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ABSTRACTS

2001 COLLOQUIUM & ANNUAL GENERAL MEETING

MONCTON, NEW BRUNSWICK

The 2001 Colloquium of the Atlantic Geoscience Society was held at the Delta Beausejour Hotel, Moncton, New Brunswick, on February 9 and 10, 2001. On behalf of the Society, we thank Meeting Chairman Mike MacDonald and his organizing committee (Sandra Barr, Les Fyffe, Susan Johnson, Tom Martel, Mike Parkhill, Ian Spooner, Chris White, and Acadia University Fletcher Geology Club) for providing an excellent meeting. We also wish to thank the corporate sponsors: Noranda Mining and Exploration, PCS Potash (New Brunswick Division), Corridor Resources Inc., and Northstar Energy.

In the following pages, we are pleased to publish the abstracts and oral presentations and posters from the Colloquium, which included the special sessions "Geological correlations between New Brunswick and Maine" (papers from which appear in this issue) and "Onshore and offshore oil and natural gas exploration and related research", as well as the traditional Current Research in the Atlantic Provinces.

The Editors

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X-ray spectroscopic investigations of the hydration structure of aqueous La^{3+} at elevated pressures and temperatures

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The first direct measurements are reported for the structure of the hydrated La^{3+} ion in aqueous solutions over a range of temperatures from 25 to 300°C and pressures up to 1600 bars. The radial distribution of atoms around the La^{3+} ion was measured using the X-ray absorption fine structure (XAFS) technique. La *L*(III)-edge spectra were collected in the fluorescence mode from nitrate solutions in a modified hydrothermal diamond anvil cell using the PNC-CAT X-ray microprobe at the Advanced Photon Source, Argonne National Laboratory. Analysis of these XAFS spectra indicates that each La^{3+} ion has a hydration number of 9 and that the hydration waters surround the ion in a tricapped trigonal prismatic arrangement. As temperature is increased from 25 to 300°C, the bond distance between the equatorial plane oxygens and the La^{3+} ions increases from 2.59 ± 0.02 to 2.71 ± 0.04Å. This study also demonstrates the capability of the modified hydrothermal diamond anvil cell for *in situ* X-ray spectroscopic analysis of a wide range of elements in weakly concentrated systems at elevated temperatures and pressures.

The Pacific Decadal Oscillation and its effects on the climate on northwestern British Columbia and southeastern Alaska

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In order to interpret long-term paleoclimate records from northwestern British Columbia and southeastern Alaska, there is a need to know which regions are most sensitive to decadal-scale climate regime shifts. The Pacific Decadal Oscillation (PDO), a newly identified phenomenon, is an index of North Pacific sea surface temperature changes over the past century and has been shown to exhibit strong decadal-scale regime shifts. The PDO has been positively correlated with North Pacific Pressure Index (NPPI). The NPPI is an index of the Aleutian Low—the low-pressure system that dominates the North Pacific and western North American wintertime climates.

In this study, locations in northwestern British Columbia (Prince Rupert, Smithers, Prince George, and Dease Lake) and southeastern Alaska (Sitka and Juneau) were investigated to determine if there is a relationship between the terrestrial climate of these six locations, and the fluctuations, or regime shifts, associated with the PDO and the Aleutian Low. Wintertime (October to March) mean temperature, total precipitation (rain plus melted snow), total snowfall, and mean sea level pressure data for these sites were obtained from the Canadian Monthly Precipitation Database and the National Climate Data Center and compared with PDO and NPPI regime shifts via time series plots. Next, to better determine the relationship between the PDO and Aleutian Low (NPPI) with the climate at the sites, the PDO and NPPI climate indices were plotted against the climate parameters and regression analysis was performed. The linear relationship was observed qualitatively by observing the slope of the linear trend line, and then quantitatively by determining the strength of the correlation coefficient (R^2 value).

From the results of this study, it was determined that the more southerly locations, Prince Rupert, Smithers, and Prince George, were more sensitive to the PDO and the Aleutian Low regime shifts than the more northerly locations. During the positive PDO phases (indicated by warmer sea surface temperatures) and deepened Aleutian Low phases, mean temperatures are higher and total snowfall is lower (indicated by moderate to strong R^2 values, >0.3), but there is no significant relationship for total precipitation (indicated by weak R^2 values, <0.1). It is suggested that the strong and weak correlation patterns between the PDO and/or a deepened Aleutian Low with the climate in the different study locations may be due to the regional effects of topography and thus regional wind direction and precipitation patterns.

The development of a Geographic Information System environmental hazard prediction model for Cheticamp River, Cape Breton Island, Nova Scotia

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This study documented mass wasting events in the Cape Breton Highlands in an attempt to develop a hazard prediction model using Geographic Information System (GIS) technology. The study area is restricted to the Cheticamp River watershed. Volcanic rocks, volcanogenic sedimentary rocks, and their metamorphic equivalents dominate the area. Soil cover is highly variable and is primarily classified as Rough Mountain Land.

Through literature reviews, interviews, airphotos, orthophotos, and a digital elevation model, 28 debris flows were identified within the study area. The debris flows generally start at the top of the plateau and terminate in the Cheticamp River. Composition ranges from shattered rock, silt, clay, and dead vegetation. The characteristics of these events (slope, aspect, soil cover, surficial sediment, geology, etc.) were evaluated and analyzed, and the information was compiled in a GIS database. The average debris flow has a slope measuring 36.6°, with a range of 27°–45°. Aspect is variable, typically between 337° and 023°. The debris flows are dominated by dead stand or soft wood vegetation. Therefore, areas within the study area that display these characteristics have a high susceptibility to failure. Factors such as surficial sediment, bedrock geology, and soil cover were found to have a limited effect on debris flow potential in this study. The model developed for the Cheticamp River watershed is applicable to much of the Cape Breton Highlands and can be used for slope hazard risk assessment and the planning of future development within this region.

New geological maps of the Pocologan - Saint John area, southern New Brunswick: implications for terrane interpretation

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A series of 1:20,000 scale geological maps have been generated, based on data from new mapping in 1998–2000 in the Pocologan–New River area, combined with previously published data from the Kingston Peninsula (NBDNRE Map Plate 98-16) and previously unpublished data from the Saint John area. The maps include part of the Caledonia terrane in the coastal strip from Saint John to Lepreau, but most of the area covered by the maps is part of the Brookville and Kingston terranes. Map details for the New River terrane to the northwest of the Kingston terrane, and for Carboniferous and younger units in the map area, mainly were compiled from the New Brunswick Department of Natural Resources and Energy map data base.

In the map area, the Caledonia terrane is represented by deformed (in part mylonitic) Late Neoproterozoic volcanic and granitoid rocks of the Coldbrook Group, overlain by sedimentary rocks of the Saint John Group, and by Devonian-Carboniferous volcanic and sedimentary rocks in the Taylors Island - Lorneville areas. The Brookville terrane extends from northeast of Saint John to southwest of the Seelys Cove area. It is represented mainly by varied calc-alkalic plutons ranging in composition from gabbro and diorite to tonalite, granodiorite, and granite. The plutons are mainly ca. 550–530 Ma in age, and have been subdivided into approximately 25 separate units based on rock type. The plutons intruded the Green Head Group (Ashburn and Martinon formations, dominated by marble and metasiltstone, respectively). They also intruded the Brookville Gneiss, a distinctive low-pressure, high-temperature paragneiss unit previously shown to have a maximum depositional age of ca. 640 Ma, and to have been intruded by granitoid rocks (now orthogneiss) at ca. 605 Ma, and metamorphosed at ca. 564 Ma.

The Kingston terrane is dominated by ca. 440–430 Ma arc-related intermediate to felsic metavolcanic rocks of the Kingston Group and co-magmatic granitic plutons, both intruded by abundant amphibolite sheets. Metasedimentary and mafic metavolcanic rocks are a minor component. The Kingston terrane narrows to the southwest, where the granitic rocks and amphibolite sheets form most of the terrane. A fault-bounded belt of distinctive high-grade metamorphic rocks of as yet uncertain age and terrane affinity occurs between the Brookville and Kingston terranes in the Pocologan area.

A suggestion from mid-coast Maine correlation enthusiasts

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Along the Maine coast, beneath Quaternary cover, between expanses of water, and among large volumes of plutons, lie tantalizing scraps of metamorphosed and deformed stratified rocks from Precambrian to Early Devonian age. A few distinctive rock units, traceable (though intermittently) long distances along strike, are generally agreed to correlate into southern New Brunswick: Bucksport and Flume Ridge formations (Silurian); Appleton Ridge and Digdeguash formations (L. Silurian); Penobscot and Calais formations (U. Cambrian–L. Ordovician); Dennys-Edmunds and Long Reach formations (U. Silurian). A few other units of similar lithology and age that appear to be more-or-less on strike, but which have more local occurrence, probably correlate: Megunticook and Crocker Hill formations (Cambrian); Castine Volcanics and Annidale Group volcanic rocks (U Cambrian–L. Ordovician); Ellsworth, Queen Brook (at type locality), and Mosquito Lake Road formations (U. Cambrian).

Problematic rocks of restricted exposure near Penobscot Bay, Maine, include Seven Hundred Acre Island, Islesboro, Rockport, and Benner Hill sequences. Though mutually isolated by faults, these sequences together span a significant portion of Late Precambrian through Late Ordovician time, with apparently (?) no overlap in age. We take them collectively to represent a single fragmented continental basement, whose stratigraphy differs from the Massabesic Gneiss and Miramichi sections to the north and west and from the Caledonia terrane to the southeast. Curiously, this array of rocks near Penobscot Bay includes individual units with presumed protoliths like certain units in the Brookville and New River belts, across strike to the east of the Silurian volcanic belt.

We suggest a unified stratigraphic model in which amphibolite, quartzite, schist, and marble intruded by pegmatite of Seven Hundred Acre Island (=? Brookville Gneiss) are overlain unconformably by Islesboro and Rockport (=? Ashburn), then unconformably by Eocambrian(?) grey sandstone with conglomerate or olistostrome of Simonton Corners (=? Martinon) grading upward into Megunticook. If the Battie conglomerate and quartzite = Matthews Lake conglomerate and quartzite, the Megunticook may partly overlie and partly relate by facies transition to the Ellsworth. Volcanic rocks at the base of the Penobscot would be distal Castine. Overlying Ordovician units (Mosquito Harbor =? Woodland; Hart Neck =? Kendall Mountain; Benner Hill) are missing to the east beneath a Silurian unconformity.

By this model, facies variation, extensional deformation, localized volcanic-arc and back-arc magmatism, thrust tectonics, and strike-slip and dip-slip faulting, all of which are known to be present, account for existing differences in a coherent Late Precambrian-Ordovician terrane whose significantly mangled and shuffled parts extend from the Caledonia fault through the St. Croix belt.

Geology, mineral zoning, and lithogeochemistry of hydrothermal alteration at the El Soldado Manto Type Copper Deposit, Chile

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The El Soldado deposit is a giant (>130 Mt @ 1.5% Cu), representative of volcanic-hosted, stratabound, epigenetic "manto" type deposits of the southern Central Andes. At the district scale the ore is restricted to the Lower-Cretaceous, shallow-marine Lo Prado Formation, composed of bimodal felsic and mafic flow lavas, dykes, and volcaniclastic sedimentary rocks. The deposit consists of numerous irregular ore bodies with intervening barren zones, distributed in clusters. Within the clusters individual subvertical fault-controlled ore bodies occupy a generally NS to NNW regional fracture system and their shape has been influenced by primary and secondary permeability. Brittle "trachyte" in domes and flows is preferentially mineralized.

Hypogene ore minerals are chalcopyrite, bornite, and chalcocite. Many individual ore bodies within a cluster are mineralogically zoned: a core of chalcocite-hematite or chalcocite-bornite-hematite is followed outwards by approximately concentric zones of bornite-chalcopyrite, chalcopyrite, chalcopyrite-pyrite, and pyrite in the most external zone. Part of this external pyrite is diagenetic, related to degraded petroleum, and some developed by sulphurization of Fe- and Ti-bearing minerals, in a pre-ore stage alteration.

Hydrothermal minerals are calcite, chlorite, albite, microcline, epidote, opaline silica, titanite and rutile-anatase, and some sericite and clay minerals. Destruction of titano-magnetite has reduced magnetic susceptibility. Geochemically, alteration caused an increase of $CaCO_3$ and redistribution of alkalis. Na/K increases in most ore zones. Alteration depleted Fe, Mg, and Mn, whereas Ti, Al, Y, Zr, and Nb behaved as relatively immobile elements. The mine unit traditionally called "trachyte" is rhyodacite, and that called "andesite" is, in part, basaltic andesite, both of which are of calc-alkaline affinity.

The evolving genetic model envisages that Cu ores formed about 20-30 My after host rock formation, diagenetic sulphidization, low-grade metamorphism, and tilting of the sequence. Basinal fluids (ca. 350°C, chlorine-rich, oxidizing, neutral to alkaline) extracted Cu from oxidized volcanic rocks in the column. This mineralizing event (ca. 105 Ma) roughly coincides with the emplacement of the Cretaceous batholith that outcrops about 13 km from the mine and which has minor Cu skarns. However, El Soldado ores show no clear isotopic evidence for a direct magmatic kinship with this batholith.

Petrology, depositional environment, and economic potential of sandstone beds within the Horton Bluff Formation in the Windsor region, central Nova Scotia

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A petrological investigation of the Horton Bluff Formation (HBF) in the Windsor area of Nova Scotia focussed on diagenetic controls on porosity development and reservoir potential. The HBF is a sequence of latest Devonian to Tournaisian fluvial- and wave-dominated lake deposits that consist primarily of cyclic grey sandstone with interbedded shale, variable siltstone, greenish-grey mudstone and nodular dolostone.

Coal is common within finer grained units but has little lateral or vertical continuity. Hydrocarbon (as phenol) in concentrations up to 1.3 ppm is common in groundwater seeps from the middle and upper members of the HBF. In general, hydrocarbons averaged 5% to 10% of rock volume in medium- to coarse-grained sandstone, though barren beds were also observed; transport distances within beds appears to be short.

Sandstone beds in the lower and middle members are generally thin (<2 m), compositionally mature, and texturally immature with average porosities of between 6% and 9%. Burial diagenesis is complex. Authigenic clay precipitation, grain alteration, pressure dissolution, and both calcite and silica cementation have resulted in decreased primary porosity. Decarbonatization has resulted in the development of vuggy and perimeter porosity which are best developed in coarser sandstone beds. These beds also commonly show evidence of some hydrocarbon migration. Lack of lateral continuity and low porosities suggest that the lower and middle members of the HBF have reduced reservoir potential. The Hurd Creek Member contains the Glass Sand marker unit (GSmu) which is a medium- to coarse-grained, texturally and compositionally mature sandstone. The GSmu is laterally continuous and can be up to 9 m thick. Much primary porosity has been preserved which has been augmented by secondary porosity. Porosities in this unit average 20% to 25% and, together with evidence of permeability, suggest that the GSmu has enhanced reservoir potential.

$^{40}Ar/^{39}Ar$ traverse across the Reindeer Zone, Trans-Hudson Orogen, Reindeer Lake, Saskatchewan

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The Trans-Hudson Orogen (THO), which extends from South Dakota through the Canadian Shield across Hudson Bay to Greenland, is a dominant component of the North American craton (Laurentia) that formed during a major period of accretion during the Paleoproterozoic. In northern Saskatchewan and Manitoba, the THO comprises juvenile (1910–1830 Ma) arc-related volcanic and plutonic rocks, derived sedimentary rocks, a continental arc batholith, and syn-collisional sedimentary rock assemblages, collectively termed the Reindeer Zone. These lithotectonic terranes are bound by the reworked margins of the Superior craton to the southeast and the Rae-Hearne craton to the northwest. Much of the deformation and metamorphic overprint observed in the orogen is the result of folding and thrust imbrication during convergence and the subsequent continent-continent collision between the Superior and Rae-Hearne cratons ca. 1830–1790 Ma.

In Saskatchewan, from south to north, the Reindeer Zone comprises the Glennie, Kisseynew, and La Ronge domains, the Wathaman Batholith and the Archean Peter Lake Domain, many of which are separated by ductile shear zones. However, metamorphic P-T conditions and U-Pb ages on monazite and titanite grains display little variation across the region from orogen core (southeast) to margin (northwest). Recently, an orogen-scale $^{40}Ar/^{39}Ar$ thermochronological study conducted across the western segment of the Reindeer Zone also revealed consistent ages across domain boundaries, suggesting that the THO cooled as a single block. The current study has been designed to test this interpretation by acquiring $^{40}Ar/^{39}Ar$ data on hornblende and muscovite from single or closely associated samples in a well exposed transect from the core region (Kisseynew Domain) of the orogen internides to the Archean Hearne margin. In some cases, results have been combined with U-Pb data from the same locations to provide well constrained cooling histories across individual lithotectonic domains and domain boundaries in the Reindeer Zone.

Preliminary results from the two southernmost domains indicate cooling to ~500°C at 1780–1740 Ma, and to ~350°C at 1740–1730 Ma. The data acquired thus far supports the hypothesis that this part of the THO most likely cooled as a single block. We believe that thermal equilibration may have been attained during the late stages of crustal thickening or

shortly thereafter, and that erosion may have been the main mechanism by which exhumation occurred.

The geology of the Fogo seamounts

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The Fogo seamounts are located approximately 500 km offshore from Newfoundland and southwest of the Grand Banks. They are early Cretaceous basalts partially buried under slope deposits that mantle a transform fault zone. It is believed that the seamounts formed one of two ways. Seamounts may form either from the relative movement of the lithosphere over a mantle hot spot or develop by magma rising along a linear fault zone. The distribution and age of the Fogo seamounts was studied to decide which of these processes was responsible for their origin.

The seamount distribution, size, and geometry were determined using bathymetry, magnetic data, and seismic reflection profiles. The distribution of the seamounts shows that there is no clear linear trend; instead a broad zone of volcanism is seen across the transform margin. Flat tops of seamounts indicate marine erosion once volcanic activity had stopped, followed by subsidence as the oceanic lithosphere cooled. The flat tops show a complex pattern but are generally deeper to the northwest, suggesting greater time for subsidence in this direction. This observation is supported by biostratigraphic and radiometric data from wells and a dredge sample taken from the area. Age progression appears to be from the northwest to the southeast.

These data support the idea that the seamounts originated from magma that was created by a plume that moved relative to the lithosphere. Reactivated faults then channelled this magma upward, making the Fogo seamounts different from typical seamount chains.

Petrological evidence for extensive liquid immiscibility in the Jurassic North Mountain Basalt, Nova Scotia

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The ca. 201 Ma North Mountain Basalt (NMB) represents a thick sequence of quartz-normative continental tholeiitic basalt erupted within a continental rift. Previous workers have subdivided the basalt sequence into lower, middle, and upper units. The lower unit is dominated by a thick (≤190 m), massive flow, the middle unit (≤50 m) consists of numerous thin (i.e., 5-8 m) flows, and the upper unit (≤160 m) is dominated by a coarse, massive flow. Petrographically, the basalts are described as containing calcic plagioclase, augite, and rarer pigeonite and bronzite, and Fe-Ti oxides, and vary from holocrystalline to variably vitrophyric (≤30%). The local occurrence of thin (1–4 cm) rhyolite bands within pegmatitic gabbro and petrographic evidence of mafic-felsic silicate liquid immiscibility have previously been reported.

In the present study, samples of basalt from throughout the NMB stratigraphy were collected from Cape Split to Digby Neck for detailed petrographic and chemical study (electron microprobe, imaging analysis). The following features are noted. (1) The basalts are dominated by calcic plagioclase (An_{50-70}), augitic pyroxene ($En_{40-50}Wo_{30-40}Fs_{15-40}$), rare bronzite, and rare equant Fe-Ti oxides as an early liquidus phase. Glomeroclasts of plagioclase-pyroxene are rare. (2) The majority of samples contain a mesostasis, which is dominated by skeletal Fe-Ti oxides, Fe-rich clinopyroxene, and apatite with associated granophyre. This mesostasis is interpreted to be a quenched basaltic melt. (3) Where clinopyroxene and plagioclase are in contact with the mesostasis, iron-rich pyroxene (to $En_{10}Wo_{40}Fs_{50}$) and sodic plagioclase (An_{10}) overgrowths occur. (4) A brownish-red to yellow glass occurs, which is locally inundated with dark brown to opaque, micron-size globules, frequently concentrated near adjacent plagioclase grains. Rarer homogeneous glass occurs with skeletal apatite grains. The average anhydrous analysis (n=13) of this glass indicates a felsic composition (in wt. %): 75.3 SiO_2, 0.65 TiO_2, 11.6 Al_2O_3, 3.85 FeO, 1.51 CaO, 0.11 MgO, 4.83 Na_2O, 1.61 K_2O, and 0.44 P_2O_5.

The petrographic and chemical features noted above are similar to those previously documented globally and considered to reflect the petrogenetic process of silicate liquid immiscibility within basaltic melts of quartz tholeiitic composition. The preponderance of these features within the NMB indicates that this process was pervasive. Extraction of these immiscible silicate liquids via filter pressing may account for the presence of rhyolite bands and sills of pegmatitic gabbro and pyroxenite in the NMB.

Seismic stratigraphy and structural setting of the McCully gas field

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The McCully gas discovery is located 11 km northeast of Sussex, in the southwestern part of the Moncton Basin. The gas-bearing interval occurs within sandstone and shale of the Horton Group between depths of 2036 to 2372 m. Lithofacies analysis of these rocks suggests that they are akin to rocks of the Hiram Brook Member of the Albert Formation. However, seismic-stratigraphic correlation to the Will DeMille well suggests the rocks are stratigraphically equivalent to the Frederick Brook Member of the Albert Formation. Spore analyses were inconclusive.

Acoustic logs from the prospective zone show very small differences in the acoustic properties between the sandstone and shale. The seismic velocity in the interval is about 4700 ms^{-1}. Low-amplitude, discontinuous reflections are imaged on existing 2D and 3D seismic data. Seismic markers were mapped at the top (basal Hillsborough unconformity) and the approximate bottom of the gas-bearing interval ("yellow reflector"). The Hillsborough unconformity dips gently to the northwest on a large, basin scale monocline. The "yellow reflector" is gently folded, forming an east-northeast-striking anticline. Consequently, the unconformity intersects the folded Horton Group rocks at different stratigraphic levels within the McCully field. The existing seismic data suggest that the "upper gas sands" are "trapped" by the unconformity, whereas "lower sands" are possibly "trapped" by anticlinal closure.

Regional seismic mapping, in conjunction with outcrop data, suggests that the northern and southern margins of the Moncton Basin in the McCully area are formed by reverse faults. The northern margin is bounded by the Berry Mills Fault. Outcrops of Windsor Group rocks and clear Windsor Group reflections demonstrate that at least 3 km of horizontal movement has occurred on a north-dipping thrust fault. Seismic evidence on the southern basin margin is less clear, but reverse faulting offers one explanation for the relationships observed.

Re-interpretation of the geology of the Cape Breton Highlands using combined remote sensing and geological databases

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The Cape Breton Highlands are underlain by rocks that range in age from more than 1200 Ma to less than 360 Ma, and that display a wide range in composition. Relationships among these varied rocks as revealed by geological mapping are not everywhere clear, in part due to limited exposure, but also due to difficulty of access in some areas. This study was undertaken to try to improve on the geological interpretation of the highlands, especially in those problematic areas, by combining geological and remote sensing databases.

Remotely sensed information used in the study included Radarsat S7, Landsat TM, gravity, magnetic (vertical gradient and total field), radiometric data, and a digital elevation model. The geological, geophysical, and remotely sensed data were integrated into a Geographical Information System, and the resulting datasets were used to evaluate the various geological interpretations of the highlands. The unsupervised classification of the radiometric data (K, eU, eTh, eU/eTh, eU/K, and eTh/K) and the integration of the different image data sets proved to be particularly useful in the interpretation process, especially with the detail of the elevation model that was constructed as part of the project.

The key result of the study is an improved geological interpretation, in particular with respect to geological contacts between known map units in poorly exposed areas, and in the location of major faults and postulated terrane boundaries. Granitoid map units were best detected and distinguished with the radiometric data. For example, the extent of the Bothan Brook Granite was modified and field checked so that the Gold River deposit is now clearly in the contact metamorphic aureole of the granite. The vertical gradient fused with the elevation model and the gravity fused with vertical gradient provided particular insight into separate metamorphic and structural domains within the Highlands. These images clearly show, for example, that the Eastern Highlands Shear Zone is truncated by a major northerly trending structure that appears to merge to the north with the northeasterly trending Aspy Fault.

Fire ecology of a Late Carboniferous floodplain, Joggins, Nova Scotia

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The facies distribution and palaeobotanical identity of fossil charcoal is described from the Upper Carboniferous (Westphalian A-B) Joggins section, Nova Scotia, in order to examine the fire ecology of early Westphalian floodplains.

Three charcoal assemblages are noted. Assemblage (1) consists of channel sandstone bodies, containing beds of calcrete breccia, cordaite logs (up to 3 m long), and coniferopsid wood charcoal. This assemblage records upland coniferopsid forest fires which altered basin hydrology and promoted flooding in downstream floodplain rivers. Assemblage (2) consists of thin (1 to 8 mm thick) coals containing hollow, sigillarian tree stumps and lepidodendrid and medullosan plant compressions. Fifteen of the 29 stumps observed have a 2 to 5 cm thick basal layer infilling the stumps, composed entirely of sigillarian charcoal. Sigillarian and medullosan charcoal is also scattered around the outside of these stumps. This assemblage represents fire in lowland peat-forming communities dominated by Sigillaria and medullosan pteridosperms. These forest fire profiles were slowly buried in floodplain mud. Assemblage (3) consists of a heterolithic sheet sandstone body containing a 2.5 m high sigillarian tree trunk with an internal, basal trunk deposit of sigillarian charcoal and a lightly charred bark rind. This also records fire in lowland sigillarian forests, but, in contrast to (2), this forest fire profile was buried rapidly in a distributary lobe.

Pre-Mesozoic stratigraphy of Grand Manan Island and possible correlation with the Ellsworth terrane in coastal Maine

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The western part of Grand Manan Island is underlain by Mesozoic basaltic flows and sills of the Fundy Group. The Mesozoic rocks are in fault contact to the east with complexly deformed volcanic and sedimentary rocks previously assigned ages ranging from Precambrian to Silurian. Numerous faults transect the pre-Mesozoic sequences and together with polyphase folding and a lack of fossils hamper efforts to establish a reliable stratigraphy. However, lithological similarities have been recognized between some of the fault-bounded blocks during recent mapping. As a result of this work, a preliminary stratigraphic nomenclature for the pre-Mesozoic sequences has been introduced and is summarized below. Radiometric dating of volcanic rocks within the Ingalls Head Formation is in progress to test its proposed Cambrian age. If this age interpretation is confirmed, it will provide convincing evidence that Grand Manan Island is part of the Ellsworth terrane of coastal Maine rather than part of Avalon.

A thick sequence of pre-Mesozoic sedimentary rocks, termed the Grand Manan Group, has been divided into three formations: The Thoroughfare Formation — thick-bedded, white quartzite and dark grey to black carbonaceous shale; Flagg Cove Formation — medium-bedded, greyish pink quartzite and green to grey shale; Great Duck Island Formation — thick-bedded, light grey quartz-pebble conglomerate passing up into medium-bedded, maroon and green silty shale and sandstone. These redbeds suggest some shallowing of the depositional basin just prior to the onset of volcanic activity.

The sequence of sedimentary rocks of the Grand Manan Group is overlain by a sequence of volcanic rocks provisionally assigned to the Ellsworth Group. An apparently conformable stratigraphic contact between the two groups is exposed on Long Island and at Flagg Cove but the boundary is a thrust on The Thoroughfare Formation. Where unfaulted, maroon silty shale of the Great Duck Island Formation is overlain by tuffaceous rocks of the Ingalls Head Formation. The Ingalls Head Formation is characterized by greyish green crystal tuff and purplish breccia interstratified with thin beds and lenses of maroon iron formation. A Cambrian age is suggested for Ingalls Head Formation on the basis of its similarity to the Ellsworth Formation in coastal Maine. Locally pillowed, hyaloclastic, mafic volcanic flows of the Ross Island and North Head formations, exposed in separate fault blocks, are interpreted as contemporary volcanic facies of the volcaniclastic rocks at Ingalls Head, and are, therefore, also included in the Ellsworth Group.

Generally less deformed rocks of the Long Pond Bay and Priest Cove formations are tentatively correlated with the Mascarene Group. The contact between these two north-facing formations is not exposed. The Long Pond Bay Formation is defined to include a sequence of oxidized, coarsely amygdaloidal mafic volcanic flows and interbedded arkosic grit on Wood Island, and a succession of hyaloclastic mafic flows, laminated siltstone and turbiditic sandstone exposed on the southeast coast of Grand Manan Island, itself. The Priest Cove Formation comprises a thick section of greyish green, bedded mafic tuff and volcaniclastic sandstone and minor felsic crystal tuff, underlying much of the northeastern part of Grand Manan Island. Sparse fossil debris in the volcaniclastic rocks of the Priest Cove Formation has previously been used to suggest an age no older than Ordovician. The Long Pond Bay and Priest Cove formations are interpreted to have been deposited in a deepening basin during Silurian time.

Provenance of detrital zircons from the Silurian Oak Bay conglomerate of southwestern New Brunswick

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Determining the provenance of detritus within the Silurian Mascarene Basin is critical to the understanding of the Paleozoic accretionary history of southern New Brunswick. The Mascarene Basin separates Ordovician sedimentary rocks of the St. Croix terrane to the northwest from Precambrian volcanic and plutonic rocks of the Avalon Composite terrane (ACT) to the southeast. The late Llandoverian to Ludlovian Oak Bay conglomerate, basal to the Mascarene sequence, lies with faulted unconformity on Tremadocian black shale of the Saint Croix terrane. A major zone of strike-slip faults marks the contact between the Mascarene and Precambrian sequences so that the depositional relationship between them has not been preserved. Black shale and quartzite pebbles in the Oak Bay conglomerate are derived from the underlying St. Croix terrane. However, the provenance of numerous felsite and granite pebbles in the conglomerate is less obvious. U-Pb dating of detrital zircons in the conglomerate was undertaken using the SHRIMP to delimit possible source areas of these components.

Results from 53 detrital zircons from crushed igneous pebbles and matrix are divided into the following age groups, although large statistical errors inherent in the analytical methodology produces considerable overlap at the younger end of the age spectrum: A) 1099–1567 Ma (6%), B) 705–672 Ma (6%), C) 630–621 Ma (4 %), D) 605–603 Ma (4%), E) 588–531 Ma (62%), F) 526–489 Ma (15%), and G) 479–461 Ma (4 %). Group A zircons are Grenville age and may be xenocrystic in origin; Grenville age rocks are exposed in the Blair River terrane on Cape Breton Island and probably form the basement beneath the Miramichi terrane. Group B zircons have no known source in New Brunswick but igneous rocks of similar age occur in the Mira terrane (ACT) on Cape Breton Island. Group C zircons are likely derived from the Caledonia terrane (ACT) of southeastern New Brunswick. Group D zircons match those of the Brookville terrane (ACT) in southern New Brunswick. Group E zircons are by far the most abundant with those at the older end of the range being sourced from the Caledonia terrane and those at the younger end from the Brookville and New River terranes (ACT) of southern New Brunswick. A zircon age of 540 +/-16 Ma from a granite pebble in the conglomerate falls within this group. Group F zircons are most probably derived from Cambrian volcanic rocks of the Ellsworth terrane in coastal Maine and adjacent New Brunswick. Group G zircons may have their origin in the Ordovician volcanic rocks of the Miramichi terrane underlying central and northern New Brunswick but taking into consideration their large associated errors do not preclude an Ellsworth source.

The presence of Late Neoproterozoic zircons in the Oak Bay conglomerate proves that the St. Croix terrane was amalgamated to the ACT no later than the mid- Silurian. Moreover, the wide range in these ages (705–531 Ma) indicates that the ACT was itself amalgamated by that time if not before. The relationship of these accretionary events to arc volcanism in the Cambrian Ellsworth and Early Silurian Kingston terranes remains to be resolved.

Lithostratigraphy and sediment failure on the central Scotian Slope

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Shallow, late Quaternary sediment failures are widespread along the Scotian Slope and are a concern for offshore hydrocarbon development. During the Wisconsinan glaciation, slope lithostratigraphy was strongly influenced by outer shelf glacial processes and probably is a factor in the location and style of sediment failures. This study focuses on a central region of the Scotian Slope between 63°10'W and 61°10'W, which contains both undisturbed and failed sediment. A seismic stratigraphy has been developed for the region by tracing nine key reflectors throughout Huntec DTS profiles. An associated composite stratigraphic sequence of ~50 meters has been sampled by piston coring specific target areas. A chronology is derived from radiocarbon dating shells and use of ice rafting events (brick red mud and Heinrich layers) of well-documented ages. Within the study area, failed sediment occurs as rotational slumps, bedding plane slides, creep blocks over décollement surfaces, debris flows, and turbidites. Failures begin at water depths of 500 m and continue downslope beyond 2500 m. One prominent décollement surface can be traced upslope where it appears to lie directly above one of several till tongues. At least three of the key reflectors within the seismic profile have acted as either failure planes or as depositional surfaces for failed sediment. Large-scale failures have occurred no more recently than 12 ka. The timing of sediment failures and their relationship to lithostratigraphy are important to predict future events.

Diagenetic and burial history of Upper Carboniferous sandstone, Sydney Basin

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During its working life, the Phalen Colliery near New Waterford experienced natural gas outbursts from the Phalen Sandstone in the colliery roof. The sandstone is up to 30 m thick, with ~15 m of relief on its base, and was deposited from braided channels within a paleovalley. We studied the diagenetic history of this tight gas reservoir in the context of its basinal history, based on >200 core samples from the Phalen and Prince collieries and samples from elsewhere in the basin.

Sandstone porosity is secondary and ranges from 1 to 22%, average 7%, with 6% average for Phalen samples and 15% average for Prince samples. Permeability ranges from <0.01 to 42.5 md, average 0.8 md, with 0.2 md average for Phalen samples and 9.82 md average for Prince samples. Earliest diagenesis in soils and the shallow subsurface generated: reworked mud aggregates; nodules of calcite, siderite, chert and phosphate; grains of Al-rich glaucony; and pyrite cubes and framboids. Glaucony and abundant pyrite suggest local marine waters. At greater depth, euhedral overgrowths formed on quartz grains, and poikilotopic calcite cement occluded most primary porosity. "Floating" grain textures indicate that cementation predated much compaction.

Dissolution of perthitic K-feldspar at near-maximum burial depths generated most of the secondary porosity. Albite lamellae and veins ($An_{<5}$) in many perthitic grains may have formed by alteration within the parent intrusion (deuteric) or during deep burial. Skeletal feldspar grains contain ankerite rhombs, and tiny sphalerite, galena, barite, and siderite crystals. Chlorite at deeper stratigraphic levels probably formed during maximal burial. The Phalen Sandstone contains brine, with up to 176,000 mg/L salinity. The brine probably originated as residual, evaporative fluid during precipitation of Windsor salt, and entered the strata during deep burial.

In Prince Colliery sandstone at ~200-330 m below sea level, calcite cement and, probably, feldspar have been dissolved, resulting in virtual collapse of the rock framework. Many pores contain neoformed kaolinite, illite, quartz, and siderite, indicating that dissolution took place long before present. Dissolution reflects near-surface aggressive fluid — Prince formation fluid is low-salinity and Phalen sandstone at greater depth (~400-700 m) has not undergone dissolution. There is little indication that corrosive fluid from maturing coal and organic-rich shale created secondary porosity within the basin.

Apatite fission-track analysis suggests that burial temperatures exceeded 125°C — probably >160°C if much of the chlorite is diagenetic. Maximum burial depths were attained during the Permo-Triassic, when hydrocarbons probably entered the Phalen sandstone. Sydney Basin strata were at surface by the Early Cretaceous and within reach of aggressive surficial fluids thereafter.

Trace fossils are useful — an example from Willapa Bay, Washington

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Few ichnological paradigms are better accepted than the brackish water model, which has been employed by trace fossil workers for over two decades. Diminutive, low-diversity suites of trace fossils distinguish brackish deposits which are further characterized by distinctive lebenspurren such as *Gyrolithes*, *Teichichnus*, *Planolites*, *Cylindrichnus*, and *Ophiomorpha*. Unfortunately, dividing salinity-stressed trace fossil assemblages into their respective subenvironments is an unresolved problem. However, the delineation of facies in subsurface estuarine-filled incised fluvial systems (IFS) depends on achieving this end.

Willapa Bay, Washington, provides an excellent opportunity to characterize the ichnologic aspects of different subenvironments in IFS. This is due to a well-accepted sedimentologic and stratigraphic framework, which has been developed by Clifton and co-workers. Also, the modern bay provides an analog that can be directly compared to the Pleistocene outcrops, which are well exposed along the bay-margin.

Detailed outcrop studies show that the ichnology of five subenvironments within IFS are distinctive. They are: 1) muddy intertidal flat deposits, which are typically thoroughly bioturbated by a somewhat diminutive suite of various vertically- and horizontally-oriented shafts and burrows cross cut locally by robust crustacean dwellings; 2) unburrowed to rarely burrowed muddy point bar deposits, which are commonly burrowed by minute *Gyrolithes*, *Skolithos*, *Cylindrichnus*, *Planolites*, *Palaeophycus*, and rare bivalve equilibrichnia. 3) sandy point bar deposits, which are similar to the muddy point bar deposits excepting rare to locally abundant *Ophiomorpha* and a preponderance of *Cylindrichnus*-dominated horizons; 4) well to thoroughly bioturbated bay deposits, burrowed by relatively robust forms of *Ophiomorpha*, *Teichichnus*, *Skolithos* and bivalve equilibrichnia, and; 5) locally bioturbated channel bar deposits, typically displaying robust bivalve equilibrichnia, rare *Ophiomorpha*, and deep-penetrating *Skolithos*. Furthermore, traces from both the modern and ancient deposits display marked reductions in size and diversity in the upper estuary.

Ongoing research at Willapa Bay confirms the validity of the brackish water model and presents data which potentially improve our understanding of these deposits. For example, vertically oriented deposit feeding structures, caused by mining, stoping, and burrow switching have been shown by many researchers to be common in estuarine deposits: evidence of these ethologies are present in the Pleistocene record at Willapa Bay and may ultimately help identify ancient IFS.

Evidence of precursor events for mega-thrust earthquakes on the West Coast of North America

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In March 1964, a 9.2 magnitude earthquake occurred just off the coast of Alaska. Since then, research has shown evidence of precursors to the earthquake using both foraminifera and diatoms, thereby detailing a previously unknown sequence of events. This project focuses on a marsh environment lying farther south in Netarts Bay, Oregon, U.S.A. Netarts Bay was also reported to have precursor earthquake events that were discovered using only diatom analysis.

However, the Alaska earthquake offers the possibility to compare a known sequence of events with the geologic record. The Netarts Bay marsh has experienced no modern earthquake events that could be used for comparison but the nature of mega-thrust earthquakes means that the modern and ancient events should be physically similar. One of the previously cored sites was re-cored to resample and re-examine transition zones using foraminifera and thecamoebians. The benefit of using a previously sampled site is that the core has already been dated and zones of transition have already been identified lithologically.

The core used for this project has five visually distinguishable transitions. Previous dating indicates that such events have occurred over a period of 3000 years. Similar studies of differing areas along the West Coast show that mega-thrust earthquakes occur as a cyclic event at a 200–400 year interval. In this study several noticeable changes have been recognized just prior (2–5 years) to the actual earthquake and subsequent tsunami, thereby suggesting a short time scale precursor to large-scale earthquakes.

Seismic velocities and reflection sequences of Wisconsinan glaciation in Emerald Basin (Scotian Shelf)

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Emerald Basin is a 2430 km^2 depression located on the central Scotian Shelf approximately 40 km off the coast of Nova Scotia. Emerald Basin contains four geological units including the Scotian Shelf drift, Emerald Silt Facies A and B and the LaHave Clay. The development of the basin and the deposition of its geological components are a direct result of the Wisconsinan glaciation. The Scotian Shelf Drift is a glacial till and was deposited during the Pleistocene beginning around 50,000 years BP. Emerald Silt Facies A was deposited during a similar time period to the till and is subglacial in origin. Emerald Silt Facies B was also deposited during the Pleistocene, between 32,000 to 16,000 years BP. This unit is proglacial but represents a time of ice retreat when areas of the Shelf were exposed to open water conditions. The LaHave Clay is a post-glacial deposit of Holocene age.

The purpose of this project is to map and detail the seismic properties of the units contained within two sites in the northern section of Emerald Basin using OBS (Ocean Bottom Seismometer) data and air-gun reflection data. Site 1 was recorded by OBS 95-1A and corresponds to an area within the basin. OBS array 95-1A shows velocity values ranging from 1.9 km/s to 2.4 kms^{-1} for three distinguishable layers. Site 2 was recorded by OBS 95-2A and corresponds to area on the Sambro Moraine, which is part of the Scotian Shelf end-moraine complex, and marks the northern boundary of Emerald Basin. OBS array 95-2A shows velocities ranging from 1.9 kms^{-1} to 6.3 kms^{-1}, for four distinguishable layers. A contact between two units in the bedrock, the Cambro-Ordovician metasedimentary rocks of the Meguma Group and the Mesozoic-Cenozoic sediment sequence, runs approximately underneath the moraine complex. The high velocity value of 6.3 kms^{-1} recorded from OBS 95-2A on the moraine agrees with this fact. The OBS array data will be combined with the air-gun reflection profiles to create a two-dimensional model of the surveyed area.

Modifications of gravity interpretations for the Shubenacadie-Stewiacke Carboniferous Basin, Nova Scotia

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Additional borehole information has been used to modify geological interpretations of two gravity profiles across the Shubenacadie-Stewiacke Carboniferous Basin of south-central Nova Scotia. The thickness of the salt-bearing Windsor Group Stewiacke Formation has been adjusted in the new models to account for the gravity anomalies within the Basin. The borehole data also gives increased thickness of anhydrite, limestone, and dolostone in the overlying Windsor Group formations. The increased amounts of these relatively higher density rocks and/or thinning of the lower density halites of the Stewiacke Formation are proposed as the likely cause of the more positive areas of Bouguer gravity within the bounds of the sedimentary basin. These more positive areas define the outline of the more negative area of Bouguer gravity values within the Basin, sometimes referred to as the 'Phoenix anomaly'.

The New Cornwall syenogranite, Nova Scotia: petrology and geochemistry

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The New Cornwall syenogranite is a 1.7 km^2 leucogranite at the southern margin of the Whale Lake monzogranite of the South Mountain Batholith, with a sharp or rapid gradational contact. The syenogranite contains 0.5–4% biotite and accessory primary muscovite, zircon, tourmaline, primary andalusite, and cordierite. Mineralized miarolitic cavities are also common. It has a mean SiO_2 content of 75.8%. Ratios such as A/CNK (~1.25), Rb/K (~215), and Nb/Ta (~3.5) show that the rock is not highly fractionated. Although binary element plots for some elements show the same regular trend for both monzogranite and syenogranite, variation in trace elements such as Rb, Ba, Th, and LREE shows that the syenogranite is not derived from the monzogranite by fractional crystallization. The similarity in P_2O_5 contents in the cores of feldspars for both syenogranite and monzogranite and the greater range of whole rock abundances of P_2O_5 for the syenogranite compared to the monzogranite both also argue against the monzogranite and syenogranite being related by fractionation. Syenogranite has lower Eu and HREE compared with monzogranite. The overall geochemistry of the leucogranitic syenogranite suggests that it was not developed either by open interaction with fluid nor by extreme fractionation. The syenogranite and monzogranite have similar Nd isotope composition, with ε_{Nd} between -1.8 and -2.2, in contrast to the substantial range in ε_{Nd} found elsewhere in the South Mountain Batholith. Similarities in LREE, Nd isotope composition, and some other geochemical indicators between monzogranite and syenogranite suggest that they were derived by partial melting of a common source. Subsequently, both rock types evolved independently by fractional crystallization and late fluids played only a minor role in the evolution of the syenogranite.

Applied Quaternary geology and till geochemistry of the Loch Lomond region, Cape Breton Island, Nova Scotia

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Southeastern Cape Breton Island is host to several former industrial minerals and base metals mines discovered by traditional prospecting methods but present exploration is hampered by a complex glacial history. Late Wisconsinan ice advances resulted in the deposition of five distinct tills. The basal grey till (LL-1) is a compact, fine-grained till found in local depressions. The regional red till contains 10–30% clasts, 20–30% clay, and was deposited by an eastward ice advance (LL- 2). Northward (LL-3) and southward (LL- 4) ice flows were responsible for two hybrid tills that formed in part through inheritance and overprinting. The local stony till was formed by a southeasterly ice flow event (LL-5) and contains 35–75% angular local clasts and less than 10% clay. The southern half of the study area is dominated by 50 m high bedrock cored till ridges. Inter ridge areas are overlain by organic deposits and glaciofluvial sediments which can provide anomalous geochemical values. Till samples were collected at a 3–5 km spacing and the <0.063 mm fraction was analyzed. Till geochemical patterns are complex as a result of lithological repetition, complex glacial history, and numerous mineralization types. Considered together stratigraphic, geochemical, and till pebble data indicate that all 5 stratigraphic units have surface expression in the study area necessitating a multi-tiered interpretation of the geochemical datasets. The re-evaluated data suggest that the regional red till which is located primarily in the Loch Lomond basin is

best suited for the investigation of mineralization which may lie to the west of the study area.

Hybrid tills located east and west of the regional red till provide less useful data due to inheritance from the regional red till and overprinting by younger glacial events. Sampling of local stony tills in the Mira Hills is recommended as the best stratigraphic target to delineate Cu (Au) concentrations in rocks of the Stirling Group. Complex Ba dispersal patterns may require a more detailed sampling strategy for future exploration.

The New River terrane revisited: insights into the relationship with the St. Croix and Ellsworth terranes in New Brunswick and Maine

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The New River terrane, which contains the westernmost exposures of Neoproterozoic rocks in southern New Brunswick, is separated from the St. Croix terrane of the Gander Zone to the northwest by Siluro-Devonian rocks of the Mascarene cover sequence. In the New River terrane, uppermost Lower Cambrian rocks of the Matthews Lake Formation unconformably overlie the Neoproterozoic granitoid rocks. Traditionally, Cambrian rocks in southern New Brunswick are assigned to the Saint John Group of the classic Avalonian cover sequence. Recently dated ash beds from the Saint John Group has allowed for a more precise temporal correlation between these rocks and the Matthews Lake Formation. However, a lithological correlation between the Matthews Lake Formation and coeval rocks in the Saint John Group could not be established. Considering the remarkable uniformity of the Avalonian cover sequence that allows recognition of identical units from Rhode Island to Britain, these important lithological differences strongly suggest that the Matthews Lake Formation is not part of the Saint John Group.

In contrast, strata of the Matthews Lake Formation display many lithological similarities to rocks in the St. Croix terrane along strike in Maine. The Matthews Lake Formation and the Megunticook Formation in the St. Croix terrane contain similar lithological successions comprising quartzite, quartzite-pebble conglomerate, calc-silicate rocks, quartzo-feldspathic wacke, grey shale and coticule-bearing sandstone. The Megunticook Formation has a minimum age of ca. 503 Ma, comparable to the Matthews Lake Formation. The latter also contains rhyolitic to basaltic volcanic rocks that are not present in the Megunticook Formation, but ca. 509 ± 1 Ma rhyolite tuff in the adjacent Ellsworth terrane in Maine is more or less contemporaneous with ca. 514 ± 2 Ma rhyolite in the Matthews Lake Formation. In Maine, the Ellsworth and St. Croix terranes are presently in separate fault blocks, however the correlation with Matthews Lake strata suggests that they were originally in depositional contact.

It has been suggested that the Avalon Zone of southern New Brunswick may be comprised of more than one peri-Gondwanan terrane, a classic Avalonian terrane with Saint John Group cover and a separate peri-Gondwanan terrane with Gander Zone cover. The correlation of the Matthews Lake Formation with rocks of the St. Croix terrane not only implies that the New River, St. Croix and Ellsworth terranes are a single terrane but provides a candidate for Neoproterozoic basement rocks to the Gander Zone.

An integrated structural, fluid inclusion, and stable isotope study of auriferous veins, The Ovens, southern Nova Scotia

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The Ovens area of southern Nova Scotia is underlain by interbedded slate and sandstone of the Meguma Group that were metamorphosed and deformed during the Acadian Orogeny. Rocks outcrop in the hinge zone of a northeast-trending anticline (chevron) and are cut by numerous auriferous quartz veins. Structural analysis of bedding-concordant and -discordant vein types indicates emplacement late in the deformation history during flexural-slip folding. Mutually cross-cutting relationships of the veins suggest synchronous emplacement of all vein types.

Quartz vein material collected from all vein types was examined for fluid inclusions. Results of a petrographic study indicate that inclusions are of secondary and pseudo-secondary origin and record fluid migration during vein formation and subsequent deformation. The presence of abundant imploded inclusions in scheelite and, more rarely, in quartz reflects fluid over-pressuring synchronous with vein emplacement. Petrography combined with thermometric measurements indicate the following inclusion types: (1) L_{H_2O}-V with 4–19 wt. % eq. NaCl and minor amounts of dissolved carbonic species; (2) L_{H_2O}-V-Halite with 30–36 wt. % NaCl; (3) carbonic CH_4- and CO_2-rich types with the latter characterized by very high densities; (4) H_2O-CO_2 with minor CH_4 and 5–10 wt. % NaCl. Isochoric projections combined with homogenization temperatures indicate a potentially large range in entrapment temperatures and/or ambient fluid pressure.

Analysis of 17 quartz vein samples from all structural settings for $\delta^{18}O$ indicate uniform results (avg. = 15.2 ± 0.5‰), implying similar temperature for veins. These data also suggest a uniform fluid reservoir with $\delta^{18}O_{H2O}$ values of 11.2 to 10.0‰, for vein formation temperatures of 400° to 350°C, respectively.

Collectively the structural, fluid inclusion, and stable isotope data suggest the following. (1) Quartz veins formed synchronously late in the folding history of the area from a fluid of uniform temperature and $\delta^{18}O_{H2O}$ value. (2) Fluid inclusion isochores imply a large variation in fluid pressure (i.e., 0.5 to 5 kbar) during vein formation. The large variation in fluid pressure may have influenced episodic flexural-slip fold growth, which is supported by mutually cross-cutting vein types. (3) Variation in the nature of the fluid chemistry may relate to interaction of a saline fluid at variable fluid pressures with graphite-bearing wall rock, thereby generating a fluid with varying CO_2:CH_4 as a function of fO_2. Alternative models involving multiple episodes of vein formation would require the fortuitous coincidence of quartz deposition from fluids of varying temperature and appropriate $\delta^{18}O_{H2O}$ values, which is considered unlikely.

Proterozoic calc-silicate rocks of the Oaxaca complex (southern Mexico): an example of sabkha evaporites

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The Precambrian Oaxacan complex in southern Mexico covers an area of 10,000 km^2. This complex is unconformably overlain by Late Cambrian to Early Ordovician metasedimentary rocks. The complex underwent granulite facies metamorphism during the time interval from 1,100 to 1,000 Ma. The complex is about 15 km thick and includes, in stratigraphic order from the bottom, (1) mafic orthogneiss and anorthosite, (2) migmatite gneiss, (3) paragneiss, (4) metagabbro and syenite, and (5) charnockite. Concordant and discordant bodies (~1.5 m thick) of calc-silicate rocks occur in the paragneiss. The intrusive calc-silicate rocks contain mineral assemblages ranging from titanite + scapolite + diopside + K-feldspar + calcite ± quartz to calcite + scapolite + forsterite + titanite + spinel ± Ca-rich amphibole. These mineral assemblages are consistent with granulite facies metamorphic conditions. U-Pb isotopic dating of titanite in a cross-cutting calc-silicate body yielded a date of 969 Ma that is interpreted as a cooling age. This age is similar to that of the pegmatites in the underlying anorthosite. Geochemically, calc-silicate rocks are characterized by SiO_2 ranging from 5 to 25 wt. % and low Rb/Sr ratios (<0.12). Their low abundances of high-field-strength elements and rare earth elements, which display unfractionated chondrite-normalized patterns, differ from those of carbonatite and skarns. The presence of scapolite, the concordant nature of many calc-silicate bodies, and their stratigraphic position within the sequence suggest that these calc-silicates are sabkha evaporite deposits metamorphosed under granulite facies conditions. These metamorphic conditions induced mobilization of calc-silicate rocks that can account for the dike-like calc-silicate bodies within the Oaxacan stratigraphic sequence. The abundance of these rocks in the Oaxaca complex implies that evaporite environments in Precambrian time were not as rare as generally assumed.

Late-glacial and Holocene stratigraphy of Piper Lake, Pictou County, Nova Scotia: evidence for Younger-Dryas perennial ice cover and sustained landscape instability during the Early Holocene

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Lake sediment stratigraphy and detailed AMS radiometric dating of sediments from Piper Lake, eastern Nova Scotia, reveal changes in productivity, sedimentation, and climate during the Late Glacial and Holocene. Piper Lake is a small, shallow (6 m), closed, glaciated basin located in the highlands of central Nova Scotia. A basal age of ca. 13,500 yr BP indicates that the site was deglaciated well before Younger Dryas (YD) cooling. The presence of gyttja (high LOI) and relatively low carbon/nitrogen (C/N) isotope ratios are indicative of a productive aquatic environment and are consistent with pre-YD warming recognized elsewhere in Nova Scotia. The Younger Dryas inorganic marker horizon (YDimh, 10,800 ^{14}C yr. BP) is a thin, very fine-grained clay layer exhibiting reduced LOI, increased magnetic susceptibility, very low organic carbon and pollen concentrations, and sharp upper and lower contacts with the bounding gyttja. The petrology of the YD oscillation is consistent with decreased sedimentation rates associated with sustained ice cover (glacial advance?) and a hiatus in productivity.

The post YD stratigraphy and preliminary pollen analyses indicates the rapid establishment of an increasingly productive and stable landscape. This trend was abruptly terminated by a thick sediment oscillation (Early Holocene Oscillation, EHO, 9,800–7,800 ^{14}C yr. BP) that exhibited decreased LOI and increased magnetic susceptibility; pollen concentrations are sharply reduced within this unit. The EHO is a diamicton at the base and fines upwards to the contact with the overlying gyttja. The EHO is a consequence of sustained landscape instability and/or ice activity during the Early Holocene. A thin sediment oscillation (7,200–6,800 ^{14}C yr. BP), indicated by a subtle decrease in LOI and increased magnetic susceptibility, is correlative with the HE-5 event. Following this oscillation, consistently high LOI, reduced magnetic susceptibility, and higher C/N ratios provide evidence of a productive lacustrine and terrestrial environment. The lake sediment stratigraphy at Piper Lake demonstrates an unusually robust response to environmental change that may be a result of the unique physical conditions at the site coupled with the reinforcing effect of the regional atmospheric conditions.

Sequence stratigraphy and palynology, Upper Missisauga Formation, Glenelg area, offshore Nova Scotia

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The Glenelg field, situated south of Sable Island in the Scotian Basin, consists primarily of gas reservoirs hosted in Lower Cretaceous sandstone. This study focuses on the sequence stratigraphy of the Upper Missisauga Formation, and extends from the level of the underlying "O-Marker" within the Verrill Canyon Formation to the top of the overlying Naskapi Member of the Logan Canyon Formation. The study uses a combination of conventional core (sedimentology and ichnology), electrical log, and palynological data collected from 5 well sections, integrated with seismic data.

Eight main lithofacies can be recognized, representing primarily deltaic and prodeltaic paleoenvironments, including the notable occurrence of tidally-influenced distributary channels with tidal rhythmites and mud-draped dune-scale crossbedding. At Glenelg, the lower part of the Upper Missisauga Formation appears to have been a fluvial-dominated delta system, while the upper part was more likely wave-dominated. Lithofacies stacking patterns, palynofacies trends, and electrical log trends demonstrate the presence of one major regressive-transgressive cycle from the level of the "O-Marker" (Lower Hauterivian), reaching its regressive acme (sequence boundary) in the lower part of the Upper Missisauga Formation (Barremian). The rest of the Upper Missisauga Formation becomes transgressive, continuing into the overlying Naskapi Member (Barremian-Aptian). Four smaller-scale progradational sequences occur in the same interval and strongly overprint the longer-term trends. They correlate through the Glenelg area, and are probably recognizable in wells up to 10 km away. The occurrence of tidally influenced facies at Glenelg suggests it is close to the margin of the ancient Sable Delta system, which has important implications for the distribution of reservoir sands more distally.

Sequence stratigraphy and hydrocarbon potential of regional Upper Cretaceous limestone units, offshore Nova Scotia

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Two regionally widespread limestone units form important seismic markers beneath the Scotian Margin and the Grand Banks: the Upper Turonian–Coniacian Petrel Member of the Dawson Canyon Formation and the Upper Santonian–Maastrichtian Wyandot Formation. They are typically composed of intensely bioturbated, fine-grained, coccolith-dominated limestone (chalk) with minor amounts of other lithologies, and vary in thickness from a few metres to 400 metres.

Most information about the Wyandot Formation is from drill cuttings, seismic, and wireline data. Only four wells on the Scotian Shelf have conventional core: Eagle D-21, and Primrose F-41, A-41, and 1A A-41. Based upon the cores, trace fossils are dominated by *Zoophycos*, *Thalassinoides*, and *Chondrites*, and are typical of a deep shelf environment below storm wave base, an interpretation also probably applicable to most of the Petrel Member.

Given the significance of similarly-aged chalk reservoirs worldwide (e.g., the Austin Chalk of the Gulf of Mexico and Chalk Group of the North Sea), the hydrocarbon potential of these units as source and reservoir warrants careful evaluation. Significant gas was discovered in the Wyandot Formation on the Scotian Shelf at the Primrose and Eagle structures, and smaller gas shows were tested in the Sable Island E-48 well. There are wireline indications of potential hydrocarbons in other wells. Organic geochemistry indicates TOC as high as 14% in the Wyandot Formation (South Venture O-59) and hydrogen indices from negligible to as high as 493 (Louisbourg J-47). Data from the Petrel Member are less promising. At some well locations (e.g., Venture B-43 and B-52), vitrinite data indicate that both units are in the oil window. Oxygen indices are generally high, suggesting that kerogens are oxidized — consistent with the degree of bioturbation seen in core.

The Petrel Member and Wyandot Formation have been interpreted by several authors as the product of pelagic carbonate sedimentation during maximum transgression and minimal siliciclastic input to shelf environments. Much of the evidence is consistent with this interpretation, but lateral variations in thickness and lithofacies from well and seismic interpretation suggest development of other facies and significant unconformities within and on top of the limestone units.

The petroleum geology of the McCully #1 gas discovery

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The Potash Company of Saskatchewan / Corridor McCully #1 discovery well was drilled for brine disposal and hydrocarbons during the summer/fall of 2000 to a depth of 2,657 m, 11 km northeast of Sussex. The well penetrated 682 m of interbedded sandstone and shale of the Albert Formation. The upper 400 m of this intersection contains between 40 and 60 m of gas-filled sandstone (in four packages), with the best porosity and coarsest grain-size in the lowest package. However, all sandstone layers contain varying amounts of bitumen that reduce porosity and permeability.

The well was drilled with air and flowed at a rate of 2.5 million cubic feet/day (70.8×10^3 m^3) in the lower sandstone package. The gas pressure is 3,500 kPa (500 psi) above the hydrostatic pressure for this depth. This overpressure suggests a thick gas column (500 m+), which could point to a potentially very large field trapped by the regional Hillsborough unconformity. Assuming uniform geology over an area of 4 sections (1,440 hectares), a gas in place volume of 300 billion cubic feet (8.496×10^9 m^3) is calculated.

The depositional environments of the strata are fluvial/deltaic/lacustrine. The thicker shale sequences were deposited in an open lacustrine environment, whereas the upper 3 sandstone packages were deposited in a deltaic system, with or without associated distributary channels. The lower (fourth) sandstone package appears mainly fluvial — possibly braided (low sinuosity) but more likely coalesced meandering stream deposits. It is the main target for future exploration in the vicinity of the McCully well.

Outcrop studies southwest of Sussex suggest that this end of the basin has a major axial-drainage delta system. The clast provenance of these channel systems is dominantly granite, in sharp contrast to the locally derived volcanic and metamorphic clasts in sandstone near the Caledonian Highlands. McCully well sandstone also shows a dominant granitic source, and is interpreted as the deltaic extension of the laterally and vertically extensive axial drainage river systems derived from outside the basin.

Our first goal is to determine the lateral continuity of the lowermost package. Over the longer term, we intend to explore the sandstone of the Hiram Brook Member of the Upper Albert Formation, which were not intersected in the McCully well. This sandstone tends to be thick and porous, and should be intersected in drilling to the south and east.

Resolved Silurian-Devonian stratigraphic correlation across the Québec-Maine-New Hampshire borders and its bearing on Silurian extension

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Prior to 1980, correlations between Québec and Maine/New Hampshire in the Connecticut Valley-Gaspé trough subscribed to the general interpretation that the Devonian Compton Formation in Québec equalled the Seboomook Formation (now Group) in Maine. The Frontenac Formation extended across the border but its age was uncertain. Detailed mapping in the 1980s and 1990s in each area revealed that the Compton and Seboomook belts contained mappable units, but the detailed successions in each area did not agree. Based on abundant younging directions, the Frontenac was placed in the Silurian below the Seboomook in Maine/New Hampshire but its age in Québec remained uncertain — Ordovician to Devonian.

We now recognize: 1) The Frontenac Formation, with two fault-bounded members, of thickly bedded, variably calcareous turbiditic wacke, and local bimodal volcanic rocks of extensional affinity, is Silurian based on preliminary isotope geochronology. Key sections in northern New Hampshire clearly show that the Frontenac is beneath the Compton. 2) Units within the Seboomook and Compton above the Frontenac in all areas share lithologic character but not stratigraphic position. In Maine, the Frontenac is conformably overlain by the Ironbound Mountain Formation, thin to massively bedded mud/siltstone with graded beds and debris flows interpreted as submarine slope/slope-base deposits. Within the formation are distinctive lenses of coarse massive wacke (Grenier Member in Maine, Hall Stream Member in New Hampshire) interpreted as channel deposits. The Ironbound is overlain by well-graded turbiditic sandstone of the Northeast Carry Formation. In Québec, the base of the Devonian section is the Milan Member of the Compton, lithologically identical to the Northeast Carry. This is overlain by the Saint Ludger Member, the lithologic equivalent of the Ironbound Mountain, including the Drolet Member which corresponds to Grenier. 3) These units represent temporally and spatially variable deposition by turbidity current from multiple sources, some deltaic, in a submarine fan/slope environment of a narrow steep-sloped but relatively shallow extensional basin.

The Baring Granite and St. Stephen Gabbro of New Brunswick and Maine: petrology, geochemistry, and tectonic setting

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The Baring Granite and St. Stephen Gabbro are a probable comagmatic suite situated in the area of St. Stephen, New Brunswick and Calais, Maine. The intrusions are traditionally included as part of the Moosehorn Igneous Complex, in addition to the Staples Mountain Gabbro, the Calais Gabbro-Diorite and several small unnamed diorite intrusions, within the Coastal Maine Magmatic Province. They intruded the Cookson Group of the St. Croix terrane of the northern Appalachian orogen, a sequence of quartzo-feldspathic sedimentary rocks, quartzite, carbonaceous pelite, and minor mafic tuff. The age of the intrusions is not well constrained but previous U-Pb geochronology suggested a Silurian age. A suite of samples has been collected from the intrusions for more detailed investigation of the petrology, petrogenesis, tectonic setting, and age.

The St. Stephen Gabbro consists of complexly intermingled olivine gabbro, olivine gabbronorite, and olivine norite, with less abundant gabbro, gabbronorite, norite, troctolite, anorthosite, and dunite. Previous chemical studies are inconclusive with respect to chemical affinity and tectonic setting at the time of emplacement. The pluton hosts numerous discrete sulphide mineralization zones. Mineralization has been interpreted to have formed in two stages, including orthomagmatic (Ni-Cu-Co) mineralization and a later hydrothermal mineralization (Ni-Cu-Zn).

The Baring Granite is coarse-grained, hypidiomorphic, granular, and is composed of microcline, plagioclase, quartz, hornblende, and biotite. Accessory minerals include zircon, apatite, and titanite. The mafic mineral content of the Baring Granite is quite low, generally 10% or less. Locally, the Baring Granite and St. Stephen Gabbro are intensely intermingled, with inconclusive cross-cutting features, such as enclaves and dikes visible at the outcrop scale. Cuspate intermingling textures suggest that the granitic magma intruded the gabbroic rocks prior to complete crystallization. Diorite is typically present between the gabbroic and granitic rocks. The cross-cutting relationships, where a gabbro outcrop is cut by diorite and then by granite may suggest that intense intermingling occurred at the onset of granite intrusion, but became less intense as emplacement of the Baring Granite continued. Comparison of the Baring Granite and St. Stephen Gabbro to other Silurian-Devonian plutons of the Coastal Maine Magmatic Province and equivalent (?) units in New Brunswick such as the Bocabec Complex may help in the definition of terrane boundaries in southwestern New Brunswick and southeastern Maine.

Geology, geochemistry, and hydrothermal alteration of the Lower AB Zone, Halfmile Lake North volcanic hosted massive sulphide deposit, Bathurst, New Brunswick

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The Halfmile Lake (HML) volcanic hosted massive sulphide (VHMS) deposit is one of several that occur in the Bathurst Mining Camp, and one of the largest undeveloped deposits in the district. Composed of several lenses, the deepest being the HML Lower AB Zone, it consists of pyrrhotite-rich breccia-matrix and pyrite-pyrrhotite-rich layered sulphides in a laterally continuous sheet that grades into regional iron formation. An extensive pyrrhotite-chalcopyrite stringer zone stratigraphically underlies the deposit. Mineralization is overturned and hosted by Tetagouche Group metasedimentary and volcaniclastic rocks. Fine-grained metasedimentary rocks interbedded with subordinate fine-grained felsic pyroclastic rocks stratigraphically underlie the deposit. Locally, crystal-rich felsic tuffs and subordinate metasedimentary rocks comprise the immediate stratigraphic hanging wall. This sequence is also cut by quartz- and feldspar-phyric intrusions.

Lithogeochemical evaluation of 222 samples from eleven drill cores through the HML Lower AB Zone indicates the existence of four volcanic compositions: rhyolite, dacite, andesite, and basalt (discriminated using Zr/Ti and Nb/Ti ratios). Although most rhyolite (n=46) and dacite (n=24) rocks are tuffs or flows, most andesite (n=4) and basalt (n=9) rocks are dykes cutting the stratigraphy. Sedimentary rocks (n=139), including two samples of silicate-facies banded-iron formation, exhibit a dacitic composition.

Pearce element ratio analysis of rhyolitic rock types indicate that background compositional variations can be explained by feldspar (predominantly albite) and quartz fractionation in a 3:1 quartz:feldspar molar ratio (2:3 by volume). In contrast, dacitic volcanic rocks exhibit no fractionation. Dacitic sedimentary rocks have compositional variations consistent with quartz fractionation (sorting) only.

The deposit host rocks are metamorphosed, deformed, and hydrothermally altered. Minor calcite occurs mostly within the rhyolite. Hydrolytic alteration is expressed differently in different rock types. With the exception of four completely chlorite altered rocks (daphnite, based on (Fe+Mg)/Al ratios of 3/2), rhyolite is partially to completely muscovite-altered. In contrast, dacitic volcanic rocks are relatively fresh to partially muscovite-altered. Meta-sedimentary rocks exhibit geochemical patterns suggesting that they are weathered equivalents of dacitic volcanic rocks. These likely contained quartz and clay minerals (weathering products; *e.g.* illite and montmorillonite) and subsequently became muscovite and chlorite altered. Sulphide minerals

(pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena in stockwork veins in the stratigraphic footwall) are restricted to rocks containing K/Al ratios <0.36, which corresponds with the stoichiometry of phengite. Because S addition is commonly observed in other VHMS host rocks that are completely muscovite altered (K/Al <1/3), this may suggest that subsequent metamorphic metasomatism (*e.g.*, Mg, Fe, and K addition) modified hydrothermal muscovite into a high-pressure phengite composition.

Type and nature of sulphides in the Whistle-Parkin Offset Dyke, Sudbury impact structure, Ontario, Canada

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The Whistle-Parkin Offset Dyke System is located in the northeast corner of the 1.85 Ga Sudbury impact structure. It strikes north-northeast and extends up to 15 km from the SIC (Sudbury Igneous Complex). The Whistle portion of the Offset Dyke is connected to the SIC via a 350 m wide embayment, in which the INCO Whistle mine is located, and narrows to a width of 10–30 m away from the SIC. The Whistle portion of the dyke extends for ~1.5 km, and is then offset by a ~2 km sinistral fault. The Parkin portion appears north west of the truncated Whistle portion and strikes north-north-eastwards. It maintains a thickness of 20–40 m, becoming thinner at the more distal end.

In the Whistle-Parkin segment rock types can be split into embayment and offset varieties. The lithologies of the Whistle embayment consist of norite, gabbronorite, and gabbro of the Sudbury Sublayer. The lithologies of the actual offset consist of Radial Breccia, Mafic Sulphide Bearing Breccia (MSBB), Inclusion Quartz Diorite (IQD), and inclusion free Quartz Diorite (QD).

The sulphides in the Whistle-Parkin Dyke vary depending on their location within the dyke. The Whistle embayment sulphides are predominantly pyrrhotite and pentlandite. The Whistle dyke sulphides become enriched in Cu with chalcopyrite, pyrite, pyrrhotite, and millerite. Traces of violarite, sphalerite, galena, marcasite, arsenopyrite, and bravoite have also been noted. Sulphides in the Parkin dyke are chalcopyrite, pyrrhotite, and minor pentlandite. The sulphides are found in most of the rock types in the dyke system. They range from blebby sulphides in the Quartz Diorite to massive inclusion-bearing sulphides in the Sudbury Sublayer lithologies.

When has a rounded cobble not traveled far? Recycling of corestones from weathered granitoids: examples from the South Mountain Batholith in Nova Scotia, Canada

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The presence of paleoweathered horizons within the South Mountain Batholith of southern Nova Scotia has been documented in the past but the research presented herein is part of the first comprehensive study of these horizons. Weathered paleosurfaces, or saprolites, occur at several localities on the granitoid rocks of the South Mountain Batholith of Nova Scotia. There are at least two ages of saprolites within the study area, Pre-Triassic and Pre-Carboniferous. Within these *in situ* weathered horizons are remnant elliptical blocks of unweathered granite, or corestones. These corestones are isolated rounded pods of relatively unweathered granitoid material surrounded by extremely weathered sandy material (grus), formed as a result of intense weathering concentrated along joints and fractures within the granitoid rocks. This weathered material which surrounds these corestones is easily eroded thereby releasing many rounded corestones of various sizes, which may be incorporated subsequently into younger sedimentary units. In cases such as these it is clear that the rounded nature of the clasts (corestones) has no direct relationship to distance or mode of transport. The rounded boulders, cobbles, and pebbles of granite within the Pleistocene glacial deposits in southern Nova Scotia were probably the result of incorporation of these saprolite-related structures into the glacial sediments, as evidenced by the locally derived nature of the tills (many within 500 m of source).

The implication of the presence of saprolites at unconformities of various ages on the South Mountain granitoid rocks is that incorporation of corestones into sedimentary strata may have occurred in the past. The recognition of this process has possible implications for the interpretation of rounded boulders, cobbles, and pebbles in conglomerates of various ages within the stratigraphic record of eastern Canada. Similar weathered paleosurfaces have been recognized in many areas worldwide and whenever there might be a possibility of incorporation of corestones into the sedimentary record caution must be exercised in interpreting the origin of such rounded boulders.

Structural orientations, architecture, and timing of auriferous quartz veins associated with mesothermal saddle reef stockwork gold mineralization, The Ovens, Lunenburg County, Nova Scotia

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A 680 m long east-west oriented cliff section of continuous exposure along the north shore of Rose Bay, The Ovens, Nova Scotia, was measured along a reference line to determine the locations, attitudes, and timing relationships of conjugate, thrust-related, and bedding parallel (saddle reef) Au-quartz-sulphide veins within the Cunard Member of the Halifax Formation, Meguma Group. Over 5,400 veins ranging from less than 1 mm to 215 mm wide were observed, and the relationships between the veins and associated structures within the sedimentary rocks were documented. Longitudinal plots and statistical tests, performed to determine whether these veins are randomly or systematically located in space, indicate that these veins exhibit a non-random, approximately uniform distribution within structural domains, and that changes in the abundance and thickness of the veins occur at structural domain boundaries.

Stratigraphic measurements of the host sedimentary rocks reveal a monotonous sequence of fine-grained turbidites over 100 m thick. Cleavage within these sedimentary rocks exhibits distinctive refraction at fine- to coarse-grained bed contacts, and fan cleavage morphology occurs within the coarser grained beds. Geological mapping indicates that two types of thrust faults exist. The first consists of several associated thrust planes that verge north and may have rotated earlier-formed conjugate veins above them (as documented by changes in calculated principle stress orientations). The second thrust type is represented by many smaller back-thrusts that are restricted to the south limb of the anticline and that verge steeply south. These are most abundant along the axis of The Ovens anticline, and commonly host auriferous quartz (spur) veins in orientations sub-parallel-to-slightly shallower than the north limb of the anticline.

Conjugate veins can be constrained to have formed during an extended period of folding and north vergent thrust faulting that involved significant rotation. East and west dipping conjugate veins appear to be synchronous; however, back thrusting and spur veins filling these back thrusts appear to have formed at the same time and after these conjugate veins, based on cross-cutting relationships. Because the spur veins are extensions of north-dipping saddle reef/bedding parallel veins, this suggests that saddle reef/bedding parallel vein formation generally post-dated the earlier conjugate vein formation event.

Cycling of mercury in southwest Nova Scotia: Kejimkujik National Park

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The loons in Kejimkujik National Park have the highest amount of mercury (Hg) of any loon population tested in North America. Determining a source for the Hg is critical for the health and reproduction success of this vulnerable bird. Over the past few years, research scientists involved in the Toxic Substance Research Initiative Mercury Project have been investigating possible Hg sources and processes in the park. Preliminary results suggest that no single source can account for the amount of Hg found in the loons. This study investigates the contribution of natural geological sources to the Hg budget.

This study tests two potential geologic sources for Hg: (1) shear zones located in and around the park, in particular the East Kemptville Shear Zone (EKSZ) and Tobeatic Shear Zone (TSZ) and (2) bedrock, in particular the mafic rocks which are thought to contain more Hg than the felsic rocks. This study also investigates various combinations of published Hg data sets using a Geographic Information System (GIS).

The preliminary results show a strong spatial relationship between the inferred trace of the TSZ and anomalous Hg concentrations. There are no anomalous Hg values along the inferred trace of the EKSZ. The lack of response may be a function of sample distribution, not an absence of Hg in the shear zone. Results for the amount of Hg in the mafic and felsic rocks are pending. The combined GIS data show that Hg levels are the highest in the western part of the park. The western part of the park is underlain by muscovite-biotite monzogranite and has a high percentage of wetlands.

Trace fossils are useful - an example from the Caribbean

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The eastern side of the small island of Carriacou in the Grenadine chain of the Windward Islands, Lesser Antilles, exposes mid-Tertiary siliciclastic and carbonate strata that have been previously subdivided into four formations, namely the Lower Miocene Belmont Formation, the Lower-Middle Miocene Kendeace Formation, the Middle Miocene Carriacou Formation and the Middle Miocene Grand Bay Formation. The Grand Bay Formation, the subject of this contribution, is the most widely (and excellently) exposed sequence, and essentially consists of a sequence of volcaniclastic sandstone with associated interlayered calcareous mudstone and minor conglomeratic horizons.

The most recently published palaeoenvironmental interpretation of this sequence has considered it to be of shallow-water origin. The strata are abundantly fossiliferous, many horizons possessing diverse assemblages of scleractinian corals, isocrinids, terebratulid brachiopods, and, particularly, molluscs. Although uncommon, several of these groups contain borings that include *Caulostrepsis cretacea*, *Caulostrepsis* n. isp., *C.* cf. *taeniola*, *Gastrochaenolites cluniformis*, *G. difugis*, *G. torpedo*, *Oichnus paraboloides*, *O. simplex*, *Petroxestes pera*, *Rogerella* isp., and *Trypanites solitarius*. Soft-sediment ichnotaxa are also present, albeit sporadically. The detailed systematics of these are still under study but the following ichnogenera are prevalent: *Chondrites*, *Diplocraterion*, *Gordia*, *Planolites*, *Scolicia*, *Skolithos*, *Teichichnus*, *Thalassinoides*, and *Zoophycos*.

Collectively, this latter ichnofaunal assemblage compares well with others described from deep-water sequences, particularly those from Cretaceous deep-sea chalks of northern Europe. We suggest, therefore, that the Grand Bay Formation is similarly a deep- and not shallow-water sequence. Our conclusions are supported by both sedimentological and faunal evidence.

Lower Ordovician (Arenig/Llanvirn) fossiliferous volcaniclastic rocks, western New Brunswick and adjacent Maine

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Three newly discovered occurrences of brachiopods in Arenig/Llanvirn-age volcaniclastic rocks in Napadogan area of the Miramichi anticlinorium, New Brunswick link these rocks with the Shin Brook Formation about 125 km to the west in the Weeksboro-Lunksoos anticlinorium in Maine. Beneath these Ordovician volcaniclastic rocks are mudstone and quartz sandstone of the Miramichi Group in New Brunswick and the Grand Pitch Formation in Maine. Accumulations of well rounded pebbles and cobbles of this sandstone, locally as much as 3 m thick, appear here and there at the base of the fossiliferous volcaniclastic rocks. Despite deformation and surficial cover, the present outcrops permit the inference that the older strata were uplifted (Penobscot Orogeny) along rift faults that initiated formation of a back-arc upon Avalonian crust. The volcaniclastic strata in the Napadogan area, as much as several metres thick, are overlain by non-graphitic, varicoloured ribbon slate and slate-chert, commonly manganiferous. The volcaniclastic strata seem to be equivalent to those hosting the Bathurst base metal ore bodies.

Despite the poor preservation of most brachiopod specimens, a few from the newly discovered localities retain features that permit their confident identification as genera that are compatible with those of the Celtic assemblage from elsewhere in Atlantic Canada and beyond. The most distinctive of these in the Napadogan area are several anomalously large dorsibiconvex, fine-ribbed shells from one locality that resemble the rare Baltic genus *Ukoa*. Smaller specimens in the shell beds associated with these probably belong to the genus *Monorthis* that was first described from Arenig-age sandstone on Anglesey, northwestern Wales and later reported from volcaniclastic sandstone of the Suri Formation of the Famatina "System", northwestern Argentina.

Core analysis of the Hiram Brook Member of the Upper Albert Formation, interpretation of the depositional environment, and determination of reservoir prospectivity

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The Hiram Brook Member is Carboniferous in age and is the uppermost member of the Albert Formation (Horton Group). The studied cores are from the Moncton Subbasin of the Maritimes Basin, which is located in southeastern New Brunswick. In this study a portion of one core (Albert Mines 4), totalling 107.4 m in length, is discussed. Detailed

sedimentological data are used to interpret the depositional environment, lateral continuity of sedimentary facies, and reservoir potential of the Hiram Brook Member.

Two lithofacies are recognized in the sedimentological succession. Facies 1 consists of sandy siltstone and comprises the basal part of the Hiram Brook Member. It generally contains low-angle cross beds and abundant pervasive penecontemporaneous soft-sediment deformation. Poorly developed paleosol horizons are locally common. Diagenetic characteristics include minor pyrite mineralization on fractures and the presence of calcite veins. There are no biogenic structures present. However, rootlets, wood fragments, and a fish fossil have been observed.

Facies 2 is a breccia/conglomerate. Facies characteristics include; sharp contacts with erosive bases, steep, poorly defined bedding, and abundant breccia/conglomerate horizons. Clasts consist of metasedimentary rocks, gneiss, and granite and range from angular to rounded. These originate from the Proterozoic to middle Devonian basement complex and are locally derived. This facies is matrix to clast supported. Bedsets characteristically fine upwards. Facies 2 is locally interbedded with facies 1. Trace fossils include *Skolithos*, *Taenidium*, and broad *Arenicolites*.

Analysis of facies 1 indicates a dynamic lacustrine environment that sporadically emerged into the influence of wave reworking. The overall succession indicates cyclic rising and falling of the relative lake level attributed to either, sediment supply or subsidence. Low-angle, thin, parallel lamination reflects rhythmic fluctuations of sediment supply under constant sedimentation. Evidence for event sedimentation include the presence of flame structures that are caused by pulses of sediment being mobilized and rapidly deposited. Abundant graded beds also support this interpretation.

Facies 2 is oxidized and is interpreted to represent a decrease in relative lake level. Large angular clasts indicate a proximal source. Cyclic reduced zones indicate rapid burial generating contrasting geochemical conditions, interrupted by event periods of deposition possibly caused by land-based floods. Bioturbation *(Skolithos)* reflects the pause between event deposits and reflects favourable conditions for colonization. Climbing current ripples suggest unidirectional currents and high sedimentation rates.

Geology of the Newbury Neck 1:24,000 quadrangle, coastal Maine

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In coastal Maine, east of Penobscot Bay, the Cambrian Ellsworth Schist crops out in the Ellsworth-Mascarene terrane between the northwesterly St. Croix terrane and southeasterly Avalonian terranes. Recent 1:24,000-scale mapping in the Newbury Neck quadrangle south of Ellsworth constrains lithologic and structural variations that bear on the regional tectonic evolution of coastal Maine and New Brunswick.

Ellsworth rock types include quartz-muscovite-chlorite schist, greenstone, and metarhyolite, and, at the head of Morgan Bay, impure quartzite and a conglomerate. Chlorite-rich greenschist suggests a reworked volcanogenic protolith for much of the formation. The sheet-form meta-igneous rocks consist of tuff and, locally, sills, indicated by gabbroic texture and possible chilled margins. Igneous sheets and the few clearly-bedded strata are close to flat-lying except where steepened on rare late folds. A subhorizontal lineation, best displayed by elongate quartz phenocrysts in metarhyolite, trends northwest-southeast. Thin quartz laminae and abundant quartz veins define pervasive cm-scale, strongly asymmetric, tight to isoclinal folds that verge southwest to north. The hinge lines are distributed around the gently ESE-dipping plane of the main foliation. Sigmoid quartz laminae and veins and shear bands indicate top-to-the-northwest sense of shear. Greenstone slabs in pelitic schist at the south end of Newbury Neck suggest that the main deformation was locally intense. Crenulation cleavages correspond with the minor and variably oriented late folds. The formation is chlorite-grade except in the aureole of the Blue Hill Pluton where rare, pelitic beds contain andalusite. A late northwest-trending fault is postulated in Patten Bay based on truncation of isograds and steep fractures at Weymouth Point.

West of the map area, pebbles of Ellsworth Schist at the base of the overlying Castine Volcanic rocks (Late Cambrian) indicate an angular unconformity. On Deer Island, 20 km southwest of Newbury Neck, the Ellsworth Schist partially encloses a serpentinite body, which may be an intrusion or a slice of mantle. The serpentinite-Ellsworth contact is sheared, and the serpentinite has a harzburgite protolith with elongate orthopyroxene grains. The strongly bimodal character of the Ellsworth igneous rocks points to extension, which may have exhumed mantle (tectonized harzburgite) in a setting analogous to the Iberian continental margin. The intense top-to-the-northwest deformation and low-grade metamorphism suggest a southeast-dipping convergent boundary active in Late Cambrian time along which rift and mantle rocks were juxtaposed.

The role of chance in exploration: the McCully #1 gas discovery – an example from southern New Brunswick

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A significant gas discovery near Sussex, New Brunswick, was announced in late 2000. The steps leading to this discovery represent an interesting mix of science and serendipity. In the early 1970s the Province of New Brunswick drilled a series of holes on gravity minima suspected of representing Windsor Group, and Albert Formation, salt deposits. The first hole, at Plumweseep, was drilled off the intended target, the crest of the evaporite structure, because of poor quality geophysical data available at the time. However, this resulted in the intersection of a thick sylvinite section within the evaporite sequence, leading to further exploration and eventually to a significant mine being developed east of Sussex.

A recent brine leak into the mine resulted in a 3-D seismic program being carried out, in 1999, to examine the structure of the caprock above the inflow area. The seismic data also showed a potential brine disposal target, at depth, in the unexplored, underlying Horton Group (?). This target was drilled (McCully #1) but the lithology was found to be a tight siltstone, unsuitable for brine disposal. However, beneath these siltstones, more than 40 m of natural gas bearing sands were intersected. The thickness of the sands, together with their aerial extent, and the in situ gas pressure, indicate that the reserves are extensive. The gas discovery in a Horton basin-centre/sub-Windsor salt setting is leading to a shift in gas exploration priorities, together with plans for increased seismic data acquisition and drilling in the area.

As we look forward to the year 2001 hurricane season: remembering the Saxby Gale of 1869

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June — too soon;
July — stand by;
August — look out you must;
September — remember;
October — all over.

Mariner's poem cited in R. Inwards,
Weather Lore (London 1898), p. 86

As anyone knows who has read Sebastian Junger's *The Perfect Storm*, which portrayed the Halloween Storm of 1991, it ain't necessarily 'all over' in October. The late October hurricane of 1991, and Hurricane Hazel which struck the Toronto area with such tragic consequences, are both now believed to be tropical cyclones which, instead of downgrading as they left the energy-giving warmth of the Gulf Stream and came over colder coastal waters, or land, lived to blow another gale. It is thought that these rare, but potentially catastrophic storms, went through an extratropical transition and combined with continental baroclinic systems to become much more deadly storms.

The Saxby Gale of October 4–5, 1869 is also thought to be one of these rare events. It was born in the Caribbean, passed up the U.S. coast some distance offshore, then came ashore in the Maine-New Brunswick border area on the evening of October 4th. The winds on the right-hand side of the anticlockwise rotational storm combined with the forward velocity of the storm to blow straight up to the head of the Bay of Fundy that night. The resultant serious storm surge in the Minas Basin and Bay of Chignecto rose right at the top of a very high perigean (or 'spring') astronomic tide. As a result, the storm surge rose to record levels that may not have been exceeded in historic time.

A comprehensive examination of this storm by the author has raised the death toll to over 100, with many deaths from flooding on the left side of the track. The hurricane winds did structural damage to buildings in the U.S.A.–Canada border area, and there was serious forest blowdown that created a forest fire hazard for the next few years. The storm surge rose over every dyke in Nova Scotia and New Brunswick on the Bay of Fundy, isolated the Minudie Peninsula as an island for a period of time, and took out the bridge between Moncton and Riverview on the Petitcodiac River in New Brunswick.

The development of softwood tree-ring chronologies in Nova Scotia: a tool for palaeoclimate reconstruction, archaeological, and heritage building research

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To date, dendrochronology has not been used to develop climate models in any of the four Atlantic Provinces of Canada. There are no published tree-ring chronologies in spruce or Eastern White Pine, and the one fourteen-tree Eastern Hemlock tree-ring chronology shows some possible erratic signals in the mid-19th century. No archaeological sites and no heritage structures have been previously dated using tree-rings in eastern Canada. Yet with Newfoundland and Nova Scotia jutting well

out into the Atlantic Ocean, there is a real potential for tree-rings to serve as a record, not only of onshore climate, but also of climate imposed by oceanographic changes offshore. Thus the tree-rings of the Atlantic Provinces represent an integrated year-by-year climate archive that is quite unsurpassed and unexplored.

This paper reports on the initial development of softwood tree-ring chronologies in south-central Nova Scotia. A large collection of heritage building samples has been assembled, ranging from the charred beams of St. George's Round Church in Halifax, salvaged after the disastrous 1995 fire, to the massive timbers of Colonel McHaffey's large hand-hewn barn at Windsor Forks. Samples from a dozen heritage structures have been supplemented with a few 'cookies' from living trees. Surprisingly, it has been easier to get samples from heritage structures than to obtain the co-operation of lumber companies and samples from living trees.

Spruce has been found to cross-date with Eastern Hemlock, but not with Eastern White Pine. A 410-year composite spruce/hemlock tree-ring chronology has emerged to date (1572–1982). A slightly longer Eastern White Pine chronology should soon be anchored. The common intraspecies growth trends suggest that the growth of spruce and hemlock over a large area of south-central Nova Scotia has responded to common climatic factors over the past four centuries. In contrast, the tree-ring width records from Eastern White Pine (*Pinus strobus*) are responding to different climatic factors. Over 100 years of temperature and rainfall records exist in the area to allow us to sort out which species are responding to which climatic factors. The first heritage structure of an unknown age has now been dated in Nova Scotia; disassembled, piled on a flatbed truck, and shipped off to the United States to be reassembled in the bars, rec rooms, and casinos of America.

The use of foraminifera and thecamoebians as freshwater/marine transition zones in mangrove environments of southern Florida

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The mangrove environment of southern Florida is expansive, dominating much of the southern coastline, including that of the southwestern Everglades. As such, it is a dynamic environment that is constantly readjusting the balance between fresh and marine waters. A major question about this region is what has happened in the past; it is difficult to reliably distinguish between past marine and freshwater deposits. Since 1995, the United States Geological Survey (USGS) has been engaged in a large-scale project to acquire high-quality, relevant information on the southern Florida ecosystem as part of the USGS's Placed-Based Studies Program. In conjunction with this project, various cores of unconsolidated sediment were collected, the portion of one, Core 15-5, is analyzed in this study.

This study was designed to examine whether or not marine and freshwater Rhizopodia can be used as reliable indicators of freshwater/marine transition zones in the mangrove environment of southern Florida to help reconstruct past freshwater/marine histories. A portion of two cores, Core 15-5 from Little Maderia Bay in Everglade National Park and Core L1011/Hwy 1 from Key Largo, were sampled, processed and analyzed under a stereomicroscope for freshwater thecamoebian and marine foraminifera faunal assemblages.

The results to date demonstrate a marked change in faunal assemblages between the younger calcareous mud and the underlying peat. Thecamoebians are the rhizopods present in the upper calcareous mud layers. Calcareous foraminifera occur in this region, but at much lower percentages than the thecamoebians. Progression through to the underlying peat reflects a transition to dominantly agglutinated marsh foraminifera species and much lower percentages of thecamoebians. Species diversity increased significantly from the upper mud to the underlying peat layers. These results demonstrate that the peat underlying the calcareous mud of the mangrove regions considered here are marine in origin. This demonstrates the utility of rhizopods as indicators of freshwater/marine transition zones, as this result was not obvious through other means of analysis.

The future of the world's oil supply: are we over a barrel?

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Educational outreach activities in Nova Scotia clearly demonstrate a growing public interest in the future of the World's oil supply. While everyone is aware of the price of gasoline at the pump, the geologically determined factors that so strongly influence our oil-based economy are poorly understood. Few of us, even geologists, are well informed about the global distribution of oil, how much has been discovered, how much is left, and how much longer it will be before demand exceeds supply.

Over three-quarters of the World's proven oil reserves are in OPEC countries, and over two-thirds of the World's reserves lie in the Middle East. Only 0.4% and 2% of the World's reserves lie within Canada and the United States, respectively. Considering that there are 41,000 significant oil fields worldwide, it is sobering to learn that all the oil in the Middle East is contained in only 537 fields while U.S. oil resides in 31,000 fields. Indeed, 94% of the World's oil occurs in 3% of all the oil fields.

About 900 billion barrels of oil have been consumed globally since the start of commercial production in the late 1800's. The volume of remaining reserves is known with much less certainty, but most experts estimate the recoverable supply of conventional (i.e., cheap) oil lies between 1,800 and 2,200 billion barrels. So, we are nearing the halfway point. This, in itself, would not be a great concern if the oil simply flowed out of a tap. However finding a Hibernia-sized oil field takes one or two decades of exploration and development work and hundreds of millions or even billions of dollars in capital expenditures. At the current rate of consumption—27 billion barrels per year—all the recoverable oil at Hibernia would last about 11 days. Remember, there are only 370 Hibernia or larger sized fields worldwide.

If the World is to successfully adapt to the oncoming shortage of cheap oil, geologists must play an active role, not only in finding technical solutions but also in education. With projects ranging from "The Last Billion Years" (a popular geology textbook) to organizing teachers' conferences, the Atlantic Geoscience Society offers many opportunities for geologists to communicate objective, meaningful information to the general public. We need to continue and expand upon these existing activities. Barrels of relevant information will gladly be supplied by the authors to those of you willing to help.

Heavy oil accumulations in the Jeanne d'Arc Basin: a case study in the Hebron, Ben Nevis, and West Ben Nevis oil fields

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The possibility of encountering heavy oil (gravity <25° API) has generally been perceived as a significant risk to hydrocarbon exploration in the Jeanne d'Arc Basin, a risk that is heightened by the lack of comprehensive published information on the subject. Hence, the processes responsible for heavy oil in the basin have been evaluated through integration of a broad range of studies, primarily focusing on the data-rich Hebron, Ben Nevis, and West Ben Nevis oil fields.

Compilation of new and previously published geochemical data demonstrates that biodegradation is the principal cause of heavy oil discovered in the basin, although early generation of heavy oil from sulphur-rich source rocks is suspected in a few cases. When evaluating the processes that may have led to biodegradation, events of the mid-Turonian prove to be very important. By this time, the major reservoir rocks of the Ben Nevis and older formations had been deposited and, as confirmed by organic petrology and fluid inclusion studies, had received a significant charge of hydrocarbons. The spatial distribution of paleotemperature, investigated both through forward modeling of basin processes and through inverse modeling of apatite fission track data, was favourable for biodegradation in every reservoir that is known to contain biodegraded oil (i.e., temperature was <60°C). Also, seismic interpretation reveals that significant erosion occurred during the mid-Turonian. Indeed, with the exception of King's Cove A-26, the Petrel Member is less than 20 m thick in every well that encountered biodegraded oil. Elsewhere, especially along the basin margins, the Petrel Member reaches a thickness of 160 metres. The Petrel Member and underlying Nautilus Shale are usually considered seals but, where eroded, may have been breached by circulating meteoric water that supplied nutrients to the oil-bearing reservoirs.

Together, these observations form a template for evaluating the risk of biodegradation which can be applied semi-quantitatively, after appropriate refinement of the models, to areas of the Jeanne d'Arc Basin that are outside the study area and to post-Petrel reservoirs.

Distribution and petrology of sandstone identified in core from the Dawson Settlement Member, Albert Formation (Carboniferous), Moncton Basin, New Brunswick

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Renewed interest in the commercial production of petroleum in the Albert Formation of the Moncton Basin has resulted in new drill-core being available for study. The Boudreau well #1 and the Albert Mines well #4 have been logged and sampled. A similar lithological succession has been identified in the Dawson Settlement Member (lower Albert Formation) of these two wells; sandstone, mudstone and sandstone interbedded with mudstone. The sandstone has a grain size ranging from very coarse to fine, and petroleum is present in some intervals.

Analysis of samples has been by thin section microscopy and Scanning Electron Microscopy. New EDX software has meant that phase mapping of thin sections can calculate precise values for porosity, interstitial phases, and detrital components. Analysis of interstitial phases has confirmed previous studies of the diagenetic history: two phases of dissolution of plagioclase and/or K-feldspars with an intervening event involving carbonate precipitation. The latter phase can be seen in fractures and as disseminated cement in the core.

Trace fossils of eastern Canada: a traveling exhibit prepared by the Nova Scotia Museum of Natural History

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The Nova Scotia Museum of Natural History, with funding from Canadian Heritage, has been preparing a traveling exhibit on the trace fossils of Eastern Canada. The exhibit will be the first of its kind to concern itself exclusively with the science of trace fossils. Approximately twenty specimens from eastern Canada were selected for inclusion within the exhibit based on their palaeontological significance, regional representativeness, or historical significance. The original fossils were replicated using silicone rubber molds and cast with a relatively new material called modified gypsum.

Nova Scotia, New Brunswick, and Québec are endowed with an extraordinarily rich and diverse palaeoichnological history that spans close to 550 million years. Highlights of eastern Canada's palaeoichnological heritage include trackways of the world's second-oldest amphibian and second-oldest reptile. Three parallel trackways of *Amphisauropus latus* provide evidence of the world's earliest herding behaviour in vertebrates. The world's smallest dinosaur trackway was fashioned by the feet of a juvenile *Coelophysis* sp. In close proximity, a prosauropod left behind an impression of its skin to captivate our imaginations. One of the largest insects to roam the Earth 315 million years ago left behind a trace that resembles a train track (*Diplichnites* sp.), while at the same time a pair of horseshoe crabs "frolicked" on a nearby beach (*Kouphichnium* sp.).

Evidence of the Younger Dryas re-activation of a Gulf of St. Lawrence glacier from the "great ditch" of Nova Scotia

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In the summer of 1999, the Maritimes and Northeast Pipeline Company excavated a 3 m deep trench across northern Nova Scotia bordering the Gulf of St. Lawrence to host the Sable Island gas pipeline. The "great ditch" of Nova Scotia exposed a continuous transect of surficial deposits along a 237 km corridor. A paleosol with preserved A horizon (peat and wood) was found buried under 2–10 m of surface till over a wide area of the pipeline route. Ten new sites were sampled and submitted for palynological analysis and radiocarbon dating. The A horizon peaty layer throughout the region is only a few cm thick consisting mainly of herbaceous plant material with few large wood fragments. It is relatively flat and dips under the trench while the trench follows the gently undulating, fluted glacial topography. Till fabric analysis in the upper reddish diamicton, indicated a strong fabric parallel to regional glacial lineations. Radiocarbon dates on large pieces of wood from 2 sites were 10.9 ka (GSC-6435) and 10.8 ka (GSC-6419).

Previous to these finds only two localities revealed till overlying peat, so the extent of Younger Dryas glaciers could not be clearly established. The regional till sheet overlying the soil can be traced to ice-marginal deposits near the Cobequid Highlands to the south, including ice-dammed glaciolacustrine sediments overlying peat found along the coasts of northern Nova Scotia and Cape Breton. Stea and Mott had proposed a glacier around eastern Prince Edward Island to account for the formation of these ice marginal glacial lakes. Glacierization in the Maritimes during the Younger Dryas proceeded simultaneously in the uplands and lowlands by concomitant upland snowfield and lowland aufeis accretion with small remaining outliers of Late Wisconsinan ice acting as "seeds" for incipient glaciers. For photos and a description of the trench discoveries, please view our website (http://www.gov.ns.ca/natr/meb/field/start.htm).

Stratigraphy and structure of the Horton Group in the Lochaber-Mulgrave area, Nova Scotia

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A detailed stratigraphic and structural study has been undertaken of sedimentary rocks in the Lochaber-Mulgrave area of northern mainland Nova Scotia. The sedimentary sequence in this area is bounded on the north by the Glenroy Fault and on the south by the Roman Valley Fault, and has been tentatively assigned to the Early Carboniferous Horton Group. It has been divided into three units (from oldest to youngest): (1) Clam Harbour River Formation, (2) Tracadie Road Formation, and (3) Caledonia Mills Formation. The Clam Harbour River Formation contains polymictic conglomerate, light grey to maroon quartz arenite and siltstone, and minor inter-bedded black laminated siltstone, and is interpreted to have been deposited in an alluvial fan-fluvial environment. The overlying (?) lacustrine Tracadie Road Formation consists of grey to black laminated siltstone interbedded with minor quartz arenite and pebble conglomerate. The overlying (?) Caledonia Mills Formation consists of red to greenish-grey, massive to well laminated, siltstone and slate interbedded with minor pebble conglomerate, and is interpreted to have been deposited in a fluvial-lacustrine environment. Based on lithological similarities, the Clam Harbour River, Tracadie Road, and Caledonia Mills formations closely resemble the Creignish, Strathlorne, and Ainslie formations, respectively, of the Horton Group in western Cape Breton Island. However, the stratigraphic sequence appears opposite to that of similar rocks assigned to the Horton Group in the St. Marys Basin. In addition, the Caledonia Mills Formation closely resembles red siltstone exposed west of Lochaber that, based on fossils, has been assigned to the Silurian Arisaig Group.

In comparison to the Horton Group in other areas, the rocks in the Lochaber-Mulgrave area are highly deformed. The western part of the area has open to tight, upright to overturned, northeast- and northwest-trending folds with well-developed axial planar cleavage. The eastern part of the area has tight to closed, upright, north-south-trending folds with moderately developed axial planar cleavage. The folded axial plane traces and the scattered cleavage orientations indicate that the area has undergone polyphase deformation and is much more structurally complex than previously thought. Possible complications in Horton Group stratigraphy in the Lochaber-Mulgrave area and its structural complexity may be related to interaction between the Avalon and Meguma terranes during their juxtaposition along the Cobequid-Chedabucto fault system.

The Foy Offset Dike, Sudbury impact structure, Ontario, Canada

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The extent of the Foy Offset Dike is controlled by a radial fault/fracture which is connected by a widened neck, known as the embayment, to the 1.85 Ga Sudbury Igneous Complex (SIC). The Foy Offset Dike is known to be the longest structure of its kind, extending ~37 km northwards into the Superior Province. Main dike lithologies, away from the embayment, comprise a polymict impact melt breccia enclosed within an igneous groundmass of granodioritic composition. The embayment groundmass is of quartz dioritic (QD) composition. Substantial ore reserves, associated with the dike, could become the subject of future mining operations. For this reason it may prove important to understand the circumstances under which these deposits were formed.

Various lithologies have been identified within the dike and embayment. These lithological variations have subtle and discreet geochemical differences. The ratio of inclusions to melt has also been quantified using point count analysis on various outcrops. Collectively, these data can be used to interpret the emplacement mechanism of the dike.

Radial dikes are only found at Sudbury and at no other impact structure. As such they require a unique set of conditions in which to form. We believe radial dike emplacement is not likely produced during the excavation stage since other craters do not possess such features. Also, pressures upon excavation are not conducive to the opening of fractures and melt injection. We propose a novel interpretation for the Foy, as a radial dilation fracture that was generated during the rebound of the collapsing transient cavity during the modification stage of cratering.

The inclusion-poor margins are interpreted to be the result of a depressed crystallization temperature associated with increased water content from wall rocks. This efficiently aids the assimilation of inclusions. We interpret embayment rocks as a captured differentiate from the evolving SIC. The geochemical signature of the main dike rocks represent the bulk chemical composition of the target rocks. The proportions of inclusion lithologies and their distribution with strike are inconsistent with lateral injection from the SIC outwards, as has previously been interpreted. The dominant inclusion lithology is representative of the adjacent host rock. Crater scaling equations suggest that the Sudbury structure could be the largest meteoritic impact on Earth.

Tectonic history of the Popelogan arc – Tetagouche-Exploits back-arc system in New Brunswick and adjacent Maine

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Detailed geological studies combined with radiometric age dating indicate that the Lower to Middle Ordovician volcanic rocks of central New Brunswick can be divided into at least 8 separate tectonic blocks and slivers; each block and sliver has its own unique Arenig–Caradoc volcanic stratigraphy and tectonic history. Nonetheless, all of the blocks and slivers are tectonically related and represent widely separated ensialic to ensimatic portions of the west-facing

Popelogan arc/Tetagouche – Exploits back-arc basin system which were structurally juxtaposed during Ashgill–Ludlow back-arc basin closure.

The Lower to Middle Arenig (479–473 Ma) arc volcanic and plutonic rocks of the Meductic block in the southern Miramichi Highlands of New Brunswick and adjacent Maine represent the vestiges of the remnant Popelogan arc, that was built on the Gondwanan Gander margin (e.g., Woodstock, Miramichi, and Cookson groups). The remnant arc formed as a result of intra-arc rifting and opening of the Tetagouche – Exploits back-arc basin, which was induced by trench-ward (west) migration of the Popelogan arc. The Popelogan arc was extensional throughout its life span and vestiges of its youngest phases are preserved in the upper Arenig–lower Caradoc Balmoral Group in northern New Brunswick and Winterville Formation in northern Maine.

The other 6 blocks and slivers recognized in central and northern New Brunswick have a limited regional extent and may not continue into Maine, although related blocks that formed part of the Tetagouche – Exploits back-arc basin have been preserved there (e.g., Weeksburo-Lunksoos and Ripogenus Dam). An important new finding is that the rifting of the Popelogan arc was diachronous along its length with the start of intra-arc rifting given by the first appearance of rift-related basalts in each block. The oldest preserved phase of intra-arc rifting took place in the middle to late Arenig (~474 Ma) whereas the youngest known phase took place in the lower Llanvirn (~465 Ma) Sheephouse block. Analogies with modern arc/back-arc systems such as Japan suggest that rifting started in arc segments characterized by a marked oblique convergence vector.

Petrography and geochemistry of mafic blocks in the Hurricane Mountain mélange in west-central Maine

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The Hurricane Mountain mélange is an accretionary zone that is exposed for 160 km in west-central Maine. It is thought to mark the suture zone between the Gander and Boundary Mountain terranes. The melange is characterized by a sedimentary matrix containing mafic and ultramafic blocks. The igneous blocks are medium-sized, generally ranging from 1.5 to 5 m in height and 2–9 m in length. Blocks at the southwest end of the mélange, on Stony Mountain and along Cold Stream vary in concentration, often appearing in clusters. The blocks are primarily metamorphosed mafic rocks. Eleven samples were analyzed by INAA for major and trace elements. Four of the mafic blocks have the following concentrations: SiO_2 (48–50%), Al_2O_3 (14–16%), $Fe_2O_3^T$ (11–13%), CaO (9–12%), MgO (6.5–7.5%), TiO_2 (1.5–2%), P_2O_5 (<0.5%), and MnO (<0.5%). Field evidence and discrimination diagrams suggest that these samples originated as basalt formed in an ocean-floor environment.

While many of the blocks are mafic rocks metamorphosed to greenschist facies, other blocks within the mélange include volcaniclastic-arkosic sandstone, quartzite, metaconglomerate, serpentinite, felsic metavolcanic rocks, granite, and amphibolite. Near Indian Pond, at the northeast end of the mélange, we observed an amphibolite block with the following mineral assemblage: hbl + ab + ep + qtz + rt + py. This mélange block of originally mafic volcanic breccia reached lower epidote-amphibolite metamorphic facies. Titanite rims and partial titanite replacement of rutile crystals suggest the amphibolite underwent later retrograde greenschist metamorphism.

Repetitions in the Kennetcook basin — structural or stratigraphic? Implications of field and seismic investigations in the Cheverie-Walton area, Nova Scotia

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The area between Cheverie and Noel Shore, on the south shore of the Minas Basin, Nova Scotia, displays highly deformed rocks of the Horton and Windsor groups. Structures in the area include subhorizontal, upright to moderately inclined folds, predominantly trending ENE-WSW, with, in the extreme northwest part of the area, axial planar cleavage. Accompanying map-scale faults trend NW-SE and are curvilinear. Apparent offsets, both sinistral and dextral, affect the mapped outcrop pattern. At Cheverie, a region of less intense deformation, gently dipping Horton and Windsor group rocks are surrounded by highly deformed strata in a map pattern consistent with a tectonic window though a sheet of more highly deformed strata. The observed structures are consistent with thrusting, associated with a positive dextral transpression structure rooted in the Cobequid-Chedabucto fault zone.

Recent petroleum exploration in the area has led to the acquisition of good quality seismic reflection profiles. Between 0.3 and 0.8 s (two-way travel), lenticular, relatively acoustically transparent regions are interpreted to represent Windsor evaporites. The overlying highly reflective blocks, truncated by faults, are interpreted as interbedded limestones and shales within the upper portion of the Windsor Group. Beneath the evaporites a high amplitude gently dipping

reflector is interpreted to represent the base-Windsor Macumber Formation. Deeper in the section, a northward-thickening package showing moderate reflectivity is interpreted as a half-graben filled by Horton Group sedimentary rocks.

A seismic profile through the site of the Walton mine shows all these units at depth, immediately beneath outcrop of subvertical Horton and basal Windsor stratigraphy. If the identification of evaporites in the subsurface is correct, two interpretations are possible: (i) all the units exposed at the surface in this area are allochthonous; or, (ii) previously unrecognized repetitions of lithologies are present in the stratigraphy.

Geology of the Cape Porcupine Complex, Guysborough County, Nova Scotia

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Varied igneous and metamorphic rocks termed the Cape Porcupine Complex form a prominent hill adjacent to the Canso Causeway. These rocks are situated in a strategic position in the configuration of tectonostratigraphic terranes in the northern Appalachian orogen. Hence this study was undertaken to describe the rock types that form Cape Porcupine, determine their age, and compare them to other "basement" rocks in northern mainland Nova Scotia and adjacent parts of Cape Breton Island.

A fault-bounded metasiltstone unit occupies the central area of the complex. The metasiltstone is typically well foliated with a strong north-trending subhorizontal lineation. A fault-bounded unit of metavolcanic rocks forms part of the eastern part of the complex, and consists dominantly of grey crystal to crystal-lithic rhyolitic tuff with phenocrysts of quartz, anorthoclase, and/or plagioclase. Like the metasedimentary unit, it is strongly foliated with a shallow, north-plunging lineation defined by stretched quartz crystals and lithic clasts. Granitoid rocks occur in both the western and eastern parts of the complex. In the west they include bodies of leucodiorite to tonalite, monzogranite to alkali-feldspar granite, and alkali-quartz syenite. In the east the granitoid rocks are dominantly alkali-feldspar granite with minor monzogranite. In addition, the easternmost granitic rocks locally display mylonitic fabric parallel to that in the metasedimentary and metavolcanic rock units. The Cape Porcupine Complex is intruded by several generations of variably altered mafic dykes. The complex is in faulted contact on its northern and western margins and unconformably overlain on its southern margin by Carboniferous sedimentary rocks of the Clam Harbour River Formation of the Horton Group.

The granitoid units in the Cape Porcupine Complex are Late Neoproterozoic, based on a U-Pb (zircon) age of 610±3 Ma from a syenogranite sample, and hence are similar in age to some granitoid units in southeastern Cape Breton Island and to the Georgeville Pluton in the Antigonish Highlands. However, analysed samples from Cape Porcupine are chemically distinct from the Georgeville Pluton and appear more similar to the felsic components of ca. 620 Ma calc-alkaline plutons of the Mira terrane. The ages of the associated metasedimentary and metavolcanic rock units are uncertain. The mylonitic units in the Cape Porcupine Complex provide direct evidence for the existence of the Canso Fault and indicate that it is a major pre-Carboniferous, north-south trending feature, and not parallel to the present-day Strait of Canso.

New insights on the geology of the southwestern Meguma terrane, Nova Scotia

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A detailed mapping project in the Meguma terrane, from Digby to Shelburne, was initiated in 1998 by the Nova Scotia Department of Natural Resources to produce a series of updated, 1:50,000 scale geological maps of the area. The oldest units in the map area are the Cambrian to Ordovician Goldenville and Halifax formations. The Goldenville Formation consists mainly of grey metasandstone interlayered with minor metasiltstone, slate, and conglomerate. Trace fossils are common in one regionally extensive metasiltstone layer. The overlying Halifax Formation has been divided into three members: Bloomfield, Acacia Brook-Cunard, and Bear River-Sissaboo River. These units consist of varying amounts of black to grey and green to maroon slate with minor metasiltstone and metasandstone. Early Tremadocian graptolites have been recovered from the Bear River Member. Detrital $^{40}Ar/^{39}Ar$ muscovite ages yield a provenance age of ca. 550 to 600 Ma for the Goldenville and Halifax formations.

The White Rock Formation in the Digby area disconformably overlies the Halifax Formation and consists of grey slate, metasiltstone, and a distinct (<30 m thick) quartzite layer. Late Silurian fossils have been collected near the top of the formation. Detrital $^{40}Ar/^{39}Ar$ muscovite ages indicate a ca. 500 Ma source area. In the Yarmouth area, this formation is in faulted contact with the Halifax Formation and is composed of metavolcanic and metasedimentary rocks, and is intruded(?) by the ca. 439 Ma Brenton Pluton. Geochemistry of mafic volcanic rocks indicates an alkalic affinity and a within-plate tectonic setting. The felsic volcanic and granitic rocks have some characteristics similar to within-plate A-type granites. A unit of felsic volcanic rocks yielded a U-Pb age of ca. 438 Ma.

Conformably overlying the White Rock Formation in the Digby area is the Early Devonian Torbrook Formation. It consists of grey, locally fossiliferous metasiltstone, slate, metasandstone, marble, and rare ironstone.

Numerous mafic sills intrude all above units and, along with the stratigraphic units, were deformed during the Devonian Acadian Orogeny into regional NE- to NNE-trending, moderately plunging folds with axial planar cleavage. Metamorphism was at greenschist facies; however, in the southwest, metamorphism reached amphibolite facies and was accompanied by ductile deformation. The ca. 370 Ma South Mountain Batholith and related plutons produced andalusite- and cordierite-bearing contact metamorphic aureoles that overprint regional fabrics. $^{40}Ar/^{39}Ar$ data suggest that the ca. 400 Ma Acadian Orogeny occurred immediately after deposition of the Torbrook Formation. A locally intense post-Acadian crenulation fabric reflects regional deformation postulated to be related to Carboniferous shear zones.

Shock metamorphic minerals in the Popigai impact structure, Siberia

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The Popigai impact structure, located in northern Siberia (71°30'N, 111°01'E) is the fifth largest terrestrial impact structure so far discovered. Popigai also represents the least-eroded but best-exposed example of a ring impact basin on Earth. Other known examples are eroded, buried or tectonized.

Impact melt rocks derived by melting of the target gneisses remain in the impact structure, and are known locally as tagamites. Our 110 tagamite samples were collected from thirteen drill cores located in the south-west of the structure. The samples span a radial distance of 6.4 km, a rim-concentric distance of ~2 km and were collected from depths ranging from 0 to 780 m in the drill cores. The impact melts, which comprise a total estimated volume of 1,750 km^3, contain clasts entrained from the target rocks. These comprise up to 35.5 vol. % of the impact melt and vary in size from the micron scale up to 10.5 mm in diameter in the 23 thin section samples which we have accurately characterized.

The clasts within the tagamites display a range of shock metamorphic effects that demonstrate that the basement rocks have experienced shock pressures from <5 GPa to >100 GPa. Quartz clasts in the tagamites exhibit planar deformation features (PDF's) consistent with shock deformation. These are heterogeneously distributed, even within single grains. These PDF's commonly coincide with regions in which the quartz has assumed a brownish, 'toasted' nature, visible in both plane- and cross-polarized light. Other quartz clasts exhibit a so-called 'ballen texture' which may indicate that they were cristobalite, before reverting to quartz at lower temperatures. The quartz clasts are commonly partially assimilated by the surrounding superheated impact melt, but paradoxically retain high strain features inherited from the target.

Both plagioclase and pyroxene exhibit textures indicative of partial melting. Similarities between the composition of the melts hosted within the porous melting clasts and the surrounding groundmass melt indicate that the intra-clastic melts must have been forcefully injected from the groundmass, rather than forming by passive *in-situ* decomposition in the absence of flow. Secondary growths of Ca-rich plagioclase mantle the partially melted plagioclases, and seal the porous melt channels in the clasts. However, clasts which possess these rims are locally broken suggesting that turbulent mixing of the impact melt was still active, at least locally, during or after their growth.

Upper-crustal fault processes in southern New Brunswick

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Upper-crustal faulting has played an important role in the structural evolution of the Carboniferous of southern New Brunswick. This study looks at two important faults in southern New Brunswick with the aim of establishing the deformation processes, fluid flow properties and permeability/porosity evolution of these faults.

Two splays of the Harvey-Hopewell fault system (HHFS) cross the Fundy coast between Alma and Waterside; the Dennis Beach fault at Dennis Beach and the Harvey-Hopewell fault at Owl Head. The Dennis Beach fault represents the main splay of the HHFS. Hopewell conglomerate is intensely deformed immediately to the north-west of this fault. Microstructural examination of these deformed conglomerates reveals that intracrystalline plasticity and recrystallization processes have been important in both calcite and quartz, despite the upper-crustal conditions of deformation. Samples from near the fault trace contain large quantities of calcite, indicating that fluid flow has been important. At Owl Head, Hopewell conglomerate has been thrust over overturned strata of the Enrage and Boss Point formations. The thrust plane is occupied by a thin gouge zone. Bedding-parallel gouge zones to the west of the thrust fault show evidence for extensional movement and contain large amounts of vein calcite. These observations show that different splays of the same fault system can have very different characteristics.

The Quaco Head fault is a dip-slip fault which outcrops at two localities in the area of Quaco Head, immediately west of St. Martins. At the coastal exposure 600 m north of Quaco Head, the fault consists of an outer zone of calcite-cemented fault breccia and an inner zone of red-grey fault gouge. The presence of large quantities of vein calcite in the gouge and calcite cement in the fault breccia indicate that fluids have been important at this locality. At the exposure 2 km south-west of Quaco Head, the fault zone consists of a 2 m thick sliver of sheared Hopewell conglomerate which underlies a thin gouge zone. Microstructural examination shows that deformation in the conglomerate is weak and has largely been accommodated by cataclastic flow and pressure-solution processes. Gouge at this locality contains folded and offset veins. The fault zone is much narrower and fluids have been less important at this locality than at the more northerly exposure of the Quaco Head fault. This has important implications for fault sealing properties and active deformation mechanisms; these may differ along strike, even over short distances.

Geochemistry and regional correlation of Middle Ordovician arc-related volcanic rocks from the Popelogan Inlier (Dunnage Zone), northern New Brunswick

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The Popelogan Inlier consists largely of mafic volcanic rocks of the Goulette Brook Formation, which underlies a thin unit of black chert (Popelogan Formation) containing early Caradocian (*N. gracilis* zone) graptolites. Four suites of mafic rocks are present, namely (1) picritic lapilli tuff, (2) basaltic to andesitic lapilli tuff, (3) low-Cr basalt, and (4) andesitic basalt. Suites (1) and (2) are volumetrically dominant. Suites (1) through (4) display incremental increases in absolute trace-element abundances, though all, except the andesitic basalt, are characterized by low HFSE contents. All samples display negative Nb and Ti and positive Th anomalies on trace-element spidergrams, typical of subduction-related basalt, and all plot within volcanic arc fields on tectonic discrimination diagrams. LREE abundances, sloping REE profiles (La_N/Yb_N = 2.7 to 7.6), and high Zr/Y (2.9-7.7) are typical of calc-alkaline basalt and andesite.

Trace-element systematics suggest derivation from a mantle source that was enriched in HFSE compared to normal MORB, prior to introduction of Th and LILE via metasomatizing fluids from the subducting slab. Primitive picritic tuff (high MgO, Cr; Mg# 62-81) must have been emplaced following rapid ascent, with minimal fractionation or crustal assimilation. Other chemical variations among the respective suites can be explained by different degrees of partial melting of a common mantle source, followed by variable amounts of fractionation.

Volcanic rocks of the Goulette Brook Formation can be stratigraphically correlated with chemically similar arc-related basalts of Arenig-Llanvirn age in northern Maine and Newfoundland. In these areas, calc-alkaline arc volcanic rocks like those of the Goulette Brook Formation are transitional between older primitive arc tholeiite and younger back-arc basalt, and were probably generated during arc rifting. Arc volcanism occurred over an east-dipping subduction zone at the eastern margin of Iapetus, and typically involved thinned, peri-Gondwanan continental crust. In New Brunswick, ensialic back-arc volcanism of the Miramichi terrane followed and accompanied rifting of the Popelogan arc. Chemical signatures in the Goulette Brook volcanic rocks similarly reflect the influence of continental crust and/or subcontinental lithosphere in enrichment of the mantle wedge.