partnership role in the NSERC-funded UNB-SFX CRYSTAL (Centres for Research in Youth, Science Teaching and Learning) project that will study the effectiveness of education outreach; a series of original watercolour paintings destined to tell us the geological history of the Fundy Basin; a new EdGEO workshop program in New Brunswick; and the 5<sup>th</sup> season of evening public talks at the NS Museum of Natural History. New activities under development are a booklet on the Fundy Basin story, resources for use at EdGEO workshops, and a book series for young readers. And ideas are always cooking on the back burner. If you are at all interested in how the AGS Education Committee earns its keep, you will want to attend the AGS Colloquium session *Education Outreach: A Required Element of the Geoscience Community*.

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#### Differentiation mechanisms in the Basement Sill, Ferrar Province, Antarctica

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The Basement Sill (BS) of the tholeiitic Ferrar flood basalt Province is > 300 m thick, with aphyric micro-gabbro-noritic marginal zones; a lower pyroxenitic tongue which varies in thickness along-strike; and an upper gabbro-noritic zone. The feldspathic websterite tongue could not have crystallized from the plagioclase-phyric chilled margins and represents

an injected pyroxene-enriched slurry. Orthopyroxene (opx) is euhedral and normally zoned, clinopyroxene (cpx) is interstitial, while plagioclase (plag) generally occurs as small (most <1mm, some 3–4mm), normally-zoned euhedral laths (<An<sub>87</sub>), some with inherited sodic cores. Euhedral plag laths included in opx primocrysts have similar compositions to groundmass or phenocrystic plag. Throughout the section, there is no systematic cryptic mineral-chemical variation of feldspar or pyroxene, and most rocks do not have cotectic plagioclase/pyroxene ratios, suggesting mechanical redistribution on a 300m scale of an inherited phenocryst load. Model melts from pyroxenite and gabbro-norite are identical to the dominant Ferrar Lavas for trapped melt fractions (TMF) of ca. 30%. The tongue contains feldspathic pipes (1–2m diameter) and layers which commonly contain foliated anorthositic edges, and gabbro-norite cores. Pipe margins appear rooted in the pyroxenite and yield model melts indistinguishable from those of the pyroxenite. We propose that the pipes are ephemeral melt+plagioclase escape structures by which the coprecipitated plag was transferred upward to form the gabbro-norite zone. In plan view, the size and number-density of the feldspathic pipes appears sufficient to have drained a pore melt containing ca. 10–20% small plagioclase laths from the pyroxenite in the time available for cooling the sill. The gabbro-noritic sequence contains anorthositic layers that differ mainly by having lower modal TMF (10%), and which may represent intra-cumulate sills of the feldspathic slurry expelled from the pyroxenite. Bedding-parallel and discordant pegmatitic 'veins' attest to the movement of Fe-Ti-PGE-rich fluids or volatile-rich melts which may have been expelled from the low-porosity anorthosites. Thus, recognition of low-TMF layers may represent a PGE-exploration guide.

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#### The effects of climate change on the coastal geomorphology of southwestern Banks Island, NWT

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Well-publicized community concern about changing coastal conditions led to Sachs Harbour being chosen as one of the first coastal sites for detailed study along the E-W gradient as part of ArcticNet Project 1.2. Fieldwork, including RTK coastal profiling, and analyses of aerial photography and QuickBird images were used to assess coastal processes, rates of coastal retreat, and long-term decadal changes in coastal erosion rates near the community of Sachs Harbour, NWT.

The southwestern coastline of Banks Island is dominated by low bluffs composed of frozen un lithified glacially derived sediments containing segregated ice lenses and ice-rich silty

sand horizons. Rising sea level and decreasing sea ice extent, coupled with regional submergence due to crustal flexure, has rendered this coastline vulnerable to erosion. Increasing effectiveness of storm events in eroding these bluffs could lead to increasing sedimentation on the shoreface and the nearshore. High sedimentation rates may have negative consequences on the marine biotic community in this region, with rapid burial of organisms hampering biological productivity.

Fieldwork in 2005 identified the dominant geomorphic processes and measured current rates of coastal erosion. Coastal surveys included 31 transects, distributed from north of Cape Kellett to southeast of Sachs Harbour. Sediment samples were taken from the shore-zone and nearshore environments to delineate longshore transport cells. Suspended particulate matter was measured in the nearshore zone and resampled during and after a small rain/wind/wave event. These results were used to determine the effectiveness of overland flow to increase sedimentation and resuspension of material in the nearshore.

The coastal bluffs are undergoing retreat, particularly west of Sachs Harbour. Bluffs in the eastern section of Sachs Harbour appear to be actively eroding. However, much of the community is sheltered from wave action by the spit to the south. West of the community where the bluffs are exposed to higher energy conditions, the sediments are finer grained, and there is increased wave erosion during storm events. Thermal erosion plays a major role in coastal retreat. Melting ground ice causes retrogressive thaw flow failures and slumping and creep of material to the base of slopes. Disturbed sediment is subject to removal during storm events. The results of a small rain/wind/wave event on August 9–10 indicate that although there was minor increase in overland flow and intensity of wave action, a much larger event would be necessary to actively transport disturbed material offshore.

Ongoing research will determine longer-term changes and quantitative rates of coastal retreat. Prediction of the future evolution of this coastline in response to changing climate conditions will allow Sachs Harbour to assess impacts and develop any adaptations necessary.

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### Seabed morphology, geologic framework, and paleoceanography of the NW Passage

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Thirty kHz multibeam echosounder and 3.5 kHz sub-bottom profiler data were continuously collected as CCGS Amundsen transited the NW Passage during the 2004 and 2005 ArcticNet field programs. These geophysical data in conjunction with sediment cores collected at key sites are being used to map seabed morphology, interpret the regional geologic framework and to investigate the palaeoceanographic history of the NW Passage over the past 20 000 years. The known, but very patchy, geologic framework of the seabed of the NW Passage inter-channels consists of bedrock base overlain by discontinuous glacial till. Thin glaciomarine sediments drape the till and/or bedrock. Discontinuous localized accumulations of Holocene sediment infill depressions with thickness varying from <1 to 10 m. Geophysical data collected on the Amundsen has significantly extended this stratigraphy to new areas not previously surveyed. Sediment coring of this sequence of sediments at key sites identified on sub-bottom profiles will define the geological framework of the inter-channel areas. Sediment core sampling is currently focused on the localized thick Holocene deposits to determine the waxing and waning of the sea-ice regime over the past 10 000 years. To date, seven piston cores ranging in length from 1.3 to 7.0 m have been acquired for palaeoceanographic reconstructions. The first piston core to be analyzed was collected in Lancaster Sound during 2004. Initial results indicate the core successfully penetrated about 5.3 m of undisturbed Holocene sediment covering the last 10,700 – 10,500 cal years BP; confirming the interpretation of the geophysical data.

Regional geological mapping of the NW Passage to locate Holocene sediment depocentres has resulted in the identification of a variety of geomorphic features on the seabed that shed light on glacial and recent processes responsible for shaping the morphology of the NW Passage. In 2004 and 2005, streamlined linear fluting features were mapped in about 400m water depth in Amundsen Gulf. These features are on strike with similar terrestrial features on Victoria Island to the east. Ice scours with irregular paths are observed seaward of the



flutes which may have been formed by icebergs calving from the glacier front. These ice scours are in 410m water depth and are not explained by the present day ice dynamics in the region. Other flutings were also observed in Dolphin and Union Strait, Lancaster Sound, Viscount-Melville Sound, and smaller scale flutings were observed in Pond Inlet and Eclipse Sound. Processes responsible for the generation of these features include glacial ice streaming and/or high velocity subglacial meltwater discharge.

A 16 × 5 km area of Lancaster Sound in approximately 860m water depth mapped in 1978 by side scan sonar was remapped in 2005 with the multibeam echosounder. The seabed is dominated by ice scours trending to the east. Preliminary interpretation of this area suggests that there are no new scours or other seabed features that have formed over the past 27 years.

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### Modeling groundwater vulnerability in the Annapolis Valley, Nova Scotia, using DRASTIC in a GIS

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The Geological Survey of Canada, in conjunction with various partners, has been undertaking a groundwater characterization project in the Annapolis Valley, Nova Scotia for the past three years. A significant component of this study has been the modeling of groundwater vulnerability, which utilizes the concept that the degree of vulnerability to potential contamination can be mapped as a function of hydrologic conditions. A regional view of the vulnerability to potential contamination of groundwater resources within the Annapolis Valley was modeled using the DRASTIC methodology. This index-overlay method uses the seven hydrogeologic parameters of Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and hydraulic Conductivity, and was programmed using object modeling available in ArcGIS.

To take into account several issues, including data quality, data quantity, and potential variability in the hydrogeologic conditions, seven different groundwater vulnerability scenarios were determined and examined for both bedrock and surficial aquifers throughout the Annapolis Valley. This exercise indicated that the vulnerability model produced by the DRASTIC method can be significantly altered by seemingly minor variations in data precision and accuracy for discrete parameters. Some of those parameters that have the highest impact on the weighting of the vulnerability model (net recharge, depth to water, and impact of the vadose zone) commonly exhibit low dataset precision and accuracy, which is an important consideration in the establishment of groundwater protection and

monitoring programs. Vulnerability results varied according to, and within, each geological unit, although generally surficial units were more vulnerable than bedrock units. The bedrock (Wolfville, Blomidon, and Horton formations) and surficial (outwash, kames and eskers, and alluvial deposits) units found to be most vulnerable to potential contamination were also the units most promising in terms of aquifer quantity and quality.

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### Mud volcanoes, diapirs, pingos and relict topographic features on the Canadian Beaufort Shelf

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Over three hundred seabed mounds have been mapped on the Canadian Beaufort Shelf using echo sounders, sidescan sonar, subbottom profiler and shallow seismic reflection profile data since 1969. Recent re-examination of 6 of these features using 3-D multibeam sonar has advanced knowledge of the morphology, activity and formation processes. These seabed features are morphologically similar to the 1400 pingos mapped on the adjacent Tuktoyaktuk Peninsula. The seabed features are collectively referred to as pingo-like features (PLFs). PLFs are frequently larger or even elongated in shape in comparison to their terrestrial counterparts. Some PLFs with surrounding moat and lake-basin shaped underlying seismic reflectors may be true pingos. PLFs actively venting gas into the water column may be mud volcanoes. Subbottom profile data showing the stratigraphy and structure associated with the features indicate the presence of mud diapirs, and relict topographic highs which survived the last transgression. Features mapped on the upper slope appear 'conical' in cross-section but when mapped in detail are ridges associated with submarine slumping.

PLFs range in width from 50 to 600 m in cross-section, 10 to 25 m in height and occur in water depths of 30 to 100 m. The height vs. water depth ratio of some PLFs makes them a hazard to navigation for deep draft vessels and they are regarded as geohazards to offshore hydrocarbon development. In addition, mud volcanoes are of special interest as they may be contributing greenhouse gases to the atmosphere, may indicate the presence of hydrocarbons at depth, and may be associated with localized unique ecosystems. The actively

venting Kopanoar mud volcano is associated with disruption of seismic stratigraphy at depth.

The Beaufort Shelf is underlain by thick ice-bearing permafrost which forms impermeable strata. Fluid and gas migrating from depth is trapped under or within the permafrost and escapes to the seabed through taliks and faults. Seepage would be concentrated around such conduits. Crest sediments of Admirals Finger and Kopanoar PLFs contain ice lenses that may relate to the freezing of fresh water seeping from depth when subjected to the -1.5 degree C subseabed temperature regime of the Beaufort Shelf. PLFs form linear patterns along the eastern and western edges of the Mackenzie Trough. Gas and/or fluids from depth may be seeping upwards along the erosional unconformity generated by the Late Wisconsinan glacial ice stream. Along the eastern edge of the trough, morphologic evidence indicates one of these features is continuing to grow while others are relict, inactive and buried in undisturbed Holocene sediments. The undisturbed crests of some PLFs suggest feature growth is faster than re-scouring processes by pressure ridge ice keels.

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**Microborings in the foraminifer *Lepidocyclina* sp.,  
Cenozoic White Limestone Group, Jamaica:  
possible causative organisms**

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The extensively outcropping Middle Eocene to Middle Miocene White Limestone Group, Jamaica, not only preserves soft-sediment and macroboring ichnotaxa but also microborings represented by *Mycelites ossifragus* Roux and *Oichnus* isp. that previously have only been recorded in shark teeth. We add to this database by reporting 14 additional ichnogenera, represented by 27 nominal ichnospecies and three problematic ichnospecies. These are *Centrichnus eccentricus* Bromley and Martinell, *Curvichnus pediformis* isp. nov., *Dendrorete balani* Tavernier, Campbell and Golubic, *Dipatulichnus rotundus* Nielsen and Nielsen, *Entobia volzi* Bromley and D'Alessandro, *Entobia* isp. cf. *E. ovula*, *Entobia* isp. form A, *Entobia* isp. form B, *Maeandropolydora elegans* Bromley and D'Alessandro, *Maeandropolydora sulcans* Voigt, *Oichnus asperus* Nielsen and Nielsen, *Oichnus excavatus* Donovan and Jagt, *Oichnus gradatus* Nielsen and Nielsen, *Oichnus ovalis* Bromley, *Oichnus paraboloides* Bromley, *Oichnus simplex* Bromley, *Oichnus* isp., *Planobola microgota* Schmidt, *Podichnus centrifugalis* Bromley and Surlyk, *Ramosulchichnus biforans* Hillmer and Schulz, *Reticulina elegans* Radtke, *Scolecica filosa* Radtke, *Scolecica maeandria* Radtke, *Stellatichnus radiatus* Nielsen and Nielsen, *Trypanites fimbriatus* (Stephenson), *Trypanites solitarius* (Hagenow), *Trypanites weisei* Mägdefrau, "Fossichnus solus" nomen non rite publicatum, and one example each of unnamed crescent-shaped and sub-horizontal to undulatory borings.

It is well known that the value of using microborings espe-

cially as palaeoecological indicators relies on understanding the distribution and ecology of their modern counterparts. Microborings are normally produced but not restricted to algae, (blue-green (cyanophyta), green (chlorophyta), red (rhodophyta)); fungi, and bacteria. As in the case here microborings cannot be assigned to such phyla and instead are also associated with boring sponges. In the fossil record, however, it is possible, albeit rare, to find borer/boring associations. From the Somerset Formation, White Limestone Group, such an association has been recorded in a foraminifer *Lepidocyclina* sp. and identified as a sponge bearing a new species name *Aka robinsoni* Blissett, Pickerill and Rigby. Normally sponges are preserved and recognized by individual signature spicules; here they are preserved as a bundled form with recognizable excurrent/incurrent canals alongside the boring identified as *Entobia* isp. based on its immaturity.

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**Filling in the gap: Correlation of onshore and  
offshore geology, southwestern Nova Scotia  
using geophysical data**

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The geology of southwestern Nova Scotia is characterized by plutons of varying compositions intruding a Meguma host rock. Onshore, the Shelburne, Wedgeport and Barrington Passage plutons intrude the alternating Halifax and Goldenville formations of the Meguma Group. The striped magnetic signature of the Meguma contrasts with a smooth, relatively uniform signature, in some cases positive, associated with the plutons. Previous studies of southwestern Nova Scotia have used gravity and aeromagnetic data to extend interpretations of this onshore lithology into the offshore. More recently, swath bathymetric studies have led to a surficial geology map of the continental shelf that shows granite bedrock exposed at the surface. This study will correlate between the coast and the outer portion of the continental shelf based on forward modeling of magnetic data. A series of profiles constrained by magnetic susceptibility values will be used to create 2D cross-sections of lithology. An onshore profile will investigate the Shelburne, Wedgeport and Barrington Passage plutons. A database of magnetic susceptibility values measured for each lithologic unit provides information on composition and the possible genetic relationships between plutons. These onshore results will be extrapolated into the offshore to develop a profile through Mud and Seal Islands to determine the relationship, if any, to the onshore plutons. The extent of plutons in the offshore will be mapped and correlated to regional geology based on their magnetic anomaly and other geophysical characteristics.

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**Trends in sedimentation and erosion at the mouth of the Petitcodiac River, Bay of Fundy, as inferred from sub-bottom profiles**

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In August, 2003, an acoustic sub-bottom profiling survey was carried out at the mouth of the Petitcodiac River on the Bay of Fundy, New Brunswick. The objectives were to determine the depositional styles and internal architectures of modern deposits forming in the sediment-laden waters of that macrotidal estuary where the tidal range is approximately 14 m. Depths of penetration for the high resolution IKB Seistec profiler were very limited by the presence of shallow gas over most parts of the intertidal flats surveyed along the river's edge, but exceeded 10 m where gas was not present in the shallow sediment, particularly along the outer edges of the mud flats. The profiler was able to resolve fine layering (as thin as approximately 20 cm), apparent slumps, and other internal architecture within deposits considered to be point bars. The profiles also show a very weak but clear reflector lying above and sub-parallel to the river bottom within the channel thalweg, which we have interpreted to be a layer of fluid-mud up to 40 cm thick.

Water level data from a temporary Environment Canada tide gauge that was operating near the mouth of the river during the time of survey enabled us to reference all of the profiles to the Geodetic datum (mean sea level). As a result, we have been able to produce bathymetric maps that can be compared to (recently digitized) bathymetry data that were collected by the Canadian Hydrographic Service in 1965 – two years prior to the completion of a causeway crossing the Petitcodiac River at Moncton. The presence of a bedrock knoll on the riverbed that was detected by both surveys allows us to confirm that we have treated the datums for the two data sets correctly.

The 1965–2003 bathymetry comparison reveals that the Calhoun Flats region, located at the mouth of the Petitcodiac River adjacent to the village of Hopewell Cape, exhibits areas of net deposition (up to ≈7 m) as well as a well-defined area of net erosion (up to ≈2 m). This differs from bathymetry comparisons that have been completed (by others) along several transects located upstream of the river mouth, which show that the river channel has been aggrading since installation of the causeway at Moncton. The zone of net erosion at Calhoun Flats therefore represents the most proximal source of net sediment supply that has been discovered to date in an

effort to determine where sediment has been removed from the floor of the Bay of Fundy and transported into the Petitcodiac (estuary) system.

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**Learning how to tell the story of a prospective geological World Heritage Site: rejoining art and science at Joggins**

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In seeking the inscription of Joggins on the list of World Heritage Sites, we have been compelled to come to grips with the significance of the story of a chapter of Earth history and of its place in the developing ideas of geological and broader scientific thought. In delivering this story, we are required to address the needs of a diverse audience, from local members of the community who have grown up on the cliff top, visitors of all ages and diverse educational and cultural background, to UNESCO officials and international country representatives who will decide on the worthiness of Joggins.

This challenge involves two cognitive steps: the first is to consider and fully understand the significance of a site beyond the confines of the discipline that may most appreciate it. The second is to communicate this relevance skillfully. Key to this delivery is careful distillation (possible only once a full understanding has been achieved), and 'economic' conveyance of the most strategic scientific principles required to avoid becoming generic or losing focus. These outcomes require the dedication of the scientist, expertise of the interpretive designer, input from others who bring the 'public' perspective, and a close working relationship for the three.

For the Joggins site, a starting point in this process is to consider the fundamental question 'Why is Joggins famous?' (or in UNESCO terms, the outstanding example in the world of this period of Earth history). Our answer is threefold, and embraces circumstances of Earth history, serendipity, and the quest for knowledge: 1) *the fossil record* of Joggins allows us to reconstruct the 'Coal Age' world here better than anywhere else on Earth (a bold statement that must be, and is, defensible); 2) *its grand exposure* on the shores of the Bay of Fundy, where its fossil record is continuously hewn and replenished by tides unsurpassed in the World; and 3) *the role that it played* in the developing ideas of some of the greatest scientific thinkers of the Nineteenth Century. From here, the story – and challenge – begins.

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## The formation of a glacial meltwater channel in Northern Alberta during the Late Wisconsinan and the potential for aggregate resources in the area

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During the last retreat of the Laurentide Ice Sheet in Northern Alberta, a 150 km long meltwater channel was created as lake water catastrophically breached an ice dam spanning the ramparts of Mt. Watt to the north and Clear Hills to the south. This occurrence released the contents of glacial Lake Peace both eroding and depositing landforms along the drainage channel. Seven aggregate pits along the meltwater channel were studied and sampled to determine the nature of channel deposition. Detailed descriptions of each site enabled the vertical extent of channel units and the lateral extent of different bedding layers to be identified. These deposits varied from clay size to boulder size, with overall fining upwards in each unit. The variation of poorly sorted units and well-sorted units suggest that channel formation probably occurred in three main stages: an initial catastrophic breaching of the ice dam that led to deposition of a massive sandy gravel unit, a more quiescent drainage period producing fine pea-size gravel layers interspersed with graded sandy gravel beds, and a final catastrophic drainage event which eroded and deposited a massive gravel layer. These descriptions and observations will be used to determine areas within the study area that may contain aggregate potential for future road construction and development.

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## Chronology development from decayed tree-ring samples in Atlantic Canada

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Decay rate studies of standing and downed coarse woody debris (CWD) from forests are able to relate information on past growing environments in a region. Wood samples that are preserved well enough to relate past growing environments can be used to extend chronologies from live trees, when the forest ages are relatively young. Two examples of chronology extension through decay rate studies are highlighted in this paper. First a study in Cape Breton Highlands National Park that was conducted in the summer of 2005, and second, a study from the Main River watershed in western Newfoundland in 2004 will be used.

Both study methodologies were arranged to parallel each

other, so as many experimental factors as possible were held in common. Detrital samples were typified and mapped using a visual classification system developed and fifty samples from the full range of decay classes were sampled and transported back to the lab. Base chronologies from live trees for each of the two sites were sampled, with all detrital samples crossdated into the living radial-growth patterns. It was found that although it was more difficult to retrieve growth data from the older visual decay classes of wood, when crossdating was possible the original base chronologies could be lengthened considerably.

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## Evaluation and characterization of the nickel-copper-PGE potential of the Red Cross Lake intrusive suite, central Newfoundland

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The Red Cross Lake Intrusive Suite (RCLIS) is a small mafic to ultramafic intrusion within the Victoria Lake Group, central Newfoundland. Mapping identified well-developed, subvertically dipping, magmatic layering in dunite, troctolite and olivine gabbro of the Lower Series (LS), and poorly layered, pyroxene amphibole gabbro in the Upper Series (US). Layering in the LS exhibits cumulate textures with gradational layering of olivine. A number of sheared, layer-parallel belts, containing 25 to 85% heterolithic xenoliths, were identified, which locally resemble hydrothermal or intrusion breccia. These belts are located parallel to the basal intrusive contact and parallel to the major boundary separating the LS and US. Sulphides are present throughout the most mafic basal units, up to a few percent, and comprise pyrrhotite, pyrite, chalcopyrite, and pentlandite.

Whole rock lithogeochemical data indicate that the tholeiitic RCLIS was emplaced in a within-plate environment. Harker diagrams indicate fractional crystallization in the LS, and a relatively homogenous, unfractionated evolved US. Calculated modal Ni-Cu-Fe sulphide abundances indicate that country rock samples contain greater amounts of Fe sulphides. Metal-silicate relationships suggest that the majority of Ni occurs in olivine rather than Ni-sulphides, that Cu is present primarily in Cu sulphides, and that Pt+Pd concentrations, which are quite low, correlate with MgO rather than sulphides.

Microprobe analyses indicate a primitive composition for the LS cumulates, averaging Fo = 83 (n = 176, SD = 2); the US is more variable averaging Fo = 48 (n = 73, SD = 14). The maximum Fo value is in a sample from the lower portion of the LS (Fo = 87.4), and the minimum is in a cumulate xenolith from the transition zone between the US and LS (Fo = 10). Though most samples have a positive correlation of MgO with Ni, some samples are clearly depleted in Ni, suggesting that a sulphide liquid interacted with olivine prior to crystallization of the LS. Most olivine grains exhibit little systematic internal zonation. Plagioclase compositions in the LS average An = 73 (n = 45, SD =

5), whereas in the US, plagioclase averages  $An = 55$  ( $n = 100$ ,  $SD = 10$ ). There is considerable rim-core zoning in US plagioclase, but the LS plagioclase is relatively homogenous.

Taken together, field, litho-geochemical and microprobe data indicate that the RLCIS is a strongly differentiated layered intrusion that may have been emplaced through multiple magma injections. Intrusion-spanning xenolith belts, parallel to the base, may define remnant basal contacts to later pulses of magma. The lack of mapped sulphide mineralization, in combination with low concentrations of precious or base metals, is not encouraging for exploration. However, a narrow zone over one kilometer north of the basal contact in the SW corner of the RCLIS exhibits strong Ni depletion in olivine, and ultramafic rocks in this area have layered cumulate textures which suggest that Ni may have been stripped by a sulphide liquid during emplacement.

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### Evaluating the source of the East Point Magnetic Anomaly, southern Gulf of St. Lawrence, based on magnetic, gravity, and seismic data

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The East Point magnetic anomaly (EPMA), located in the southern Gulf of St. Lawrence between western Cape Breton Island and eastern Prince Edward Island, is approximately 50 km wide and 150 km long, trends east-west, and has an amplitude of about 500 nT. The presence of the EPMA makes it difficult to correlate terranes between Cape Breton Island and mainland Nova Scotia and New Brunswick using their geophysical signatures. In this study, the source of the EPMA has been evaluated by forward-modeling of magnetic and gravity data, with additional constraints from seismic and petrophysical data and on-land geology. The second vertical derivative magnetic anomaly map resolves the EPMA into four separate approximately circular anomalies termed the Mabou Highlands (MHMA), east (EMA), central (CMA), and west (WMA) magnetic anomalies. These anomalies are attributed to plutons. The source of the easternmost anomaly (MHMA) is the ca. 375 Ma Port Ban Diorite, part of the Mabou Highlands of western Cape Breton Island. The diorite extends offshore for 12 km beneath the Carboniferous and younger sedimentary cover, and appears to have a steep intrusive contact at a depth of about 4 km with the EMA pluton to the west. The EMA, CMA, and WMA plutons have densities and magnetic susceptibilities consistent with granitic bodies which are progressively deeper, denser, and more magnetic toward the west. The unusually high magnetic susceptibility suggests correlation with the highly magnetic ca. 390 Ma Gaytons Quartz Monzonite in the Brookville terrane of southern New Brunswick. Basements at depths of ca. 3–7 km on the north and ca. 5–6 km on the

south of the EMA and CMA plutons appear to be different, mainly on the basis of density characteristics. The northern basement has characteristics consistent with those determined in southern New Brunswick for Ganderia, whereas the southern basement is a better match for the Brookville-Bras d'Or terrane than for the Avalon terrane. The four EPMA source bodies may be "stitching plutons" emplaced along the Canso Fault in the mid- to Late Devonian.

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### Authigenic carbonate mounds and hydrocarbon seeps of offshore Cape Breton Island

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Carbonate mounds that have been dragged up from the seafloor during fishing offshore the Northern Cape Breton Highlands are very distinctive in their nature. The carbonate mounds range in size from a few cm<sup>3</sup> to larger than a m<sup>3</sup> in size. Worldwide, other carbonate mounds have been documented but are either much larger or formed in different settings. By studying seismic sections and sampling the hand specimens, the process of their formation can be proposed. Using both Huntect and Airgun seismic data, distinct areas of hydrocarbon mixing with the sediments can be detected. The seismic data also showed a distinct layering between glacial deposits and more recent sediments. Carbon 13 values determined from isotope analysis of shelly debris encased in the mounds showed a distinct negative value in each of the samples. The range for the C13 values is -9.41 to -35.27, with one distinct outlier -61.38. Considering the isotopic analyses and the seismic data it seems likely that these carbonate mounds were formed by methanogenesis of hydrocarbon from slow seeps on the seafloor.

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### Putting it in motion: plate tectonics as a classroom activity

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Most students are familiar with the basic concept that the lithosphere, or outer shell of the Earth, is divided into several relatively rigid plates that move over the underlying asthenosphere. The theory of plate tectonics describes the interactions of these plates, and the deformation, such as stretching, folding or shearing, that takes place along their edges. Many of the present and past geologic processes can be related in some way to plate tectonics: nearly all earthquakes and most of the Earth's volcanism occur along the plate boundaries; mountains have formed, ocean basins opened, and flora and fauna have

thrived or died, as a result of plate motions and interactions; even climate and ocean circulation have been affected by plate positions. A solid understanding of plate tectonics will underpin other lessons in earth sciences.

One approach to teaching plate tectonics is to involve the students in a live demonstration of plate motions through time. This latest version of a popular classroom activity uses the students themselves to represent continental fragments and landmarks, such as the poles and equator. As geologic time progresses through several hundred million years, the students move around the “globe” and experience firsthand the transition from a position near the poles to latitudes where warmer climates prevail. Interactions along plate boundaries are experienced as groups of students separate, or occasionally collide to form supercontinents. The physical activity is typically accompanied by a discussion of climate, fossils, active tectonics, and local geology. The activity has been prepared for a junior high level class with 20 or more students, but can easily be tailored to different age groups and class sizes. A quick demonstration will provide a graphic – and entertaining – overview of the activity.

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### The Atlantic region teleseismic experiment: a new study of regional structure and seismicity

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A new experiment is underway to improve our understanding of the geologic structure beneath Atlantic Canada through the analysis of teleseismic waves. Ten VSAT Libra seismic stations were installed at various locations throughout Atlantic Canada during September to December 2005. Each station consists of a 3-component broadband seismometer, a satellite dish for real-time data telemetry, and an AC or DC (solar panel) power source. These temporary stations, leased from the POLARIS consortium, will augment the existing permanent stations of the Canadian National Seismic Network for the next two years. Teleseismic energy from large global earthquakes will be analysed to identify major crustal and subcrustal boundaries beneath the region, and to determine the velocity structure under the various stations. Each station is positioned to address a particular geologic problem, and the stations loosely form two transects across the region. One of the primary objectives of this study is an improved understanding of the development of the Paleozoic and Carboniferous sedimentary basins in the Gulf of St. Lawrence. Additional controls on Appalachian crustal structure, and hence better estimates of paleoheat flow, will help to differentiate between models of

basin evolution. In addition, these new stations will aid in the positioning and analysis of local seismic events.

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### On the rocks with geoscience outreach

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Understanding the world of geoscience begins with rocks and deposits. We believe that successful geoscience outreach activities involve some way of connecting with rocks. In many cases the connection is made through interpretive walks in provincial parks, Crown land, wilderness areas and along streets in Nova Scotia towns and cities. The challenge is to create an environment that allows your audience opportunities for active and experiential learning. Walks can be sponsored through museums, government programs such as the *Parks are for People* program, special events like the Nova Scotia Mineral and Gem Show, municipalities and the Atlantic Geoscience Society. In each of these examples, interpretive walks may have all ages of people, language differences, a variety of educational backgrounds and different learning styles. The geological materials may be bedrock, surficial deposits and building stones. These variables present challenges for effective communication. So how do you communicate with such diverse audiences? We assert that effective outreach communications always have a commonality of certain techniques. The most important attributes for your audience will be your friendliness and enthusiasm. If you don't have these, your message may not have much chance of being 'heard.' The starting point is a good introduction about you, the purpose of the walk and the rocks followed by the beginning of geological explanations that build the experience of understanding geological concepts. Making simple comparisons such as the connection between rocks and landscapes helps people visualize the affect of rocks. Children will help break down many barriers to communication. Ask them questions and help them with answers. Build on the answers. Now you are ready to ask very general, open-ended questions to the entire audience. Compliment good answers and thoughtful insights. With the build-up of the audience's confidence, you can now begin to develop more complicated themes such as deformation of rocks or the inner workings of magma chambers. Watch your audience; their body language indicates how they are learning. Invite them to use their senses to gain an understanding of the rocks. Whenever possible, we have made use of coloured illustrations. These have the effect of allowing visual learners to understand our point by seeing as well as hearing us. At this point in the walk you are usually able to develop more complicated concepts. On various walks, we have discussed the deformation of rocks in fault zones, terrane and plate movements, fluvial deposition, development of landscapes and the origin of granite. Our audiences have

enjoyed learning. They have taken away several very important messages such as geoscientists are important to society; understanding earth systems and processes helps us predict what may happen to parts of the earth and geoscientists help find the needed mineral wealth on which our society depends. We urge you to try your own walking tours. They're fun and they provide a needed involvement for people. You will be helping with global education about the Earth and its processes because the more we know about the Earth, the better we understand it and the more we can sustain it.

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**SEM cathodoluminescence imaging of quartz phenocrysts in the Nepisiguit Falls Formation, Bathurst Mining Camp: evidence of explosive fragmentation**

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Cathodoluminescence (CL) is a technique commonly employed in the geosciences to reveal internal structures, growth zoning and lattice defects of a variety of mineral specimens (feldspars, carbonate minerals, etc.). The conventional optical CL technique images photons emitted when a sample is irradiated by an electron beam. This type of CL works well for many minerals, but can only distinguish between detrital and non-detrital quartz grains. However, when used in conjunction with the scanning electron microscope (SEM), it can reveal internal structures, growth zoning, and lattice defect features in minerals that exhibit weak luminescence, i.e., in quartz grains such features are not discernible by means of other analytical techniques. In quartz, variations in luminescence intensity may result from trace elements present in the grain structure or from the ordering degree of the quartz lattice. These variations are a reflection of the P-T-t-x conditions that the quartz grains formed at, such that high-temperature volcanogenic quartz grains usually exhibit little zoning in the blue spectrum and low-temperature metamorphic quartz grains may exhibit complex zoning in the red spectrum.

Preliminary examination of quartz phenocrysts from the felsic tuffaceous rocks of the Nepisiguit Falls Formation was done using the JEOL JSM-5900LV SEM running at an accelerating voltage of 20 kV, fitted with a Gatan retractable MonoCL3 detector at Acadia University. SEM-CL techniques show zoning is present in some quartz phenocrysts from the Nepisiguit Falls Formation. Zoning in quartz grains from a volcanogenic source suggests there has been a change in composition, pressure or temperature within the magma chamber prior to eruption. The observed zoning does not correspond with the phenocryst grain boundaries suggesting these grains may have been explosively fragmented. Feldspar phenocrysts

from these samples show patchy textures related to pervasive albitization, and do not provide evidence to support the cause of zonation in quartz phenocrysts.

Highly embayed quartz, from the massive megacrystic tufflava of the Nepisiguit Falls Formation, shows no zonation suggesting only one phase of quartz crystallization in the magma chamber prior to eruption. Petrographic examination of these highly embayed phenocrysts shows that they have sharp boundaries though they were not explosively fragmented. If explosive fragmentation had occurred in these phenocrysts, it would be expected that fragmentation would obliterate the embayments breaking the phenocrysts into smaller fragments. In addition, these embayments were preserved during ascent in the conduit indicating the system did not behave as a two-phase gas-pyroclast system, but rather as a one-phase mixture.

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**Tracking the Ministers Island dyke using marine magnetics, St. Andrews, New Brunswick**

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The early Jurassic Ministers Island dyke is a quartz normative tholeiite coincident with extensional stresses related to the breakup of Pangea. The intrusion has an ENE-WSW trend, a near-vertical northern dip and outcrops at several onshore locations within northeastern Maine and southwestern New Brunswick. A map of the vertical magnetic gradient derived from a regional airborne survey flown in 2001 shows several kinks in the linear anomaly associated with the dyke, as well as an abrupt weakening and termination of the anomaly in the eastern part of Passamaquoddy Bay. With the objective of resolving post-early Jurassic movement along the dyke, a high-sensitivity marine magnetic survey was undertaken over the St. Croix River and Passamaquoddy Bay areas in August of 2005.

The survey was conducted using a Marine Magnetics SeaSpy total field magnetometer employing an Overhauser sensor. The instrument was towed approximately 1 m below surface and 24 m behind UNB's 13 m fibreglass research vessel 'Mary O'. A sampling rate of 1 reading per second at a boat speed of  $\approx 4$  m/s provided measurements at intervals of approximately 4 m along each line. A DGPS receiver on the boat was used for both navigation and to provide input to the recording system that calculated the layback position of the magnetometer. Water depths measured by the ship's depth sounder, and temporal variations in the earth's magnetic field at a base station were also recorded for later use in data processing and interpretation.

Preliminary gridding of the magnetic data shows that the dyke exhibits an apparent sinistral offset of approximately 220 m along the Oak Bay fault in the St. Croix River. This represents, to our knowledge, the only direct evidence to date of post-early Jurassic movement along the Oak Bay Fault,

although the fault has long been cited as a possible source of ongoing low level seismicity in the region. We recognize, however, that the evidence is not entirely conclusive as it is possible that the dyke may have been offset at the time it was emplaced across the pre-existing Oak Bay Fault zone.

In Passamaquoddy Bay, the dyke's magnetic anomaly exhibits a distinct local kink towards the south where it crosses the Big Bay fault. Given the presence of a trench with a vertical drop of 25 m in water depth in this area, we speculate that the kink could be explained by the dyke subcropping farther to the south (provided its dip is locally southward). Eastward of the kink, the anomaly associated with the dyke weakens abruptly where it is offset 190 m to the north by what appears to be a subsidiary fault. This weakened portion of the anomaly extends another  $\approx 1750$  m to the east before disappearing. Previous workers have speculated that an eastward continuation of the dyke may appear on land 2–3 km to the north of the termination as a result of additional dextral faulting.

Work in progress includes the production of a first vertical derivative map which may reveal more subtle features associated with faulting and modeling of the Ministers Island dyke to gain information on its depth, thickness and dip orientation.

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### The past, present and future geoscience research in understanding the Bay of Fundy

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Over the past decade numerous groups have convened meetings and workshops on environmental issues of the Bay of Fundy that include topics such as marine habitats and the fishery, environmental health, river damming, dredge disposal and coastal sedimentation. A common observation is that conditions in the Bay appear to be rapidly changing but many of the observations are largely anecdotal and not well-understood or documented. This is in concert with the pace of science that has substantially slowed from the heydays of tidal power assessment several decades ago.

The key to understanding the Bay of Fundy and the complex relationships between the seabed, strong currents, biology and the influence of human activities, is a basic and essential high-resolution knowledge of the environment. The Geological Survey of Canada has had an on and off again program in the Bay but a regional study has not been a priority for over 20 years. In the meantime, new technologies for high resolution study of seabed processes, benthic habitats and oceanography have been developed and largely applied elsewhere.

Regional marine geological assessments of the Bay of Fundy conducted in 1997 and 1999, have revealed previously unknown aspects of the history of glacial advance and retreat, marine archaeology, sea level change, seabed habitat, sediment dynamics, aggregate potential and the discovery of mussel reefs. Much of this new knowledge was based on a high graded

multibeam bathymetry study that evaluated specific geoscience questions and features that were determined from previous geological/geophysical surveys and modeling. Considerable insight has now been gained into the complex stratigraphy of the Bay that includes the formation of till tongues from floating ice fronts during ice retreat, late glacial iceberg furrowing, and unique mussel bioherms. These examples underscore the need for a comprehensive high resolution understanding of materials and processes which is essentially less talk and more action.

In order to take the next major step in understanding the environment of the Bay of Fundy, it is imperative that regional multibeam bathymetric surveys be conducted, integrated with high quality sampling, geophysical surveys, and interpreted. This will form the basis for the many Fundy-related environmental groups and government agencies to understand change in this unique and extreme environment and begin a true science based dialogue on appropriate management decisions.

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### The making of an AGS educational film: from design to production

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In our high technology world, one of the most effective ways of communicating science to the non-scientist is through visual media. This can be accomplished by the production of videos/documentary films that are of relatively short duration, preferably about 30 minutes, and of international, national or regional interest. For over twenty years, the Atlantic Geoscience Society has focused on producing videos that satisfy a demand for regional content; not an easy task considering the escalating expense of such productions. The latest, now nearing completion, is about the geological origins and modern history of Halifax Harbour that was conceived over a decade ago.

During the eighties and early nineties, new geological research and technological advances in sea bed mapping revealed some fascinating information about the geological evolution of the great Harbour of Halifax and its role in the settlement of eastern Canada. The bedrock forming the Harbour originated as deep water sediments off Africa. This bedrock, constituting the Meguma terrane, was molded by the last glaciation and that part forming the present Harbour was subsequently flooded during the post glacial rise in sea level. Today's Harbour reflects human activities such as dredging, ship anchoring, use as a disposal site for sewage and other pollutants, numerous shipwrecks, the Halifax Explosion and the footings of old railroad bridges to name a few. Any one of these topics could fill an entire hour of the video, so the challenge has been to present a balanced story while maintaining the interest of the viewer.



We will present the making of the 26 minutes' video from the prospective of the writer, the producer and the narrator. Also, we will discuss the important topics of funding, design concepts, graphics, animation, interviews, filming, production techniques, and the story board. Other concerns, often overlooked, are the need to inject some humour, difficulties caused by bad weather especially when filming on a limited budget, equipment problems, the concept of trespassing, economic repercussions, good timing and luck. And as an added bonus, we plan to screen a short promotional clip.

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### Late Cretaceous–Cenozoic biostratigraphic control on the Scotian Margin: an eventful story

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Since the 1970s, little has been published on the Mesozoic–Cenozoic biostratigraphy of the Scotian Margin. In the interim, however, significant progress has been made on preparation techniques, taxonomic concepts, and refinement of biostratigraphic ranges. Moreover, calibration of biostratigraphic events to magnetostratigraphy and the global time-scale has further increased the potential for more accurate and detailed age control. The present study is based mainly on information from six wells selected to provide a composite section. The Late Cretaceous–Cenozoic interval from each of these wells was analyzed for dinoflagellates and pollen and spores and, in some of the wells, for calcareous nannofossils, and planktic and benthic foraminifers. These studies have yielded a detailed sequence of biostratigraphic events. The biostratigraphic information will be integrated with available non-biostratigraphic event information (e.g., sedimentological events marked by well-log spikes and lithologic markers). The combination of stratigraphic data from several disciplines provides a remarkably refined and reliable composite stratigraphy for the Scotian Margin, and this resolution will be further enhanced by integration with seismic stratigraphy.

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### Dinosaurs, deserts and volcanoes: the creation of a series of paintings depicting scenes from the Mesozoic Fundy Basin of Nova Scotia and New Brunswick

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A team consisting of an artist (JP) and numerous geologists (the rest of us) has created a series of five paintings, mostly watercolours. Four of the images represent the four principal Fundy Basin formations (Wolfville, Blomidon, North Mountain Basalt and McCoy Brook) that are collectively the late Triassic to earliest Jurassic Fundy Group. The fifth painting dramatically portrays Canada's oldest confirmed dinosaur. The geologists on the team represent various specialities, such as sedimentology, vertebrate paleontology, paleobotany and volcanology. The principal challenge was to construct a coherent vision of what the Mesozoic Fundy region looked like based on accurate scientific observations and information, and convey that vision to the hands of the artist. In building the images, evidence from Fundy Group rocks was used wherever possible. All the terrestrial and aquatic vertebrates shown are based on known skeletons or footprints. The dinosaur that peers at us through 200 million years in the fifth painting represents a new genus of prosauropod, several skeletons of which have recently been found in the McCoy Brook Formation at Wasson Bluff, near Parrsboro. As for aerial vertebrates, although no evidence for pterosaurs has been found in the Fundy Group, we decided that, as these flying reptiles had evolved by Blomidon times, we could indulge in a couple of these exotic creatures. Despite common root casts locally in some horizons, very few well-preserved plant fossils have been found in the Fundy Group – discoveries are limited to a few ferns and sparse spores and pollen; hence, coeval forms known from elsewhere had to be used to portray the flora. Beyond fossils, structural geology suggested major landscape features such as the bluffs along the

Cobequid Fault. Sedimentology provided us with evidence for braided streams, playa lakes, alluvial fans, sedimentary structures such as mud cracks, and other features. Close study of images of modern lava lakes and fountains provided inspiration for the North Mountain Basalt painting. Although paintings representing the other three formations are not intended to be location specific (other than within the Fundy Basin), for the McCoy Brook painting we couldn't resist an attempt at portrayal of the Wasson Brook locality: the structural re-entrant seen in the modern bluffs is represented by a small tributary valley of the main basin, and the talus slope, dunes, braided stream, foreground lake and boulders at the foot of the cliffs are all based on evidence from the rocks. The fauna, too, reflects accurately the fossil finds at Wasson Bluff. Funding for the project was supplied by the Atlantic Geoscience Society and the Canadian Geological Foundation. The paintings belong to the Atlantic Geoscience Society and will be on display at the Fundy Geological Museum. Reproductions of the images are available for educational purposes.

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#### Dating of raised beach deposits in Gipsdalen, coastal west Svalbard, using surface exposure dating ( $^{10}\text{Be}$ , $^{36}\text{Cl}$ ) and radiocarbon ages

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Raised beach deposits were sampled in the Gipsdalen area (inner Isfjorden) to quantify the isostatic rebound of the area in western Svalbard. The region has been covered by a 300–100 m thick Weichselian ice sheet extending west from the Barents Sea (Siegert and Dowdeswell, 2002, *Marine Geology* 188, 109). Isostatic rebound of the land mass after the melting of the ice raised late glacial beach deposits in the study area up to 90 m above the present sea level. A series of raised beach deposits were mapped and surveyed in the Gipsdalen and Gipshuken area. Three samples from glacially abraded bedrock constrain the downwasting of the Late Weichselian ice cover in the area. The surface exposure ages ( $^{10}\text{Be}$  and  $^{36}\text{Cl}$ ) of these samples provide a maximum age of the Late Weichselian Marine Limit of the research area. Amalgamation samples were taken from sediment bodies of raised beaches at five different locations. Surface as well as depth samples were taken to quantify the inherited nuclide concentrations of the sediments. We found shells and whale bones in the same sediment bodies that we sampled for radiocarbon dating. They allow evaluating the reliability of our age modeling. Furthermore, we found organic material (whalebones and wood fragments) well-embedded in raised beach deposits from a series of nine raised beaches of probable Holocene age. Our results will constrain the late glacial uplift rates of the area as well as the marine limit for different time

periods. This combined approach of radiocarbon and surface exposure dating allows investigating the applicability of surface exposure dating with terrestrial nuclides for young, Holocene sedimentary surfaces at low altitude and high latitude. Field results will be presented at the conference.

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#### Mongolian women in geosciences: the appearance and reality of changing gender roles

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Mongolia is emerging as a major new frontier for mineral exploration and development, and one of the fundamental problems arising is the need for a stronger indigenous highly educated geoscience and mining labour pool. However, gender issues present barriers that must be overcome. This presentation will overview the way in which geosciences and mining, in particular, are gendered activities in Mongolia. Mongolia offers an ironic combination in that more young women than young men are entering the field of geosciences, but this is not translating too well into career opportunities for the women. While the presence and activity of women geoscientists in the educational and research institutions is high, many women are facing resistance to their employment by mining companies and other venues for their education and talent. Men are still, by and large, preferred for most jobs. In the last ten years, the proportion of women enrolled in Ph.D. programs has increased from 30% to 50% of total enrollment. The proportion taking leadership roles as chairpersons or deans in educational institutions is 51% whereas only 21% of leadership positions in industry and government are women.

This brief statistical summary highlights both the traditional attitudes regarding the suitability of men and women for gender defined roles and the new emerging effects of political and economic realities that are negatively influencing the education of young men, especially from rural areas. So what on the surface looks like a considerable positive gain for women masks a deeper gendered reality that requires analysis. The maintenance and growth of a healthy and robust geoscientific community in Mongolia requires careful attention to the way in which gender roles are changing. For educated young women geoscientists, the issue is gaining acceptance in what have traditionally been male roles. At a recent conference on Women in Geoscience, co-sponsored by the Canadian International Development Agency and the Mongolian University of Science and Technology in Ulaanbaatar, the Mongolian women founded the Association of Mongolian Women Geoscientists. The Association will work to increase the awareness of gender related issues among relevant individuals and institutions, including mining companies, and to develop strategies for the further integration of women into all spheres of geoscience related research and careers. Likewise, the presentation will at-

tempt to elucidate the challenges and promise associated with the gendered face of geosciences in contemporary Mongolia.

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### Cu-Mo porphyry deposit of the Erdenetiin Ovoo: an environmental study

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Erdenetiin Ovoo, the largest porphyry copper-molybdenum deposit in Mongolia (1.78 Gt @ 0.62 % Cu and 0.025 % Mo) is exploited by the Erdenet mine located in northern Mongolia, 240 km northwest of the capital, Ulaanbaatar. The deposit was discovered in 1964 and has been mined since 1978. The mine is an open pit which extends over an area of 2500 × 1150 m. Its annual production rate is approximately 20 Mt of ore; the mine produces over half of the total Mongolian income and export earnings.

The deposit is hosted by the Erdenet pluton, a part of the multistage Permo-Triassic Selenge Intrusive Complex which occurs within the Orkhon-Selenge volcano-sedimentary trough that developed on an active continental margin. The mineralization and alteration post-date the emplacement of the pluton and are related to the shallow-level porphyritic intrusions (stocks and dikes). These intrusions are genetically related to the trachyandesitic volcanic series of late Triassic-early Jurassic age emplaced in a continental collision setting. The deposit is a cylindrical body of quartz-sulphide stockwork veinlets hosted by an ore-bearing granodiorite porphyry intrusion about 2.4 × 1.4 km in area. Mineralization yielded an age of 240.7 ± 0.8 Ma (Re-Os on molybdenite).

Ore-bearing porphyries are medium-high K calc-alkaline granitic rocks of the I-type, magnetite series. Their mantle-normalized trace element patterns show depletion in Nb, Ti and P and are typical of granitic rocks from an active continental margin environment. There are three alteration assemblages which show a distinct concentric zonation. From the core to the periphery, the alteration zones are sericitic (quartz-sericite), intermediate argillic (chlorite-sericite) and propylitic (chlorite and epidote-chlorite). The deposit occurs within the quartz-sericite alteration zone. Quartz-molybdenite and quartz-chalcopyrite veinlets are related to this alteration stage. The alteration halo is about 2.7 × 2.2 km in size.

An environmental study in the area of the Erdenet open pit mine and surroundings shows that, apart from the tailings, the mining impact is relatively small. The average of 195 soil samples from the Erdenet area is (in mg/kg): As 7.1 mg/kg, Be 1.0, Cd 0.1, Co 11.4, Cr 39.5, Cu 34.9, Mo 0.50, Ni 22.3, Pb 11.7, V 75.9, Zn 64.2, Hg 0.02. The values are below the government limits for all these elements. Likewise analyses of vegetation yielded values which do not exceed the limits. The results show that airborne dust from the open mine pit, tailings

and mine roads has not significantly contaminated the mine surroundings.

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### Monsoon-generated fluvial sequences: Climatic control in the Quaternary of the Himalayan Foreland Basin

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The Himalayan Foreland Basin is among the world's most tectonically active regions, with huge earthquakes on Foothills thrust faults, on faults below the plains, and on the cratonic foreland to the south. It would be reasonable to infer that the alluvial fill is "controlled" by tectonism. In testing this hypothesis, much of our knowledge of Himalayan foreland-basin dynamics comes from the Neogene Siwalik Group, exposed in the Foothills, with little information from the modern plains. However, excellent cliffs with floodplain deposits extend along the Ganga and other rivers towards the craton in the western plains, some 1200 km inland. The successions date back to ≈130 ka, spanning the last glacial cycle.

A remarkable aspect of the cliffs is the presence of discontinuity-bounded sequences a few meters to tens of meters thick, the bounding surfaces of which can be traced for tens of kilometers. Some surfaces are gullied erosional surfaces with local groundwater cements and a mantle of reworked gravel. Others represent large badland gully systems, and include former gullies up to 10 m deep filled with colluvium and reworked carbonate gravels. Still others represent an abrupt change from floodplain to lacustrine and eolian deposits, implying major changes of paleoenvironment.

Fluctuations in monsoonal precipitation – driven by changes in sun's energy and glacial boundary conditions – have affected large parts of Asia, as documented from computer-based modeling and facies evidence. For example, precipitation in some parts of northern India was probably double present values about 10 000 years ago. Such changes in monsoon intensity should have exerted a strong driving force on the plains stratigraphy.

Suites of OSL, TL, and radiocarbon dates were obtained to bracket the age of key surfaces in the cliff exposures, for comparison with the proxy modeling record. The resulting age model shows a first-order correlation between precipitation changes inferred from modeling and periods of incision and accumulation observed in the field. Wider correlations show that incision and valley formation affected rivers across northern India and Nepal as monsoonal precipitation intensified following the Last Glacial Maximum – in the foreland basin, in extensional basins in Gujarat, and in mountain valleys. A corresponding large sediment pulse is recorded in the Ganga-Brahmaputra Delta and Bengal Fan. Carbonate-filled joint sets that terminate upwards at one discontinuity surface testify to earthquake events, suggesting that faults were active locally.

In areas such as Asia where the monsoon exerts an over-

whelming effect, changes in fluid and sediment discharge affect the sediment transport capacity of rivers, resulting in floodplain incision and accumulation cycles. The study area is too far inland to record sea-level changes, which generated paleovalleys fills no farther than 300 km inland. Thus, even in tectonically active basins such as the Himalayan Foreland Basin, precipitation (climatic) change may control much of the architecture of the river deposits. Although tilted successions and unconformity-bounded sequences in the Foothills reflect tectonic activity, climate-controlled architecture may be prominent over most of the foreland basin, especially where long-term subsidence rates are modest ( $\approx 0.3$  mm/year) towards the cratonic margin.

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### Stratigraphic revision of the Codroy and Barachois groups (Carboniferous) of western Newfoundland

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New palynological data suggest that stratigraphic revision is required for some Carboniferous rock units of the Codroy, Bay St. George and Deer Lake basins. In the Deer Lake Basin, only the youngest Codroy Group is present, comprising redbeds of the North Brook Formation with no indications of marine influence. The Codroy Group in the Bay St. George Basin is comparable to the intermittently marine Windsor Group of Nova Scotia. Youngest Codroy Group strata represented by the fossiliferous marine Crabbes/Jeffreys limestone and associated beds, were deposited very near the Viséan–Namurian boundary, as were youngest Windsor Group marine strata in Nova Scotia. The uppermost part of the Codroy Group in its type area in the Codroy Basin contains a significant volume of grey fossiliferous mudrocks suggesting that marine conditions persisted longer in that area than in the Bay St. George and Deer Lake basins.

The Overfall Brook Member in the Codroy Basin (and its correlative, the Brow Pond Lentil in Bay St. George Basin), previously assigned to the Robinsons River Formation of the Codroy Group, contains palynomorph assemblages of early Namurian (Arnsbergian) age and is here considered a basal member of the Searston Formation. These rock units are respectively unconformable on Late Viséan strata of the Mollichignick Member of the Robinsons River Formation (Codroy Group), or on pre-Carboniferous rocks. The Searston Formation in the Codroy Basin is entirely early Namurian (Arnsbergian) in age. All strata of the “undivided Barachois Group” of the Bay St. George Basin are also Arnsbergian in age, including coal measures in the upper parts of that succession. Thus these coal measures pre-date the mid-Namurian floral crisis and are not correlative with Bolsovian (Westphalian C) coals in the Stephenville area which we suggest should be excluded from the Barachois Group. These Arnsbergian coal measures prob-

ably correlate with coal-bearing strata of the Howley Formation in the Deer Lake Basin. In the latter basin, the early Namurian (Pendleian) Rocky Brook Formation separates youngest Codroy Group North Brook Formation rocks from the Humber Falls Formation which we consider a Searston Formation equivalent. The base of the Humber Falls Formation in the Deer Lake Basin is locally identified as an unconformity. We suggest that this unconformity becomes increasingly significant towards the south in the Codroy Basin where no Rocky Brook Formation equivalent strata are preserved.

Regional correlation of the Codroy Group with the Windsor Group is supported by palynological data. The Rocky Brook Formation correlates with the Hastings Formation of Nova Scotia. The Humber Falls and Howley formations of the Deer Lake basin succession, and the revised Barachois Group in the Bay St. George and Codroy basins are Arnsbergian in age and correlate with the Pomquet Formation (Mabou Group) of Nova Scotia. With the single exception of Bolsovian coal measures in the Stephenville area, all Carboniferous strata so far documented in western Newfoundland predate the mid-Namurian floral crisis and are of Mississippian age.

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### Analysis of hierarchical unsupervised clustering of IKONOS data for Pointe de l'Est, Îles de la Madeleine, Quebec

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Pointe de l'Est is a depositional spit with an area of 25 km<sup>2</sup> located at the northeast end of the Îles de la Madeleine archipelago in the southern Gulf of St. Lawrence. The landscape is a complex mosaic consisting of active and stabilized sand dunes, mature forest, coastal marshes, and beaches. It contains important natural habitats that are protected as wildlife refugia at the federal and provincial levels. The transitional nature between elements of the landscape mosaic, and the heterogeneity of the surface cover, makes it very difficult to develop a supervised classification scheme suitable for application to remote sensing data, particularly in relation to the image pixel size being used (IKONOS multispectral data, 4m pixels). Therefore, the choice was made to employ the K-means unsupervised clustering technique for classification.

A key choice that is required when conducting unsupervised clustering is to specify the number of clusters. Often in remote sensing studies this choice is made based on a qualitative assessment of the landscape, rather than being based on a quantitative estimate of the most appropriate number of clusters. The first question addressed in this study is: what number of clusters maximizes the separation of clusters of multispectral image pixels? By analyzing the results of successive images with increasing number of clusters the Davies-Bouldin cluster separation index, modified to weight clusters by size, is used to answer this question for the IKONOS image of Pointe de

l'Est. Results indicate that, for this image, about 15 clusters should be specified and labelled subsequently based on field investigations.

A second question addressed is: as the number of clusters in successive images increases, how are the pixels re-grouped? The null hypothesis is that clusters break down with complete hierarchical integrity, i.e., pixels in one cluster at a more detailed level of the hierarchy were all grouped in the same cluster at a given less detailed (higher) level of the hierarchy rather than being drawn from multiple parent clusters. The alternative hypothesis is that there is a re-organization of the pixels, where cluster structure at the more detailed level is poorly related to cluster structure at the less detailed level. These results qualitatively suggest rejecting the alternative hypothesis because there is a strong hierarchical tendency. Pixels that comprise more detailed clusters tend to be derived (greater than 80%, approximately) from a single dominant parent cluster.

These investigations will help to produce a better classified image of Pointe de l'Est than would be possible using supervised classification. Greater understanding of the landscape's hierarchical structure and more confident labelling of pixels will be achieved using these techniques prior to conducting field assessment work.

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#### Andalusite in the South Mountain Batholith contact aureole, Halifax NS: a tale of two isograds

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The contact aureole of the South Mountain Batholith cuts obliquely across the Halifax Formation in the area of the Halifax peninsula. Isograds have been mapped based on outcrops on the Dalhousie University Campus, railroad cuts, Point Pleasant Park and scattered outcrops and construction sites throughout the peninsula. Within the study area two lithological units are recognized based on contrasts in lithology, bulk composition and contact metamorphic mineral assemblages. The Cunard Member is an aluminous, graphitic black slate with sparse metasiltstone layers and characteristic rusty weathering, which extends from the southeast side of the Dalhousie Campus north to the Fairview area. The "Bluestone" member (informal name), which stratigraphically overlies the Cunard Member, is a blue-grey slate with abundant metasiltstone layers and local calcareous concretions. It is exposed from the vicinity of Oakland Road to Point Pleasant Park, and underlies the Williams Lake area on the west side of the Northwest Arm. Prior to the intrusion of the South Mountain Batholith the Halifax Formation was deformed into NE-SW trending upright folding with associated slaty cleavage and a chlorite zone regional metamorphic assemblage. Contact metamorphism overprinted the chlorite zone assemblage and progressively annealed the slaty cleavage proximal to the contact. The outer

limit of the aureole, about two kilometers from the contact, is marked by sparse cordierite "spots" in both the Cunard and "Bluestone" members. The biotite isograd, which is continuous between the Cunard and "Bluestone" members is marked by nucleation of biotite within the muscovite/chlorite stacks inherited from the regional metamorphism. Between the biotite-in isograd and the granite contact, the modal abundances of both cordierite and biotite increase in both units. In contrast, there is a striking difference in the texture and first occurrence of andalusite between the Cunard and "Bluestone" members. In the Cunard member idioblastic chiasolite appears after cordierite, but before biotite. Its early appearance is attributed to the reaction  $\text{Prg} + \text{Qtz} \rightarrow \text{And} + \text{Ab} + \text{H}_2\text{O}$ . Crystal size and modal abundance increases towards the contact. In the less aluminous "Bluestone" member andalusite first appears as ovoid xenoblastic aggregates within 300 metres of the contact, probably as a result of the reaction  $\text{Mus} + \text{Cor} \rightarrow \text{And} + \text{Bio} + \text{Qtz} + \text{H}_2\text{O}$ . Adjacent to the contact the assemblage  $\text{And} + \text{Crd} + \text{Kfd} + \text{Bt} + \text{Qz} \pm \text{Sil}$  (fibrolite) is present in both the Cunard and "Bluestone" members. In both units, Ilmenite (after rutile) first appears close to the biotite-in isograd, and pyrrhotite is the dominant sulphide phase throughout the aureole. The contact mineral assemblages are locally overprinted by retrograde chlorite-bearing assemblages and brittle-ductile structures. Probably related to post-intrusion flexural-slip folding.

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#### Kemptonville Shear Zone; regional shearing, mineralization and granite emplacement?

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The Kemptonville Shear Zone (KSZ) is a regional-scale structure developed within the metasandstone dominated Goldenville Formation. This shear zone is several hundred metres wide, has a defined strike length of 10 kilometres and an inferred strike length of 25 kilometres; extrapolation of the eastern half of the KSZ is assisted by aeromagnetic data. In the field the KSZ is characterized by a shallow, northwest-dipping, foliation. This foliation is characterized by significant and variable shear, a lack of evidence of pressure solution, and is interpreted as an extensional shear band-like fabric that deforms an associated steep, northwest-dipping, mylonitic fabric. Shear band geometry indicates north-side-up, dip-slip displacement along the KSZ.

Several mineral occurrences occur within the KSZ, including the Kempton Back Lake gold district. Variably deformed quartz veining and local intense sericitic alteration with associated sulphide mineralization demonstrate significant hydrothermal fluid flow during shear zone development.

The KSZ parallels the linear northeast-trending contact of the South Mountain Batholith (SMB). Evidence of shearing

and the linear distribution of intrusions along this contact suggest syn-to post-intrusive faulting (referred to as the East Kemptville shear zone). The region between the KSZ and the SMB is characterized by anomalous granophile mineralization, often occurring within locally defined shear zones, elevated radiometric values and low gravity data, all of which are consistent with the presence of an intrusion at shallow depths. That the KZS defines the north boundary of this region leads to the interpretation that at depth it represents the granite-metasediment boundary. A syn-intrusive age for shearing, similar to along the East Kemptville shear zone and other mineralized shear zones, would explain the variably deformed veins and alteration.

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### Landslides and avalanches in Cape Breton Island, Nova Scotia, Canada

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Landslides and avalanches are common occurrences in Cape Breton Island, particularly within the highly-incised river valleys common to highland regions. Both have resulted in significant environmental impact and injury or loss of life. Failure is most common on steep slopes (> 30°) where either highly compacted, impermeable clay-rich lodgement till or impermeable weathered bedrock is overlain by highly permeable colluvium. Redirected surface and ground water accumulates at the base of the colluvium producing an effective glide plane for initial translational movement. Complex failures involving rock topple, rotation slip, translational sliding and flow have been recognized throughout the Cape Breton Island; large scale rock slumps (sackung) have also been noted. Avalanches occur in all highland regions but one in particular has been documented in the East Bay Hills. A particularly large avalanche occurred on February 5th, 1856 in which five people were killed and their home was destroyed. This avalanche was preceded by heavy snow and rain which increased snow-water content which led to failure at the base of the snowpack.

Rock slides have caused problems on highways in the Cape Breton Highlands. Geo-technical and construction methods to control rock slides on Cape Breton Highland highways have met with varying degrees of success due to costs and terrain obstacles. A landslide hazard model has been completed for the Cape Breton Highlands National Park. Continued hazard documentation and mapping is required to better delineate vulnerable areas.

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### Earth science at the junior high level: a teacher's perspective

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Teachers have an informed perspective on how to bring earth science into the classroom and to make it a fun learning experience. This perspective must be included in the development of education outreach programs, activities or resources if these products are to be useful to the teaching community. Heather Johnson has taught for several years in the Halifax area and has a particular passion for the earth sciences. After attending an EdGEO workshop in 2000 at Saint Francis Xavier University, Heather volunteered to sit on the Nova Scotia EdGEO Workshop Committee. Since then, she has helped to develop workshop sessions and related resources and to participate in these annual workshops offered throughout the province. Attendees of this presentation will learn about resources available to teachers as well as the kinds of resource materials teachers wish they had. Depending on time available, a shortened or full-length version of the Carousel activity will be included. This activity is a great way for students, teachers and or workshop participants to brainstorm about geoscience. It's a great way to introduce earth science into the classroom and it can help focus a class or group before any unit of study. Audience participation will be encouraged.

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### Impact of magmatism on the petroleum system of the Sverdrup Basin, Canadian Arctic Islands, Nunavut; a numerical modeling experiment

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This study uses numerical modeling to investigate for the first time the interactions between a petroleum system and sill intrusion in the northeastern Sverdrup Basin, Canadian Arctic. Although exploration was successful in the western Sverdrup Basin, the results in the northeastern part of the basin were disappointing, despite the presence of suitable Mesozoic source rocks, migration paths and structural/stratigraphic traps, many involving evaporites. These results were explained by invoking (1) the development of structural traps during inversion of the basin in the Eocene followed the main phase of petroleum generation and migration, and (2) the proximity of evaporite diapirs that locally modified the geothermal gradient and led to overmature hydrocarbons. This project investigates the local thermal effects (positive and negative) of Cretaceous sills and

extrusive volcanism to determine their potential impact on the petroleum system.

The 1-D numerical model explores the effects of rifting and magmatic events on the thermal history of the L-24 Depot Point well near Eureka Sound on eastern Axel Heiberg Island. The thermal history is deduced from vitrinite reflectance data, fission track data, and the regional geology and when modeled, identifies when petroleum generation is possible. The subsequent introduction of units representing sills or erupted lava flows illustrates the temporal and spatial links between petroleum production and igneous activity. A comparison between classic hydrocarbon systems and magmatic systems is essential in interpreting the L-24 Depot Point model results. Modeling also makes it possible to investigate the causes of petroleum system degradation and estimate their relevance. The results are completely compatible with previous apatite fission track inverse modeling for the immediate region.

PetroMod® 1-D was the software program chosen for model construction and simulation. This program allows the user to display the results of the modeling using a range of graphical solutions that include diagrams, graphs, and overlays. In addition, a critical examination of the model results allows the user to identify knowledge gaps. This iterative process eventually leads to more robust numerical solutions and a higher quality of model results that form a basis for groundtruthing and future work.

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### Carboniferous plays in the eastern Gaspé and Chaleur Bay areas: a synopsis

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As of January 2006, the only productive oil well in the areas of eastern Quebec and northern New Brunswick is hosted by Alleghanian breccia of the Troisième-Lac Fault in eastern Gaspé (the Galt #3 Well). Age relationships for this fault is based on the 5 km lateral displacement of a Mississippian diabase dyke. Although productivity is quite low in this well, it has been instrumental in starting an unprecedented boom in petroleum exploration in the area by underlining its petroleum potential. In response to this, extensive vibroseis land surveys were effected in different sectors of the Gaspé Peninsula by JUNEX Inc. and Petrolia Inc. during the summer and autumn of 2005, largely targeted at Carboniferous plays. A synopsis of Carboniferous plays in the eastern Gaspé and Chaleur Bay areas is presented here based on recent research on its Carboniferous tectonostratigraphy and adapted to recent data presented by JUNEX. The main source rocks are shales of the Middle Ordovician Mictaw Group in the Chaleur Bay area, and shales of the Lower Ordovician Rivière-Ouelle Formation and Lower Devonian Indian Cove Formation in eastern Gaspé. The potential for large reservoirs is mainly in the southern Gaspé Peninsula, where source rocks are ex-

tensive and of high quality. This area is also characterized by large stromatoporoid-tabulate reefs of the Silurian West Point Formation and continental clastics of the Upper Devonian Saint-Jules Formation as potential reservoir rocks. The latter unit is fault-bound and postulated to be overlain by evaporites in the Chaleur Bay subsurface. Moreover, recent seismic data reveal that post-Acadian faults in southern Gaspé have a reverse fault geometry, opening the possibility for structural seals as well. Syn-depositional thrusting of potential reservoir rocks is inferred for the Upper Devonian Saint-Jules Formation of southern Gaspé and for the early Pennsylvanian Bathurst Formation of northern New Brunswick. In the Percé area and throughout the southern Gaspé area, large brittle Alleghanian fault corridors provide similar plays as the Troisième-Lac Fault. Finally, south of Percé, the possibility for a large lens of coarse clastics capped by evaporites at the base of a ≈900 m thick Carboniferous succession is inferred from seismic data paired with sedimentologic extrapolation from outcrop analyses.

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### Lithofacies and spectral gamma-ray analysis of a potential outcrop analogue for a secondary reservoir in the McCully Gas Field, Sussex, NB

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The McCully Gas Field, near Sussex, New Brunswick, comprises a succession of gas-filled sandstone units interbedded with organic shale that are collectively included within the Hiram Brook Member of the Albert Formation (Horton Group, Tournaisian). The sandstone has been interpreted as the deposits of lacustrine deltas, shorelines and fluvial systems, based on limited core extracted from the reservoir interval in the gas field, and on broad interpretations of Hiram Brook Member outcrop in the region. The purpose of our ongoing research is to provide a more detailed lithofacies and sequence stratigraphic interpretation of outcrops and to better correlate these outcrops with producing horizons in the subsurface.

The main producing horizon in the McCully field is the 'A-sand', which from total-gamma-ray wireline logs is interpreted to be a sharply based, fining-upward sandstone. An equivalent outcrop analogue has yet to be identified. In contrast, overlying secondary targets include overall sandstone packages that appear to coarsen upward over a scale of several tens of metres. Outcrop of a coarsening-upward succession within a roadcut of Highway #1, between Sussex and Norton, has been identified as potentially correlative. Detailed sedimentological logging and spectral gamma ray data has been collected over an approximately 40 m thick (vertical) interval of the outcrop succession.

Preliminary interpretations indicate sedimentation in a periodically and progressively shallowing (likely prograding) wave-dominated lake shoreface. A possible root horizon near the top of the succession could indicate a temporary lowering of

lake-level and development of a shallow lagoon or back-swamp whereas an overlying limestone conglomerate is identified as a storm-beach deposit. There is no conclusive evidence of fluvial deposition within the succession. Accompanying spectral gamma-ray data initially appears to indicate that radioactive Uranium and Thorium (from organic detritus in the rock), and Potassium (from K-feldspar and micas in the siliciclastic fraction) all decrease upsection in tandem with an overall increase in grain size from silt to fine sand.

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**The first submarine occurrence of baricite:  
a rare hydrated Fe-Mg phosphate mineral,  
Mackenzie Bay, Beaufort Sea, Canada**

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Baricite is a rare mineral which has so far been reported only in three areas. This paper reports the first offshore occurrence within the clayey sediments in four cores taken from Mackenzie Bay, Beaufort Sea, northern Canada. Baricite is concentrated as tiny flakes, spheres and clusters within black muds at core depth of 1.22 m (water depth 223 m) in Core-2, 1.73 m (water depth 57.5 m) in Core-3, 3.9 m (water depth 193 m) in Core-04-Amundsea-250p and 4.70 m (water depth 246 m) in Core-04-Amundsea-650p. Electron microprobe analysis of 24 baricite grains shows that their average composition is 30.22%  $P_2O_5$ , 29.33%  $FeO_t$  and 9.04%  $MgO$  with minor to trace amounts of Si, Mn, Ca, Al, Na and Sr; the remainder % is water. Compared to the reported baricites from elsewhere which show some compositional differences between each other, the currently studied baricite is considerably richer in iron and poorer in magnesium. This indicates substitution between Fe and Mg to various extents in accord with extensive solid solution possibilities between the members of the vivianite group, to which baricite belongs. The correlation coefficient between Mg and Fe is -0.19, confirming substitution between them, and that between P and (Mg+Fe) is +0.77. The expected provenance source is the type locality of this mineral, which occupies fracture-fillings in a sideritic iron formation in the Rapid Creek area, Richardson Mountains, Yukon Territory. This locality lies 141 km inland in the direction of the two cores which are  $\approx$ 362 km (Core-3) and  $\approx$ 491 km (Core-2) offshore, respectively. Baricite-bearing iron ore was probably eroded and transported by rivers such as the Big Fish River, Blow River and/or other rivers which were feeding the Mackenzie Delta, to be dispersed in suspension in the Beaufort Sea and was deposited at limited depth interval within the Mackenzie Bay. The other possible source indicated by the presence of spherulitic clusters of baricites, is *in situ* growth within muds at the sea bed. The grains were deposited some 1713 years (Core-3) and 2974 years (Core-2) ago which are the  $^{14}C$  ages for the baricite-bearing sediments. Baricite is concen-

trated within a very narrow interval of about 1 cm in three of the four offshore cores, which are hundreds of kilometers apart, and may provide an important stratigraphic marker as a "blue zone" for recent sediments in the Beaufort Sea area.

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**A geological map of the Jurassic North Mountain Basalt,  
southern Nova Scotia: a 200 km transect  
from Cape Split to Brier Island**

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The first regional map showing the distribution of the three flow units comprising the Jurassic North Mountain Basalt from Cape Split southwestward to Brier Island is presented. Along this 200 km traverse the NMB is divided into three continuous volcanological flow units that have a ca. 500 m aggregate thickness and are referred to as the lower- (LFU), middle- (MFU) and upper- (UFU) units. Exceptional volcanological features of the units are displayed along continuous cliff faces bordering the Bay of Fundy and in numerous quarries. The LFU ( $\leq$ 180 m) is a massive, medium-grained, dominantly holocrystalline basalt with well-developed polygonal jointing (i.e., columnar joints  $\leq$ 2 m) of colonnade and complex entablature patterns. Several features distinguish the upper part of the flow: (1) the upper 5–10 m is finer grained and rarely red-brown; (2) the upper 5–10 m may be amygdaloidal; and (3) layered pegmatites locally occur in the upper 30–40 m. These sheet-like layers ( $\leq$ 2–5 cm to  $\leq$ 1–3 m) are comb-textured and pyroxene-rich with a granophyric matrix and concordant or discordant rhyolite or granophyre seams ( $\leq$ 3 cm) occur. The presence of circular structures, now water-filled in some cases, along the central and western parts of the map area may reflect outpouring of the LFU over water-rich surfaces resulting in formation of rootless cones. The MFU ( $\leq$ 165 m) contains multiple ( $\leq$ 15–20), thin ( $\leq$ 15–20 m), geometrically-complex flow sheets with abundant, zonally-arranged vesicles, now zeolite occluded (i.e., amygdules). Abundant field evidence (e.g. flow lobes, stacked lobes, vesicle zonation, tumulis) indicate the MFU consists of inflated pahoehoe flow sheets that formed over days to a few months, but red-brown oxidized tops and "neptunian" dykes in the upper half of flows indicate a time hiatus between flows. The UFU ( $\leq$ 150 m) contains  $\leq$ 30–40% mesostasis in a medium-grained, ophitic-textured host. This unit consists of 1 or 2 flow sheets and also has colonnade style, polygonal jointing ( $\leq$ 1 m). The lower 10–20 m of the UFU locally contains felsic material (ca. 65–74 wt. %  $SiO_2$ ) in the form of dykes, amoeboid masses and spectacular segregation pipes (3–60 cm;  $\leq$ 10–15/m<sup>2</sup>) that are sometimes cored by agate and crystalline silica. The distribution on the flow units shows several notable features: (1) the surface exposure of the LFU broads to three times its width in the western part of the map to 3 km; (2) coincident with the latter is a change in thickness (20–35 m to 165 m), number of flow sheets (4–6 to 15–20) and



surface outcrop area of the MFU from west to east; (3) gradual progression of outcrop exposure of the UFU towards the Bay of Fundy from west to east; (4) consistent dextral offsets of the flow units along prominent N-S faults. These features are considered to reflect a change in the structural evolution of the Fundy Basin, with maximum subsidence occurring in the central and eastern part during deposition of the MFU. Finally, the new map can be used for assessing the resource potential of the NMB. The LFU and UFU are preferred for high-quality aggregate, whereas the zeolites are constrained to the MFU and are most abundant in the central and eastern parts where the flow unit is thickest with the most individual flow sheets.

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**Mineralization at Brookfield barite deposit:  
structurally controlled mineralization formed  
from 250°C, COHN basinal brines in the  
Carboniferous Maritimes Basin**

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Barite mineralization at Brookfield occurs in highly-deformed, dominantly terrestrial clastic sedimentary rocks forming part of the Carboniferous Maritimes Basin. This mineralization has been considered as part of the Carboniferous MVT metallogenic domain (Zn-Pb-Ba-F) of Nova Scotia (e.g., Walton barite; Jubilee and Gays River Zn-Pb deposits), but is anomalous in that the mineralization is within terrestrial rather than marine sedimentary rocks. The Horton Group sedimentary strata distal to mineralization are greyish sandstones (Horton Bluff Formation), whereas proximal mineralization they change to red-brown siltstones (Cheverie Formation). The mineralization, filling a ca. 25 m wide fault zone, occurs as coarse, white, crystalline barite in steeply-dipping, fault breccia veins cutting a thrust-thickened package of sedimentary rocks. Recrystallized, aphanitic barite is cut by undeformed, coarse barite veins and indicates that mineralization occurred in an active fault zone environment. Adjacent the mineralized veins the red-brown host rocks are intensely bleached, as manifested by their olive-green colour, and replacement of muscovite/illite to quartz+kaolinite and destruction of hematite, both confirmed by Rietveld analysis. The veins are dominated by barite, but siderite (10–20%) generally occurs at vein-wallrock contact and trace quartz-calcite (trace) occlude open space.

Fluid inclusion studies of the veins indicate that saline brines (20–30 wt. % equiv. NaCl+CaCl<sub>2</sub>) coexisted with an immiscible N<sub>2</sub>-CO<sub>2</sub>-CH<sub>4</sub> gas. Laser Raman analysis and thermometric measurements of the most common gas-rich inclusions indicates a uniform fluid chemistry of X(N<sub>2</sub>) = 0.66, X(CO<sub>2</sub>) = 0.34. Homogenization temperatures for primary, L-V and L-V-Halite inclusions in quartz intergrown with barite provide minimum trapping conditions of 210°C. Conditions at the time of entrap-

ment, based on intersection of aqueous and gaseous isochores, are estimated at ca. 750 bars and 250°C.

Stable isotopic data for vein minerals (barite, siderite, quartz) are uniform and indicate  $\delta^{18}\text{O}_{\text{fluid}} \approx +12\text{‰}$  at 250°C for siderites and +9.8‰ for quartz; and  $\delta^{13}\text{C}_{\text{fluid}} = -4$  to  $-6\text{‰}$  from siderites and  $\delta^{34}\text{S}_{\text{fluid}} = +12\text{‰}$  from barite; fluid inclusion extracts indicate D values of  $-47$  to  $-71\text{‰}$ . Collectively, these fluid compositions are consistent with a basinal-type fluid derived from modified meteoric water with sulfur derived from Carboniferous evaporites and carbon of mainly marine limestone origin (i.e., Carboniferous Windsor Group) with a minor biogenic component from the Horton Group.

Mineralization at Brookfield resulted from fluid focusing of over-pressured fluids of modified basinal origin into an active fault zone environment. The association of the barite mineralization with intensely altered wall rocks represents a rare example of such alteration in this metallogenic domain. However, similar alteration associated with Ba-Fe-Mn mineralization along the Cobiquid-Chedabucto Fault Zone does raise the possibility that the Brookfield deposit may, instead, be part of another mineralizing environment and is not, *sensu stricto*, part of the 300 Ma MVT Zn-Pb-Ba metallogenic event.

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**The relationship between mafic intrusive units  
and the Devil Pike Brook orogenic lode gold  
deposit, south-central New Brunswick**

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The Devil Pike Brook gold-bearing quartz-carbonate vein system is located in a deformed band of mafic volcanic rocks of the Grant Brook Formation (Mascarene Group) in south-central New Brunswick. The locally high grade (>200 ppm), structurally controlled veins are generally north-trending, consistent with the localized intense foliation, but oblique to the regional NE structural trend. The occurrence is located approximately 500 m south of the regional northeast-trending Taylor Brook Fault Zone that separates the Early Silurian Mascarene Group to the south and the Late Cambrian to Early Ordovician Annidale Group to the north. It is believed that this major terrane boundary, probably related to back-arc basin closure and reactivated during later tectonic events, is a strong controlling factor in the formation of the deposit, which is typical of structurally controlled orogenic deposits. Also consistent with other structurally-controlled lode gold deposits, mafic intrusive units and notably an alkali feldspar-phyric gabbro are present in the vicinity of this gold deposit and throughout the Mascarene Belt. These units are unrelated to the vein-hosting mafic volcanic rocks and, although it is unlikely that they

represent a precious metal source, they are responsible for generating a thermal anomaly possibly concurrent with gold deposit formation.

Geochemical analyses (XRF, INAA, and ICP-MS) appear to support a singular mantle-derived within-plate tholeiitic basaltic magmatic source for all intrusive units in the Mascarene Belt, though individual units were tapped at various evolutionary stages. Also, the crystallization sequence appears to have been completed without mineral segregation during cooling: there does not appear to be any plagioclase fractionation, suggesting lower to mid-crustal emplacement levels. These two aspects suggest that the intruding system resembles a large, deep-seated parent with lower to upper crustal dyke emplacement. The importance of these intrusive units lies in that they may have played a role in heat advection that may have been significant in the formation of the gold deposit, irregardless of the source of hydrothermal fluids. If gold-bearing hydrothermal fluids were generated by metamorphic devolatilization reactions, deep mafic intrusions (similar to the nearby Stewarton Complex) may have played an important part in accelerating dehydration-decarbonation reactions. Conversely, if gold-bearing hydrothermal fluids were derived from infiltrated meteoric water, high-level bodies may have aided the circulation by creating more prominent buoyancy contrasts through fluid temperature increase. These two non-exclusive fluid source end-members may contribute to a mixed hydrothermal fluid source from which lode gold deposits may form.

Thermal modeling using HEAT 3D (Kware, programmed by K. Wohletz) has shown that duration of thermal influence on surrounding lithologies is approximately 1–2 Ma for high level intrusive units, possibly as much as 3–4 Ma for larger deep intrusions. Although the aforementioned effects occur unequivocally, it is difficult to appropriately assume that thermal anomalies can be specifically related to a deposit due to radiometric dating technique constraints. Synchronous lode gold deposit formation and mafic intrusion emplacement within the 4 Ma period of the thermal anomaly may be sufficient to suspect the causality of heat advection in the formation of a lode gold deposit.

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### Upper Cretaceous-Cenozoic salt movement in the Abenaki Subbasin, offshore Nova Scotia

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Three large salt diapirs occur in the western part of the Abenaki Subbasin within the Scotian Basin, offshore Nova Scotia. These diapirs were active in three phases, as indicated by subsidence of the Mesozoic and Cenozoic basin fill and growth on syndepositional faults. The first phase of activity began soon after the deposition of salt in the Late Triassic and continued through the Jurassic and earliest Cretaceous. This phase was

one of rapid diapiric growth, accommodating a thick infill of sediments in adjacent withdrawal “minibasins”. The second phase of activity began in the Early Cretaceous (Hauterivian), approximately coeval with the deposition of the O-Marker. During this time only a modest amount of salt movement and associated sediment growth occurred. Salt movement accelerated in the Late Cretaceous (Campanian-Maastrichtian), resulting in the formation of a salt withdrawal syncline that was subsequently infilled with younger Cenozoic sediments. The renewed movement was approximately coeval with deposition of Upper Cretaceous and Paleogene prograding sediments of the lower Banquereau Formation. Diapiric activity probably began to slow down again in post-Eocene time and by the Oligocene or Miocene had stopped completely. The cause of this third phase of reactivated movement is the main focus of this study.

There are a number of possible mechanisms for the third phase of reactivated salt movement. Because of its coeval timing and location, sediment loading by the prograding Banquereau Formation is a plausible mechanism for reactivation; however, theoretical understanding of salt diapirism clearly indicates a simple horizontal salt layer system would be too stable for renewed motion to be expected under the observed conditions. It is therefore likely that additional factors such as the weakness of pre-existing diapirs, tilting, or overpressures made the system more sensitive and allowed the system to move, even if Banquereau progradation was the main cause of renewed salt movement.

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### Climate reconstructions from five conifer species in southwestern Nova Scotia

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The growth patterns of five species of conifers (white pine (*Pinus strobus*), red spruce (*Picea rubens*), larch (*Larix laricina*), eastern hemlock (*Tsuga canadensis*), and balsam fir (*Abies balsamea*) from southwestern Nova Scotia were collected in the summer of 2005. Red spruce illustrated a median position between two groups with more distinct, closely related growth patterns. Eastern hemlock and balsam fir formed one group limited by precipitation, while white pine and larch form another group limited by temperature parameters.

Because the two groups fall into two distinct climate-forcing categories, two separate models of paleoclimate were constructed. Classic single-species reconstructions were first attempted, and then multiple species reconstructions were created to improve upon the initial models. These results highlight the need to find different methods of extending base chronologies, as in both cases, the reconstructions are relatively short lived.

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### Hydrothermal dolomites in Paleozoic rocks of eastern Canada: a story from identification to recent hydrocarbon production record

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In North America, world-class conventional hydrocarbon discoveries in the last decade were made in hydrothermal dolomites of Ordovician (Trenton-Black River play in the Appalachian basin in eastern USA), Devonian (Ladyfern and Tay River discoveries in the Western Canadian sedimentary basin) and, speculatively to Mesozoic (Deep Panuke in the Atlantic margin of Nova Scotia) age rock units.

Controversies exist on the exact definition and criteria for recognition of hydrothermally altered carbonates in the rock record. By definition, a hydrothermal fluid has temperatures over that of the ambient burial fluid. A difference of at least 15°C is required to designate such fluid as hydrothermal. Therefore, it is important to note that even if late burial allows the rock unit to be exposed to temperatures higher than those recorded by an early hydrothermal event, it is the difference of temperature at that specific event which is critical for the hydrothermal alteration process. Any later high temperature, sedimentary to tectonic burial events will only serve to mask and render difficult the recognition of hydrothermal alteration.

Whatever the age of the host rock, efficient (e.g., porosity/permeability generating) hydrothermal alteration of a carbonate precursor will follow a rather unique suite of tectono-diagenetic events that will be recorded in an almost ubiquitous mineral paragenetic succession. High temperature and saline fluids will move upwards along early extensional to transtensional faults and flow laterally into a porous precursor carbonate host. It can be demonstrated for most hydrothermal reservoirs that alteration occurred within the first 500–1000 m of burial. The initial faulting will enhance permeability through brecciation. However, an economic reservoir can only be formed if fluids are confined to specific intervals and do not breach any upper seal layer that preserve the integrity of the newly formed reservoir. The high temperature fluids will dissolve a significant volume of limestones and with increased carbonate ion saturation, eventually precipitate the peculiar high temperature saddle dolomite cement, the latter also occurring as a matrix-replacive phase. Following porosity generation and saddle dolomite precipitation, some late calcite and sulphate cements are commonly observed in most hydrocarbon fields. Diverse geoscience tools are used for the recognition of hydrothermal alteration: regional tectonic scenario, petrography and geochemistry of the diagenetic phases and the seismic expression of brecciation known as platform sag.

In 1995, the discovery of a hydrothermal dolomite reservoir in Lower Ordovician rocks in the Port au Port #1 well was a milestone for hydrocarbon exploration in the Appalachians of

eastern Canada. Since that discovery, hydrothermal dolomites have been documented in Lower and Middle Ordovician, in Lower and Upper Silurian and in Lower Devonian carbonate rock units in eastern Canada. Small hydrothermal dolomite hydrocarbon fields have been put into production (both oil and gas fields in Lower Devonian Upper Gaspé limestones in eastern Gaspé peninsula) and major Canadian exploration companies have started to extensively explore the Paleozoic belts in eastern Canada looking for hydrothermal dolomite reservoirs.

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### Preliminary investigations of Nb in melt-fluid systems using *in situ* X-ray spectroscopy

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Knowledge of Nb partitioning between coexisting aqueous fluid and silicate melt is needed to model the geochemical behaviour of Nb in ore deposits and other crustal rocks. Previous experimental studies have focused mainly on the solubility of Nb in silicate melts. However, Nb mineralization is known to occur in fenites and other metasomatic rocks, and evidence of Nb mobilization by aqueous fluids at submagmatic temperatures is indicated by the presence of Nb-rich minerals in some hydrothermal veins. *In situ* studies, over a range of geologically relevant pressures and temperatures using Synchrotron radiation X-ray fluorescence (SR-XRF) are in progress to investigate the geochemical behaviour of Nb in different melt-fluid systems. Synthetic Nb-bearing granitic glasses and four different fluids having various compositions and densities provide the starting materials used in our preliminary experiments. SR-XRF of samples within a hydrothermal diamond anvil cell (HDAC) permits separate analyses fluids *in situ*, at elevated T and P. Starting experimental fluids include distilled water with 1000 ppm Br, distilled water with no Br, 0.5 M Na<sub>2</sub>CO<sub>3</sub> with 500 ppm Br, and 1 M Na<sub>2</sub>CO<sub>3</sub> with 1000 ppm Br. Br serves as an internal standard for XRF analysis. XRF spectra are quantified using a fundamental parameters program and the known concentration of Br in the fluid to calculate the concentration of Nb via relative peak intensities. The quantification routine incorporates the X-ray path media (diamond, air) and lengths, solvent composition, and incident energy level to determine the concentration of the desired element.

Relatively high density fluids (carbonate and distilled water, ≥0.95 g/cm<sup>3</sup> and ≥0.965 g/cm<sup>3</sup>, respectively) render a single aqueous-siliceous fluid phase. The aqueous-siliceous fluid (±carbonate) contains up to 25 ppm Nb. Carbonate-bearing fluids acquire Nb from coexisting silicate melts at lower pressures (0.85 g/cm<sup>3</sup>). In contrast, Nb is not strongly partitioned from a melt into pure water. The Nb concentration in a single phase fluid incorporating Nb glass in a 1 M carbonate fluid ( $\rho =$

0.95 g/cm<sup>3</sup>) is 25 ppm, corresponding to an initial glass-to-fluid ratio of 0.05 (by mass). Nb concentration in the aqueous fluid decreases with decreasing temperature and pressure, from 19 ppm at 600°C ( $\approx 7$  kbars) to  $\leq 3$  ppm at 400°C ( $\approx 3.5$  kbars)

Carbonatites are the primary ores for Nb. Nb is also concentrated in alkaline igneous rocks and pegmatites. Our initial results show that a carbonate alkaline fluid coexisting with a melt provides an alternate/parallel host or transport medium. Carbonate-charged aqueous fluids may play a significant role in the formation and distribution of some Nb ores.

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### Post-glacial climate change and its effect on the thermal structure and habitat in a shallow dimictic lake, Nova Scotia, Canada

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To provide context for the recent loss of cold-water habitat for Brook Trout (*Salvelinus fontinalis*) in shallow (<6m av. depth), dimictic lakes in Nova Scotia, a high resolution (decadal- centennial scale) and well-dated (7 <sup>14</sup>C dates, <sup>137</sup>Cs, <sup>210</sup>Pb) record of post-glacial climate change has been reconstructed for Canoran Lake, Nova Scotia. Chemostratigraphic (organic carbon, total nitrogen, stable isotopes ( $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ ), Hydrogen Index), biostratigraphic (pollen), and lithostratigraphic (magnetic susceptibility and smear slides) proxies were used to understand how past shifts in climate and basin infilling have affected primary productivity and the thermal regime of Canoran Lake.

Canoran Lake reacted strongly to rapid climate change events associated with late glacial and early Holocene cooling events including the Younger Dryas (13 000 – 11 500 cal yr BP) and the 8.2 kyr event (8200 cal yr BP). During the Younger Dryas cooling, Canoran Lake became a cold monomictic lake with short ice free periods (anomalously high  $\delta^{13}\text{C}$ , low C/N ratios, low %TOC, low %N, low HI), paludified shorelines (wetland pollen,  $\delta^{15}\text{N}$ ,  $\delta^{13}\text{C}$ ), and a destabilized watershed (clastic sedimentation). Rapid climatic cooling that was coincident with the 8.2 kyr event resulted in an increase in clastic input and/or a decrease in primary productivity (decrease in bulk density, %TOC, %N). However, the response of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values to 8.2 kyr event was delayed or buffered by lakeside wetland development. After  $\approx 8000$  cal yrs BP, proxies indicate that the climate was relatively stable, warm, and dry until  $\approx 5900 - 4600$  cal yr BP when a change in precipitation patterns resulted in wetland formation. Climate change apparent in historical records (1800 AD – present) did not strongly effect the proxy record of Canoran Lake even though 3 years of water temperature monitoring indicated that modern-day climate variability has a significant effect on the hypolimnic water temperatures and cold-water habitat for brook trout.

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### Marine evidence on the Northeast Newfoundland Shelf of outburst floods from glacial Lake Agassiz and the 8.2 cold event

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Previous studies have suggested a causative link between the rapid drainage of the combined waters of glacial lakes Agassiz and Ojibway impounded south of the Laurentide Ice Sheet in Hudson Bay and abrupt North Atlantic climatic cooling recorded in Greenland, ice beginning about 8.4 and culminating about 8.2 cal BP (ca. 7.7 and 7.5 <sup>14</sup>C BP). Massive Agassiz outburst floods (about 5 Sv), initially discharged subglacially, are thought to have exited Hudson Strait into the Labrador Sea, and to have induced cold atmospheric conditions by curtailing thermohaline circulation (THC) there. A lack of evidence for THC in the Labrador Sea at that time raises questions about the proposed causative link.

Our findings of an Agassiz-age, calcite-rich bed of silt-sized detrital carbonate in two cores from Notre Dame Channel (NDC), a 500 m deep basin on the mid-northeast Newfoundland Shelf (NENS), together with a correlative carbonate bed on the shelf farther south close to Grand Bank, provides evidence of a routing mechanism linking Agassiz outflow and the climatic cooling via transport southward as plumes of low salinity water and suspended carbonate sediment in the outer Labrador Current. Possibly adjacent to, or south of Grand Bank, low-salinity waters may have dispersed into, and been transported by northward-flowing currents to areas of THC in the Norwegian-Greenland seas.

A 60–80 cm thick upper carbonate bed in the NENS shelf basin is tied to an origin in Hudson Bay (underlain by Paleozoic limestones) by its relatively high calcite content. Within the sediments are benthic foram species normally resident in upper slope habitats. This co-deposition is interpreted to imply that both sediment and forams were forced over a shelf-edge 330 m deep sill into the shelf basin during enhanced (Agassiz flood-driven) transport and swelling of the outer Labrador Current. Radiocarbon dates on planktic foraminifers (*N. pachyderma* s.) at the base and top of this bed are statistically identical, with a pooled age of  $7710 \pm 120$  <sup>14</sup>C BP, indicating rapid deposition. These ages are also identical to those of a redbed flood marker in Hudson Strait and the marine transgression in Hudson Bay, both closely-related to the age of the Agassiz outburst flood. This correlation is obtained by applying reservoir age corrections typical of Hudson Bay and Strait, consistent with the entrainment and advection of carbonate sediment and Hudson Bay waters by subglacial lake outburst floods, in Labrador Current surface plumes.

An underlying thinner bed (20–25 cm) of calcite-rich detrital carbonate in the NENS shelf basin, dating slightly less than  $8980 \pm 35$   $^{14}\text{C}$  BP, is interpreted to originate with subglacial release into the Labrador Current of impounded and runoff melt water during retreat of the Noble Inlet ice advance across Hudson Strait. Re-evaluation of previously published results from cores collected on the Labrador Shelf corroborates the foregoing interpretations.

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**Distribution of arsenic and mercury in marine sediments impacted by gold mine tailings, Wine Harbour, Nova Scotia**

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This study focuses on the environmental impacts of historical gold mining and milling practices in the Wine Harbour gold district, Guysborough County, Nova Scotia. Gold mining was intermittent at Wine Harbour between 1862 and 1939, producing a total of 42,726 oz. of Au from 72,413 tonnes of crushed rock. The gold occurs in a series of quartz veins, typically associated with arsenopyrite, that are hosted by the Goldenville Formation of the Meguma Group. Stamp milling and mercury amalgamation were the primary gold extraction methods. Wilfley tables and a cyanide plant were also employed to recover additional gold from arsenopyrite concentrates and stamp mill tailings. The tailings were slurried directly into surrounding streams and low-lying areas around the shores of Wine Harbour. The main objectives of this study are: (1) to evaluate the spatial extent of gold mine tailings in both the terrestrial and marine environments; (2) to determine the concentrations and speciation of As, Hg, and other elements in mine wastes, sediments, and waters; and (3) to provide geoscience data that can be used to assess potential risks to ecosystem and human health.

In July 2005, mine tailings, waters and marine sediment samples were collected throughout the Wine Harbour gold district. Marine sediments were collected using both a grab sampler ( $n = 21$ ) and a gravity corer ( $n = 6$ ). Chemical analyses of 10 tailings samples collected on-land show very high concentrations of both As (200 to >10 000 ppm; mean 5800 ppm) and Hg (4900 to >100 000 ppb; mean 19 000 ppb). Electron microprobe analyses indicate that arsenopyrite is the main host for As in the tailings, and also confirm the presence of elemental Hg in one sample collected from a stamp mill. The distribution of As and Hg in marine sediments confirms that most areas of Wine Harbour have been impacted by historical gold milling activities. Chemical analyses of 233 marine sediment subsamples show a wide range in both As (4 to 1500 ppm; mean 75 ppm) and Hg (5 to 9500 ppb; mean 850 ppb) concentrations. In general, the highest As and Hg values are located

close to known stamp mill structures along the shores of Wine Harbour. However, high levels of both As and Hg also occur in the bottom sediments of a small inlet on the western end of the harbour, within the bounds of an active mussel aquaculture operation. Contamination of this latter site is likely related to a mill site(s) that is not shown on the historical maps for this gold district.

This investigation is part of an ongoing project involving both Federal and Provincial government departments, which is assessing the marine environmental impacts of historical gold mining activities throughout Nova Scotia. Results from this study will aid in determining the precautionary measures necessary for minimizing risks associated with elevated levels of As and Hg in the Wine Harbour area.

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**Stratigraphy, depositional setting and volcanism of the Letete Formation, southwestern New Brunswick**

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The Late Silurian Letete Formation, located on the Mascarene Peninsula of Passamaquoddy Bay, is part of the northeast-trending Mascarene subbelt which makes up the southwest part of the Late Ordovician to Late Silurian Mascarene Group. It is bounded to the north by the St. George Fault, which separates it from the shallowly southeast dipping rocks of the Late Silurian Eastport Formation, and to the south by the Back Bay Fault, separating it from the composite Proterozoic New River belt. The Letete Formation is thought to have been deposited in an extensional back-arc setting, but its relationship to adjacent units, in particular the Eastport Formation, is unknown.

During June to August 2005 we conducted detailed mapping of the felsic tuffs and volcanic and sedimentary members of the Letete Formation, located in the upper to middle part of the Letete. The objective of the field work was to describe the stratigraphy of the Letete Formation in order to determine its depositional environment, paleotectonic setting, relationship to the Eastport Formation, and mineral potential. A  $\approx 4$  km long section of coastline on the southwest coast of the Mascarene Peninsula, from McNichols Cove to Fraser Beach, was mapped on a bed by bed basis. This section includes the lower part of the Late Silurian Eastport Formation to the north, a previously undivided zone of tuffs and intrusions, and the Early Silurian Letete Formation.

Within the Letete we described a  $\approx 900$  m thick section of mafic flows, mafic and felsic tuffs and sedimentary rocks. The upward-facing direction is to the northwest. This section is characterized by dominantly mafic volcanism, but the abundance of felsic volcanism increases upward in the section. The section records an upward-shoaling sequence with at least three phases of subaqueous to subaerial deposition. Shallow level synvolcanic and deeper level coarse-grained mafic sills

intrude the Letete. The coarse-grained sills are associated with disseminated sulphide (Py +Cpy) occurrences.

The mapped part of the Eastport Formation comprises red quartz wackes and felsic and mafic tuffs. The upper part of the Letete and the Lower part of the Eastport are separated by a 200 m thick rhyolite intrusion through which the previously mapped St. George Fault was placed. The lower part of the Eastport Formation is dissected by abundant northeast-trending faults and mafic sills, and only fault slivers of tuffs and red sandstones are present. Similarly, the Letete is characterized by increasing deformation of black siltstones and mafic tuffs and increasing mafic intrusions approaching the rhyolite intrusion. The Eastport Formation contains subaerial to littoral depositional facies, and the Letete Formation is an upward shoaling sequence. Despite the complexities caused by the St. George Fault, the interpretation that the Eastport overlies the Letete is consistent with stratigraphic relationships and isotopic ages.

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### Geology, mineralogy and alteration of Chehelkureh polymetallic ore deposit, southeast Iran

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Chehelkureh is an ancient copper mine in the Kuh-e-Lunka area, located 120 km NW of Zahedan (SE of Iran) at longitude 060° , 07.480' N and latitude of 30° , 14.155' E. The Kuh-e-Lunka area is in the eastern part of Dasht-e-Lut, which is located near the border with Pakistan and Afghanistan. The area is underlain by a sequence of Eocene intercalated greywackes, siltstones, and shales that host the ore deposit, and is bordered to the west by ophiolitic mélangé and to the east by Middle Eocene limestones. Several dykes and small stocks of a monzodiorite intruded the sedimentary sequence; they are oriented parallel to the major NW–SE fault set.

The Chehelkureh ore field is complex with numerous lenses and veins, with an irregular outline. The ore field has an overall strike of N23°W and is displaced by faults striking roughly E–W. The proven strike length of the mineralization at 1500m above sea level is 1350m. The mineralization occurs along the major N–S striking faults. The fault-fill mineralization includes quartz, dolomite, ankerite, siderite, calcite, molybdenite, pyrrhotite, arsenopyrite, pyrite, chalcopyrite, sphalerite, galena, Se-rich galena, bornite, marcasite, ilmenite, and rutile. In spite of high contents of base metals (4.1% Cu+Zn+Pb) and silver (22 ppm) in the ores, they are poor in Au (average 0.14 ppm in 45 samples). The oxidized upper part of the ore includes: limonite, goethite, malachite, azurite, smithsonite, native copper, cerrusite, plombojarosite, chrysochola, and anglesite.

The major portion of the secondary copper leached from oxidized chalcopyrite should be precipitated at or below the ground water table at Chehelkureh as covellite or chalcocite, although a secondary supergene sulphide zone enriched in copper is not evident here. There is also a large oxidized to sulphide transition zone at depths between 50–110m. The limited precipitation and the deep-seated groundwater table in the area are two mainly factors, which play important roles in the absence of economic amounts of secondary covellite or chalcocite in Chehelkureh.

Complex primary intergrowth textures, some of which represent exsolution textures, are common in ore minerals and include intergrowths of chalcopyrite in sphalerite, sphalerite in chalcopyrite, chalcopyrite in pyrrhotite, pyrrhotite in sphalerite, bornite in Se-rich galena and chalcopyrite in Se-rich galena. Blebs of chalcopyrite in sphalerite are more or less uniformly distributed through sphalerite in Chehelkureh, giving an emulsion texture. Texturally, the Chehelkureh deposit formed at temperatures greater than 400°C and is a unique type of hydrothermal ore deposit.

The base-metal mineralization is also accompanied by chloritization, carbonatization, silicification, pyritization, sericitization, and alunization of the host sequence within and around the faults. They extend a few metres to tens of metres from the faults, depending on the amounts of mineralization. Chloritization and dolomitization are especially very strong and widespread. There is a general depletion in REE contents associated with different alteration types, such as chloritization, dolomitization, kaolinization, silicification, and minor sericitization. Samples with carbonatization (magnesite and siderite) have been enriched in REE contents. SEM-EDS evidence indicates that enrichment by REE-bearing phosphates occurred with carbonatization.

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### Biostratigraphic constraints on the Cretaceous Strand Fiord Formation flood basalts, central Sverdrup Basin, Canadian Arctic Islands

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The Strand Fiord flood basalt province is the largest of several Cretaceous-aged igneous episodes in the central part of the Sverdrup Basin, Canadian Arctic Islands. Though the unit has been recognized since the 1960s, the exact determination of its age has been hindered, initially, by a lack of age-diagnostic macrofossils, and, in subsequent work, an impoverished aquatic palynological flora indicative of brackish-water depositional environments. Despite these challenges, the published literature on age-diagnostic macrofossils from units above (Kanguk Formation) and below (Hassel and Christopher formations) the Strand Fiord Formation place constraints on its plausible

age. More recent palynological work in the same units, and the basal, “normal marine” part of the underlying Bastion Ridge, place tighter constraints on the age. There is no biostratigraphic evidence known that is consistent with a post-Cenomanian age, and nowhere does the Strand Fiord interfinger with the overlying, marine Kanguk Formation, the basal parts of which is partly Upper Cenomanian. The Strand Fiord Formation is only known to interfinger with sediments characteristic of the underlying Bastion Ridge Formation, or, at a few sites, it is locally overlain with thin terrestrial sediments consistent with the development of a subaerial unconformity at its top, prior to marine flooding by the Kanguk. Such a stratigraphic interpretation is also consistent with the lack of intrusives within the basal Kanguk, in stark contrast to the extensive intrusion of units below the Strand Fiord Formation.

At their widest extent, the biostratigraphic constraints from these units imply the Strand Fiord Formation could span the upper part of the Upper Albian to the lower part of the Cenomanian. There is no stratigraphic evidence for a post-Cenomanian or pre-Upper Albian age for the Strand Fiord Formation (i.e., its age must be  $>93.5 \pm 0.8$  Ma or  $<104.4$  Ma according to current timescales). The likely age is probably a narrower zone within these limits, though whether the unit straddles the Albian/Cenomanian boundary (currently estimated at  $99.6 \pm 0.9$  Ma), or is on one or the other side of it is still debatable.

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#### Petrology and geochemistry of granitoids, Mandalgobi area, central Mongolia

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Early Mesozoic alkali feldspar granites (alaskites) and associated granitic rocks of the eastern Mandalgobi are a part of the Central Mongolian Igneous Belt, which extends from west to east across central Mongolia for about 1500 km. These intrusions are spread over an area of several hundred square kilometres and are associated with coeval bimodal volcanic rocks (basalts and trachydacite to rhyolites). All these rocks have faulted contacts and/or are covered by terrigenous and continental sedimentary rocks of Jurassic and Cretaceous age.

The alaskites have a uniform mineralogy with alkali feldspar and quartz as the main phases and subordinate or no albite plagioclase. The coarse-grained alaskites show a sub-equigranular isotropic fabric with little evidence of flowage or an oriented arrangement of tabular to prismatic feldspar crystals. The alkali feldspar is either a strongly perthitic K-feldspar, often displaying an incipient microclinization, or mesoperthite, typical of hypersolvus granites; micrographic alkali feldspar-quartz intergrowths are common. The alaskites are distinctly

leucocratic containing only traces of biotite. Accessory minerals are sphene, apatite, zircon and iron oxides; rare fluorite forms single minute grains or the lining of minute cavities. The grain size is highly variable, ranging from fine (0.5 mm) to coarse, but the dominant rock types contain large (cm-size) alkali feldspar crystals set in a fine-grained, leucocratic quartz-rich matrix.

The chemical composition of these granitoids displays a wide range of SiO<sub>2</sub> content (68–78 wt %); the alkali content is typically around 8–9 wt %. The rocks have been assigned to a high-K calc-alkaline series.

Numerous dikes are aplites, which sometimes contain pegmatite pods. Irregular quartz veins are frequently close to the intrusion contacts. The Mesozoic granitoid intrusions were emplaced at a shallow depth as indicated by the occurrence of cogenetic rhyolitic rocks, border facies showing gradual changes of grain size, miarolitic cavities and an extensive network of aplitic and quartz veins.

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#### Coastal processes, hazards impacts, and resilience in Canadian Arctic communities

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Arctic regions are expected to be more affected by climate change than temperate regions. Potential impacts include: increased rates of relative sea-level rise for areas already undergoing transgression or transition to a transgressive regime in areas where relative sea level is currently stable or falling; reduced sea ice extent resulting in increased effective fetch and more frequent high waves; increased air and ground temperatures and increased thaw of ice-rich cliffs; and increased frequency of the most severe storms. Overall, increased rates of coastal change (cliff retreat and beach reworking) and increased frequency and severity of flooding are expected.

In many Canadian Arctic communities, baseline data are insufficient to understand the impacts of coastal processes and hazards such as flooding and erosion on communities, in the context of both community infrastructure and socio-economic well-being. Without baseline data, climate change impacts assessments and evaluation of adaptation strategies are not possible. This research, part of ArcticNet Project 1.2 (Coastal Vulnerability in a Warming Arctic), aims to develop or expand the necessary baseline data to determine impacts and, in consultation and collaboration with community organisations, incorporate results into decision-making and adaptation strategies that will build community resilience.

The communities under consideration include: in the

NWT: Tuktoyaktuk, Sachs Harbour, Paulatuk, and Holman; in Nunavut: Kugluktuk, Gjoa Haven, Resolute, Arctic Bay, and Qikiqtarjuaq. These have been selected to reflect an east-west cross-section across Canada's Arctic. Continuously operating GPS sites have been installed at Inuvik, Tuktoyaktuk, Sachs Harbour (discontinued), Holman, Resolute, Alert and Qikiqtarjuaq to monitor rates of vertical crustal motion. To establish rates of eustatic sea-level change, tide gauges have been installed at Tuktoyaktuk, Holman, Alert and Qikiqtarjuaq. High accuracy GPS surveys have been carried out at least once in all communities to establish baseline data on coastal morphology. In several communities, multiple surveys have been completed and rates of change are known. Aerial photography and satellite imagery are being used to extend the survey record back in time and expand it spatially. Some survey profiles have been extended offshore using an echosounder linked to a differential GPS and nearshore morphology has been further investigated using sidescan sonar and bottom grab sampling with differential GPS positioning. Community consultation is occurring in all communities and will be enhanced in selected communities with particularly severe coastal hazards or strong community interest.

In general, the western Arctic is transgressive and shorelines tend to be composed of ice-rich glacial and marine sediments whereas the central and eastern Arctic are regressive with greater amounts of rocky shoreline. In the absence of ice, fetch is greater in the west than in the east and storms tend to occur earlier in the open water season. Depending on community resilience and adaptability, climate change impacts may affect coastal communities in the western Arctic more than in the eastern Arctic.

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#### Nannofossil biostratigraphy of Sauk A-57 and Shubenacadie H-100, offshore Nova Scotia

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Drill cuttings were obtained for several wells drilled offshore Nova Scotia, including Sauk A-57 and Shubenacadie H-100. Results from Sauk A-57 show moderate conditions for nannofossil deposition and/or preservation in Pliocene and younger sections, where species diversity and abundances are low. This is attributed to high clastic input and nearshore conditions during deposition. Higher abundances and more diverse assemblages of nannofossils are found in Miocene and older strata, especially during the Eocene, which indicates increasing oceanic influences. Deeper Paleocene sediments show another poorly preserved section. Shubenacadie H-100 showed similar results: the top of the well representing Pliocene and younger intervals have poor to moderately preserved nannofossils

with very low diversity. Diversity and abundances increase in Miocene and older intervals. Like Sauk A-57, the Oligocene does not appear to be represented in Shubenacadie H-100.

The rich nannofossil occurrences in the Miocene and older sections show that excellent and dependable stratigraphic subdivision can be achieved. This research will contribute to the development of a more detailed stratigraphic framework for the Tertiary and Upper Cretaceous offshore Nova Scotia.

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#### Chaleurs Group stratigraphy in the Petit Rocher area, northern New Brunswick

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Petit Rocher is located approximately 20 km north of Bathurst and 80 km southwest of Port Daniel in southern Gaspé Peninsula, the type area of the Chaleurs Group. It is situated at the northeastern end of the Nigadoo River Syncline, which is part of the much larger Chaleur Bay Synclinorium that extends some 250 km from Hartland (NB) into southern Gaspé (QC). The internal stratigraphy of the Chaleurs Group exhibits significant differences from one locality to another in this Synclinorium, but in general it comprises: 1) lower clastic rocks, 2) a lower limestone unit, 3) middle clastic rocks and/or volcanic rocks, 4) an upper limestone unit, and 5) upper clastic rocks.

The stratigraphic position of rocks along the coast in the Petit Rocher area has been problematic for many years, in particular a recessive-weathering sequence of red, green and grey mudrocks exposed north and south of Pointe Rochette. In 1975, Noble assigned these rocks to a new formation (Petit Rocher), which he considered to overlie the La Vieille Formation, the lower limestone unit in the Chaleurs Group. In 1993, Walker and others showed that the Petit Rocher Formation encompassed more than one mappable unit; they abandoned this name and reassigned rocks in the type locality, north of Pointe Rochette, to the Simpsons Field (middle clastic unit), La Plante (upper limestone unit) and Free Grant (upper clastic unit) formations. The clastic rocks to the south of Pointe Rochette, they assigned to the Clemville and Weir formations, which predate the La Vieille Formation and constitute the two oldest units in the Chaleurs Group.

In 2005, a re-examination of the coastal section near Petit Rocher revealed that changes to the stratigraphic interpretation are required, as follows: 1) there is no Free Grant Formation north of Pointe Rochette – the section ends in La Plante Formation; 2) most of the rocks south of Pointe Rochette are younger than the La Vieille Formation and can be assigned to the Simpsons Field and La Plante formations, with a minor amount of Free Grant Formation; 3) a thin unit of mudrocks, which gradationally underlies the Weir Formation at Pointe Rochette, is correlated with the Clemville Formation;



this unit appears to gradationally overlie dark grey limestone that is tentatively assigned to the Matapedia Group (Upper Ordovician); 4) these pre-La Vieille rocks at Pointe Rochette are unconformably overlain by a limestone-clast conglomerate that probably belongs to the Simpsons Field Formation and if so, provides further evidence of Salinic deformation in northern New Brunswick; 5) this conglomerate and the pre-La Vieille rocks appear to be in fault contact with the section referred to in the second point above, and 6) much of the red colour in the mudrocks is related to Carboniferous weathering.

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### Carbon isotope chemostratigraphy in the Late Ordovician in Arctic Canada: the signal of the Hirnantian glaciation

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Four sections through late Ordovician to earliest Silurian strata in the central Canadian Arctic Islands have been studied for carbon isotopes, derived from the organic matter ( $\delta^{13}\text{C}_{\text{org}}$ ) and whole-rock carbonate ( $\delta^{13}\text{C}_{\text{carb}}$ ) fractions. The lithologies and graptolite faunas provide good constraints on the age and depositional environment of these strata.  $\delta^{13}\text{C}_{\text{org}}$  data appear to provide a signal that mainly reflects chemical changes in the seawater. However, sediment reworking and diagenesis appears to have had a significant influence on the  $\delta^{13}\text{C}_{\text{carb}}$  signal.

Results show that a positive  $\delta^{13}\text{C}_{\text{org}}$  excursion of 3–6 ‰ begins just below the base of the Hirnantian Stage and peaks in the lower part of the *N. extraordinarius* Biozone of lower Hirnantian. This is followed by an interval of reduced  $\delta^{13}\text{C}$  values and a second peak of similar magnitude, which occurs in the lower *N. persculptus* Biozone (upper Hirnantian). These peaks appear to correlate well with episodes of glacial expansion described from West Africa and this is supported locally by the relationship between the isotope shifts and lithologic evidence for sea level fall.

Global correlation of  $\delta^{13}\text{C}$  curves suggests that the timing of positive excursions is not synchronous in all regions of the world. In particular, the lower Hirnantian peak seen in Arctic Canada and some other areas appears to be reduced in some circum-Iapetus regions, where peak values occur in later Hirnantian time. The hypothesis that one regional  $\delta^{13}\text{C}$  curve can reliably serve as a benchmark for high-resolution, global correlation, is not supported by these observations.

These data suggest that an important factor in controlling the  $\delta^{13}\text{C}$  values in Late Ordovician epeiric and continental margin seas was the variation in rates of weathering of carbonate platforms, exposed during the glacio-eustatically controlled sea-level fall. This caused the isotope value of the C-weathering

flux to shift towards the  $^{13}\text{C}$ -enriched carbonate end-member, increasing the  $\delta^{13}\text{C}$  value of carbon transported by rivers to both epeiric seas and the oceans. Differences in magnitude between Hirnantian  $\delta^{13}\text{C}$  excursions in shallower- and deeper water parts of epeiric sea basins, as well as between different regions, may be explained by water mass differentiation between those regions and differences in regional sea level histories.

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### The post-glacial history of the Labrador Current (dynamics and composition): micropaleontological evidence of outburst floods and Atlantic Canada climate changes

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Near-surface detrital carbonate (DC) layers present on the Labrador and Newfoundland continental shelves are correlative to the 8.4–8.2 cal yr BP (7.6–7.7  $^{14}\text{C}$  ka) outburst-flood drainage of glacial Lake Agassiz and the climatic cooling event recognized around the North Atlantic. Study of Labrador Current dynamics suggest that outburst waters, with entrained Paleozoic calcite-rich carbonate sediments originating from Hudson Bay and Strait, were transported in the outer Labrador Current to the Grand Banks. There are DC layers at two locations indicating that a weaker outburst event occurred earlier, with retreat of the Noble Inlet advance (8.9–8.6  $^{14}\text{C}$  ka) which northwardly-transversed Hudson Strait and impounded meltwater behind it.

There is strong new, and recently re-evaluated, benthic foraminiferal, dinoflagellate cyst, and pollen evidence supporting this theory. The most convincing foraminiferal evidence is found on the Northeast Newfoundland Shelf (NENS). There were abrupt, significant, bottom water-mass changes, coincident with initial DC deposition; short-lived periods when the outer Labrador Current, with its increased flux, breached a 330-m deep shelf-edge sill at Notre Dame Channel, carrying the indigenous slope fauna with it. With flux reduction, the freshened waters were isolated in the shelf basin, mixed with overlying waters, and decreased shelf-water salinities. Upper-slope benthic faunas were replaced by significant, short-lived, increases in the abundances of hyposaline-tolerant species.

Salinity gradually returned to normal ranges and shelf faunas reappeared.

At three locations along the margin, surface ocean parameters, calculated using dinocyst transfer functions, indicate large, sudden, sea-surface temperature and salinity decreases, and annual sea ice cover increases, coincident with the Agassiz outbursts. Oxygen isotope measurements made on southern NENS, and other data reported from Cartwright Saddle, Notre Dame Bay, the Scotian Shelf, and Cape Hatteras, all show correlative shifts to lighter  $\delta^{18}\text{O}$  values.

The deglaciation of Foxe Basin was complete by 7.6  $^{14}\text{C}$  ka. Initially the main outflow was Atlantic Water, a flow made possible by isostatic depression of the submerged sills and bathymetric highs in Foxe Basin and the Arctic Island Channels. The benthic foraminiferal faunas along the margin were dominated by *Nonionella labradorica*, a species that prefers Atlantic water salinities and temperatures. As rebound decreased water depths, Atlantic Water flow waned, then ceased, and only colder, fresher, Arctic surface waters could outflow from Foxe Basin. This change in source waters is reflected by the development and predominance of an agglutinated benthic foraminiferal shelf fauna, along the inner margin, beginning about 5.8  $^{14}\text{C}$  ka, and continuing until the present day.

These water-mass shifts may have contributed to Holocene climate changes in Newfoundland and Nova Scotia. Some terrestrial and marine pollen records indicate vegetation changes indicating a mid-Holocene climatic warming, followed by cooling to the present day, approximately coincident with changes in coastal water composition from predominantly Atlantic to Arctic sources. The 8.4–8.2 ka event has also been recognized in lake sediments in Nova Scotia.

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### Preserving geoscience heritage in Saint John, New Brunswick

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Since the middle of the 19<sup>th</sup> century the complex geology of Saint John, New Brunswick has attracted a fascinating list of scientists to unravel its story (including Alcock, Ami, Bailey, Dawson, Gesner, Hartt, Hayes, Howell, Lambe, Matthew, Stopes, and Walcott). Hundreds of technical papers and reports have been published about the Saint John region and the city has been the focus of countless field trips. The diverse geology includes the late Precambrian Green Head Group marble containing the first Precambrian stromatolite fossil to be scientifically described. This group forms a high ridge through the centre of the city producing prominent landscape

features, including the hill at Fort Howe, and the rock ridges responsible for the Reversing Falls at the mouth of the Saint John River. The Cambrian-Ordovician rocks that dominate much of the old city have produced an Avalon fauna that once included some of the oldest and largest trilobites found in North America. The Upper Carboniferous “Fern Ledges” shales are also of scientific interest. When first described they were believed to include the oldest known insect fossils. The Saint John area remains a favourite stop for geology conference field trips and university geology classes. Not only is Saint John important for geological research, but its geology has sparked public interest as well. Local kayaking and jet boat companies highlight some of the geological history on their public tours. Information panels about geology have been in the city’s Rockwood Park for almost 20 years, while the new Harbour Passage trail has provided an opportunity to develop public interpretation along the waterfront.

Research grants from the Community–University Research Alliances (CURA-SSHRC) and the New Brunswick Environmental Trust Fund (ETF) have allowed a risk assessment of geological and paleontological sites in the Saint John region, with a focus on heritage preservation. Site assessment involves evaluating scientific importance, identifying natural and human threats to site preservation, and assessing suitability for public access and interpretation. Understanding the geoheritage of Saint John is important to preserve access to the unique geology, especially in a growing urban setting. In the end we hope to develop a heritage plan to address the preservation of significant geological sites in the Saint John region, while promoting public enjoyment and understanding of the city’s fascinating geoscience history.

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### Mud breeds mud: the non-linear effect of high sediment concentrations on channel infill downstream of causeways

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Understanding of the importance of fine-grained high-concentration sediment suspensions (fluid mud) in coastal and shelf sedimentary processes has improved over the past two decades. The formation of fluid mud can lead to the unexpected accumulations of fine sediment in energetic environments because of the ability of the fluid mud to suppress turbulence. Formation of fluid-mud layers and subsequent transport via gravity flows has been shown to be a key process in delivering sediment to depositional areas on the Amazon and Eel River shelves as well as to areas of accumulation on the Po River delta. Work carried out at these locations suggests that density stabilization by fluid mud at Richardson numbers near  $\frac{1}{4}$  plays a crucial role.

Construction of causeways in the late 1960s in the Upper Bay of Fundy resulted in the deposition of sediment which decreased the downstream cross-sectional areas of the chan-

nels by as much as 90%. While some infill of the channels was expected, the extent of the infill and, in the Peticodiac at least, the continuing rapid channel infill was not. The cross-sectional area of the Peticodiac River at Dover NB, more than 20 km downstream of the causeway, is still decreasing today. Underestimating the effect of high concentrations of mud on turbulence is the most likely reason that engineers failed to predict the extent of sediment infill at both Moncton NB and Windsor NS following causeway construction.

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**Comparison of Late Holocene and Pleistocene sedimentologic and oceanographic records in the Amundsen Gulf, Northwest Territories, Canada**

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Analysis of sediments of two box cores from Canadian Arctic Shelf Exchange Study (CASES), stations 403B (59 m) and 415B (56 m) located in the Amundsen Gulf, allow the determination of the sedimentologic and oceanographic records from the area. Arctic benthic foraminiferal assemblages of the Late Holocene (403B) and Pleistocene (415B) show differences in foraminifers between an environment of high sedimentation (core 403B) and an area of low sedimentation (415B) with evidence of erosion related to glaciation. This contrast will provide insight into glacial records and Arctic productivity.

Potential impacts on the Arctic ecosystem need to be explored, since the Arctic is most vulnerable to changes in climate and specifically changes in sea ice cover. This study will contribute to the assessment of the factors that presently influence sea ice cover which are important in the understanding of the impacts on coastal shelf region of the Arctic.

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**Suspended sediment cycles in the mid and outer Bay of Fundy**

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In the Bay of Fundy the combination of strong tidal currents, high suspended particulate matter (SPM) loading and a highly productive water column results in high rates of transport of both inorganic and organic particulate matter. This mostly occurs in the form of flocculated aggregates. Specialized sampling gear is required to sample accurately, especially near the seabed. Samples taken over several tidal cycles in the mid and outer portions of the Bay showed that, not only does the concentration of bulk suspended solids change over several orders of magnitude between the upper water column and the benthic boundary layer, but that the percent organic compo-

sition of the suspended solids can change by a factor of five. Resuspended large inorganic particles, traveling within a few tens of centimeters of the seabed, dominate the particle size spectrum at high current speeds.

The application of SEM and elemental analysis techniques to the study of sediment transport shows great potential for elucidating particle sources but also for deriving mineral-specific particle size spectra. As has been done in the study of the incorporation of barite from drilling platforms into offshore sediments, elemental maps superimposed on scanning electron images could be used to identify, and provide size ranges of, particular mineral grains from SPM samples. This technique has application to many questions of sediment dynamics in the Bay of Fundy, including the food supply to benthic organisms, tracking anthropogenic materials and minerals of economic interest.

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**Granitoids of Mongolia and metallogeny: GIS database**

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Granitoids occupy the major part of Mongolia's territory forming elongated Phanerozoic accreted belts. The major ore deposits and mineral occurrences in Mongolia are associated with granitoids and the interpretation of accreted belts plays a key role for mineral exploration and mineral deposit prognosis and assessment, particularly with respect to porphyry copper-molybdenum and gold deposits.

The integrated GIS, geology, petrography and petrochemical databases for the territory of Mongolia provide a geodynamic framework and tectonic interpretation of key magmatic arcs in Mongolia. The use of these data with the available mineral deposit database connects the evolution of magmatic arcs with metallogeny. The GIS package has been used to illustrate the evolution of magmatic arcs during the late Paleozoic to late Mesozoic.

A GIS product includes terrane maps, consisting of a series of time slices describing the spatial distribution of different terrane types with a georeferenced set of spreadsheets. The spreadsheets contain whole rock geochemical data of granitoids and some volcanic rocks for the major arc successions, information on petrography, post-magmatic alteration, metamorphism, structure, geochronology, occurrence of mineralization, and many others. The system is highly flexible, compiled in ARC and MapInfo formats with databases in the form of Excel spreadsheets. It can be used not only to outline prospective belts for exploration but can also be used as a tool for petrological, tectonic and metallogenic research in the region. Examples of the maps and interpretation will be demonstrated for the Mongolian Altai and southern Mongolia.

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### **Cenozoic tectonic framework of the Baffin Bay – Nares Strait region of Arctic Canada and Greenland**

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During the Mesozoic and Cenozoic evolution of the North Atlantic rift system, the independent movement of the Greenland Plate resulted in a complex intraplate tectonic history between Canada and Greenland. In this study, a new plate kinematic model is presented for the Paleocene – Eocene motion of Greenland relative to Canada (North American Plate). The model is constrained by seafloor spreading magnetic anomalies in the Labrador Sea and the fracture zone geometry defined by satellite-derived gravity data over Baffin Bay. In the Nares Strait region between northern Greenland and Ellesmere Island, 175 km of NE-oriented sinistral motion is defined during the Paleocene followed by 250 km of northwestward convergence during the Eocene. The change in direction occurred during chron 24N (Lower Eocene). This new model is consistent with the different episodes of the Cenozoic Eurekan orogeny.

Marine magnetic data have been re-interpreted in context with the new kinematic model. Linear anomalies over central Baffin Bay are interpreted as Paleocene seafloor spreading anomalies. Over northern Baffin Bay, a new Eocene fracture zone is identified by a small amplitude linear anomaly parallel to the fracture zones defined by satellite-derived gravity. New aeromagnetic data were collected in the Nares Strait region as part of a Canadian-German research program to improve the details of the intraplate boundary. The northern Hall Basin survey identified a narrow magnetic anomaly that correlates with a fault-bounded (Tertiary) sedimentary basin onshore Judge Daly Promontory (Ellesmere Island). The basin is mapped offshore as an elongated NE-trending feature and is interpreted to be the transpressive (Eocene) plate boundary. The southern Kane Basin survey identified an offshore extension of a Proterozoic dyke which can be mapped westward from an outcrop on Greenland to the Ellesmere coast with no offset, suggesting that the plate boundary identified to the north does not extend as a continuous linear feature through Kane Basin and the Archean crustal block of SE Ellesmere Island is part of the Greenland Plate.

New gravity observations over Ellesmere Island and Axel Heiberg Island have been integrated with existing Canadian and Danish data sets to produce a comprehensive regional-scale compilation. A large amplitude gravity low crossing Nares Strait is cut obliquely by the frontal thrust of the Cenozoic Eurekan orogeny and corresponds with thick Paleozoic strata along the Franklinian margin rather than crustal thickening from the Eurekan orogeny. The gravity modeling also identifies substantial crustal thinning beneath the Lancaster Sound sedimentary basin, and is interpreted to be a failed rift-arm of the Eocene Baffin Bay spreading system. Calculations of crustal thickness suggest that as much as 40 km of extension occurred, enough

to consider Ellesmere Island (and Devon Island) as a separate plate from North America during the Eocene. Also, the association of the basin development with the oceanic (volcanic) rift system implies that the strata (>6 km) are predominantly Eocene and a high heat flow is expected. As such, the tectonic framework provides critical constraints on potential development of petroleum systems.

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### **The Northwest Passage: future dream getaway?**

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Climate change and global warming have become part of our everyday life and the focus of our government and the scientific community. Climate scenarios indicate that the Northwest Passage, the shortest route between Europe and Asia, will be seasonally free of ice by the year 2030, therefore open to commercial shipping with all the risks involved. In order to understand the natural variability of climate, especially for the Arctic, instrumental data covering long periods of time are needed. Data coverage for the Arctic does not extend further than about 20 or 30 years in the past, at the most. We must therefore turn ourselves toward the geological record in order to obtain longer time series that will help in the development of regional climate models and to understand climate variability and cycles at decadal, centennial and millennial timescales.

In this talk I will provide an overview of 2 Canadian-lead programs: CASES and ArcticNet, and the geology projects that are part of it. Mostly, these projects aim at reconstructing the evolution of marine conditions in the Canadian Arctic (Beaufort Sea and the Northwest Passage), with special attention to the evolution of sea ice during the Holocene period. Since 2002, we have participated to 5 oceanographic cruises on board 3 different research vessels, and collected numerous cores (box and piston) at key locations in order to reconstruct the evolution of sea surface parameters. We hope to be able to provide a relatively detailed picture of the evolution of oceanic conditions since the retreat of the last ice sheets at centennial to millennial time scales, and in certain cases, at the decadal time scale.

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### **Weathered granites as potential chemical sieves: impacts of ancient pre-glaciation weathering on the granitoids of southwestern Nova Scotia and the environment**

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Granitoids in some regions of southwestern Nova Scotia have been deeply weathered to a soft, friable, highly perme-

able material (a.k.a. saprolite), which because of its relative ease of quarrying, is used as domestic fill. Whereas on fresh granite trees grow with difficulty, in saprolites plants take hold readily, and vegetation can re-cover these quarried regions within a matter of years. Deeply weathered granites are commonly developed in more tropical climates than our own, and their presence here in glaciated Nova Scotia is not expected. Closer stratigraphic, mineralogical, and geochemical examination of these horizons indicates that they are relics of warmer climates of earlier periods. Not only do these saprolites result in loose, permeable material being exposed, they also provide a window into climate conditions in the past, and a closer look at their chemistry provides information as to the liberation and mobility of elements in the near-surface environment. Saprolites of 3 different ages (pre-Carboniferous, pre-Triassic, and pre-Pleistocene), exhibit increases in oxidation and hydration, and decreases in rare earth elements with increasing degree of weathering. In addition, changes in Ca, Ba, Rb, Zn, Pb, and Co and other elements, including U in the pre-Carboniferous horizon, indicate relative element mobility during weathering, either enrichment or depletion. In addition to engineering considerations revolving around the structurally weakened and highly permeable nature of these horizons, despite our cool temperate climate, exposure of these partially-weathered horizons to today's acidic precipitation may result in enhanced liberation and migration of elements from these saprolites, and thus pose an environmental concern.

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#### Extreme ice-scouring processes on the Canadian Beaufort Shelf caused by sea-ice pressure ridge keels

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Knowledge of the processes of seabed scouring by pressure ridge keels and the spatial and temporal distribution of extreme scour events is required to protect Arctic subsea pipelines and well heads from damage by ice keels. The seabed is saturated with ice scours that range in age from new to several hundred years old. Annual repetitive mapping of the same sectors of the Beaufort seabed with traditional digital sidescan sonar, echo sounder and subbottom profiler allows for the identification of new ice scouring events against a seabed populated by relict scours. Such surveys during the 70s and 80s resulted in the generation of a digital database of new scour events and the identification of extreme scours as those events equal to or greater than 2 metres in depth below the seabed. Insufficient numbers of extreme events were mapped to generate a database statistically adequate for regulatory guidelines or engineering design requirements. After an 11 year hiatus, repetitive mapping was

resumed in 2001 using both the traditional survey equipment and new multibeam technology.

From a database of 8560 new events generated between 1979 and 2004, only 188 new extreme events have been mapped. Depths range from 2 to 5 metres, widths vary from only a few meters to 444 metres for multikeeled scours and the orientation of these scours is dominantly NW-SE. These extreme events occur in water depths ranging from 13 to 39 metres across the Beaufort Shelf. In addition, extreme ice keels have also been identified generating ice scours in water depths of 25 to 55 metres – the limiting water depth for ice scouring by the present day sea-ice regime. The spatial distribution of extreme events across the shelf is primarily controlled by water depth, geographic location and sediment strength properties. The ice scouring process is complex. Along track, ice scours are observed to increase in depth, rise-up, drop-down and run at constant depth.

Due to limited numbers, the impact rates of extreme events across the shelf are poorly known and the return periods of extreme events over a 100 year time frame have yet to be determined. The impact of ameliorating climate conditions on the recurrence rate of extreme events over the next few decades is also poorly constrained because of the wide range of predictions for sea-ice distribution.

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#### Temporal-spatial association between Tertiary lamprophyre dykes and epithermal Au-Ag mineralization in Sonora, northwestern Mexico

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Lamprophyres are mafic to intermediate volatile-rich igneous rocks that occur mainly as dykes and are often been associated with metallic (mainly Au) ore deposits. Although clearly in most cases the relationship between the lamprophyres and the mineralization is not genetic, there are numerous cases where there exists a spatial and/or temporal relationship between them.

The present work focuses on the petrology and geochronology of the lamprophyre dykes of the Hermosillo area, Sonora, northwestern Mexico comparing their age and genesis to that of known Au-Ag ore deposits in the region. In Sonora, the lamprophyres commonly crosscut the 90–40 Ma Sonoran batholith; however, they have also been observed in hydrothermal gold deposits in the north-central and northwestern portions of the State. In the Hermosillo area the dykes vary in width from about 10cm to as much as 5m. They vary in mineralogy from hornblende-phyric spessartite to phlogopite-phyric kersantite, which have medium-K calc alkaline and shoshonitic affinities respectively.

In the area of study <sup>40</sup>Ar/<sup>39</sup>Ar geochronology for the lam-

prophyre dykes has yielded ages from  $\approx 22$  to  $\approx 25$  Ma, which fall within the period through which northwestern Mexico began shifting from an active continental margin to a continental rift; eventually leading to the separation of the Baja California from the North America Plate. While Cu-porphyry mineralization dominates through the late Cretaceous-early Tertiary, Epithermal Au-Ag mineralization is the most common through the mid-Tertiary, coincident with the formation of the lamprophyre dykes.

The initial stages of continental extension should allow for preferential melting of the metasomatized mantle after the long-lived subduction of the Farallon Plate beneath North America. This could possibly be a common source for the formation of lamprophyres and precious-metal enriched fluids, the ascent and deposition of which would also be facilitated by extension. Perhaps it would be of interest to consider transitional tectono-magmatic environments of interest for precious-metal exploration.

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### Lower Carboniferous history of the Indian Mountain deformed zone, Westmorland County, SE New Brunswick

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The Indian Mountain deformed zone, north of Moncton, exposes an inlier of Lower Carboniferous rocks and their pre-Carboniferous basement. The zone divides into two domains along the ENE-WSW line of the North River Fault. The northern domain exposes rocks of the Horton Group (McQuade Brook Formation (new name), Albert Formation and Indian Mountain Formation), while the southern domain consists of a more complex Sussex Group succession resting with angular unconformity on crystalline basement.

In the northern domain the early Tournaisian Horton Group begins with the McQuade Brook Formation, a unit of red and grey sandstone, siltstone and mudstone. These beds are succeeded by the Albert Formation, comprising mostly grey to black dolomitic marlstone, siltstone, and minor kerogenous shale, but with increasing sandstone beds towards the top. The Albert Formation is overlain conformably by the predominantly siliciclastic Indian Mountain Formation, whose lower part consists of feldspathic greenish sandstone interlayered with olive-green shale and siltstone, but which is dominated by buff to red-brown, often mottled sandstone and interlayered red-brown mudrock. No formations younger than Horton Group are preserved in this domain.

In the southern domain the late Tournaisian Sussex Group rocks rest with angular unconformity directly on crystalline basement. The Sussex Group from base to top comprises a

three-part coarse-fine-coarse stratigraphy. The basal part, the Stilesville Formation (new name), is an angular clast polymictic conglomerate with a basal regolith, megabreccia and rare silcrete beds. It is overlain by a succession of red and grey shale and sandstone of the Gautreau Formation, which coarsens upward into polymictic conglomerate, sandstone and minor mudstone of the Briggs Cross Formation (new name).

In both domains two phases of deformation have been identified. The first is characterized by north verging folds (F1) related to thrusts or steeper reverse faults whose movement is top-to-the-north. These folds are consistently overprinted by a second set of folds, F2, that can locally be related to strike-slip motion along major ENE-WSW trending faults. In the northern domain this deformation is associated with a slaty cleavage and low grade metamorphism. By way of contrast, in the southern domain the deformation appears to have occurred before the Sussex Group sediments were completely dewatered.

The Indian Mountain deformed zone originated as a basement high separating the Tournaisian Moncton and Cocagne subbasins, or at least it did so by the onset of deposition of the Sussex Group. In post-Sussex Group time the zone evolved into a fold-thrust belt. Subsequent evolution involved deformation related to ENE-trending strike-slip faults. This late strike-slip faulting juxtaposed two domains from very different levels of the same fold-thrust belt. The northern domain, containing a slaty cleavage, has been buried to depths well below the oil and gas windows.

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### Applications of Quaternary geology and till geochemistry projects in northeastern New Brunswick

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Quaternary mapping and till sampling in the Pointe-Verte and Bathurst areas provides baseline geological data for mineral exploration, environmental applications, land use planning, and forest management, and assists in locating sources of aggregate and clay-rich basal till. The study area is located in northeastern New Brunswick and includes part of the Jacquet River Gorge protected area, a significant amount of private land, municipalities, including the city of Bathurst, and the Port of Belledune.

A total of 369 basal till samples were collected, and surficial mapping was done to develop a model for glacial dispersion and to assist mineral exploration. Glacial striations, roches moutonnées, and drumlinized topography indicate ice flow in an east-northeast direction in the Pointe-Verte area and western part of the Bathurst map area. Ice flow in the central part of the Bathurst sheet is towards north-northeast, along

the Curventon–Bathurst Valley towards the Bay of Chaleur. Approximately 75 pebbles were collected at each site to determine glacial transport distances. Most pebbles are locally derived but dispersal in an east-northeastward direction is indicated away from well-defined point source lithologies (Antinouri Lake, Nicholas Denys, Pabineau and Nigadoo felsic intrusive rocks).

In the Pointe-Verte area, particular attention was paid to field tests for texture, coarse fragments, consistency etc. in order to compare the accuracy of the standard field methods with detailed lab. analyses performed on bulk till samples collected at the same sites. At 105 sites that met the field tests for approximate percentage of clay material, a 10 kg bulk till sample was collected to outline areas of clay-rich till in the Port of Belledune area. The bulk samples were sieved to define the percent of the sample from 9 size fractions ranging from 8 cm down to <3.5 µm. They were also processed like other till samples that have been collected in the past, to define the sand/silt/clay ratio of the fine fraction and added to the province-wide database. In the samples that contain more than 10 percent clay (<3.5 µm) by the sand/silt/clay ratio lab. tests, the field tests also are relatively accurate in terms of indicating potential sources of clay-rich till. Initial mapping revealed that the till was more clay rich north of the Antinouri Lake Granite and west of the village of Pointe-Verte and in the eastern part of the Bathurst map area where the till has a primary source in Devonian and Carboniferous sedimentary rocks.

Till geochemical data for New Brunswick, including this survey, are part of a joint Geological Survey of Canada/New Brunswick Geological Surveys project to look at background trace metal concentrations in basal till. This is part of the federal government's Metals in the Environment program. New Brunswick has a large dataset (>10 000 samples) well-distributed over the province (all bedrock geological units). Some re-analyses will be required to assist in the levelling process. Till samples collected in the eastern part of the Bathurst map sheet will be used to further define background till geochemical concentrations over Carboniferous sedimentary rocks which underlie most of eastern New Brunswick.

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**Multidisciplinary approach to assess sediment transport and environmental impacts at an offshore disposal site near Saint John, NB**

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For the past 40 years, material dredged from shipping channels and around the wharves in Saint John Harbour, New Brunswick, has been placed in an offshore disposal site in the approaches to Saint John Harbour. The site is affected by strong currents, 8 metre high tides, and waves from winter storms. In 1999, a joint project was initiated between Environment Canada and the Geological Survey of Canada (Atlantic) (GSCA) to define the zone of influence of the dumping and assess the physical, chemical and biological impacts caused by disposal activities. The study utilized integrated geophysical, sedimentological, geochemical, and biological techniques to characterize the nature, distribution and remobilization of marine sediments. Seafloor samples, photographs, and video transects were analyzed to assess the physical and chemical characteristics of the seabed habitats and composition of benthic communities.

Repetitive multibeam bathymetry surveys showed accumulation of dredge spoils due to disposal in the summer, and transport and redistribution by currents and waves over the winter months. Currents, waves, and *in situ* sediment re-suspension were monitored using instrumented platforms and used to constrain a 2-dimensional hydrodynamic tidal model and a sediment transport model. Field measurements and model predictions show that fine sand could be mobile throughout 54% of the tidal cycle. Sediment transport rates during a one-year storm could be 1–2 orders of magnitude greater than from the tidal current. A sediment dispersion model enabled tracking of fine-grained dredge spoils throughout the tidal cycle.

Physical habitat characteristics, and the type and relative abundance of benthic fauna were interpreted from seafloor photographs at 56 sites. Textural and structural characteristics of habitat were described. All visible species of megabenthos were identified to the highest possible taxonomic resolution. Cluster analysis of the numerical rankings assigned from photographs discriminated distinct benthic assemblages and physical habitats which served as a basis for habitat mapping. While distinct benthic assemblages could be differentiated for mud, sand and gravel sediments, the disposal site contained a mix of species from all types of assemblages.

Metal concentrations were analyzed in the sediments and used to trace dispersion of the dumped materials. Sedimentation rates were determined and found to be highest near the mouth of the harbour channel, exceeding 2.0 cm/a. Near the disposal site, sediment accumulation was 0.5 to 2.0 cm/a. The concentrations of most potentially toxic trace elements (As, Cr, Cu, Pb, Zn) in surface sediments at the disposal site are below the Interim Canadian Marine Sediment Quality Guidelines. In general, the concentrations of most trace elements are relatively low compared to many industrialized harbours, and are probably not contributing to adverse biological effects in Saint John Harbour.

This multidisciplinary approach is essential for assessing the environmental impacts of offshore disposal in high-energy settings such as those found in the Bay of Fundy and has improved our understanding of the dispersion and fate of the dredged materials at the disposal site and surrounding area.

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### Environmental legacy of historical gold mining activities in Nova Scotia

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Historical stamp milling activities at lode-gold mines in southern Nova Scotia have generated more than 3 million tonnes of tailings. From 1861 to the mid-1940s, gold was mined in 64 districts throughout the Meguma Terrane resulting in a total production of 1.2 million oz. of gold. Most of this gold was recovered using Hg amalgamation, and an estimated 10–25% of the Hg used was lost to the tailings and to the atmosphere. In addition to Hg added during the milling process, toxic metal(oid)s (primarily As) also occur naturally in the ore, and are present at high concentrations in the mine wastes. Tailings from these early operations were generally slurried into local rivers, swamps, lakes, and the ocean.

This study is a multi-disciplinary, multi-partner investigation of the dispersion, transformation, and fate of metal(loid)s in freshwater and marine environments surrounding abandoned gold mines in Nova Scotia. From 2003 to 2005, samples of tailings, soil, till, rock, sediment, and water were collected at 15 past-producing gold mines. Field studies reveal that most mine sites contain large volumes of unconfined tailings, and in several districts the tailings have been transported significant distances (>2 km) offsite by streams and rivers. At most mines, the tailings are overgrown and difficult to recognize; however, some tailings deposits have recently been disturbed by human activities (e.g., off-road vehicle usage).

Whole-rock chemical analysis of unmineralized Meguma Group bedrock away from lode-gold deposits suggests background levels for Hg and As to be  $\approx 3$  ppb and  $< 5$  ppm, respectively. Within gold districts, however, concentrations for Hg and As in the ore zones average  $\approx 50$  ppb and  $\approx 1000$  ppm, respectively. Chemical analyses of 433 tailings and downstream sediment samples show high concentrations of Hg ( $< 5$  ppb to 350 ppm; mean 7 ppm) and As (9 ppm to 31 wt %; mean 1 wt %). The highest Hg levels are found near mill structures, reflecting Hg loss during amalgamation and retorting. Arsenic concentrations  $> 1$  wt % (measured in  $\approx 22$  % of all tailings/sediment samples) are generally restricted to areas containing arsenopyrite (FeAsS) concentrates, or where weathering of the tailings has concentrated As in secondary phases such as scorodite ( $\text{Fe}^{\text{III}}\text{AsO}_4 \cdot 2\text{H}_2\text{O}$ ). Water chemistry data indicate that dissolved As concentrations are very high at some locations (0.2 to 6600 ppb; mean 390 ppb;  $n = 122$ ), as compared to background values of generally  $< 25$  ppb. Dissolved Hg levels range from 1 to 60 ppt (mean 13 ppt;  $n = 122$ ). In general, the dissolved Hg concentrations in surface waters are relatively low even in close

proximity to tailings with high levels of Hg, suggesting that most Hg is present in relatively insoluble forms.

Ongoing studies are characterizing the background levels, speciation, mobility, and bioaccumulation of metal(loid)s in both freshwater and marine systems. Results from this study have recently led to the formation of a Provincial-Federal Historic Gold Mines Advisory Committee. This committee is evaluating the potential ecological and human health risks associated with gold mines throughout Nova Scotia, and developing recommendations for management of these tailings sites.

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### Interplay of tectonics, volcanism and diagenetic processes in Lower Cretaceous sediments of the Chaswood Formation and Scotian Basin

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The Chaswood Formation is a fluvial succession deposited over a long period of time in the Early Cretaceous, during deposition of the Missisauga and Logan Canyon formations offshore. Deposition was synchronous with strike-slip faulting, basin formation, and uplift of horsts that shed local detritus. The formation is cut by a major regional unconformity corresponding to the top-Missisauga unconformity in Orpheus graben. Chaswood Formation tectonics form a linked system with the Laurentian sub-basin and Jeanne d'Arc basin.

Lignites from the Chaswood Formation have several features indicating the presence of volcanic ash: unusual abundance of high-field-strength elements such as Nb, Ta and Hf; the presence of augite in EMP and XRD analyses; the rare presence of euhedral quartz; and aluminophosphate-sulphate minerals that appear to pseudomorph volcanic ash. Some wood or charcoal fragments appear mineralized and diagenetic talc is present. Much of the terrigenous component of the lignites consists of background detrital sediments (characterized by detrital illite) and most of any ash component has been altered to kaolinite. Bulk composition of ash is inferred to range from basaltic to rhyolitic. The closest sources of ash are the early Albian volcanic rocks within the lower Cree Member of the Orpheus graben, correlated with the middle member of the Chaswood Formation, and Berriasian to Barremian volcanic rocks on the SW Grand Banks and Fogo Seamounts, correlated with the lower member.

Early diagenesis by meteoric water at unconformities resulted in widespread kaolinitization of the Chaswood Formation and the upper member of the Missisauga Formation in Orpheus graben. During burial diagenesis of the Chaswood Formation, sandstones were cemented by pore-filling illite, barite, and quartz. Strong cementation in the lower member is related to high Albian geothermal gradients. Late diagenetic phases controlled by  $\text{CO}_2$  and  $\text{H}_2\text{S}$  in the Scotian basin during



hydrocarbon charge are lacking. The Chaswood Formation was in diagenetic continuity with the Scotian basin until Oligocene uplift, which led to erosion of at least 700 m of overlying Dawson Canyon and Banquereau formations that are recognised along strike in Orpheus graben. The Chaswood Formation is now preserved in only a few basins that were not uplifted in the Oligocene tectonic event.

Ilmenite was a major detrital mineral in the Chaswood Formation and its breakdown to silt-sized pseudorutile provided a source of labile Fe for early diagenesis in the Scotian basin. Volcanic ash by direct fallout and fluvial reworking was another important source of labile Fe. These sources promoted the authigenic or early diagenetic formation of berthierine and chamosite in the Missisauga and Logan Canyon formations. These minerals are important in the formation of chlorite rims that preserve porosity in reservoir rocks of the Missisauga Formation.

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#### Historical and dendrochronological assessment of the Bay of Fundy forests for dendroclimatological modeling, New Brunswick

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Using historical documents and dendrochronological tests, the remaining forests along the Bay of Fundy were assessed in the summer of 2005. Since the first European settlers arrived in the region, Maritime trees have been in high demand for many different types of construction materials. As a result, most of the region's forests have undergone substantial transformation in the areas of species composition, age class and genetic diversity. Tree-ring analyses at the few sites that remain have begun to build a continuous record of the environment in the region.

After a difficult search, several remnants of old-growth red spruce dominant forest were found. Exceptional circumstances have protected these trees from anthropogenic attack and other disturbance regimes. These few rare groves of trees have now established a continuous 300+ year chronology of annual radial-growth rings. By creating a model of red spruce growth response to climate, hindcasting should now be possible to generate a 300+ year paleoclimatic record for the region. This exciting new breakthrough for the region was further punctuated by the discovery of the oldest red spruce tree in the world (445 yrs old). These findings can now be transformed into a dendroclimatological model which will be the longest of its kind in Atlantic Canada.

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#### Origin and tectonic significance of the Early Cretaceous Fogo Seamounts

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The Lower Cretaceous Fogo Seamounts were formed along the transform margin of the southwestern Grand Banks, at the northeastern extremity of the mid Jurassic – early Cretaceous central North Atlantic ocean, and have been partially buried by younger progradation of the continental margin. Volcanism of similar age is known from hydrocarbon exploration wells in the Orpheus Graben and the southern Grand Banks and slightly younger volcanic rocks are found in the Newfoundland Seamounts and ODP Site 1276. Otherwise, the Iberia – Grand Banks rift is remarkably non-volcanic.

The J-Anomaly Ridge was sampled by DSDP Site 384 and represents an area of anomalously thick crust formed at the mid-ocean ridge at the southeastern end of the Fogo Seamount chain. New samples were obtained from the Narwhal F-99 exploration well, which penetrated olivine basalts in the northwestern part of the chain and trachybasalt conglomerate was dredged from Seamount G in the central part of the chain. In chemical composition and radiogenic isotopes, the basalts range from mildly alkalic to mildly tholeiitic, with chemical analogues, for example, in Hawaii. The voluminous tholeiitic magmas result principally from decompression melting, with the ocean-island-basalt signature of the alkalic rocks also suggesting upwelling of deeper asthenosphere.

The distribution of the seamounts has been determined from magnetic, bathymetric and seismic data. Some seamounts are flat-topped and resemble guyots in being capped by carbonate platform rocks, penetrated at DSDP Site 384 and Narwhal F-99, and interpreted from seismic-reflection profiles on some other seamounts. A few seamounts appear to define linear trends parallel to the inferred transform faults paralleling the continental margin, but much of their distribution appears random and occurs within a broad zone 200 km wide. There is no systematic pattern to the elevation of flat-topped seamounts.

Various hypotheses for the origin of the magmatism are evaluated. The distribution of the seamounts and the J-Anomaly Ridge suggests that they developed from edge-controlled convection in the upper mantle that developed due to thermal and density gradients at the transform transition between the spreading ocean and the continental block of the Grand Banks. The location of the volcanic centres was strongly influenced by crustal-scale strike-slip faulting. The Fogo Seamount chain thus has a different tectonic origin compared with many oceanic seamount chains. The widespread volcanism affected the thermal evolution of the continental margin and may have created conditions favourable to the widely distributed crustal

extension that produced the Cretaceous basins of the Grand Banks and the Iberia – Grand Banks rift.

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**River in a box: sedimentary geology  
with modified Hele-Shaw cells**

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There are many challenges in teaching sedimentary geology. As geologists we sometimes forget how foreign many of the concepts are to the non-expert: principles of superposition and geologic time, weathering, erosion, transportation, deposition, and reworking. But such concepts are vital to understand if we want to explain petroleum basins or offshore geology.

How then can we introduce these concepts before resorting to textbooks, photographs or computer models? How can we build on common-sense intuitive understanding about moving water and the sedimentary patterns observable all around us in rocks, the landscape, and on the beach? One teaching tool that can help comes in the form of a plexiglass box with ports to allow inflow and outflow of sediment-laden water.

The design is based on a laboratory apparatus known as the Hele-Shaw cell whose construction and use is uncomplicated and which can be readily used in a classroom with groups of 2–5 students. Using the cells, we have been able to explore concepts and processes that are relevant to a river delta, a petroleum basin or an oceanic margin. What's more, the Hele-Shaw cell shows us a slice of the sediments in depth and how they were constructed and modified through time (which is a terrific aid for geologic understanding).

The cells have been used in EdGEO teacher's workshops, classroom visits, and university geology labs. Some of the phenomena one can demonstrate are: angle of repose, sorting, erosion, deposition, aggradation, progradation, porosity/permeability, slope instability and sediment mass failures, and even salt tectonics. During this presentation we will demonstrate some of these applications.

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**The Kashafud Formation of Iran: Jurassic turbidites in  
the Neotethys Ocean, and their reservoir evaluation**

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The Kopet-Dagh Basin of northeast Iran formed in the Neotethys Ocean after the closure of Paleotethys, during which a suite of microcontinents accreted to the Turan and Eurasian

plates. A thick Jurassic to Miocene succession was deposited on the craton and in local extensional depocentres, after which collisional events created mountains along much of southern Asia, with extensional faults reactivated locally as thrusts.

The Kashafud Formation (Middle Jurassic) of the Kopet-Dagh Basin rests unconformably on Triassic volcanogenic rocks and ultrabasic rocks of the Mashad (Paleotethys) Suture Zone, and comprises nearly 2 km of marine turbidite and fluvio-deltaic facies. The sandstones have considerable reservoir potential, and the shales acted as source rocks for hydrocarbon reservoirs in the overlying Mozduran and Shurijeh formations, including the Khangiran Gas Field. The type of turbidite system and the scale of sandstone bodies make the formation well-suited as an analogue for sand-rich turbidite plays around the world.

The basal fluvial strata are conglomeratic mass flow deposits of boulder grade that occupy valleys cut into the underlying bedrock. The bulk of the formation comprises interbedded sandstone and shale packages with trace fossils and sparse ammonites, and with shallow-marine facies (including red sandstones) and oolitic carbonates at the top. Sandstone packages are mainly 1-10 m thick (maximum 84 m thick) with thinning- and fining-up trends, although some packages thicken- and coarsen-upwards. Most packages have erosional bases, and many contain channel fills with mudstone clasts at their bases. Some lensoid packages tens of metres thick and <200 m wide represent submarine channel fills cut into shales and sandstones. The turbidite facies is interpreted to represent lobes on a basinal slope, and paleoflow data suggest that they were sourced from the south, perhaps funneled through upland river valleys. Abundant plant fragments suggest proximity to terrestrial sources, and hummocky cross-stratification in the upper parts suggests that some turbidites were modified by waves.

The diagenetic history of Kashafud sandstones was determined from analysis of 270 thin sections, backed up by microprobe analysis. The sandstones underwent porosity reduction through compaction, pressure solution, and precipitation of cements (quartz, carbonates, clay minerals, Fe-oxides, and K-feldspar). Carbonate cements include calcite, dolomite, ankerite, and siderite. Porosity of 24 samples averages 9%, and is largely secondary due to dissolution of feldspar and ultrabasic rock fragments, as well as fracture generation. Diagenesis mainly reflects deep burial in the eo- and mesodiagenetic realms (shallow to deep burial), and the presence of a lava flow and a sill suggests locally enhanced geothermal gradients. Some diagenetic effects probably reflect telodiagenesis (exhumation), linked to Mesozoic hiatuses and/or Miocene to Recent collisional events that created the Kopet-Dagh Mountains.

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### A study of buried forests from two bogs in northern New Brunswick

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Peat extraction from two bogs in the Shippagan area of northeast New Brunswick has led to the unearthing of buried trees covering a large area. This suggests the existence of a former forest that must have been present before the beginning of the development of the present day bog. Numerous stumps and logs were found laying on 20–25 cm of highly humified peat. Before peat extraction, they were buried under approximately 2.5 m of poorly humified *Sphagnum* peat. Wood remains were at the contact of the two different peat types suggesting that an accelerated peat accumulation rate most likely killed the trees. Identification of wood was conducted with the help of a scanning electronic microscope and macrofossil analysis. Results indicate the presence of *Picea mariana* and *Larix laricina*.

Radial growth of trees as shown by dendrochronological analysis was fairly good in the beginning of their life span, but a sharp decline is evident after a certain number of years indicating growth stress. The presence of adventitious roots on all observed stumps indicates that trees were surviving by developing roots above the rising water table as peat accumulated. When accumulation rates accelerated drastically, trees could not adapt their root system quickly enough and they died. Trees were fairly old (average: 105 yrs) when they were killed and crossdating implies that most died within a 30 years span of each other. Radiocarbon dates on a wood sample from each site suggest that the forests existed at two different times at the sites (1820 yrs BP and 1280 yrs BP).

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### Future treeline migration based on past radial tree growth, Jasper National Park, Alberta

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The main objective of the project was to determine how future meadow habitat will evolve in the next 100 years in a representative mountain environment in the Canadian Rocky Mountains. A vegetation analysis of the Maligne Pass area of Jasper National Park was used to assess how treeline has changed over the past 100 years, and this baseline information was used to predict potential changes in the next 100 years. We mapped and obtained core and disc samples from representative trees in a 3000 square m centerline plot. Trees were counted and classified as seedling (shorter than 0.5m), sapling (between 0.5m and 1.5m) or tree (taller than 1.5m). In total 534 trees were assessed within the grid, as well as their spatial

characteristics. A climate/tree-ring analysis found that growing season temperatures were the most important factor relating to radial growth. Based on this assessment, future predictions of treeline migration were generated from data available from the Canadian Centre for Climate Modeling. In Maligne Pass, results indicate that no accelerated change in treeline migration will occur in the next 100 years. Instead the major shift in treeline position that occurred at the end of the Little Ice Age in the region (ca. late 1860s) is seen as the most abrupt threshold change in the treeline position.

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### Holocene paleoceanography of the Mackenzie Trough, Beaufort Sea, Canada: preliminary results

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A series of 3 piston cores collected in 2002 in the Mackenzie Trough (Canadian Beaufort Sea) will serve for the reconstruction of sea surface parameters during the Holocene (last 10 000 years), with emphasis on the evolution of sea ice conditions. Preliminary results of core MR02-K05-PC2 (Lat. 69° 55' 30.68" N, Long. 138° 23' 03.69" W, length: 9 m, water depth: 223 m) are presented here. The chronostratigraphical framework of the core relies on 3 AMS-<sup>14</sup>C ages obtained on bivalves, and the sequence encompasses the last 9000 years BP. The sediment consists of olive grey hemipelagic silty clay. The analyses of the sediment's physical properties (density, magnetic susceptibility, resistivity, P-Wave) and colorimetry reveal no important change throughout the sequence, which suggests a continuous deposition without interruption or hiatus. Fossil dinoflagellate cyst assemblages will be used as proxy for the reconstruction of sea surface parameters (temperature, salinity, sea ice cover) using transfer functions based on the best analogue method.

Preliminary palynological analyses performed at ≈1 m intervals reveal relatively diversified dinoflagellate cyst (dinocyst) assemblages composed of 12 cyst species routinely recovered from surface sediments of the Canadian Arctic Archipelago and Beaufort Sea, with the exception of one taxon characteristic of the Pacific Ocean. Dinocyst concentrations are relatively high and vary between 800 and 3400 cysts.cm<sup>-3</sup> of wet sediment. The lower 4 m of the sequence are characterized by the dominance of the "Arctic species", *Islandinium minutum*, *Polykrikos quadratus*, *Spiniferites frigidus*, accompanied by *Brigantedinium* sp. and the cyst of *Pentapharsodinium dalei*. These taxa represent more than 80% of the assemblages and indicate freezing sea surface temperature for several months of the year and abundant sea ice cover.

Between 4 and 2 m down core (≈5422 to 3575 years BP) the Arctic species relative abundances reach minimal values,

while the relative abundance of *Operculodinium centrocarpum*, which dominates modern dinocyst assemblages in the northern Pacific Ocean, increases to 50%. In the same interval, we also observe the maximum abundance of the cyst of *P. dalei* and the presence of the cyst of *Protoperidinium americanum* (recorded for the first time in the Arctic), which are also present in modern dinocyst assemblages from the northern Pacific. The maximum abundance of these 3 taxa suggests warmer sea surface temperature and less sea ice relative to modern-day values, and increased input of Pacific water into the Beaufort Sea during that period, which also corresponds to the Holocene thermal maximum as recorded in sediment cores from the eastern Canadian Arctic. This in turn suggests that both eastern and western Arctic were simultaneously characterized by warmer water masses during that period relative to modern-day values. Finally, the dinocyst assemblage recovered in the upper 2 m of the sequence indicate a gradual return to the dominance of Arctic species and modern-day conditions of sea surface temperature and sea ice cover.

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**From an Éphémérides to ‘Observations on The Changes of The Air’: documenting the farfield parameters of the November 1, 1755 “Lisbon” tsunami in the western Atlantic**

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The arrival of the tsunami from the 0930 (LT = 1006 UTC) Saturday, November 1, 1755 tsunamigenic marine earthquake offshore of the Iberian Peninsula seems to be well known. However few authors cite references for this phenomenon, and even fewer refer to primary accounts. In the present day the Prime Minister of St. Lucia’s website notes that the “Lisbon” Tsunami struck the coast of his nation, yet when queried as to how he knows this no verification can be offered.

An ‘undead tsunami’ persists in the historical tsunami records of the Atlantic even to the present day as having been caused by the 0412 (LT = 0856 UTC) November 18, 1755 “Cape Ann”, Massachusetts Earthquake. This misinterpretation by Harvard Prof. John Winthrop II in his published “Lecture on Earthquakes” prepared in late 1755 can be removed from the record. Winthrop is mistakenly referring to the “Lisbon” Tsunami of November 1st as it arrived in Saint-Martin/Sint Maarten.

Primary, or near-primary, reports of the “Lisbon” tsunami have been found for Bonavista, Newfoundland, from a vessel in port in Antigua, from an arriving vessel report in a Boston colonial newspaper and in a Dutch history of 1817 for the island of Sint Maarten, from Martinique in an éphémérides recorded in French, for Barbados in a tropical disease medical text’s extensive footnote, in Spanish apparently for Santiago de Cuba, and in Portuguese from Lisbon archival records for Brazil some 4° of latitude south of the equator. Bermuda can be added to the list via a Charles-Town, South Carolina rice merchant’s secondary

account in a letter to a colleague. Report arrivals in Saba, St. Lucia and Dominica cannot yet be verified. No reports for Nova Scotia or eastern United States have been found.

If the farfield parameters of the “Lisbon” tsunami can be determined, then these data may assist in the determination of the location, orientation and length of the seafloor rupture of the “Lisbon” Earthquake – parameters that as yet are not agreed upon or well understood.

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**Uranium and radioactive elements in the Horton Group: possible connection to palaeosaprolites developed under the Carboniferous unconformity in the Maritimes Basin of eastern Canada**

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The presence of anomalous concentrations of uranium, radium, and radon in the Horton Group and underlying basement rocks of Atlantic Canada has been known for many years. The exploration model for the sandstone-hosted occurrences was that of a uranium roll-front similar to the deposits of Texas and the western United States. However, the recognition of deeply weathered granitoids below the unconformity of the Horton Group on the South Mountain Batholith suggests an analogy to regolith-related unconformity deposits such as the Athabaska Basin of Saskatchewan may also be applicable. There is no doubt of the presence of roll fronts in the Horton Group sandstones; however, the source of the uranium within the system may be related to the weathered horizons beneath the Horton Group rocks and not exclusively the result of diagenetic change of the sandstones.

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**Recent palaeoceanography of the Mackenzie Trough (Beaufort Sea) with comparisons to Lancaster Sound (Baffin Bay) using foraminifers as proxies**

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Over the past 30 years, important temperature changes have been documented in the Arctic related to the extent and thickness of the ice cover. Sea ice plays a major role in regulating the ocean-atmosphere heat exchange. The observed decrease

of  $\approx 14\%$  in sea ice extent has raised concerns in the scientific community, government and populations that live in those areas. General circulation model experiments suggest that global warming will be amplified in the polar regions due to the positive feedback induced by the reduction of sea ice cover.

There is a need for high resolution geological proxy data to provide realistic initial values for calibrating climate models. The sedimentary records of the western Beaufort Sea and eastern Lancaster Sound may provide a decadal-centennial scale record of the palaeoceanographic changes in the Canadian Arctic for the Holocene. By employing data from several microfossil proxies it will be possible to reconstruct the variations of sea ice cover, the influx of freshwater to the Mackenzie Canyon area, the influence of the Mackenzie plume in relation to the sea ice history, in comparison to the duration of Recent sea ice history in the North West Passage and the influence of Arctic Ocean water-NWP exchange into Baffin Bay.

Three piston cores were collected from the Mackenzie Trough (Canadian Beaufort Sea) in 2002 onboard the Japanese research vessel RV *Mirai* over a range of depths. A fourth core, 2004-804-850 (1054m) was collected in 2004 by the NGCC *Amundsen* at the tip of the Trough. The fifth piston core, 2004-804-009 (772m), was collected by the NGCC *Amundsen* in 2004, from the entrance of Lancaster Sound in the eastern Arctic.

The objective is to reconstruct the evolution of palaeoceanographic conditions in the area since the last glaciation ( $\approx 11\,000$ y, or Holocene). The foraminiferal data gathered from these 5 sediment cores during CASES 2002-2004 help to provide a basis for these interpretations.

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#### Foraminifers and associated organisms on the present Mackenzie Shelf/Amundsen Basin, Canadian Arctic and comparison to the Antarctic faunas

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As part of the Canadian Arctic Shelf Exchange Study (CASES) over 50 surface locations were sampled for foraminifers for the first time in 40 years. These samples were collected in water depths ranging from 50 to 1100m. The ultimate purpose of the surface samples is to calibrate the faunas to determine paleo-ice cover. Unlike previous studies smaller size fractions ( $>45 > 63\mu\text{m}$ ; and above) instead of the usual 63 or 150 $\mu\text{m}$ , above fractions were examined. Some species not previously observed here were recorded such as *Elphidiella han-nai*, a species commonly found along the British Columbia coast and a series of large agglutinated forms including two Komokiacea species, a group not recorded before anywhere in the Arctic Ocean. One species, *Ammotium cassis*, only occurred near methane seeps (a mud volcano and pingo-like

features) suggesting that this species might be more tolerant to methane and provide a good proxy for past methane emissions when observed down core. In the smaller size fraction (45–63  $\mu\text{m}$ ) there were a set of species in some places (the Amundsen Gulf) that provided evidence of deep Arctic water penetrating to depths as shallow as 150m. The smaller size fraction often had more specimens per 10cc than the 63 $\mu\text{m}$  and above fraction but less diversity. There was a fairly even division between the calcareous and agglutinated species which is the fundamental difference between the Arctic and Antarctic where the former has mostly agglutinated forms. Also, because the Mckenzie Shelf has a large surface freshwater component the sedimentation rates are much higher there than the Antarctic which will provide us with higher time resolution records of the Holocene. Our main purpose was to be able to reconstruct the history of sea ice cover in the Holocene. The key to this was obtaining cores and samples where there were sufficient planktonic foraminifers which are sensitive to ice cover changes. In samples deeper than 500m there was a significant percentage of planktonics and where there was large freshwater input, there were tintinnids so that we now have two proxies for ice cover and freshwater (if there is a lot of freshwater, there isn't much ice cover). Hence we will be able to achieve our main goal of reconstructing Holocene ice cover history.

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#### Tree-ring chronology development from house structures in Dorchester, New Brunswick

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To conduct dendroarchaeology studies, radial growth patterns of wood of an unknown date must be compared to radial growth patterns of wood with a known date. This simple process becomes problematic when wood from a structure pre-dates the living trees from the same species in the area of the structure. But when an overlap does exist, wood from the structure can significantly strengthen the base chronology for the area.

A case study of this type of strengthening is illustrated by a dendroarchaeological study in a historic house located in Dorchester, New Brunswick. A rough history of the lot of land on which the house sits has been recorded since 1786. The original inhabitants of a house currently on the lot as well as the date of construction have remained a mystery. The owners of the structure suspect that it was constructed sometime during the first decade of the 1800s by a man named Cyphrim Kellam. Our dendroarchaeological study indicated that the original building was constructed in the period from 1820 to 1821. By using dendroarchaeology a much clearer history of the original inhabitants of the building and the site was uncovered. The data gained by assigning a time frame to the wood of

an unknown date has significantly strengthened the regional chronology for the tree species used in construction. That data can now strengthen the robustness of models looking into the past environments of the forests in the region.

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**The origin of reaction textures in mantle peridotite xenoliths from Sal Island, Cape Verde: the case for “metasomatism” by the host lava**

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Reaction zones around minerals in mantle xenoliths have been reported from many localities worldwide. Interpretations of the origins of these textures fall into two groups: mantle metasomatic reaction or reaction during transport of the xenoliths to the surface. A suite of harzburgitic mantle xenoliths from Sal, Cape Verde, show clear evidence of reaction during transport. The reactions resulted in the formation of olivine – clinopyroxene Si- and alkali-rich glass around orthopyroxene and sieve-textured clinopyroxene and sieve-textured spinel, both of which are associated with a Si- and alkali-rich glass similar to that in the orthopyroxene reaction zones. Reaction occurred at pressures less than the equilibration pressure and at temperatures close to the liquidus temperature of the host magma. In addition, there is a clear spatial relation of reaction with the host lava: reaction is most intense near the lava / xenolith contact. The residence time of the xenoliths in the host magma, determined from Fe-Mg interdiffusion profiles in olivine, was approximately four years. Our results contradict a recent model for the evolution of the mantle below the Cape Verde Archipelago. We contend that alkali-rich glasses in the Sal xenoliths are not remnants of a kimberlitic melt, but rather they are the result of reaction between the host lava or a similar magma and xenolith minerals, in particular orthopyroxene. The formation of a Si- and alkali-rich glass by host magma – orthopyroxene reaction appears to be a necessary precursor to formation of sieve-textured spinel and clinopyroxene.

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**Furthering understanding of Arctic marine geology through the United Nations Convention on the Law of the Sea**

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In November 2003 Canada ratified the United Nations

Convention on the Law of the Sea (UNCLOS), which establishes under international law the concept of the 200 nautical mile exclusive economic zone (EEZ). Within the EEZ, coastal states exercise sovereignty for the purposes of exploration, exploitation, conservation, and management of natural resources of the water column, seabed, and subsoil. Beyond the EEZ, article 76 of the convention allows countries with wide continental margins to claim jurisdiction of the seabed and subsoil using criteria involving bathymetry, sediment thickness, and geological interpretation of the crust. Along the Atlantic and Arctic margins of Canada the territory potentially claimable under article 76 is equivalent to the area of the three prairie provinces.

The Canadian claim will be based on existing and newly acquired geophysical data including single- and multi-beam bathymetry, spot soundings, gravity, magnetics, and seismic reflection and refraction surveys. The government allocated \$70 million to the Department of Fisheries and Oceans and to Natural Resources Canada in September 2004 to acquire and compile all the necessary data and to prepare the claim, which must be submitted by November 2013.

Remoteness and the presence of sea ice pose significant challenges to data acquisition along the Arctic margin, and little is known about the bathymetry, sediment thickness, and geology especially in comparison with the Atlantic margin. Fortunately, potential Canadian and Danish claims parallel Lomonosov Ridge, which is a 1500–2000 m high by 200 km wide, flat-topped, crustal feature extending 1800 km between the North American and Eurasian plates. This provides the impetus for a joint Canadian and Danish seismic refraction experiment, which will be conducted during April and May of 2006, to determine if Lomonosov Ridge can be used to extend the Canadian and Danish Arctic claims. The experiment, named Lorita-1 (Lomonosov Ridge Test of Appurtenance, phase 1), will also be a valuable step in building logistical support for future UNCLOS data collection programs in the Arctic.

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**Bedrock geology of 21G and 21B,  
New Brunswick geological compilation project**

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In the mid 1980s and early 1990s, 1:50 000-scale bedrock geology maps for central (NTS 21 J), southwestern (NTS 21 B and 21 G), and southeastern (NTS 21 H) New Brunswick were prepared as an initial step in the production of 1:250 000-scale regional geology maps (NR-4, 5, and 6). Since that time, more detailed and up-to-date geological maps have been produced, and a new procedure for digitizing these maps has been implemented. This new procedure involves incorporating digitally updated geological and legend information onto existing 1:50 000-scale geology maps using CARIS. This Geological

Compilation Project was initiated in order to produce a standardized set of 1:50 000-scale bedrock geological maps and new 1:250 000-scale maps for all of New Brunswick for use by exploration companies, municipalities, the public, DNR employees, and other government departments.

Compiling the most up-to-date geological information for the 26, 1:50 000-scale maps encompassing southwestern and southeastern New Brunswick began in January 2004. Currently, 15 of the 26 maps are in the publication stage, and the remaining 11 maps are in various editorial stages. Revision of the 16, 1:50 000-scale maps encompassing central New Brunswick began in April 2005. To date, 10 of those 16 maps have undergone a preliminary review. It is anticipated that the project will be completed early in 2006 upon publication of the remaining maps. Funding for this project is provided by the New Brunswick Department of Natural Resources, Geological Surveys Branch.

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### Schlieren structures in the South Mountain Batholith, Nova Scotia

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Many leucogranites exhibit melanocratic schlieren structures that can form in a variety of ways. Schlieren bands are meter-scale, ellipsoidal, bifurcating, biotite-rich, foliations commonly found near the margin of a granitic pluton. Four localities (Aspotogan, Peggy's Cove, Prospect, and Pennant Point) along the southern contact of the South Mountain Batholith (SMB), Nova Scotia, retain well-developed schlieren bands. These fine-grained biotite-rich structures differ from their coarse-grained hosts only in modal abundance of phases. These intricate structures contain information about the fluid dynamics of the system and also the physical state of the magma at time of formation. Such schlieren are most likely to form in a solidifying granite mush between the rheological percolation threshold (55% crystalline) and the particle locking threshold (75% crystalline). Innovative analogue modeling of a xenolithic block(s) falling from the roof, and a bubble train ascending from the walls simulate the *in situ* schlieren bands in the field. However, the absence of xenolith debris associated with schlieren structures of the SMB implies that their formation is more likely the result of a bubble train passing through a granite mush.

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### Monitoring coastal change in the eastern Canadian Arctic

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During the 1970s and 1980s there was an active coastal mapping program in the Canadian Arctic Archipelago by the Geological Survey of Canada (GSC). Repetitive aerial reconnaissance and ground surveys were initially completed along several of the inner islands and later extended to outer parts of the archipelago including the western shores of Baffin Bay and a small portion of the Arctic Ocean coast. More than 100 shoreline monitoring sites were established where cross-shore survey lines, sediment samples, thaw depth measurements and photographs were collected. Repetitive surveys of these shorelines provide important baseline information for assessing the rates and causes of longer term coastal change.

In 2005, twenty-one shoreline monitoring sites along Lancaster Sound-Barrow Strait were resurveyed to assess their physical changes since our last visit in 1985 or 1992. Three sites had been established at Resolute Bay in 2003. One objective of the 2005 survey was to document whether physical shoreline changes and beach thaw depths have accelerated since the 1970s. Sites selected for resurvey spanned a wide range of environmental conditions. Relative sea level is rising at the east end of Lancaster Sound and falling in Barrow Strait and wave fetch decreases in an east to west direction.

A preliminary analysis of the 2005 surveys suggests shores at the eastern entrance to Lancaster Sound have been significantly reworked by waves. Some barrier beaches have been overwashed by waves and forced landward. Beaches along southern Barrow Strait have been eroded and significantly built up by one or more unknown storms since 1992. Beaches along the north coast of Barrow Strait near Resolute Bay show little or no change since 2003. Thaw depths beneath gravel beaches were deeper than those observed in the 1970s; however, depths of thaw beneath sand beaches were no greater than those observed in 1985.

A new island and potential new barrier beach complex were observed forming off the north coast of Somerset Island. It was not present in 1992. Islands and shore ridges built by sea ice have been observed in the western Arctic but this is our first observation in the eastern Arctic. It provides further evidence of how gravel beaches are initiated on low gradient coasts and the importance of sea ice in beach development.

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### Metallogeny of the Caledonian Highlands, southern New Brunswick: a pilot study

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The Caledonian Highlands consist mainly of volcanic, sedimentary, and plutonic rocks formed in a continental margin magmatic arc complex in combination with later extensional tectonic events over a span of at least 70 million years in the Late Neoproterozoic. The southern and eastern parts of the highlands are dominated by the Broad River Group, an assem-

blage of ca. 620 Ma volcanic and sedimentary rocks with associated co-magmatic plutons. The ca. 560–550 Ma Coldbrook Group, together with related plutons forms most of the western part of the highlands, but also extends into the eastern part, where it is inferred to originally have had an unconformable relationship with the underlying Broad River Group.

The Caledonian Highlands contain numerous mineral occurrences which have not previously been studied on a regional basis. Some mining work took place during the late nineteenth and early twentieth centuries (e.g., Teahan, Lumsden, Chambers Settlement, Vernon) but was discontinued due to poor returns and/or lack of geological understanding. During the 1960s through 1980s, Noranda, U.S. Borax, and Irving Exploration uncovered massive sulphide anomalies which were deemed unprofitable at the time of their discovery. The number of mineral occurrences and the results of previous exploration work suggest that an understanding of the metallogenic processes in the Caledonian Highlands might lead to the discovery of new deposits and a better understanding of known occurrences.

During the summer of 2005, over 70 reported occurrences of mineralization in the Caledonian Highlands were compiled from assessment files. Except for those in the Cape Spencer area, which were excluded from the study for logistical reasons, most occurrences were visited, described, and sampled. The majority are hosted by the Broad River Group, and include vein systems with and without surrounding disseminated mineralization, disseminated systems, fault breccia mineralization, and a few suspected VMS occurrences. Most known occurrences are of the disseminated type, in some places associated with quartz/carbonate veins.

Geochemical and petrological analyses of samples collected during two transects of the alteration system at the Chambers Settlement occurrence have yielded a strong Cu and Mo anomaly, and enriched Bi, As and Hg values, surrounded by an argillic alteration envelope containing pyrophyllite, as confirmed by XRD. Although varying degrees of alteration hamper precise identification of the tuffaceous host rocks, conserved element analyses suggest that there may be at least two different rock populations, with one of them bearing the bulk of the alteration and Cu enrichment. Core samples from the Vernon occurrence and samples from outcrop in the old mine area yielded a Cu anomaly and moderate Ag and As values. Minor Au was reported from one sample. The host rocks contain regional-strike parallel alteration bands which gave Cu, As, and Mo anomalies. Core samples from the Teahan VMS(?) occurrence yielded high Cu, Zn, Pb, and Ag values, with moderate amounts of Hg, As, Cd, and Tl. Geochemical analyses of samples from the waste pile at the Lumsden returned high Cu and Zn values, and moderate Hg, Mo, Bi and Cd values. Identification of conserved elements and PER analysis is expected to help establish mineralization models for these occurrences.

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**Petrographic and chemical variations through  
the Goldenville and Halifax formations, Bear River,  
High Head, and Broad River sections,  
southwestern Nova Scotia**

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The Meguma terrane of southern Nova Scotia is the most outboard terrane of the northern Appalachian orogen. It is characterized by the Meguma Group, made up of the Late Proterozoic(?) – Cambrian Goldenville Formation which consists mainly of thickly bedded, massive metawacke with minor interbedded metasiltstone and slate, and the conformably overlying Cambrian to Lower Ordovician Halifax Formation, composed mainly of slate with thin beds of metasiltstone and metawacke. Although generally interpreted to have formed at a continental margin, whether that continent was Africa or some other peri-Gondwanan area is still debated.

Sedimentary rock geochemistry is a viable tool for regional correlation and provenance studies. During the summer of 2005, samples were collected from three relatively well-exposed stratigraphic sections through the Goldenville and Halifax formations in the Bear River, High Head, and Broad River areas of the Meguma terrane. The purpose of this project is to compare petrographic and chemical data from these samples to look for systematic regional or stratigraphic variations in the Meguma Group. These data will be integrated with other available geological and geochronological data to interpret the depositional/tectonic setting and provenance of the sediments that now form the Meguma Group.

Thirty-five samples were collected, ten samples over a section 12 000 m in stratigraphic thickness in the Bear River area, 12 samples over a section 7600 m in stratigraphic thickness in the High Head area, and 13 samples over a section 3200 m in stratigraphic thickness in the Broad River area. The Bear River section covers the upper part of the Goldenville Formation and the Cunard and Bear River members of the Halifax Formation, whereas the High Head section incorporates most of the Goldenville Formation and the lowest unit in the Halifax Formation. The Broad River section crosses the upper part of the Goldenville Formation and the lowest unit (Cunard member) in the Halifax Formation. The analyzed samples range in SiO<sub>2</sub> content from about 45% to 90%. The Broad River section is bimodal, with pelitic samples (now garnet-staurolite schist) with about 45–55% SiO<sub>2</sub>, and psammitic samples with 75–85% SiO<sub>2</sub>. Samples from the other areas have intermediate SiO<sub>2</sub> contents. A strong positive correlation exists between SiO<sub>2</sub> content and quartz content, whereas an inverse correlation exists between SiO<sub>2</sub> content, chlorite and mica content, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, MgO, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>, and loss-on-ignition. Variation in CaO and Na<sub>2</sub>O are better linked to carbonate and feldspar content, respectively. On tectonic setting discrimina-



tion diagrams, most samples plot in active continental margin or active arc fields. Hence the common interpretation that the Meguma Group was deposited at a passive continental margin may require re-evaluation.

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### Volcanology of the upper cone of the Rockeskyller Kopf volcano, West Eifel volcanic field, Germany

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Rockeskyller Kopf in the West Eifel volcanic field of Germany is a composite volcanic complex that was erupted onto Devonian dolomite at around  $500 \pm 100$  ka BP. The eruption style evolved as interaction with ground- and surface-water decreased; from maar-like deposits in the oldest volcanic edifice to weakly phreatomagmatic scoria deposits topped by a 10–50 m thick lava flow in the youngest part of the complex. The youngest deposits are a scoria cone and lava flow that is exposed in a near perfect radial cross-section in a disused quarry on the west side of the hill. The scoria cone was erupted in three main stages: a) initial crater wall building stage ( $\approx 10$  m thick) that is characterized by poorly layered to massive, subangular, welded scoria, that average 1.25 cm in size. The middle five meters include a succession of coarsening-upwards, ash to 6 cm lapilli, layers. b) The main stage deposits,  $\approx 14$  m thick, exhibit well-developed, meter-scale bedding, with the majority of the units containing lapilli up to 6 cm and bombs as large as 1m. The lapilli are round to subround and vesiculated; bombs range from vesiculated to weakly vesiculated and round to angular. c) Waning stage deposits ( $\approx 12$  m thick) are characterized by a reduction in lapilli size and smaller scale, better defined layering. These deposits comprise  $\approx 2$  cm, vesiculated, and round to subround lapilli, with sparse bombs up to 15 cm.

Bomb size and frequency increase and then decrease along with lapilli size. Several features such as the proportion of basement rock fragments and variations in bomb morphology also highlight this waxing and waning characteristic noted throughout the section. This has implications for the intensity of eruption and magma chamber dynamics as well as the eruption mechanism.

The crater wall deposits are disconformably overlain by crater fill deposits that pinch out at the edge of the crater. These fill deposits are up to 2.5 m thick at the base of the crater and are composed of poorly layered and poorly sorted lapilli averaging 2 cm. Two welded scoria with ash layers are draped over the entire crater wall unit, from the bottom of the crater to the outer most exposure of the wall. The next stage of eruption was dominated by effusive eruption producing spattered material including fragments with flow structures as well as bread crust bombs that filled and spilled over the crater wall.

We interpret the crater wall deposits to have been formed by

Strombolian activity. The initial stage is composed of massive Strombolian deposits with a minor phreatomagmatic component. Within the main stage, the eruption style changed from Strombolian to more phreatomagmatic deposits which are concentrated toward the top of this sequence. In the waning stage activity became less explosive; however, the occurrence of abundant basement rock fragments in these deposits indicates that the eruption had sporadic phreatomagmatic phases. The crater fill deposits are interpreted to be the result of fire-fountaining with the formation of spatter deposits and local bomb-rich horizons. This fire-fountaining activity culminated in the formation of a thick lava flow.

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### Rules of Engagement

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Are terms like *inquiry-based*, *active learning*, and *engagement* simply fashionable buzzwords, or are they important concepts that truly inform the educational process? How can the simple question “What will the learners do?” radically alter the design of lessons and programs? This presentation will explore some simple learning models, interpretive theories, and program development techniques that will help scientists and educators to design and implement genuinely engaging educational experiences. Educational programs developed at the Royal Tyrrell Museum of Palaeontology and Discovery Centre will be presented as examples.

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### Ecomorphodynamics of salt marsh and mudflat systems in the Upper Bay of Fundy

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‘Ecomorphodynamics’ refers to the study of the interaction and adjustment of topography, vegetation, fluid and hydrodynamic processes, morphologies and sequence of change dynamics involving the movement of sediment. These feedbacks are clearly evident within the vast intertidal ecosystems located in the Bay of Fundy. Salt marshes and mudflats represent delicately balanced systems between hydrodynamic forces and ecological, sedimentological and morphological responses. Changes in marsh or mudflat surface elevation within the tidal frame or changes in edge morphology will in turn induce changes in tidal prism, hydrodynamic forces, vegetation community structure, rates of sedimentation and dissipation (marsh platform) or amplification (cliff) of wave energy. The rate of these changes can be significantly influenced by human development such as the construction of tidal barriers or installation of shore protection.

This presentation will examine our current understanding of the sedimentary processes operating within salt marsh and mudflat systems in the Upper Bay of Fundy. It will focus on the integration of meso-scale (decadal/basin wide) quantification of geomorphic changes in the intertidal zone using ArcGIS with micro-scale (seasonal to tidal cycle/marsh level) investigations of the relative and seasonal contributions of biophysical variables controlling sediment accretion and erosion within salt marshes and mudflats of this region. Examples will be drawn from research conducted within the Cumberland and Minas basins over the last decade. In addition, potential forcing functions controlling the ecomorphodynamics and overall evolution and resilience of macrotidal intertidal systems will be explored. These include tidal height, wave climate, tidal channel location, winter conditions, dyking history and engineering structures. Several key observations will be highlighted, namely the importance of waves and ice in controlling and initiating vegetative growth as well as the highly variable and cyclic nature, both in time and space of intertidal geomorphology in the Upper Bay. Fundy salt marshes undergo cycles of progradation and erosion similar to marshes studied elsewhere (e.g., Europe). Mudflat elevations may vary by as much as several meters within one year, returning to the same base level in the spring and are highly dependant on the position of the main tidal channel thalweg. An accurate assessment of the response of these systems to change (e.g., causeway construction or rising sea levels) and the development of valid hydrodynamic models to predict changes in the future requires these systems to be studied at both large and fine spatial and temporal scales. Too often management decisions are made based on spatially limited (e.g., one site) and temporally restrictive (e.g., one season) data. Despite a flurry of research into salt marsh and mudflat processes over the last decade, major research questions remain. These include: quantifying the winter contribution to the overall sediment budget; modeling sediment dynamics (e.g., sediment flux) and wave climate within the inner estuaries of the Upper Bay; determining the cumulative impact of small (e.g., aboiteau) versus large (e.g., causeway) barriers on intertidal geomorphology and how these ecosystems will respond to the removal of tidal barriers both large (e.g., Petitcodiac) or small (e.g., Cheverie).

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#### **Coeval granulites and granites in a metamorphic core complex: the Liscomb complex, Nova Scotia**

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The Liscomb complex is dominated by massive to tectonically foliated, peraluminous granites, mafic intrusive rocks, and high-grade, Bt+Grt+Crd+Sil+Kfs+Pl+Qtz-bearing metapelites and other quartzofeldspathic gneisses, and Opx-bearing metabasites. It constitutes the only known outcrop exposures of the basement to the Cambrian–Ordovician Meguma Group.

The Liscomb gneisses and granites yield overlapping U-Pb (zircon, monazite) ages (377±2, 374±3 Ma, respectively). Moreover, geochemical data confirm that the metapelites and other quartzofeldspathic gneisses are suitable source rocks for the granites. The paucity of migmatitic features in the granulites suggests that the granites were derived from comparable gneisses at deeper crustal levels. Peak metamorphic pressures determined for the Liscomb gneisses and coeval granulite xenoliths in a lamprophyre dyke at Popes Harbour are in the order of 8–6 kbar, respectively, significantly higher than the pressure that has been reported for the crustal level at which the granites crystallized ( $P \approx 3$  kbar). Coupled with the age determinations, this indicates that the Liscomb complex was decompressed through  $\approx 20$  km over a  $\approx 3$  Ma time frame. The available data suggest that these rocks were diapirically emplaced in an extensional setting related to pull-apart tectonics along the Minas Fault. Future work will focus on using mineralogical and microstructural features of the gneisses to reconstruct the decompressional history of the Liscomb complex.

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#### **The Guitard Brook shear-zone hosted As–Au–Ag–Cu occurrence, northern New Brunswick**

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The Guitard Brook As-Au occurrence, located ca. 25 km northwest of Bathurst, is the first significant occurrence of shear-zone hosted Au mineralization recognized in allochthonous mafic volcanic rocks of the Fournier Group of northern New Brunswick. Here, auriferous arsenopyrite-pyrrhotite ± pyrite veins occur within a hydrothermally altered zone that overprints and lies within a zone of high ductile-brittle strain. This small gold deposit is surrounded by deformed slates, greywacke, and conglomerate of the Early to Middle Ordovician Elmtree Group.

The host rocks consist of Ordovician mafic plutonic rocks of the Fournier Group, specifically the Black Point Gabbro, and related narrow ( $\leq 2$ m) fine-grained mafic dykes. The Black Point Gabbro is Llandeilan ( $463.9 \pm 1.0$  Ma) and fine- to coarse-grained ophitic to subophitic gabbro. The basalts are grey to dark grey with greenish to yellow alteration with epidote and/or chlorite. Fractures, filled with quartz, calcite, and hematite, cross the main foliation at a high angle.

Mineralization, in the form of sulphide- and quartz-sulphide veins, and disseminated sulphides occurs within a wider zone of hydrothermally altered (white to yellowish bleached) mafic rocks. The mineralized zone has been intersected, by drilling, over a strike of 400 m and width of 200 m and to depths of 300 m. Gold mineralization is associated with the sulphide-bearing zones, i.e. where arsenopyrite, pyrite, and pyrrhotite are best

developed. The best assay interval from this occurrence is 1.2 g/t Au over drill intersection of 15.5m, with the best single assay of approximately 6 g/t Au.

Mineralization is synchronous with or post-dates the development of penetrative fabric in the host sequence and elevated granophile element contents, i.e. Sn, W, Mo, Pb etc., in the mineralized zone suggest a granite affinity. The Antinouri Lake Granite ( $372 \pm 2$  Ma) is the closest (approximately 9 km to the west) felsic intrusion to the Guitard Brook showing; however, the lack of evidence of contact metamorphism in the study area suggest that this interpretation is equivocal and more work is necessary in order to locate the source(s) for the mineralizing fluids.

Hydrothermal alteration occurs in three zones; 1) distal silicification, 2) proximal silicification and chloritization, and 3) late carbonatization. The chlorite altered zones are marked by moderately negative Eu anomalies that are attributed to feldspar destructive alteration.

Further work will have a two-part focus; 1) determine the origin of the hydrothermal fluids and compare the results to other gold showings in northern New Brunswick, and 2) to determine the principal controls of gold mineralization in relationship to the tectonic evolution of the Elmtree Inlier and the Miramichi Zone.

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### The Alpha-Mendeleev Magmatic Province, Arctic Ocean: A new synthesis

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Since the 1970s, the Alpha-Mendeleev Ridge (AMR) has been considered oceanic by most researchers, with a thickened (ca. 35km from seismic data) crustal or/and abnormally low-density mantle root, and linked to a “hotspot”-type, Cretaceous-aged aseismic ridge, perhaps generated by the controversial Iceland mantle plume. The high amplitudes of AMR magnetic anomalies (locally over 1000nT at 600m flight elevation) were shown by more recent NRL aeromagnetics to be sublinear, largely correlated with  $\pm 20$ mgal free-air gravity anomalies and bathymetric/basement topography. Such correlation is consistent with most or all eruptions/intrusions dating from the long Cretaceous normal polarity interval (120–83Ma). (However, some present basement topography may have formed tectonically, slightly postdating the magmatism).

Building on post-1999 papers by authors such as M. Jakobsson, A. Grantz, Y. Kristoffersen and W. Jokat, multi-beam bathymetry from the 2003 Healy expedition, and other sources, we present a new synthesis of the mid-Cretaceous-age Alpha-Mendeleev Ridge (AMR) complex, a ca. 300–700km  $\times$  1500km Arctic Basin rise ( $>700\,000$  km sq; minimum basement depths  $<1.5$ km and depth residuals of  $+2$ – $3.5$  km relative to normal Cretaceous crust). Bathymetric, aerogeophysical, and terrestrial geology (Canadian Arctic Islands bordering the polar continental margin) suggests magmatism extended over a much larger area than the AMR proper. We compare and contrast the AMR with the Pacific Ontong Java, Shatsky and Hess rises, and the Atlantic Iceland-Faeroe Ridge. Assuming Airy compensation, we calculate  $>10^7$  km<sup>2</sup> (preliminary estimate) excess mafic materials under the AMR, a volume exceeded only by the Ontong Java Plateau.

Multibeam bathymetry collected on *USCGC Healy* in 2003 discovered probable volcanic seamounts in the Northwind Basin and also mapped “Healy Seamount”, rising from the deep Nautilus Basin off the tip of the Chukchi Rise, previously inferred from archival soundings and aerogeophysical crossings. We suggest these edifices, and linear aeromagnetic anomalies—suggesting major dikes or dike swarms crossing the continental Chukchi Rise—are part of the same large, probably extended igneous episode that created the AMR.

Other evidence for a more extensive “AMR Magmatic Province” (AMRMP) includes: 1) Basement peaks/seamounts in the Sever and Peary spurs and Nautilus and Stefansson basins, which together would bring the total AMRMP area to ca.  $10^6$  km<sup>2</sup>; 2) Aeromagnetics, showing AMR-type magnetic and gravity anomaly patterns well beyond the AMR; and 3) Mafic rocks (125–89Ma) of the Sverdrup Basin Magmatic Province (SBMP), as shown by M-C. Williamson and her colleagues. The northeastern SBMP adjoins the polar margin, not far from the poorly dated AMR. The two final SBMP igneous episodes are coeval with AMR magmatism, and comprise ferrogabbroic sills and thin successions of ferrobaltic lavas, a clue that high AMR magnetic anomalies may have a similar origin, as first suggested by Williamson and Van Wagoner in 1985. However, simple amplitude comparison would be incorrect—the higher geomagnetic field intensity near the poles, shallow AMR basement, high AMR basement relief, and possibly stronger middle Cretaceous dipole would all contribute to increasing anomaly amplitudes relative to typical Cenozoic oceanic crust created at lower latitudes. We hypothesize that the AMRMP constitutes a vast mass of anomalously fractionated, highly magnetized FeTi basalts and ferrogabbros. We cannot exclude the possibility of admixed continental crust, especially at the Siberian end of the AMR, and only deep drilling into AMR basement will provide firm answers.

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## Carboniferous tectonics, sedimentation and evaporite mobility in the Cumberland and Kennetcook basins

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The Cumberland Basin of Nova Scotia, a large depocentre in the Late Paleozoic Maritimes Basin, contains a Carboniferous succession that is more than 6 km thick. Industry seismic profiles show unusually good resolution of even steeply dipping reflectors, which can be traced to surface and identified using existing geological maps. The geometry of reflectors provides information on the subsidence history of the basin, and indicates a complex interplay between tectonics and evaporite movement. There is a conspicuous difference in history between the eastern and western parts of the basin.

In the eastern basin, the Pennsylvanian Cumberland and Pictou groups onlap southward on to basement rocks of the Cobequid Highlands, and on to Devonian volcanics of the Fountain Lake Group. However, to the north, in the central part of the basin, the Cumberland Group rests with clear angular unconformity on the late Mississippian Mabou Group, identified by tracing reflections to surface along the flanks of the evaporite-cored Claremont anticline. The Mabou Group is conspicuously wedge-shaped in cross-section, with overall geometry that suggests deposition in a half-graben that subsided into underlying Windsor Group evaporites (also identified by tracing them to surface at the Claremont anticline). However, the southern margin of the Mabou-filled basin is clearly bounded by a normal fault against basement, within which reflections can be traced to outcrop in the Devonian Fountain Lake Group. These relationships indicate that Namurian normal faulting was tectonically initiated but triggered the withdrawal of Windsor Group evaporites. Internal reflections within the Windsor Group suggest earlier episodes of mobility and minibasin formation, probably beginning soon after the deposition of thick lower Windsor evaporites.

In contrast, the western Cumberland Basin, in the Athol syncline area, shows no unconformity at the base of the Cumberland Group. Instead, an extremely thick and variable Cumberland succession overlies a thinner Mabou stratigraphy which does not show conspicuous thickness or facies variation. The Mabou Group in this area appears to rest on an evaporite weld, marking the Pennsylvanian withdrawal of thick Windsor evaporites. Subhorizontal reflections, poorly resolved beneath the evaporite weld, probably represent basal Windsor, Horton, or Fountain Lake Group. They can be traced beneath much of the basin and continue subhorizontally under the north edge of the Cobequid Highlands.

A difference in the orientation of the basin margin between the eastern and western areas may explain the difference in basin history. In the west, the basin margin strikes ENE, whereas

the subsurface fault that bounds the eastern basin strikes almost E-W. In Mississippian time, dextral strike-slip motion along ENE-striking faults in the western basin led to transtension in the east, allowing development of half-graben and triggering expulsion of evaporites during Mississippian time. A change to more E-W tectonic transport in Pennsylvanian time led to transpression in the west, thrusting a wedge of Fountain Lake Group into the basin, and triggering withdrawal of remaining evaporites beneath the Athol syncline. The striking difference between the western and eastern areas has important consequences for resource exploration in the Cumberland Basin.

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## Structure of the western Cumberland Basin: implications for coalbed-methane exploration

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The Cumberland Basin of Nova Scotia, a large depocentre in the Late Paleozoic Maritimes Basin, contains a Carboniferous succession that is probably more than 6 km thick. Previous hydrocarbon exploration has focused on anticlines cored by Mississippian Windsor and Mabou groups, with targets in the underlying Horton Group. New seismic profiles in the Cumberland Basin show reflectors that can be traced to surface, allowing correlation with surface mapping. The basin is currently a target for exploration for coalbed methane.

Subsidence and tectonism in the Cumberland Basin were clearly in part controlled by differential flow of Windsor Group evaporites, which may have begun as early as late Visean time, and which continued intermittently through the Namurian began and Pennsylvanian time. Non-marine clastic units were deposited in synclinal minibasins, and abut against adjacent evaporites or are truncated beneath internal unconformities.

In the western part of the Cumberland Basin, known as the Athol Syncline, the Joggins Formation, famous for preserved upright fossil trees, thins conspicuously eastward onto an evaporite-cored antiform at Springhill. To the south, a transition in the character of reflectivity suggests a lateral facies change, and map relationships indicate that coal-bearing units interdigitate with conglomerates of the Polly Brook Formation. At depth, reflectors identified as representing the Namurian Mabou Group appear to rest directly on basal Windsor Group at an evaporite weld, indicating that the entire thickness of evaporites was evacuated, mainly during Pennsylvanian subsidence. Early Westphalian evaporite withdrawal is largely responsible for the great thickness of coal-bearing Cumberland Group strata.

Contouring of reflections in the seismic profiles provides better definition of the subsurface geometries and potential extent of coal-bearing units in the Athol syncline, presented as a series of time-structure maps for selected horizons. The

subsurface geometries also suggest a number of new exploration targets for this and similar depocentres in the Maritimes Basin. Potential traps for conventional hydrocarbons may be located where thick fluvial sand units abut against salt walls at the margins of minibasins. Coal distribution was strongly influenced by both tectonism and differential withdrawal of evaporites.

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**Controls on VMS mineralization,  
Bathurst Mining Camp, New Brunswick**

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The Middle Ordovician VMS deposits of the Bathurst Mining Camp occur in three groups, namely: Tetagouche, California Lake and Sheephouse Brook groups. Although there are many subtle differences between deposits they can be divided into three categories based on their host rocks, specifically: 1) autochthonous volcanic sediment-hosted massive sulphides, 2) autochthonous volcanic-hosted massive sulphides, and 3) allochthonous sediment-hosted massive sulphide deposits.

The first category includes the majority of the larger massive sulphide bodies: e.g., Brunswick No. 12 (geologic resource 229 MT @ 7.66 wt. % Zn, 3.01 wt. % Pb, 0.46 % Cu and 91 g/t Ag) in the Tetagouche Group and the Caribou deposit ( $\approx$ 70 Mt) in the California Lake Group. All deposits of this group have siliciclastic (locally graphitic) or tuffaceous sedimentary rocks in the immediate footwalls, most display evidence of footwall hydrothermal alteration and metal zoning within the massive sulphide lens, and many have a recognizable vent-complex and stringer sulphide feeder-zone. Most of these deposits are associated with the Nepisiguit Falls Formation (lower part of the Tetagouche Group), which is dominated by quartz-feldspar phyrlic tuff-lavas or crystal tuffs, and volcanoclastic and epiclastic equivalents.

In the eastern part of the Bathurst Camp, Brunswick-type horizon deposits are associated with a laterally extensive, sulphide-capping Fe-rich chemical exhalite (iron-formation) that has been traced for several km's along strike. In contrast, deposits occurring at this stratigraphic level in the western part of the camp lack, or have very poorly developed iron formations. Iron-formation is less well-developed in the upper part of the Tetagouche Group and is not known to occur in the Sheephouse Brook or California Lake groups.

A second type of deposit consists of felsic volcanic-hosted sulphide bodies such as the Armstrong B and Stratmat deposits hosted by feldspar-phyric rocks of the California Lake and Tetagouche groups, respectively. These bodies have felsic rocks in both footwall and hanging wall, are of small (< 3 Mt) size, and commonly do not have well-developed metal zoning or a recognizable vent complex.

A third type of deposit (of which the Canoe Landing Lake

deposit is the only example) consists of resedimented sulphides hosted by sedimentary rocks. This deposit is unique in that footwall hydrothermal alteration, metal-zoning, and stringer-sulphide feeder veins are absent.

Regardless of host rocks, several factors appear to influence the formation and preservation of VMS deposits. Of primary importance is the development of metal-bearing, hydrothermal fluid. This is enhanced by permeable footwall rocks, high geothermal gradient, and contribution to the metal budget by a degassing magma. These fluids may vent in narrowly focused zones or spread out over large areas. Topography, i.e. basin development, is particularly important in terms of concentrating the metal sulphides as is sufficient time to form large deposits. Finally, the local chemistry of the water column is important in terms of preserving the sulphide bodies from oxidation prior to burial by later volcano-sedimentary units.

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**The Kopanoar mud volcano on the Mackenzie  
Shelf, Beaufort Sea: implications for methane  
release on Arctic shelves**

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Fifty sites were sampled for foraminifers as part of the 2004 Canadian Shelf Exchange Study (CASES). A group of species observed on the Kopanoar mud volcano are described, along with the possibility of using the foraminifers to detect methane gas on the shelf and the implications (if any) this may have on the atmosphere.

The samples were taken every centimeter, in two cores, 805A from the top of the mud volcano and 805C from the moat of the mud volcano. Another core, 609A, from a non-mud volcano control site, was sampled every 5 centimeters. The foraminifers in the core samples are typical for the Arctic shelf marine environment and include species such as *Islandiella teretis* and *Elphidium exc. flavatum*. The presence of *Ammotium cassis* in parts of the cores may be an indicator that thermogenic methane is being released from the mud volcano area; along with the possibility of oxidation of biogenic methane in the non-mud volcano area. The presence of *Trochammina macrescens* implies ice transport from salt marshes. This report of *Elphidiella hannai* is the first time it has been found north of Vancouver Island.

The three cores contain 37 species. The > 63  $\mu$  had the highest diversity of formaminifers and the > 45  $\mu$  < 63  $\mu$  had large numbers and relatively few species. The species that were found in the small fraction were normally not found in the >63 $\mu$  size fraction. The 805A sample had formaminifers in the top three centimeters followed by a dead zone with no formaminifers until the 14 centimeter level. This dead zone could be interpreted as a sign of higher than normal methane activity. No such zone was found in the 805C which is at the base of the mud volcano; although there is a good presence of

*Ammotium cassis*. This suggests that, at least during one period of time, there were much higher volumes of methane seepage at the summit of the volcano, than there were at the areas of the other two cores.

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### A paleoecological record of climatic deterioration from middle to late Wisconsinan time on the Interior Plateau of British Columbia, Canada

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The Indianpoint section, 90 km southeast of Prince George, presents a >25 ka record of paleoenvironmental changes from non-glacial Middle Wisconsinan time to just before Late Wisconsin ice from the Cordilleran Ice Sheet overran the site. Detailed plant and insect macrofossil analyses of a 5–6 m thick fine-grained unit reveal that it represents a small lake, based on aquatic plants and insects, and taxa indicative of riparian or shoreline environments. This unit appears to be a large rip up clast in the Late Wisconsinan till. A total of 11 radiocarbon ages, most obtained on willow (*Salix*) twigs provide chronological control for 8 levels. Radiocarbon ages of >44 ka (CAMS-96170) and 46.5 ka (CAMS 93938) were obtained near the base and are associated with spruce macrofossils (abundant needles, seeds and seed wings) and high spruce pollen. Between 37.0 ka (CAMS115785) and 25.9 ka (CAMS117312) alternations between open spruce forest, based on pollen as no spruce macrofossils were identified, and tundra with minor willow and birch. In the upper 2.5 m of the section, between 24.5 ka (CAMS 93940) and 20.4 ka (CAMS 93939), the vegetation changes to dry shrub tundra, dominated again by willow with minor birch. Most pollen from this interval comes from herbs such as sedges, grasses and *Artemisia*. Also present are characteristic insects such as the weevil *Vitavitus thulius* and the ground beetles *Trichocellus mannerheimi*, *Pterostichus (Cryobius) nivalis*, and *Amara alpina* that are presently only found in dry tundra habitats. The decrease in the occurrence of willow and birch in the upper 40–50 cm reflects increasingly harsh conditions as glaciers approached the site. An age of 19.9 ka (AA44045) has been obtained on a willow twig 20–30 cm below where the unit is truncated by a Late Wisconsinan till.

The lacustrine unit of the Indianpoint section spans >25 ka and records climatic deterioration associated with the growth of the Cordilleran Ice Sheet during the Late Wisconsinan. The alternations in the middle portion of the record are thought to represent climatic oscillation recorded in the GISP2 Greenland Ice Core. The increasingly dry and cold conditions indicated by the macrofossil assemblage likely reflect the growth of ice

in the Coast Mountains that would reduce the availability of moisture to the Interior Plateau from Pacific air masses. This is confirmed by reconstruction of the growth of the Cordilleran Ice Sheet during the Late Wisconsinan based on published radiocarbon dates.

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### Canadian Geology 12 – The inspiration point for many future geologists!

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Having made a life-altering career choice which had been greatly influenced by enrolment in a grade 12 geology course, Tracy Webb earned a degree in geology and now has been teaching for more than 20 years. Tracy will give an overview of the grade 12 course offered in Nova Scotia and will present some broader perspectives of earth science from an educator's point of view. The presentations will also include a brainstorming session on how the various geoscience industries can help to support teachers and raise the profile of geology.

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### The application of high-resolution DEMs derived from LIDAR for geoscience

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High-resolution laser altimetry (LIDAR) is applied to geological problems such as bedrock and surficial mapping and local surface processes in two different terrain types in Nova Scotia, Canada. One terrain type represents folded Paleozoic metasedimentary rocks in contact with ca. 370 Ma granite. The other type occurs in the Fundy Basin and represents a Mesozoic rift basin that has been affected by up to 4 ice sheets during the last glaciation. LIDAR data map derivatives have been interpreted for these different geological environments to demonstrate the utility of LIDAR for geoscience applications. All of the areas investigated are covered with dense vegetation that obscures the geological features on aerial photographs.

Subtle topographical differences among three flow units of the Jurassic North Mountain Basalt (NMB) are clearly visible on a LIDAR DEM for the Fundy Basin. Boundaries between flow units extracted from the DEM were verified by field mapping. Several ring structures in the lower flow unit, distinguishable only in the LIDAR data, are interpreted to be the remnants of rootless phreomagmatic cones. Two new sets of surficial landforms have been identified that indicate ice was directed northwestward into the Bay of Fundy during the late stages of glaciation depositing a blanket of till over half of the catchments draining the NMB into the bay.

Contrasting resistance to erosion of beds in folded Ordovician rocks result in subtle ridges visible on the LIDAR DEM. The contacts between the units and information on the structural deformation can be inferred directly from the LIDAR maps. A fold axis is clearly visible and a fault has been interpreted from these data. The morphology of Devonian granite in the area differs significantly from that of the folded metasedimentary rocks allowing the contact between them to be easily defined based on their topographic expression visible on the LIDAR maps. These examples demonstrate that the high-precision and resolution of LIDAR can improve bedrock and surficial mapping and our understanding of how landscapes form and evolve.

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### New constraints on deciphering the origin of the Meguma Group in southwestern Nova Scotia

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Detailed mapping in the Digby to Liverpool area of the Meguma terrane was initiated in 1998 by the Nova Scotia Department of Natural Resources to produce a series of updated geological bedrock maps. The Meguma terrane, includes the Goldenville and Halifax formations (Meguma Group) and the younger White Rock and Torbrook formations, intruded by mainly Devonian plutonic units and overlain by Carboniferous and younger rocks. The new maps, combined with detailed petrography, geochemistry, and geochronology, have better defined the distribution, age, and character of the Meguma Group in southwestern Nova Scotia.

The Goldenville Formation can be subdivided into a lower metasandstone-dominated Green Harbour member, a middle metasandstone/slate Government Point member, and an upper metasiltstone Bloomfield/Moshers Island member. The Green Harbour member, north of Yarmouth, contains a distinctive metasiltstone unit (High Head) with abundant trace fossils including the early Cambrian deep-water ichnofossil *Oldhamia*, suggesting that the Goldenville Formation below the fossiliferous member likely extends into the Neoproterozoic. In the area north of Liverpool, the Green Harbour member contains the Lake Rossignol unit, composed of regularly bedded metasandstone and metasiltstone with a distinct aeromagnetic pattern. The upper part of the Government Point member was shown by earlier workers to contain a Middle Cambrian trilobite faunule of Acado-Baltic affinity. The overlying slate-rich Halifax Formation has been divided into the Cunard and Bear River members. The upper part of the Bear River Member locally contains the graptolite *Rhabdinopora flabelliformis* and acritarch species that are Early Ordovician, suggesting that underlying Cunard, Bloomfield, and Moshers Island members

are of Late Cambrian age, and that a significant unconformity exists between the Halifax Formation and the overlying late Ordovician – Early Silurian White Rock Formation. Both the Goldenville and Halifax formations are locally intruded by swarms of syn-depositional mafic sills of within-plate chemical character. A revised minimum thickness for the Meguma Group is 10 km.

Protoliths of the Goldenville Formation were predominantly immature feldspathic to quartz wackes, whereas protoliths of the Halifax Formation were mainly mudstones. Preliminary whole-rock geochemical data show that most of the clastic material in the Meguma Group was deposited on an active continental margin and (or) oceanic island arc, not on an Atlantic-style passive continental margin. Although a Neoproterozoic Pan-African source is implied for the Meguma Group, the new chemical data combined with recent published work on equivalent units in northern Africa suggest that it was not deposited on the northern margin of Gondwana as previously assumed.

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### First steps in the production of a Geographic Information System for Îles-de-la-Madeleine, Québec

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Current geological knowledge of the Madeleine Basin is almost entirely based on seismic surveys and drilling carried out since the 1960s. For this reason, the Îles-de-la-Madeleine archipelago occupies, at the centre of the basin, a strategic position that enables the groundtruthing of geophysical and borehole data acquired from offshore and aerial surveys. There is agreement in the scientific community that this is an important aspect of the Madeleine Basin's geological framework.

A GIS project is currently underway through a collaborative effort between the Geological Survey of Canada, the Department of Earth Sciences at Dalhousie University, and Mines Seleine. The first step is a formal revision of the current geological map published by D. Brisebois in 1981 to resolve some outstanding questions concerning the volcanic history of the islands. Previous studies have shown that the stratigraphy of the islands is complex, and in places unresolved, particularly along coastal sections where igneous rocks and evaporites have been intensely deformed. Field work in Îles-de-la-Madeleine in August 2005 was conducted along the east-facing coastline of l'île du Havre Aubert, l'île du Cap aux Meules, and l'île Havre aux Maisons, and included a traverse at l'île d'Entrée. In addition, some remarkably well-preserved volcanic rocks were

sampled at quarries and along road cuts. The field programme had two objectives: (1) to define, for the first time, a spatial frame of reference for volcanic rocks associated with the salt structures; and (2) identify key samples of igneous rock for absolute age dating. The results are being applied to a study of the thermal effects of igneous activity and salt diapirism on source rocks, reservoirs, and traps in the Madeleine Basin. Both geophysical and geological databases will be integrated in the GIS to correlate the complex pattern of faults mapped onshore with offshore structures and lineaments identified from marine and aeromagnetic surveys.

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### New 1:250 000 geological map for northern New Brunswick

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New Brunswick Map NR-3, compiled by J.L. Davies in 1979, provides a 1:250 000 overview of the geology of the economically important Bathurst Mining Camp and environs. For twenty-five years NR-3 has been one of the N.B. Geological Surveys Branch's most popular map products; however, since 1979, much of northern New Brunswick has been remapped (notably during the 1994-1999 EXTECH-II project) and scores of new stratigraphic and plutonic units have been introduced. An updated version of NR-3 is therefore warranted to better serve the needs of the exploration community and other client groups. The map coverage has been expanded to the west to include 4 more 1:50 000 sheets, so that it now encompasses all of NTS 21 O, along with 21 P/04, 05, 12 and 13, and 22 B/01 and 02. The number of mineral deposits and occurrences has increased from 54 to 70, including 2 industrial mineral producers. Because of space constraints, only the 51 deposits in the Bathurst Camp with defined tonnage have been included. Also shown on the map are the locations of 54 radioisotopic age determinations. Other geographically referenced data, such as lithochemical sample sites, could be added in response to specific client requests, although high data-density precludes inclusion of this type of information on the primary map product.

As with all modern digital map products, revisions and additions can be quickly and easily carried out as new information is acquired or new interpretations adopted. The map, with its updated geological interpretation of the province's major metal-producing region, will be an important addition to the revamped Minerals website. Website users will also be able to access a list of the many source maps, reports and papers that went into this production – a handy bibliography of Bathurst Camp geology. All bedrock units appearing on the map have been, or soon will be incorporated into the online lexicon of New Brunswick stratigraphy.

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### The Wolves – a missing link in southern New Brunswick geology

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The Wolves islands are located in the Bay of Fundy approximately 10 km offshore from mainland southwestern New Brunswick. Extensive outcrops of bedrock occur along the shores of the five islands that make up The Wolves (East Wolf, Flat Wolf, Spruce, and South Wolf islands and Green Rock). The Wolves are located in a geologically complex area through which it is difficult to trace rock units and terranes from New Brunswick into the state of Maine (USA). Because of their offshore location, The Wolves may provide one of the missing links in these correlations. The Wolves are located along strike of the Neoproterozoic–Cambrian Brookville terrane and the Silurian Kingston terrane, and east of the Oak Bay Fault which may offset these terranes into the Bay of Fundy. Prior to this study, only East Wolf Island had been mapped, and only from the perspective of mineral (gold) exploration.

Based on mapping in 2004 and 2005, the main rock type, which makes up most of The Wolves is medium- to coarse-grained, grey to pink quartz monzodiorite, gradational to monzodiorite. The rocks are unfoliated, except in proximity to small, localized shear zones. They consist of weakly zoned plagioclase, biotite, and amphibole with interstitial quartz and potassium feldspar. The amphibole contains relict cores of clinopyroxene. Cumulate texture is apparent in samples from the more northern islands, but becomes obscured by increasing alteration to the south. Average chemical composition is moderate SiO<sub>2</sub> (56%), relatively high Al<sub>2</sub>O<sub>3</sub> (18%) and low K<sub>2</sub>O (2%). Abundant meta-igneous xenoliths ultimately may provide clues about the petrogenesis of the host rocks, although they vary in mineralogy, texture, and degree of alteration.

The southernmost portion of South Wolf Island is underlain by coarse- to very coarse-grained pink granodiorite. The granodiorite consists of allotriomorphic equigranular plagioclase, quartz, and potassium feldspar with interstitial biotite and amphibole, and displays intense alteration. This rock type is more siliceous than the monzodioritic rocks on the other islands (average 73% SiO<sub>2</sub>), with lower Al<sub>2</sub>O<sub>3</sub> (14.5%) but similarly low K<sub>2</sub>O (2%). It may represent a related but more evolved magma composition.

A sample of quartz monzodiorite from East Wolf Island previously yielded a U-Pb age of 437 ± 5 Ma. Hence most, if not all, of the rocks on the Wolves are significantly younger than and unrelated to the petrologically similar Neoproterozoic to Cambrian granitoid rocks that characterize the Brookville terrane. In contrast, The Wolves rocks are similar in age to volcanic and high-level plutonic units of the more inboard Kingston terrane, but do not resemble those rocks in lithological characteristics. However, the similar ages combined with some chemical similarities, including positive epsilon Nd values, suggest that The Wolves may be linked to the Kingston terrane.



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### Suspended sediment concentrations in the Shubenacadie Canal, Dartmouth, Nova Scotia

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In the fall of 2005 a study in Dartmouth, Nova Scotia, was performed on the concentration and grain size distribution of suspended sediment entering into Lakes Charles and Micmac, and the Shubenacadie Canal during heavy rainfalls. Weekly sampling was carried out to determine 'background' values, and event sampling was performed during heavy rainfalls. One example of a large rainfall event was documented during the October 7<sup>th</sup>–10<sup>th</sup> weekend when Dartmouth received over 100 mm of rain. The Shubenacadie Canal region has a history of increased suspended sediment concentrations due to increased urban development in the local area since the early 1970s. During the summer of 2005, construction resulted in the removal of vegetation from the lands west of the Shubenacadie Canal. Heavy rainfall during this time resulted in sediment washing off the construction site and entering into the lakes, resulting in an increase in visible sediment in the water entering the lakes. Although the water was highly discoloured, the resulting concentrations of suspended sediment were low, ranging between 0.2 – 50 mg/l. Sediment concentrations were higher in portions of the Shubenacadie Canal called the Deep Cut and Grassy Brook during and after rainfall events. Measurements of the grain size of sediments entering the lakes showed that the sediments were clay/silt sized (ranging from 1 to less than 63 µm). During the study both construction companies improved their methods of water retention in the settling ponds to allow suspended sediment time to settle out. The result of this was that after the initial Thanksgiving suspended sediment overflow, the concentrations of sediments entering the lake system during large subsequent rainfall events were reduced.

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### Deep crustal structures as controls on magmatism and copper mineralization in the Urumieh-Dokhtar arc, Iran

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The relationship between basement lineaments, volcano-plutonic suites and distribution of major copper provinces has been studied in three parts of the Urumieh-Dokhtar magmatic arc, using satellite images and geological data. This magmatic arc is the result of the closure of the Neo-Tethys Ocean and the collision of the Iranian and Afro-Arabian plates. The majority of copper deposits and occurrences in this belt are associated

with subduction-related granitoids of Eocene to Miocene age, distributed in the northwestern and central-southeastern parts of the Urumieh-Dokhtar belt. The peak of copper-mineralization occurred in the Miocene. In this study, three mineralized areas were selected for detailed investigation: Shahr-e-Babak (second major porphyry copper belt in Iran: e.g., Mieduk deposit), Sungun (second largest porphyry copper deposit in Iran) and Khezr-Abad (major copper mining district in central parts of the Urumieh-Dokhtar belt). These areas have a semi-arid climate, scarce vegetation and excellent outcrops, making them suitable for the application of remote sensing techniques.

Geological and structural data and the location of the deposits were extracted from Landsat TM and IRS images, and geological maps and reports. Satellite images reveal a pattern of NW-SE faults that cross the central and southeast parts of the Urumieh-Dokhtar belt (Shahr-e-Babak and Khezr-Abad regions). These faults were reactivated during collision and they are intersected by N-S, NE-SW faults. In the northwest region, intersections of old lineaments and the Urumieh-Dokhtar belt are important in localizing porphyry type deposits.

Fracture analysis of mineral deposits, especially of porphyry type, suggests that in the 3 study areas, these deposits were formed in transtensional domains of reactivated faults, intersections of strike-slip faults and intersections of deep lineaments. Therefore, in the Urumieh-Dokhtar magmatic belt, as in other mineralized districts worldwide, brittle fractures associated to orogen-scale strike-slip structures have provided suitable permeability essential in the emplacement of volcanic centres, high-level plutons, and hydrothermal and porphyry type copper mineralization.

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### Primary distribution and possible supergene enrichment of zinc in the Chuquicamata porphyry copper-molybdenum deposit, Chile

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The presence of zinc in hypogene copper sulphides at Chuquicamata has been known from chemical analyses and polished section descriptions for half a century, but it was only in the 1990s, when zinc interfered with innovative metallurgical processes that it was given any attention. Although it has never been recovered, zinc is probably as abundant as molybdenum. The background concentration in the deposit's porphyry rocks (0.010% Zn) is an order of magnitude greater than similar granodiorites elsewhere. Zinc was introduced relatively late in the hydrothermal evolution of the deposit and is strongly structurally controlled. Zinc occurs in sphalerite (ZnS) and in rare tennantite (Cu<sub>12</sub>As<sub>4</sub>S<sub>13</sub> to Cu<sub>10</sub>Zn<sub>2</sub>As<sub>4</sub>S<sub>13</sub>) in which it contains up to 8% Zn. Enargite (Cu<sub>3</sub>AsS<sub>4</sub>) contains up to 2% Zn but in general all other copper sulphides contain less than 0.6% Zn, the detection limit of the microprobe in these assemblages. There are two main styles of sphalerite occurrence: 1) crystals

or grains and 2) rims. 1) Sphalerite grains of up to several millimetres occur in thin veins and disseminated, generally associated with anhydrite ( $\text{CaSO}_4$ ), bornite ( $\text{Cu}_5\text{FeS}_4$ ), covellite ( $\text{CuS}$ ) and enargite; this sphalerite contains little Cu in solid solution, but contains chalcopyrite ( $\text{CuFeS}_2$ ) inclusions and is considered hypogene (primary). 2) Sphalerite thin (2 to 5  $\mu\text{m}$  thick) shells or “rims” coating hypogene digenite ( $\text{Cu}_9\text{S}_5$ ) and often hypogene or supergene covellite and supergene djurleite ( $\text{Cu}_{1.97}\text{S}$ ). Rim sphalerite contains from 1 to 12% Cu, but some of the Cu may be present as intermixed Cu mineral phases. Whereas the grain sphalerite is mainly associated with late veins, the sphalerite coatings or “rims” are distributed in a sub-horizontal blanket that parallels the bottom layer of supergene copper minerals, mainly chalcocite ( $\text{Cu}_2\text{S}$ ). This sphalerite we interpret to be supergene in origin, but this interpretation is still controversial, because supergene sphalerite is extremely rare. Whereas hypogene crystalline sphalerite is relatively easy to separate during flotation and could be recovered economically, the concentration of “rim” sphalerite would carry along Cu that would be difficult to separate metallurgically.

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**Thermal effects of warm fluid circulation associated with the rise of evaporite diapirs in the east-central Sverdrup Basin, Canadian Arctic Archipelago**

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Upper Mississippian to Middle Pennsylvanian evaporites (Otto Fiord Formation) in the Sverdrup Basin have risen diapirically through 6–9 km of Mesozoic and Cenozoic strata of

the Sverdrup Basin, Canadian Arctic Archipelago, and participated in the structural deformation of the Eurekan orogeny in the Paleocene – Eocene. It is also clear that diapirs interacted with Mesozoic mafic magmas at depth, and many diapirs include rafts of intrusive and extrusive basalt. Because evaporite minerals are better conductors of heat than other sedimentary rocks, geothermal heat is preferentially funnelled by deeply rooted diapirs. Although some of this heat is transmitted by conduction, it is apparent that warm fluids have circulated within, peripherally, and in structures associated with diapirs, thus transmitting heat by convection. The evidence for fluid circulation includes various generations of brine fluid inclusions within anhydrite-gypsum, some with hydrocarbons, and crystalline calcite-quartz veins and cemented breccia bodies, some containing sulphides. During field work in 2004, we identified pyritiferous mounds and chimneys where basaltic flows intersect faults at the periphery of evaporite structures, indicating that hydrothermal activity was focused therein. The anomalous thermal effects of diapirs have been recorded in the vicinity of the McGill Arctic Research Station at the head of Expedition Fiord, Axel Heiberg Island in the form of: 1) relatively young apatite fission track ages, for which inverse time-temperature models indicate that the Mesozoic rocks now at the surface may have been at temperatures of nearly 100°C as late as the Miocene, long after the Eurekan orogeny; and 2) the presence of springs where the thick permafrost has melted and brines discharge year round at 5°C irrespective of air temperature. These warm springs host microbial life, and their habitat has been investigated by the McGill group as analogs of potential environments in which to search for evidence of past life on the frozen Mars surface. During the 2005 campaign, a large (>100 × 50 m) exposure of calcite ( $\pm$  pyrite) vein network and calcite-cemented breccia was recognized west of the Thompson Glacier. Their geomorphology, mineralogy and texture suggest that the veins represent the remnant roots of ancient (pre-glacial) springs similar to the presently active ones. We speculate that its warm fluids were in part responsible for the persistent geothermal anomaly recorded in the area by the apatite fission track thermochronology.

