Atlantic Geoscience Society

ABSTRACTS

1999 COLLOQUIUM & ANNUAL GENERAL MEETING

AMHERST, NOVA SCOTIA

The 1999 Colloquium of the Atlantic Geoscience Society was held at the Wandlyn Inn, Amherst, Nova Scotia, on February 5 and 6, 1999. On behalf of the Society, we thank Peter Wallace and Laing Ferguson, Colloquium Co-chairs, and their organizing committee for providing an excellent meeting. We also wish to thank the corporate sponsors: Dalhousie University, Noranda Mining and Exploration Inc., Etruscan Resources Inc., and Voisey's Bay Nickel Company Ltd.

In the following pages we are pleased to publish the abstracts of talks and posters presented at the Colloquium, which included the following special sessions: Geoscience Software for the Professional, Teacher and Student; Current Research in the Atlantic Provinces; Geology of the Maritimes Basin (dedicated to the memory of Sir William Dawson); and Offshore Petroleum Geology and Geological Resources.

The Editors

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Late Wisconsinan glacial movement in the Petitcodiac map area, southeastern New Brunswick

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Mapping of surficial deposits and till analyses have contributed to an understanding of the Late Wisconsinan stratigraphy and directions of ice movement for the Petitcodiac (21H/14) map area. Clast and matrix samples were collected from the C-horizon of basal till at 2 km intervals across the map area. Ice flow directions were identified from the dispersal patterns of the till matrix geochemistry, clast provenance, and the orientation of glacial landforms and striae.

Known mineral occurrences are reflected by geochemical anomalies in the till matrix. Generally, the topological position of the occurrence determined the shape of the anomaly. Source occurrences on topographic highs produced long dispersal trains as opposed to "bulls-eye anomalies" originating from sources located in valleys. The striae data and the dispersal patterns both indicate that the dominant ice flow direction varied between south-southwest and southeast over the entire map area. However, dispersal trains found in the northern half of the map area are indicative of multiple ice flow directions. This is particularly evident in the northeastern region of the study area where drumlinoid features, rat-tails, and dispersal patterns of chromium, beryllium, vanadium, and scandium record a late easterly flow event. During the early part of this glacial event southward flowing ice moved into the northwest corner of the study area. It is likely that portions of this ice flow were diverted toward a more easterly, and possibly a northeasterly direction.

Dispersal patterns of till clasts and geochemistry suggest the occurrence of unmapped volcanic units located in the northwestern section of the map area. Similar units found elsewhere in the region contain mineralization. Therefore, the new bedrock sources implied by the surficial mapping represent potential prospecting targets.

Significance of calcium sulphates in the Chuquicamata porphyry copper system, Chile

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Besides being one of the largest accumulations of copper on Earth, the Chuquicamata porphyry copper deposit in the Chilean Andes represents an even larger concentration of sulphur in the form of sulphides and sulphates. At Chuquicamata, gypsum found in the near- surface levels of the mine has been assumed to be the product of supergene oxidation of sulphides. However, ubiquitous hydrothermal anhydrite veins are accompanied by copper sulphide ores in the deeper levels of the system, well below the supergene zone, within both potassic and sericitic alteration. Consequently, it is likely that much of the gypsum in the upper levels represents hydrothermal anhydrite that has been hydrated by meteoric waters. Gypsum and anhydrite may impart different physical and chemical properties to the rocks and ores causing mining and metallurgical problems, thus the definition of the gypsum/anhydrite boundary is of practical importance. Furthermore, the presence of these minerals poses interesting questions regarding the sources and cycles of calcium and sulphate during the evolution of the magmatic-hydrothermal-supergene system.

Gypsum is associated with both supergene and hypogene sulphides, and anhydrite is found mainly with hypogene covellite, digenite, and molybdenite. The progressive hydration of anhydrite to gypsum is texturally evident in thin section. Electron microprobe analyses show anhydrite to be simple $CaSO_4$ with up to 2 weight % strontium. Strontium content shows no obvious correlation with assemblage, depth or location in the deposit. Sulphur isotope data confirm that much of the gypsum in the upper levels is indeed hydrated anhydrite. Isotopic equilibration temperatures calculated from sulphide-sulphate pairs in the quartz- sericite alteration zone indicate that the vein-anhydrite formed between 330°and 375°C, which is further evidence of a hydrothermal origin for the anhydrite. Anhydrite veining in the early potassic alteration (older than 34 Ma) could have derived its calcium from the destruction of magmatic plagioclase, titanite and amphibole, but the relatively greater abundance of anhydrite veins in the later (ca. 31 Ma) quartz-sericitic assemblages makes it difficult to derive so much calcium from already calcium-depleted rocks in the potassic-altered zone. Calcite is rare in the Chuquicamata orebody, and strontium isotopes of the anhydrite-bearing ores are not compatible with a source of strontium in Mesozoic calcareous country rocks; hence, a source in a younger (ca. 31 Ma), still-unrecognised mineralising intrusion at depth can be hypothesised.

A new geological map of the Kingston terrane, southern New Brunswick

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Remapping of the Kingston terrane shows that it consists mainly of Silurian metavolcanic rocks of the Bayswater Group and associated granitoid plutons and amphibolite dykes. On the northwest, the brittle Belleisle fault separates the Kingston Terrane from Neoproterozoic and Lower Paleozoic granitoid, volcanic, and sedimentary rocks of the New River Terrane. On the southeast, the Kennebecasis fault separates the Kingston Terrane from mainly Neoproterozoic metamorphic and plutonic rocks of the Brookville Terrane. Farther southwest, well developed mylonitic rocks occur along this margin, but it is not yet clear whether or not rocks of the Kingston Terrane are involved in these mylonitic zones. Timing of terrane juxtaposition has not yet been well constrained but was probably Late Silurian and Devonian.

The Bayswater Group is divided into six, as yet unnamed, formations on the basis of lithologic variations. Most of the formations consist of dacitic and rhyolitic crystal and lithic crystal tuff. Two formations are dominated by basaltic and andesitic tuff, and the most northerly formation includes abundant tuffaceous sedimentary rocks. The central core of the terrane consists mainly of texturally varied, high-level granitoid rocks. They have yielded a Silurian U-Pb age, similar to the age of the host volcanic rocks, and the granitoid and volcanic rocks are interpreted to be co-magmatic. All of these units contain amphibolitic dykes, but they are most abundant in the granitoid core of the belt. Because the dykes tend to be more resistant to weathering than their host rocks, they form many of the outcrops in the terrane. Regional metamorphic grade may decrease from southeast to northwest across the Kingston Terrane, but no increase in metamorphic grade was noted from northeast to southwest along trend, in contrast to previous interpretations which suggested that grade increases to the southwest

EarthNet: A virtual resource centre for Canadian earth science educators

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EarthNet (http://agcwww.bio.ns.ca / schools / esrc / esr-home.html) provides Canadian educators with a virtual resource centre of information to help in the teaching of earth science. Recent website developments, made possible by funding received from the Geoscience Knowledge Network initiative of the Geological Survey of Canada, include: Classroom Activities that teachers can download for no cost; an illustrated Glossary of Terms; a Calendar of Events that informs users of events in their part of Canada; Geology in the Classroom, a Q&A section where previously answered questions are also posted; Earth Science Site of the Week where a new science site is featured every week; and a section of links to other earth science sites. The searchable database of teaching resources, the initial segment of EarthNet, forms the foundation of the website.

To ensure that educators are accessing current and complete information, the EarthNet development group is constantly collecting resources, activities, events, images, and text from contributors across Canada. Initially, this volunteer group comprised members of the Canadian Geoscience Education Network (CGEN) and the Education Committee of the Atlantic Geoscience Society. Over the last year, the group has grown to include many others throughout Canada interested in ensuring the success of EarthNet. Education outreach representatives at museums, science centres, EdGEO workshops, and provincial surveys across Canada have also assisted with development by providing resources, activities, images and text, and by promoting EarthNet to educators and scientists in their area.

Recent presentations at teacher conferences in Nova Scotia and Ontario were well-received. Most teachers were familiar with the WWW as a reference tool and were eager to obtain information useful in the classroom. Also, talks at science meetings were met with enthusiastic interest from the national and international science community. A number of Canadian science association and agencies (i.e. CGC, CGF, GAC, CSPG, AGS), along with the GSC, have financially supported EarthNet. The hope is that this support will continue, and hopefully improve, considering the increasing demand from the education sector for science resources. CGEN considers EarthNet to be one of its priority activities.

Future expansion of the site includes a section, Exploring

the Dynamic Earth, that will concentrate on earth science topics or themes. Animation and video will supplement illustrations, photos, and text. This style of presentation of information is effective in explaining principles. In addition, a Teachers Online Forum will allow educators to share and discuss ideas and experiences.

Those involved in the creation of EarthNet hope that the website will become Canada's gateway to earth science information for teachers, students, the general public, and the scientific community involved in education outreach.

Will the year 2000 mark the end of an era ... for EdGEO workshops?

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Since 1994, the Nova Scotia EdGEO Workshop Committee of the AGS Education Committee has been hosting workshops for science teachers from all regions of the province. The program has been an overwhelming success with most workshops overbooked and all participants providing positive and encouraging comments to the organizers. But the Committee needs to decide whether these workshops should continue after the year 2000. If you asked any one of the over 100 teacher participants, the answer would be a resounding "yes". During the feedback session following each workshop, the participants express their absolute need for workshops on earth science topics. The mix of classroom hands-on activities and field trip gives them the unique opportunity to apply basic principles to their local geological environments. The resources and contacts obtained during the two days prove to be invaluable to the science teacher who can have little or no background in earth science. So, the teachers want the workshops to continue. What do the organizers think? The first few years were a struggle convincing the corporate education sector that the workshops were worth supporting. But a grant in 1998 from the Nova Scotia Department of Education and Culture with the Nova Scotia Association of Science Teachers (a group that fully supported the workshops from the start) convinced the organizers that they were making headway. And certainly the outreach component of the science community strongly supports the existence of these workshops. So, it would seem that the program fulfils a need and this need is realized by the communities involved. It is likely the program will continue past the year 2000. However, to maintain the positive momentum, the organizers believe there is a need to revitalize the format. One possibility is a change in the theme to specific earth science topics. (The teachers support this concept). Perhaps, the Committee needs an infusion of "fresh blood", meaning some new faces. The year 2000 will mark a change in the EdGEO program - but a change that we hope will ensure the continuing of a success story.

Sandstone reservoir characteristics of the Upper Carboniferous in the central Maritimes Basin

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Reservations regarding the storage and productive capacity of reservoirs in the Carboniferous to Permian succession of the Maritimes Basin have discouraged exploration in this large, under-evaluated basin. Using a revised stratigraphic framework emerging from PERD-supported work in progress at the GSC-Atlantic, we have documented the characteristics of sandstone reservoirs, with an initial focus on those in the Westphalian to Permian succession of the Gulf of St. Lawrence, traditionally assigned to the Pictou Group. This forms the basis of ongoing diagenetic studies aimed to quantify reservoir risk.

Core measurements within the Central Maritimes Basin are sparse. However, compiled regional data suggest that the Green Gables Formation has the highest overall reservoir quality (porosities of 1.5-10.5%, median of 8.7% and permeabilities of 0-1.45mD, median of 0.28mD). Within the Bradelle and Cable Head formations porosities range between 0.4 to 9.7% (median 5.8%), permeabilities range between 0.01 to 1.41mD (median 0.04mD). Effective porosities estimated using wireline data are generally less than 10%. Over some intervals, however, median porosities range up to 15%. Although porosity tends to decrease with depth, localized variations in this trend suggest development of secondary porosity at depth. Upper Carboniferous clay mineral assemblages in the Maritimes Basin are typically a mixture of illite, chlorite, koalinite and mixed layer clays. Variability of

clay mineral assemblages might have a controlling effect on both primary and secondary porosity.

Internationally, Upper Carboniferous petroleum systems exhibit similar reservoir qualities and have proven reserves. For example, the Red Fork sandstone of the Anadarko Basin, USA, has an average porosity of 8 %, an average permeability of 0.1mD and reserves of 250 million m^3 of gas. The Slochteren sandstone of the Groningen Gas Field, North Sea, has proven gas reserves of $2.4 \times 10^{12} m^3$ and porosities ranging between 10-25% and permeabilities between 0.1-1000mD. Maritimes Basin reservoirs therefore compare well with proven Carboniferous reservoirs elsewhere.

The contact metamorphic aureole of the South Mountain Batholith in the Bear River-Clements area, Nova Scotia

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Rocks from the Meguma Zone form the substrate of southern Nova Scotia, part of the Scotian Shelf and the Bay of Fundy, south of the Minas Geofracture. The Meguma Zone is composed of the Goldenville Formation, the Halifax Formation, the White Rock Formation, Kentville Formation, and the Torbrook Formation. The White Rock, Kentville, and Torbrook formations are found only on the northwestern side of the South Mountain Batholith, which occupies an area of 7300 square kilometres between Halifax and Yarmouth. In the Bear River-Clements study area these formations are in contact with the Scrag Lake and Ellison Lake monzogranites.

Preliminary age data for the batholith using rubidium-strontium methods yielded an age between 373 and 368 Ma. The use of strontium methods, K-Ar, $^{40}Ar/^{39}Ar$, U-Pb, and fission-track dating confirmed that the age of the batholith is ca. 370 Ma. The South Mountain Batholith was mapped by the Department of Natural Resources from 1985-1989, and distinct phases within it were recognized. Subsequent studies have resulted in a systematic subdivision of the batholith into six main divisions based on petrography and field relations.

Andalusite and cordierite have been observed in the country rock around the batholith in both the Bear River and Clements areas. No sillimanite has been found. Preliminary analysis of multivariate equilibria in hornfelses from the Bear River area indicate lower pressures of metamorphism than at any other location around the South Mountain Batholith, possibly as low as 2.5-3 kbars. The depth of intrusion has therefore been determined to be about 6 km along the northwestern margin as opposed to near 10 km along the eastern margins of the batholith. Continuing analysis of hornfelses will define more precisely the conditions of contact metamorphism.

Geochemistry and petrography of part of the Sprogge property, Yukon Territory

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Underlain by Hyland Group off-shelf Selwyn Basin sedimentary rocks, the Sprogge property contains mineralization in the form of quartz-arsenopyrite veins, pyrrhotite-bearing calc-silicate replacement horizons, and pyrrhotite (± chalcopyrite) pyroxene skarns.

On the property, the Hyland Group consists of the Precambrian Yusezyu Formation, a sequence of sedimentary lithologies consisting of limestone, sandstone, siltstone, and quartz-pebble conglomerate. These units are planar bedded and traceable along strike across the study area (4 km^2) except where displaced by faults. Felsic to intermediate porphyritic dykes intrude stratigraphy in a steeply dipping north-south direction, coincident with regional structural trends. Minor diorite dykes and older mafic dykes are present. Hydrothermal alteration minerals consist of clinopyroxene, garnet, hornblende, wollastonite, muscovite, chlorite, and sphene. Large areas of biotite ± cordierite, and calc-silicate hornfels suggest the presence of a larger intrusive body at depth.

Analysis of 3,168 soil samples collected on a property-wide grid, demonstrates that lithologies are broadly mappable using the distribution of trace element soil concentrations. Thin sections of 24 representative samples of the dominant lithologies in the study area indicate that the region has undergone lower greenschist metamorphism and that skarns are pyrrhotite-bearing and that clinopyroxene has a salite to hedenbergite composition.

Concentrations of gold on the property are generally low (< 30 ppb) except where associated with quartz-arsenopyrite veins. These veins generally occur too sparsely and too far apart to be a viable exploration target. Isolated anomalous copper and base metal concentrations occur throughout the property; however, economic grades have not yet been discovered in sufficient quantity to motivate further mineral exploration.

Storm tides in the Bay of Fundy

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Storm tides, or storm surges, as measured and defined along a coast, are the differences between the observed water level and the predicted astronomical tide as a result of atmospheric disturbance. Historically, storm tides have played havoc in the Bay of Fundy region. Here the tidal system resonates close to the 12 hour, 25 minute dominant lunar tide of the Atlantic Ocean. The main variations in normal Fundy tides are caused by astronomical factors. The most favourable combination of astronomical factors to produce strong tides in the Bay of Fundy is when four elements: perigee, spring tide, and anomalistic and tropical monthly cycles peak simultaneously. The closest match occurs at intervals of 18.03 years. Problems arise when storms coincide with these intervals. A strong case can be made for the coincidence of the Saros with several major historical storm tides in the Bay of Fundy, including: the 1976 Groundhog Day storm, the 1869 Saxby Tide, and the 1759 storm tide. Due to continuing global sea level rise, and regional crustal subsidence the possible recurrence of destructive storm tides has perilous implications for property owners and settlements in the Fundy coastal zone.

Origin of the Odd-Twins: A magnetic unit in the Ordovician foreland basin of the western Newfoundland Appalachians

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A conspicuous pair of magnetic anomalies, known as the 'Odd-Twins,' is present off the coast of Western Newfoundland (Ruffman and Woodside 1970). Recent swath bathymetry and magnetic mapping north of Port au Port Peninsula allow this anomaly to be traced near the coast, within 7 km along strike from outcrop of the Late Ordovician Long Point Group.

A magnetic survey was carried out on land using a portable proton magnetometer. Six hundred and eleven readings were taken on 22 traverses. Fifteen traverses intersected a conspicuous, NE-SW trending linear feature that projects towards the eastern offshore anomaly. A second anomaly, approximately 1 km to the northwest, was intersected by five traverses. Projected, it is aligned with the western offshore anomaly.

The eastern anomaly occurs close to the base of the Misty Point Formation of the Late Ordovician Long Point Group. The western anomaly occurs within the Misty Point Formation. Both anomalies strike NE, and are asymmetric, with steep gradients on the SE side. This is consistent with an origin in NW-dipping, stratigraphically controlled magnetite-bearing units in the Long Point Group observed in outcrop. Toward the southwest, the asymmetry reverses. This effect probably results from overturning of the Long Point Group in the footwall of the Acadian Round Head Thrust.

The Odd-Twins anomaly provides an essential stratigraphic tie between the on-land succession and an extensive offshore seismic data-set resulting from petroleum exploration.

RUFFMAN, A. AND WOODSIDE, J. 1970. The Odd-Twins magnetic anomaly and its possible relationship to the Humber Arm Klippe of Western Newfoundland, Canada. Canadian Journal of Earth Sciences, 7, pp. 326-337.

Coral species diversity in a modern epeiric sea and open ocean environments: The Java Sea versus eastern Indonesia.

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Epeiric seas were important marine environments through much of earth history, but are rare today. Elimination of epeiric seas during major regressions has been proposed as a contributing factor in mass extinctions; evaluating this question requires estimating the proportion of marine biodiversity which can be found in epeiric seas. The Java Sea, a modern tropical epeiric sea that was drained during the Pleistocene glaciations, lies near the centre of marine biodiversity for corals, molluscs, fish, and other marine biota. The proportion of total marine biodiversity which can be found in epeiric seas was estimated by comparing coral species diversity on Java Sea reefs with that on eastern Indonesian reefs in open marine habitats that were not drained during the Pleistocene glaciations. Among reefs not affected by land-based pollution or anthropogenic damage (anchor damage or blast fishing), eastern Indonesian reefs were 20% more diverse than Java Sea reefs. The total species pool found on the Java Sea reefs was 74% that of reefs in eastern Indonesia. 61% of the species recorded were pandemics, occuring in both eastern Indonesia and the Java Sea, 31% were

recorded only in eastern Indonesia, and 8 percent were recorded only in the Java Sea. Rare species and apparent endemics formed a significantly larger proportion of the coral fauna in eastern Indonesia than in the Java Sea. These results partially match published comparisons of Middle Devonian (highstand) rugose coral diversity between the epicontinental Eastern Americas Realm and the open ocean Old World Realm. The Indonesian data suggest that epeiric seas can host a large fraction of marine biodiversity, but fewer endemic species than open ocean regions. For most marine invertebrates, colonization times into epeiric seas are below the resolution of the fossil record. The epeiric sea marine biodiversity cup is three quarters full, rather than one quarter empty.

Prosauropod dinosaurs of the Jurassic McCoy Brook Formation, Nova Scotia

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The sandstone of the Lower Jurassic McCoy Brook Formation at Wasson's Bluff, Cumberland County, Nova Scotia, has produced material from two additional dinosaur specimens at the site where a partial, small prosauropod dinosaur was collected in 1992. The material is typical of Wasson's Bluff in its highly faulted nature, but the abundance of bone material, and location of three individuals within a 5m span of outcrop is unusual and of great interest.

The preparation of this fossil material is being carried out at the Fundy Geological Museum. Further collection at the site is ongoing and is certain to yield more material. The concentration of bones at the current expedition site offers a great opportunity to further determine how these animals relate to other prosauropod specimens found in Nova America.

The Last Billion Years: The story of the Maritime Provinces

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A surprising discovery, when searching for a readable geological history of the Maritime Provinces, is that no such book exists. "The Last Billion Years" was conceived as a way to fill this gap and to appeal to a broad readership; this includes high school students and the general public, who are often not given a full appreciation of geology. Preparation of the book is now in its fifth year, with publication planned in 2000 (an apt timing) during the next two months. The fourth draft will be reviewed by non-geologists and final choices made on illustrations. We hope the text will be enjoyable; the illustrations are superb. There are several water colour paintings, specially commissioned for the book, plus about ten others courtesy of the New Brunswick Museum. And there are some beautiful colour photographs, several new geological maps, excellent line drawings of fossils and some innovative schematics and plate reconstructions. One encouraging development this last year has been increased financial support: we have now raised $42,500 to publish the full-colour book, the total cost of which will be over $100,000. The funding should let us achieve our goal of keeping the book's retail cost below $20. The most rewarding experience, however, has been the unstinting support of the geological community. This has been outstanding.

GIS-based fuzzy logic modelling in the earth sciences with an application to acid rock drainage prediction in the Meguma Supergroup, Nova Scotia

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Fuzzy logic, based on fuzzy set theory, forms the basis for approximate reasoning. Approximate or "fuzzy" reasoning is reasoning under uncertainty, where "uncertainty" is considered non-random and is due to vague, ambiguous, or inexact data. When such data are used, conclusions about a specific problem or task can be drawn when fuzzy logic is combined with a set of fuzzy rules. This is the basis of "fuzzy logic modelling". The entire process of fuzzy logic modelling provides a means for quantification of qualitative data, as well as modelling complex non-linear relationships, both of which are frequently encountered in geology.

Here we present an example of fuzzy logic modelling applied to acid rock drainage (ARD) in the Meguma Supergroup in Nova Scotia. The objective is to produce a regional-scale map showing areas within the Meguma Supergroup that have the potential to produce ARD if the rocks are exposed to oxidizing surface conditions. Fuzzy membership values were chosen for six GIS-based map layers (fuzzy sets) including bedrock geology, regional metamorphism, contact metamorphism, regional-scale

anticlines, Goldenville-Halifax Transition zone (GHT), and airborne vertical magnetic gradient. The layers are combined using the fuzzy gamma operator. The final ARD potential map is colour coded using ten equal intervals between 1.0 (highest potential) and 0.0 (lowest potential). The results indicate that fuzzy logic modelling has a great potential in environmental (ARD) prediction that is unattainable by conventional methods, especially when utilizing incomplete, qualitative data of varying reliability. The success of fuzzy modelling lies in the fact that it is robust in addition to being easy to understand, implement, and maintain.

Petrology of the St. Stephen gabbroic pluton and associated sulphides

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The St. Stephen pluton includes a variety of mainly mafic and minor ultramafic rocks, as well as intermediate and felsic plutonic rocks and metasedimentary xenoliths. The pluton intruded sedimentary rocks of the Ordovician Cookson Group and produced a high-grade contact metamorphic aureole with mineral assemblages including sillimanite, microcline, cordierite, muscovite, and biotite. On its southern margin, and locally throughout, the pluton was intruded by the Silurian(?) Baring Granite, and the gabbro and granite are interpreted to have been comagmatic. Both the gabbro and granite are part of the much larger Moosehorn Igneous Complex, in turn part of the extensive Coastal Maine magmatic province.

Surface outcrops, as well as new drill core from the Rogers Farm area made available by Cobrun Mining Corporation, were sampled for petrological study. The results show that the pluton consists of complexly intermingled olivine gabbro and olivine gabbronorite, with less abundant gabbro, gabbronorite, norite, troctolite, anorthosite, and dunite. It does not appear to be possible to separate these units into mappable areas as implied by earlier workers. The gabbroic rocks locally contain abundant amphibole and biotite replacing pyroxene, indicating that water was present during late stages of crystallization. The pluton is most similar to the Pocomoonshine pluton in Maine, for which detailed studies have shown a complex igneous history. Mineral and whole-rock chemical data from the St. Stephen pluton will be used to compare its petrogenesis with that of the Pocomoonshine gabbro.

An additional focus of this study is an examination of textural relations in sulphide-rich samples. Microprobe analyses confirm the dominance of pyrrhotite, with pentlandite generally forming blebs and exsolution lamellae in pyrrhotite associated with silicate minerals. Chalcopyrite tends to occur around the margins of pyrrhotite grains in contact with silicate minerals. Present in lesser amounts are magnetite, cobaltite, Cd-rich sphalerite, and galena. Preliminary study of textural relations supports previous interpretations that the sulphides were concentrated through subsolidus mobilization, as evidenced by deformation lamellae within the pyrrhotite and by the brecciation of silicates. Sulphur was probably derived from the adjacent Cookson Group.

Stratigraphy of the western Maritimes Basin, Prince Edward Island, and adjacent Gulf of St. Lawrence

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Subsurface data from wells drilled for coal and hydrocarbons on Prince Edward Island provide critical insight into the stratigraphy of the western Maritimes Basin. With well-documented Permian strata at surface, Prince Edward Island provides a rare opportunity to assess the lithostratigraphic framework for the complete basin fill. A stratigraphic cross-section from western PEI to the East Point E-49 well which incorporates all available onshore subsurface information and four petroleum wells from the adjacent Gulf of St. Lawrence, reveals strata ranging in age from early Tournaisian to Permian. Several important unconformities can be identified, the lowest being the contact with crystalline basement rocks in western PEI, representing the post-Acadian unconformity and the base to the fill of the Maritimes Basin. The cross-section reveals a significant unconformity at the base of the middle Viséan Windsor Group, and a major stratigraphic break in the early Westphalian. The latter unconformity is represented in the Sydney Basin at the base of the Morien Group and appears to be regionally significant. Of particular interest is the apparent scarcity of middle and late Namurian strata in the PEI cross-section. Rock units of that age are well known in onshore areas of northern Nova Scotia and western Cape Breton Island, where they reach thicknesses of several thousand metres. Their absence throughout much of the Gulf of St. Lawrence indicates the significance of the early Westphalian unconformity, and suggests that marked basin inversion occurred in latest Namurian time. A five-part subdivision of strata above the Westphalian unconformity is suggested by the cross-section, comprising three major sandstone-dominated intervals separated by fine-grained rocks which, in the lower parts of the succession, contain the well-known Westphalian B to early Stephanian coal measures of eastern Canada. Relationships of these Westphalian to Permian lithostratigraphic subdivisions to established, more formal rock units mapped in onshore areas, are not everywhere clear, and nomenclature issues have yet to be resolved.

Revision of the Upper Carboniferous to Lower Permian stratigraphy in the central Maritimes Basin of eastern Canada

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Synthesis of lithostratigraphic and biostratigraphic data for late Namurian to lower Permian rocks of the western Maritimes Basin in the Gulf of St. Lawrence and on Prince Edward Island confirms that a regionally significant unconformity separates Westphalian B and younger strata from older Carboniferous rock units. Earliest Westphalian rocks above this over-stepping unconformity range in age from Westphalian B in deeper parts of the basin, to Westphalian C and D in areas more proximal to the basin margin. We recognize a five-part subdivision of Westphalian-Permian strata, comparable only in part with earlier work. At the base, ranging in age from Westphalian B to early Stephanian, is the Bradelle Formation, sand-dominated, and containing typical coal measures facies. The top of the Bradelle Formation is a diachronous facies boundary. Overlying fine-grained red strata are assigned to the Green Gables Formation, significantly expanded in definition from earlier work. The Green Gables Formation is overlain by the sandstone-dominated Cable Head Formation (Stephanian) which blankets the entire western Maritimes Basin. The Naufrage Formation overlies the Cable Head abruptly but apparently conformably, and comprises fine-grained red strata with abundant pedogenic carbonate as nodules and discontinuous beds. The Naufrage Formation is transitional upwards into a thick, sandstone-dominated succession of Permian age which was included within the Naufrage Formation by earlier workers. The Permian sandstone may lie directly on older strata where salt flow has elevated older rocks to produce local unconformities. Correlation of this five-part subdivision with onshore rock units is only partially successful, perhaps reflecting differing data sources (outcrop versus well cuttings for example). The stratigraphic framework which emerges from our synthesis suggests close comparison with the Sydney Basin, where a significant unconformity separates Westphalian B to Stephanian strata of the Morien Group from early Namurian rocks of the Mabou Group.

Detrimental trace elements in porphyry copper deposits: As, Sb, Zn, and Pb at Chuquicamata, Chile

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Trace elements in copper mines are of more concern than ever as the technology of copper extraction changes to become both more efficient and more environmentally controlled.

We have embarked on a project to establish dependable metal ratios based on mine geology, ore mineralogy, and assay chemistry, to provide input for ore models to allow detailed prediction of trace metal content at the Chuquicamata copper mine in northern Chile. To establish the controls for trace metal variation we are studying data from trench and drillcore samples from and below the current mining surface which is near the base of the supergene enrichment blanket.

Arsenic and antimony occur in two distinct settings. There is a low-As background setting of As and Sb as trace components of Cu-sulphide minerals. Superimposed on this background are high-As enargite-pyrite vein arrays. Both of these settings have been affected by subsequent supergene processes which mildly enriched As and Sb near the base of the Cu enrichment zone. Just below the base of supergene Cu enrichment, is a broad zone of high zinc. Within the zone of high Zn values is a much narrower zone of high Pb. Both Zn and Pb are virtually absent within the lowermost supergene Cu-ores.

Arsenic and antimony occur mostly in enargite (Cu_3AsS_4), Zn in sphalerite, and Pb in very small galena grains. Other trace-metal sulphide minerals are present in significant amounts only where the total trace metal content is very high. Colusite $Cu_{24}(As,Sb,V,Fe,Ge)_8S_{32}$ and wittichenite $Cu_3(Bi,Pb)S_3$ are the most important of these trace minerals primarily due to their content of additional deleterious trace metals.

Apatite fission track constraints on the late Cretaceous heating of the Atlantic margin: Possible effects of anomalously high palaeo-mean surface temperatures

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Modelling of new apatite fission track (AFT) data from the Digby D1 drillhole in the South Mountain Batholith (close to the Triassic unconformity), indicates that near surface rocks were heated to temperatures in excess of 60°C during late Cretaceous times (ca. 100-80 Ma). These results must be evaluated in the context of previous studies. AFT studies had determined that the Atlantic margin, including the Maritimes Basin, was buried under at least 4-5 km of strata in late

Palaeozoic times, and that basin inversion removed much of this cover by Triassic/Jurassic times. Vitrinite reflectance of Cretaceous lignite within exposed sinkholes at Gays River, and AFT data on mainland Nova Scotia suggested Cretaceous heating of a few tens of degrees above present surface temperatures. Maturation parameters in the Jurassic sequence of the Bay of Fundy also imply substantial heating in late Mesozoic times. AFT studies on the Scotian Basin by the authors confirmed an episode of late Cretaceous heating in most wells, meaning that the Cretaceous sediments were at one time hotter than their present temperature in the wells. New AFT data, and better constrained time-temperature modelling on samples from outcrops (pre-Carboniferous basement, Permian strata, Mesozoic dikes, Triassic unconformity sediments) and drillholes onshore and wells offshore Nova Scotia indicate that the late Cretaceous heating event is widespread and significant. Heating of subsurface rocks to oil-window temperatures in the Late Cretaceous has obvious implications for hydrocarbon charge models.

There are several possible explanations for the heating event: 1) an increased palaeo-geothermal gradient, perhaps related to regional magmatic activity; 2) circulation of warm fluids at depth, in response to some structural/tectonic driving force; 3) considerable burial by sediments and subsequent exhumation; 4) sub-surface heating in response to a thermal blanket, the result of a long-term increase in the palaeo-mean annual surface temperature, or a combination of several of these causes.

The AFT data for samples from 60 to 1437 m in the Digby D1 drillhole suggest a normal late Cretaceous palaeo-geothermal gradient of 25°C/km; hence, hypothesis one is unlikely. Alkalic magmatism in New England and the Montreal area occurred around 90 Ma and localized mafic magmatism on the margin (New England Seamounts) could have had local effects. Late Mesozoic faulting was important in the Atlantic margin, and warm fluid circulation through them is a likely possibility, but is an unlikely cause of heating in the Digby well. There is geological evidence for late Cretaceous high sea levels and considerable sediment accumulation, but not to the extent of the >2 km that would be required to explain the regional AFT data as a result of simple burial heating. The fourth option may provide an explanation for heating with only limited burial, since a major world-wide climate change took place in the Turonian-Coniacian (92-86 Ma) which brought anomalously high mean annual surface temperatures to the Canadian Arctic Archipelago and consequently to the lower latitudes. Simple numerical calculations demonstrate that a long-term (1-10 my) increase in mean annual surface temperature (by, for example 15-20°) would cause a similar magnitude of heating at depths extending to several kilometres within the crust. The appraisal of the above hypotheses and time-temperature parameters for the Atlantic margin are the subject of the first author's Ph.D. thesis.

Lacustrine environmental facies of Scots Bay Formation, Nova Scotia, Canada

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At the top of the Fundy Group, the Early Jurassic Scots Bay Formation is exposed along the south shore of the Bay of Fundy. These cherty lacustrine sandstone and limestones range in thickness from 2.5 to 7 meters and rest nonconformably on the North Mountain Basalt, as indicated by palaeo-weathering, erosion, topographic surface irregularities and an old soil horizon.

Four environmental facies are recognized in the Scots Bay Formation: 1) marginal channel facies, 2) offshore facies, 3) nearshore facies, and 4) shoreline facies. The marginal channel facies is represented by moderately sorted, mixed coarse to fine subarkosic sandstone with clasts mainly composed of basalt fragments and sand-sized quartz grains. The basalt fragments may indicate subaerial erosion of nearby basaltic lava deposits. The fining-upward nature of this unit may indicate that a meandering stream deposited this sandstone.

The offshore facies, represented by a silty sandstone unit, is characterized by fine siliciclastic materials. It is a massive or thinly laminated unit containing a significant amount of dark basaltic grains. The presence of claystone suggests that deposition involved settling of at least some suspended material in a quiet environment. Bioturbation may indicate that the bottom waters and sediments were well oxygenated and below local wave base.

The nearshore facies is represented by two subfacies: a lower high-energy nearshore subfacies that is characterized by mixed carbonate and siliciclastic content and an upper low-energy nearshore subfacies that is characterized by fine-grained limestone. The high-energy nearshore facies consists of bioclastic, silty, sandy limestone and peloidal calcareous sandstone. It contains desiccation cracks, horizontal laminations, rock fragments and chert. Scattered, uncommon oolite grains are present. The low-energy nearshore subfacies is micrite-dominated and consists of a wackestone-packestone unit and a silicified stromatolitic (LLH) unit. These stromatolites are a series of small domes or hemispheroids stacked upon each other and composed of dark argillaceous and calcareous sandstone.

The nearshore facies of the Scots Bay Formation contains a higher percentage of carbonate than the offshore and shoreline facies, possibly because carbonate production rates were highest in shallow, nearshore environments. Calcareous fossils, such as ostracodes, mollusks and calcareous algae, may have been the major carbonate sources. Fossils in the nearshore facies include gastropods represented by *Hydrobia*, *Valvata*, and *Gyraulus* and ostracodes represented by *Darwinula*, *Timiriasevia* and *Metacypris*. Specimens of a "giant ostracode" and a small clam have not yet been identified. Travertine-like deposits and charophytic remains

are also present.

The shoreline facies is represented by feldspathic litharenitic sandstone that contains truncated ripple marks associated with low-angle cross-stratification and horizontal current laminations. Desiccation cracks and dinosaur footprints suggest subaerial exposure was routine during the deposition of this sandstone.

The vertical stratigraphic sequence of these facies record a regressive phase during most of the history of "Scots Bay" lake. The source area for the siliciclastic materials is thought to be from the southeast .

Gravity, salt and gas

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The low density evaporite (salt) deposits in the Shubenacadie-Stewiacke Carboniferous sedimentary basin are being assessed for their natural gas underground storage potential. Gravity measurements may be used to define the resulting negative gravity anomalies and produce preliminary geological models. More than seventeen hundred gravity stations from ten different surveys spanning forty-three years have been combined for this study. About two thirds of these are from older surveys (1955-1981) most of which were replotted and reprocessed to modern standards. The remainder are from a 1998 survey which was designed to infill areas of sparse older data coverage.

The resulting Bouguer gravity contour map has defined a northeast to east-northeast trending, linear, negative gravity anomaly with an amplitude of about 20 mGal. The anomaly width is about 14 km and is the result of the lower density Carboniferous Horton Group sediments and Cambro-Ordovician Meguma Group metasediments. Boreholes in the area have intersected salt within the Windsor Group sedimentary basin. A preliminary, geological cross-sectional model has been produced utilizing the gravity and available geological data.

Thrusting of Horton Group over Windsor Group rocks, Cheverie, Nova Scotia

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Strongly deformed Carboniferous rocks of the Horton and lower Windsor groups are exposed along the coastline of the Minas Basin from Cheverie Point eastward towards Truro. The distribution of units has previously been interpreted as resulting mainly from high angle faults.

Detailed mapping of this area shows that Horton Bluff Formation has been strongly deformed, when compared to the younger Cheverie Formation. Horton Bluff Formation black shale and fine grey sandstone show open to tight folds with major fold axes trending northeast to southwest. Most folds are inclined to overturned toward the southeast. Cleavage is absent in the southeast but increases in intensity toward the northwest. There are both thrust and conjugate normal faults. Cheverie Formation red mudstone and sandstone are mildly deformed at Johnson Cove, east of Cheverie. Near the top of the formation at Cheverie Point, duplex and fault-propagation fold structures are seen. Macumber Formation (Windsor Group) laminated limestone and calcareous sandstone are strongly folded. Pembroke Breccia (Windsor Group) is massively deformed with angular elongate blocks of Macumber Formation. White Quarry Formation gypsum and anhydrite (Windsor Group) show anastomosing ductile (planar and linear) structures, and brittle planar structures. Interconnected diabase dykes and sills intrude the Horton Bluff Formation; thin sections from dyke margins show that the intrusions cross cut the tectonic fabric of the Horton Bluff host rock. There is an unconformable, normally faulted contact between Triassic sandstone and Horton Bluff Formation, which truncates the diabase sill at Johnson Cove. A re-interpretation of the data leads to a conclusion that low angle thrust faulting placed Horton Bluff Formation strata over younger strata of the Cheverie Formation and Windsor Group. Transpressional thrust faults present along the coast of the Minas Basin have a possible relationship with the Cobequid-Chedabucto Fault System, a major zone of tectonic activity near the south margin of the western Maritimes Basin.

Superimposition of quartz-carbonate-talc sinter deposits with massive sulphide mineralization in a 680 Ma hydrothermal sea floor setting at Stirling, southeast Cape Breton Island, Nova Scotia

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The Stirling volcanogenic massive sulphide (VMS) deposit (historical production 1.2 Mt of 6.4% Zn, 1.5% Pb, 0.74% Cu, 2.2 oz./t Ag, 0.03 oz./t Au) is hosted by intermediate pyroclastics and finely laminated volcaniclastics of the Late Hadrynian (680 Ma) Stirling Group, SE Cape Breton Island. The volcanic strata are intruded by a quartz-feldspar porphyry (Stirling rhyolite) of elongate shape, which is subparallel to and underlies the ore zone along its 1500 m of

strike length. Logging of drill core, surface mapping and a review of previous work indicate: (1) The footwall (FW) and hanging wall (HW) rocks consist of graded (cm to 3-4 m scale) volcaniclastics of intermediate composition; sedimentary features indicate tops are NW. (2) The Stirling rhyolite is a high-level, polyphase intrusion with variable crystal (quartz, feldspar) content (<3% to 25%), well-preserved spherulitic textures and Na-metasomatism. Eruptive equivalents may occur in the highest part of the stratigraphy. (3) Massive sulphides, consisting of finely laminated (tectonic ?) Zn-Fe-Cu-Pb sulphides dominated by Fe-poor sphalerite and pyrite, occur along a single horizon within a shear zone (Mine Shear). (4) Polyphase deformation has overturned the strata (dips 70-80° SE) and dismembered the sulphide mineralization. (5) The immediate HW and FW strata, now carbonate-talc schist, represent altered intermediate volcaniclastics and not felsic volcanic rocks, as previously considered by some workers. (7) Extensive zones (to 10s of m) of fine- to coarse-grained quartz-talc-carbonate (QTC) rock replace sections of both intermediate volcaniclastics and rhyolite porphyry throughout the FW. These zones formed from alteration processes and are not of exhalative origin. Minor disseminated calcite occurs as alteration in HW rocks. (8) The QTC is generally barren, but rare zones of disseminated to massive pyrite (±sphalerite, galena) occur. Textural observations suggest the QTC post-dates the sulphide rock. (9) In one locality a quartz-carbonate mound (palaeo-sinter deposit) underlies a 2 m thick massive sulphide zone. The above observations are interpreted to indicate that VMS mineralization and QTC zones formed from fluid focusing of heated sea water, but under different thermal and chemical conditions such that two distinct hydrothermal systems formed, one high temperature (ca. 250-300°C) and analogous to modern black smokers and the second a lower temperature (ca. 80-100°C) system akin to hot springs depositing travertine at Yellowstone Park, U.S.A. The porphyry unit is considered the source of thermal energy to initiate and drive the hydrothermal cells.

The EXTECH-II CD-ROM: A CARIS-based system for accessing exploration and assessment data from the Bathurst Mining Camp, northern New Brunswick.

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The EXTECH-II CD-ROM is a self-contained CARIS-based program that will run on any PC using Windows 95 (or later) as its operating system. No other software is required. It incorporates the results of geoscience studies spanning the Bathurst EXTECH-II program (1994 1999), as well as mineral deposit, claim block, and drill-hole data from Provincial files. Topographic and base-map information was obtained from the Provincial Digital Topographic Database.

The database can be searched by a simple drop-down menu system that allows the user to show or hide various information "layers", such as NTS map boundaries, water courses, roads, claim blocks, mineral deposits, etc. Certain digital point-data, i.e., results of stream sediment and till geochemical analyses and airborne geophysical surveys, can be displayed as background raster images. Basic information about most features is either present on-screen or by mouse-clicking on the feature itself. Where applicable this information includes the provincial Assessment Report Number, allowing the user to do more detailed follow-up research. The program can also link to other New Brunswick Government databases, which can be purchased separately.

This system is designed to be used as a simple first-order exploration tool as well as a data archive of the EXTECH-II project. It is due for final release by the end of March 1999 at a cost of about $100 Cdn.

EarthStation Library: A new millenium teaching tool in the earth sciences

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EarthStation Library is state-of-the-art interactive multimedia courseware for earth and environmental science education for students in grades 6 through 12+ and a resource for teachers of grades K through 5. The six *EarthStation Library* Volumes (two complete, four in development) are comprehensive geology, oceanography and meteorology teaching tools that provide an interactive CD-ROM environment for students to explore earth science from a remote sensing perspective. The Library is brimming with 3D and 2D animations, movies, slide shows, narrations, photographs, charts, graphs, projects, plus many interactive exercises and games in which students and educators explore a fun (and challenging) new medium. *EarthStation Library* CD-ROMs are supplemented by traditional User's Guides and Teacher's Manuals, Lab Manuals and a Rock and Mineral Kit. *EarthStation Library* CD-ROMs act as a springboard into the *EarthStation WebChannel* (in development) to link students and teachers to a hub of on-line worldwide earth science information.

The dynamic nature of scientific discovery and the accelerating pace of development in the information technology industry, combine to provide an exciting environment from which educational sector learning outcomes can be satisfied (a local example is the learning outcomes of

the Oceans 11 course in Nova Scotia). *EOA Scientific Systems* multi-media products are developed through the collaboration of scientists, educational experts, programmers, 3D and 2D animators, and graphic artists. Gathering, organizing and presenting earth science material in a dynamic multi-media framework is a challenging endeavour that requires collaboration between experts in diverse fields. In addition to the existing well-received interactive multi-media favoured by educators, *EOA Scientific Systems* has begun to incorporate cutting-edge virtual reality into its products.

The effects of large-scale artificial lake level fluctuations on sediment redistribution, Aylesford Lake, Nova Scotia.

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Lake level fluctuations were found to have a significant effect on lacustrine sedimentation in Aylesford Lake, Kings County, Nova Scotia. Aylesford Lake has been subject to yearly hydroelectric draw-down of approximately 4 m since the 1940s. Hardwood Lake, also located in Kings County, was chosen as a control lake for the study, as its morphology approximates that of Aylesford Lake and its waters are not artificially drawn-down. Both lakes can be classified as polymictic and remain wind mixed throughout the summer months.

Initial sonar profiling showed that the transition from littoral to profundal sediment varies from 7 m below the highwater mark at Aylesford Lake to 3.5 m at Hardwood Lake and can not be attributed to variations in the storm wave base (< 3 m) between the two lakes. The profundal sediments in each lake were cored using a Glew gravity corer. Similarities between loss on ignition, grain size and bulk density values from the sediment cores collected suggest that the same processes are influencing profundal sedimentation in basin deeps in each lake. However, analyses of cores collected in the profundal-littoral transition zone at each lake indicate that the processes controlling transition zone sedimentation vary. The transition zone at Aylesford Lake is characterised by a coarse clastic horizon (3 cm thick, max. 0.7 g/cm^3 wt. sand) not observed in Hardwood Lake cores. This horizon has gradational boundaries and the overlying gyttja (8 cm) is also characterised by increased clastic content. The clastic horizon was most likely the result of basinward transfer of littoral zone sediment by wave and/or ice-influenced processes. These data indicate that profundal sedimentation can be strongly influenced by the lake level fluctuations.

A laboratory study of the interaction between free-falling fine gravel-sized clastic sediment and organic gyttja indicated that introduced clastic sediment can settle through the gyttja. These experiments indicated that clastic layers have the potential to be significantly younger than the bounding gyttja, an important observation in the interpretation of the age of clastic horizons in lacustrine sediments.

North Mountain zeolite deposits

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The Jurassic basalts of the North Mountain, Nova Scotia are host to world-class zeolite deposits whose quantity and quality are rivalled only by zeolite deposits in Poona, India. Recent exploration has determined that commercial quantities of zeolite are present in a number of locations, giving Nova Scotia an opportunity to become a commercial producer for the large East Coast markets of North America. A preliminary diamond drill program conducted in Fall, 1997 and a bulk sample program in Fall, 1998 have outlined zeolite reserve potentials in excess of twenty million tonnes of high-grade zeolite.

The industrial markets for zeolite continue to expand at a rate of 10% per annum with the increasing need for environmentally-friendly materials. C_2C Mining Corporation has advanced the technology to the point where extraction of zeolite from basalt is not only possible with high intensity magnetic separation, but also highly effective. High efficiency in extraction and processing will be achieved through 100% usage of all mined material. C_2C has discovered the magnetic fraction of separated ore has a high reactivity and when coupled with recent advances in technology creates potentially large volume markets.

Zeolites are currently used in a wide variety of industries including agriculture (animal nutrition, effluent control, desiccants, feed binders and barn de-odorizers), horticulture (soil amendments, compost additive and slow release fertilizers), construction (concrete additive, light-weight concrete products), and manufacturing industries (filler/extender in paper, desiccants and industrial absorbents). C_2C's continued product development and research will assure new and dramatic growth for Nova Scotia zeolite products.

The most common zeolites found on the North Mountain are heulandite, clinoptilolite and stilbite. Chabazite, laumontite, mordenite, analcite and the natrolite family of zeolites are less common in this region. Each zeolite region on the North Mountain has a specific physiochemical signature which is used to formulate its usage.

Petrology and geochemistry of the Benjamin River South porphyry Cu deposit, northeastern New Brunswick

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The Benjamin River South porphyry Cu deposit is one of several small (60 to ~600 m dia.) cupolas located along Benjamin River, in northeastern New Brunswick. It is reported to contain approximately 20.8 Mt of 0.18% Cu and 0.02% Mo (URN 0055). The host rocks to the intrusions are pink to red, feldspar-phyric rhyolite and fine-grained, dark grey, green, to black mafic volcanic rock of the Middle Silurian Bryant Point Formation. The Early Devonian (400 Ma) intrusive granodioritic to tonalitic phases that host most of the mineralization, are tan-coloured, biotite- (8-12%) (after hornblende) and plagioclase porphyritic with a fine-grained hypidiomorphic-granular groundmass. The typical intrusion also has up to 4-6% opaques (magnetite & sulphides) and an average magnetic susceptibility of 0.40 (emu/g) consistent with it's oxidized character. The least-altered intrusive suite have calc-alkalic, low Fe/Mg (0.92-1.86), weakly peraluminous (A/CNK = 1.1) compositions; these compositions fall near the low Or end of the 1 kb cotectic in the An-Ab-Or-Qtz system (~850°C). The low Zr/TiO_2 (0.03 1), Nb (8.5 ppm), Y (11 ppm), Rb (47 ppm), Th (4.3 ppm), Rb/Sr (0.05-0.72), total REE (50-70 ppm), and steep La_N/Lu_N (40-103) are consistent with a calc-alkalic (volcanic arc) origin, with many features typical of oxidized I-type granitoid suites, although no hornblende is preserved. The slightly positive Eu/Eu* (1.04) indicates that there has been negligible plagioclase fractionation.

Typical high-T alkalic alteration, which is associated with the chalcopyrite-pyrite mineralization, is dominantly pervasive K-feldspathization and biotitization of pre-existing ferromagnesian phases and feldspars; this is manifested by an increase in K/Na, Fe, and S with Cu. The pervasive to vein-controlled, low-T phyllic (muscovite) to propylitic (clay) alteration is superimposed on earlier assemblages generally making the rocks more aluminous; although weak, the low-T alteration has only minor alkali leaching coupled with phase changes. Late pyrite-bearing, base-metal veins cut the disseminated chalcopyrite-pyrite mineralization. Molybdenite commonly occurs in secondary quartz-bearing veins.

Detailed stratigraphy and porosity development in the Swan Hills Formation, west central Alberta, Canada

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The Swan Hills Formation is a Devonian fringing reef system and is a major oil and gas reservoir in western Canada. It has been the focus of a number of studies but the association between particular facies and porosity development is still not well understood. In this study, the stratigraphy and porosity of a section of core from the Swan Hills Formation is investigated in detail to determine the controls on porosity and reservoir development.

The Home Oil core was retrieved from west central Alberta (4-31-67-10 W5) at a depth 2611 m to 2534 m. Preliminary analysis of the core shows that it is a reef system characterised by stromatoporoids including *Amphipora* and to a lesser extent brachiopods, gastropods, echinoderms, and bryozoans. Six distinct facies were observed. Facies 1 (2611 m – 2603 m) is characterised by *Amphipora* in a light brown vuggy matrix. This facies was developed in a low energy, back-reef environment. Facies 2 (2603 m - 2567 m) is characterised by bulbous stromatoporoids and *Amphipora* in a dark-brown matrix, and is interpreted as having been deposited in a platform environment. Facies 3 (2567 m – 2564 m) is characterised by the presence of dendroid stromatoporoids in light to medium-brown coloured matrix indicating a reef environment. Facies 4 (2564 m – 2557 m) is characterised by a light crystalline homogenous matrix with no recognisable macrofossils; this facies probably represents a reworked *Amphipora* bed. Facies 5 (2557 m – 2543 m) is marked by a diverse fossil assemblage but is characterised by the introduction of brachiopods. Its matrix ranges in colour from dark brown to light brown. This colour change is most likely due to fluid interaction. This facies was most likely deposited in a fore-reef environment. Facies 6 (2543 m – 2534 m) is characterised by its vuggy texture and the presence of subspherical stromatoporoids in a light brown silty matrix and was probably deposited in a reef environment.

Porosity was studied through thin section and computer image analysis. Porosity is primarily secondary and was best developed in facies that contained *Amphipora* and other stromatoporoid material. Porosity development was due primarily to the presence of open galleries and intergranular pore spaces and ranged as high as 12%. Interconnectivity was best developed in reef and fore-reef zones where porous *Amphipora* were in close contact to each other. This study shows that a detailed understanding of fossil assemblages and facies architecture may be essential to identifying where porosity is best developed.

U-Pb detrital zircon age constraints on evolution of the late Palaeozoic St. Marys Basin, central mainland Nova Scotia

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The St. Marys Basin, central mainland Nova Scotia, lies along the southern flank of the composite Late Devonian-Permian Magdalen Basin in the Canadian Appalachians and along the Avalon-Meguma terrane boundary, which is defined by the E-W Minas Fault Zone. The basin fill consists of Late Devonian-Early Carboniferous continental clastic rocks of the Horton Group that were deposited in fluvial and lacustrine environments after the peak of the Acadian orogeny.

SHRIMP II GSC data for approximately 100 detrital zircons from three samples in the Horton Group show that most of the zircons have been involved in a multi-stage history. Although there is a minor contribution from Early Silurian and Late Devonian suites, most detrital zircons are recycled from clastic rocks in the adjacent Meguma and Avalonian rocks. Neoproterozoic (ca. 680-550 Ma) and Palaeoproterozoic (ca. 2.0 to 2.2 Ga) zircon populations predominate although there is an important, but minor contribution from ca. 1.0 Ga, 1.2 Ga and 1.8 Ga zircons.

U-Pb analyses of single zircon grains from clastic sedimentary rocks of the Meguma and Avalon terranes show that these terranes have different populations of detrital zircons, suggesting they are sourced from different portions of the ancient Gondwanan margin. Both terranes contain Neoproterozoic and Late Archean populations. However, Avalon terrane rocks also contain important Mesoproterozoic zircons between 1.0 Ga and 1.8 Ga.

In general, the SHRIMP data, when combined with geochemical and Sm-Nd isotopic data, indicate that the Horton Group basin fill sediments are largely attributed to uplift and erosion of Meguma terrane metasedimentary and granitoid rocks immediately to the south of the St. Marys Basin in the waning stages of the Acadian orogeny. Regional syntheses indicate that this uplift occurred before and during deposition and was coeval with dextral ramping of the Meguma terrane over the Avalon terrane along the southern flank of the Magdalen Basin.

Alluvial fan deposits of the Grantmire Formation (DDH PE 83-1), Horton Group, at Point Edward, Cape Breton Island, Nova Scotia

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The Early Carboniferous (Tournaisian) Grantmire Formation belongs to the Horton Group and is ~800 m thick, based on exposures and drill core in the northern part of the Sydney Basin onshore. The 503 m measured section of the Grantmire Formation in drillcore PE 83-1 is dominantly pebble conglomerate with interbeds of siltstone and minor beds of sandstone. The conglomerate (facies 1) is light to medium red, polymictic, poorly sorted, and clast supported with subangular to subrounded clasts. Conglomerate beds reach 15 m thickness with a maximum recorded clast size of 22 cm. They are divided into three subfacies: interbedded pebble conglomerate/sandstone, pebble to cobble conglomerate, and small boulder conglomerate. The other facies are sandstone (facies 2), siltstone with multiple sandy layers (facies 3), gritty siltstone (facies 4), and fine siltstone (facies 5). Siltstone is medium reddish brown and in two facies has calcareous nodules with green reduction patches and/or envelopes suggesting palaeosol or shallow groundwater origin. Sequences of large scale upward-coarsening alluvial fan units contain smaller scale upward-fining cycles.

The Grantmire Formation has been interpreted as the clastic fill of fault-bounded basins within the region of the Sydney Basin. Currently, the Grantmire Formation is the only mapped unit in the Sydney Basin Horton Group. The presence of black shales in the Atlantic Canadian Horton Group is important for hydrocarbon potential regionally; they are not presently identified in the Sydney Basin. Porosity and permeability tests reveal that reservoir quality ranges from poor to good and is likely controlled by variable amount of detrital clay, authigenic minerals, carbonate cement, palaeosol development, and irregular laminae of finer material.

Distribution of uranium in selected rock types in central mainland Nova Scotia: Implications for the occurrence of high levels of radon in domestic well waters and indoor air

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Elevated levels of the radioactive gas radon have been detected in well waters and in indoor air in diverse geologic and geographic areas in Nova Scotia. Ultimately the source of radon is the uranium in the rocks themselves. This project attempts to determine the nature of the uranium distribution within the rocks, and the processes involved in uranium

release into the environment, in order to develop a model of radon potential for a region. Rocks in which all the uranium is locked in resistate minerals such as zircon, will not readily release uranium into the environment at near-surface conditions. Uranium concentrated along grain boundaries, cleavage traces, shear or alteration zones, or in weathered or altered minerals may be more loosely held in the mineral structures themselves. Such sites may readily release uranium and may serve as channelways for uranium or radon migration in the near-surface environment.

This study represents a first attempt at quantifying the mineralogical distribution of uranium in selected rock types. Preliminary fission track maps of granitoids of the South Mountain Batholith (SMB) and other spatially associated rocks, reveal the distribution of uranium in these rocks.

These data suggest that much of the uranium in "fresh" rocks is locked in resistate minerals such as zircon, and therefore is not readily mobilized. In altered and weathered samples of the granitoids of the SMB, the uranium occurs in resistate minerals, in cleavage traces within the biotite and chlorite, and along grain boundaries where the uranium is commonly associated with iron oxides; uranium may be more readily mobilized under these conditions.

In proximity to the granite, anomalously radioactive Meguma Group metasedimentary rocks exhibit uranium concentrations along veins postdating the contact metamorphism. These veins are sub-parallel to bedding planes and may serve as potential channels for uranium and radon migration. In anomalously radioactive Horton Group sandstone, uranium is concentrated in the matrix. This sandstone is loosely cemented, so uranium and radon could be readily released into the environment when the rock is physically or chemically disturbed.

The next stage of the project will integrate the above mineralogical relationships with airborne radiometric data and geological parameters, and spatially analyse these associations using GIS.

Uranium, radium, and radon in streams and domestic well waters: A GIS analysis of geological, geochemical and geophysical relationships

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Anomalous levels of Uranium and its daughter products ^{226}Ra and ^{222}Rn in domestic water supplies have the potential of posing health risks. High levels of naturally occurring radioactive elements in water may correlate with high radon in indoor air. This project attempts to determine whether elevated levels of U, Ra, and Rn in well and stream waters can be predicted by integrating data from pre-existing data layers. These layers include geochemistry, airborne radiometrics, geology, and structures, varying in scale from 1:2500 to 1:500 000. U, Ra, and Rn data from 1978 to 1981 mining exploration activities have been entered into a GIS and spatially analyzed against these layers. The test area chosen is located in central Nova Scotia, around the town of Windsor. Over 3000 data points, entered at a scale of 1:50,000, have been integrated to compile the basic radiogenic element geochemistry layer. Various analyses of the data include the generation of graphs, tables, buffering, distance equations, and queries, as well as the synthesis of map data. The results suggest that the approach used is promising in assessing the potential for high U, Ra, and Rn in domestic waters, which may correlate with high indoor radon risks.

Morphology, timing, and implications of ancient submarine canyons in the Carson Basin, offshore Newfoundland, Canada

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The Carson Basin underlies the Grand Banks, offshore Newfoundland, and is composed of several depocenters, the deepest of which holds over 10 km of Mesozoic and Cenozoic sediments. To date, only four exploration wells have been drilled. The basin lies to the southeast of the more intensely studied and developed Jeanne d'Arc Basin, which contains the Hibernia production platform and other developing oil-fields. A basement high separates the Carson Basin from the Jeanne d'Arc. The basins formed in response to the opening of the North Atlantic Ocean in a complex series of rifting events. Uplift and erosion which accompanied the rifting phases created unconformities and deposited clastic sequences.

Submarine canyons and erosional scours have been recognized in the northern end of the Carson Basin and mapped using industry seismic profiles. Work to date shows two canyon complexes trending east-west. The canyons are at least 6.5 km wide and 1000 m deep, and are covered by more than 1100 m of sediment. The erosional features have a wide range of implications, including possible subaerial exposure of the continental shelf. The size and morphology of the canyons infer large scale clastic deposition in submarine fans basinward. Synthetic seismograms created from the exploration wells allow correlation of seismic reflectors with formations, lithology, biostratigraphy, and unconformities present in the well data. By relating the reflectors to the major tectonic sequences of deposition and erosion, the formation of the canyons can be temporally constrained. Work is in progress to determine which of the Late Cretaceous, Early

Palaeocene, or Early Eocene erosional unconformities excavated the canyon complexes.

The West Moose River anorthosite, Cobequid Highlands, Nova Scotia

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The West Moose River anorthosite occurs as rare blocks (cm to m in size) in a gravel pit along the Cobequid Fault near West Moose River together with abundant blocks of magnetite/ilmenite rock (some of which show contacts with anorthosite). The abundance of anorthosite and magnetite/ilmenite blocks in the gravel pit and their absence in either outcrop or drift elsewhere in the region suggests that they are associated with, and restricted to, the Cobequid Fault zone. A prominent magnetic anomaly extends about 5 km along the Cobequid Fault zone in this area.

The anorthositic rocks consist of feldspathic anorthosite, gabbronorite and megacrystic gabbronorite with orthopyroxene and amphibole megacrysts. The orthopyroxene (matrix and megacryst) has a limited compositional range from En_{62}-En_{70}. The orthopyroxene megacrysts are very aluminous (up to 8.0% Al_2O_3). The matrix amphibole is ferroan pargasitic hornblende and the amphibole megacrysts are tschermakitic hornblende and magnesio-hornblende. A number of lines of evidence suggest original in situ growth for the megacrysts. The oxide rocks comprise coarse-grained magnetite (45%), ilmenite (40%), spinel (Mg-rich hercynite) (10%), and minor hematite and titano-magnetite (<5%), all of which show exsolution lamellae. The oxide rocks poikilitically enclose silicate mineral and sulfides. Feldspathic anorthosites have a corona texture at their contact with oxides, with a minimum temperature of formation of 600°C. The sulfides identified include: pyrrhotite, various types of pentlandite, chalcopyrite and some late pyrite.

A Nd-Sm isochron indicates that the anorthosites are unrelated to the Devonian-Carboniferous gabbros and are of Mesoproterozoic age. They thus provide further evidence for Mesoproterozoic basement slivers in the "outboard" terranes of the Appalachians. Various textural evidence and the assemblage of pentlandite, pyrrhotite, and Mg-rich spinel in the oxides all suggest a genetic link between the oxides-sulfides and the anorthosites. How was such a middle crustal rock assemblage brought to upper crustal levels? Three hypotheses are examined:

a) magmatic rafting in the Carboniferous. Given that the anorthosite occurrence comprises > 70% oxides with a high S.G., this seems improbable.

b) Carboniferous uplift in a strike-slip zone like that suggested for late Devonian-early Carboniferous mafic granulites at Clark Head, which formed at 9 kbar (25 km depth if pressure was all lithostatic) from a magma isotopically and geochemically similar to that of the Wentworth Pluton. Maximum uplift of Carboniferous granite plutons along the Cobequid Fault zone is estimated as 8 km for Pleasant Hills from amphiboles, of which perhaps 4 km is Triassic. The Clarke Head granulites might have a few km diapiric uplift in addition. The lack of higher grade metamorphic detritus in local Carboniferous basins is a problem if there were widespread vertical Carboniferous tectonic transport in the Cobequid fault zone.

c) Late Neoproterozoic uplift resulting from slab detachment or convective thinning of lower lithosphere. This process could account for the unusual formation of amphibole megacrysts and the 600°C coronas on the feldspathic anorthosites. This hypothesis would preclude a Grenville origin for the anorthosites.

Tournaisian thrusting in the northeastern Cobequid Highlands, Nova Scotia and its regional significance

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Distributed crustal-scale shear faulting in the Cobequid Highlands in the middle Devonian to Carboniferous resulted from the oblique convergence of the Meguma and Avalon terranes. In the northeastern Cobequid Highlands, seismic reflection profiles show Neoproterozoic and lower Palaeozoic rocks, together with enigmatic foliated rocks, overlying early Carboniferous Fountain Lake Group. The foliated rocks form the hanging wall of a north-vergent thrust fault. Their protolith is inferred from petrography and geochemistry to be principally Neoproterozoic rhyodacitic tuffs and late Palaeozoic hypabyssal intrusions. The age of thrusting is stratigraphically constrained to the late Tournaisian - early Visean and sericite from mylonite yielded a Tournaisian K-Ar age of 352 ± 8 Ma. The thrusting occurs at the base of a tectonic-escape sheet and resulted from a constraining bend in the master Rockland Brook fault. Farther west, where the Rockland Brook fault trends almost E-W, Tournaisian extensional features include the Nuttby basin and widespread small gabbro intrusions. At deeper structural levels, granite plutons were intruded in a similar tectonic regime of thrusting and local extension through tectonic escape. The emplacement process resulted from progressive widening of initial dykes, analogous to those deformed in the thrust hangingwall. The regional pattern of Tournaisian half-graben formation in the southern Maritimes Basin, synchronous with pluton emplacement and thrusting in adjacent horsts, is compared with similar Miocene deformation in the southern Aegean sea and is argued to be inconsistent with the postulated regionally

extensive detachment termed the Margaree shear zone.

Occurrence of microgarnets coring plagioclase crystals in granodiorite of the South Mountain Batholith, Nova Scotia

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We report on the occurrence of microgarnets (<3 mm) occurring in the granodiorite phase of the South Mountain Batholith (SMB), a 370 Ma, polyphase peraluminous batholith that outcrops throughout southern Nova Scotia. Samples come from a diamond drill hole (NSDNR hole # DDH-1) collared in metasedimentary rocks of the Meguma Group near Digby, southwestern Nova Scotia. At depth the hole intersects variably altered, biotite-rich granodiorite which forms a marginal phase of the SMB. Within fresh granodiorite (samples taken from between 12-32 m, 102-104 m and 249-264 m depths) occur deep red microcrystals of garnet, of which some coexist with biotite, consistently occurring in the cores of plagioclase grains. We also noted the presence of small fragments (1-25 cm) of biotite-rich (ca. 30 - 40%) xenoliths scattered throughout parts of the core. Bulk analyses of the granodiorite (n=12) indicate 68.92 wt.% SiO_2, 0.59 wt.% TiO2 and a peraluminosity (A/CNK) of 1.11. In thin section the rock is hypidiomorphic granular with normal and oscillatory zoned plagioclase (An_{18-45}), perthitic K-feldspar, dark brown biotite [Fe/(Fe+Mg) = 0.643] with abundant accessory phases, intragranular apatite and rare garnets invariably enveloped by plagioclase. Observations of about 25 garnets indicate anhedral shapes dominate and that reaction rims are totally absent. The majority of garnets analysed occur within close limits of partially digested biotite-rich xenoliths, but in thin section no garnets have been observed in the xenoliths. Electron microprobe analyses indicate spessartine-rich almandine garnet compositions with a core to rim enrichment of Mn (i.e., 3 vs. 7 wt.% MnO). Currently a variety of models are being considered to account for the garnets, including xenocrystic (source yet unknown) and cognate (high- or low-P magmatic).

The 'Saxby Tide' of October 4-5, 1869: A possible geological marker around the Bay of Fundy?

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An exhaustive event-specific search supported by the Atmospheric Environment Branch of Environment Canada has been completed for October 1869 'Saxby Gale'. Most of the primary sources from Atlantic Canadian and Maine newspapers have been captured, along with later articles and some personal accounts in letters, diaries, and vessel logs. The original Stephen Martin Saxby (1804-1883) letters to The Standard of London, England in December 1868 and September 1869 have been recovered, wherein he predicted, on a worldwide basis, not only a very high 'spring' (or perigean) astronomic tide, but that it would be accompanied by equinoctial gales at 0500 local time on October 5, 1869. He was fortuitously proven right in the Bay of Fundy and Maine though the cause was a tropical cyclone that had been travelling up the eastern seaboard of the U.S. for at least two days before.

Newspaper accounts present an often graphic view of the eye of the hurricane making landfall in the area of the Maine/New Brunswick border. Winds on the 'righthand' side of the track were strong enough to cause blowdown and an increased forest fire hazard in the years following. Significant building damage was reported in the area immediately adjacent to the border, with roads and railways blocked by debris. Many vessels blew ashore in the Passamaquoddy Bay area. As the storm came ashore it may have been a category 2 event and the counterclockwise winds drove the storm surge, or 'Saxby Tide', up the Bay of Fundy. As the storm surge arrived on top of one of the highest perigean tides of the period and overtopped most, if not all, of the Acadian dykes in the Minas Basin and Chignecto Bay and flooded lowlands such as the Tantramar Marsh and areas of the present-day communities of Moncton, Taylor Village, Sackville, Amherst, Truro, Great Village, Maitland, and Windsor. On the 'left' side of the track huge amounts of rain were unloaded in the northern New England states through to eastern New York State.

The forensic analysis of primary sources as well as family and folklore are all beginning to confirm the Saxby storm surge as the highest historically documented storm surge in the Bay of Fundy being in the order of 1.7 to 2.1m; had the hurricane arrived two or three days later, the perigean tide would have been about 0.6m higher. By capturing recoverable levels of the highest water levels on October 4-5, 1869 these can be corrected for eustatic sealevel rise over the past 130 years and for differential isostatic rebound to allow maps to be plotted showing the coastal areas that would be inundated today were such an event to recur. The 1869 saltwater inundation flooded into parts of marshes, farmland, coastal lowlands, and lakes or ponds where no saltwater had been known for perhaps more than 110 years or since at least the 1759 storm and related storm surge that so impacted the early Acadian settlements in western Nova Scotia. A careful

examination of the microfossils and flora in cores in such strategic locations may well find a thin Saxby Gale marker horizon.

A graptolite taphofacies model.

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Graptolite-bearing carbonate concretions from the Cape Phillips Formation, Arctic Canada, yield valuable biostratinomic information, making the creation of a graptolite taphofacies model possible. The concretions lithified during shallow burial before extensive physical compaction, preserving the three-dimensional nature of the graptolites and the sediment. The method of layer-by-layer dissolution enables the examination of the orientation, preservational condition and small-scale lateral and vertical heterogeneity in graptolite distribution within single bedding planes and through successive strata. The model relates the evidence of biostratinomic reworking and the vertical variability in graptolite distribution to the lithology of the laminae in which they occur in an attempt to define the palaeoecological and taphonomic processes that acted on the fossils. We define 5 graptolite taphofacies; mass transport, sediment starved, in situ lag, graptolite bloom, and constant sediment and graptolite input. Chi square analyses of 15 concretions revealed that 7 displayed an even distribution of graptolites on the measured layers and 8 showed a concentration of graptolites on one or more layers (5% level of significance). We observe the range of taphofacies in the 15 concretions, with approximately 80% of the concretions plotting in or near the taphofacies of constant sediment and graptolite input. This graptolite taphofacies model provides a framework for the interpretation of the taphonomy of graptolites in wide variety of depositional settings and preservational styles.

Geometry of the western Newfoundland Appalachian foreland basin and thrust front: interpretation of industry seismic profiles

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Offshore Western Newfoundland has been extensively explored by petroleum companies within the past ten years, resulting in the release of an extensive set of seismic reflection profiles that show the geometry of the Palaeozoic deformed continental margin, the Appalachian thrust front, and a thick foreland basin succession.

A lower series of reflections is identified as representing the Late Proterozoic to Early Ordovician shelf succession. Middle Ordovician extension associated with the Taconian orogeny produced numerous normal faults, extending the foundered platformal succession. Later reactivation of some of these faults, associated with the Acadian orogeny, led to basin inversion.

The platform succession is overlain by widespread coherent reflectors representing Late Ordovician to Devonian foreland basin sediments. A well-defined magnetic anomaly offshore has now been located on land. This provides a marker within the foreland basin succession at the level of the Late Ordovician Misty Point Formation, and shows that a significant thickness of the foreland basin stratigraphy is in fact Late Ordovician.

The foreland basin succession is deformed at its eastern margin by the Appalachian thrust front. A broad syncline is developed, with its eastern limb deformed by a tectonic wedge thrust into position in the Acadian orogeny. Strong short reflectors are evident within the otherwise incoherent tectonic wedge, a possible indication of tectonically eroded pieces of the earlier platform succession now present within the allochthonous wedge. To the south the tectonic wedge is intersected by the Round Head Thrust; structures in the footwall of the thrust were the target for recent drilling on and around Port au Port Peninsula.

South of the Port au Port Peninsula, the northern margin of the Carboniferous western Maritimes Basin is imaged on numerous profiles. Carboniferous salt-cored anticlines trend SW-NE, roughly parallel to the faulted south coast of the Peninsula.

Thermal evolution of the Maritimes Basin: A review

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Burial history plots for the various parts of the Maritimes Basin and the surrounding areas have been constructed using the available geological information. The plots were constructed based on present day stratigraphy, minimum stratigraphic thicknesses of the units based on the overall basin facies relationships, unconformities, temperatures necessary to produce the measured vitrinite reflectance, minimum temperature estimates based on the clay mineralogy studies, apatite fission track closure ages, estimates of the geothermal gradient based on the vitrinite reflectance profiles, maximum temperatures based on T_{max} from RockEval pyrolysis, and maximum temperatures based on Thermal Alteration Index (TAI) measurements. The burial history plots suggest that there was 1-3 km of additional cover throughout most the Maritimes Basin.

The time-temperature paths derived from the burial history plots for the various areas within and adjacent to the Maritimes Basin were corroborated by both forward and inverse modelling. The modelled apatite fission track ages, distribution of the fission track lengths and the modelled vitrinite reflectance values closely correspond to the measured values. The apatite fission track analyses of the samples from the basin accurately constrain the timing of the additional cover throughout the basin. The thermochronological evidence suggests that an additional 1-4 km of strata were deposited throughout the Maritimes Basin and were subsequently eroded. These sediments accumulated to a maximum thickness in the Permian and were eroded during exhumation that preceded the Triassic/Jurassic rifting of the Atlantic margin. The timing of the maximum burial in the Maritimes Basin has important implications for hydrocarbon generation and preservation. Hydrocarbons produced during the regional maximum burial episode (Permian) would require a very tight cap rock in order to preserve oil and gas to the present day. Basal Windsor Group carbonates and sandstones of the Horton Group that are covered by thick salt and evaporites of the lower part of the Windsor Group represent the most prospective hydrocarbon horizons in the Maritimes Basin.

Late-glacial and Early Holocene stratigraphy and Palaeoecology of Taylor Lake, Nova Scotia, Canada

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Lake sediment, diatom, sponge spicule and pollen stratigraphy of sediments from Taylor Lake, eastern Nova Scotia reveal changes in vegetation, ecology and climate during the Late Glacial and Early Holocene. Though the Taylor Lake site was deglaciated in advance of Younger Dryas (YD) cooling the diatom and sponge spicule data indicate that a pre-YD warming trend was absent. The Younger Dryas inorganic marker horizon (YDimh, 10090 B.P.) is coarse-grained, exhibits reduced pollen concentrations and contains no diatoms or sponge spicules. Complete ice-cover was thought to prevail during the YD and the development of aufeis and perennial snow cover was likely at this time. The YDimh was formed as a consequence of both increased sedimentation rates associated with landscape instability and reduced productivity.

Post YD aquatic conditions were acidic and possibly turbulent. Pollen and sedimentological data indicate the rapid establishment of a stable and productive landscape. An upper oscillation (UO, 7720 - 7660 B.P.) is the result of a cooling event indicated by both a decrease in LOI and a resurgence of alkaliphilic, benthic diatoms and cold-water-tolerant sponges. Image and grain size analysis of the bounding gyttja and the UO indicate that the these sediments differ primarily in their respective volumes of fine silt and clay; the maximum grain size of each unit remained unchanged. This would indicate that changes in sediment transfer mechanisms in response to cooling were subtle. The UO correlates with a regional cooling event that has been recognised in northwestern Europe.

Graphical detection of hydrothermal alteration in slates and greywackes from the Goldboro Saddle Reef Au vein deposit, Nova Scotia, Canada: A projective geometry approach

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Hand samples of: (1) slate, (2) mixed slate, siltstone and greywacke, (3) greywacke, and (4) greywacke with well-developed pressure solution cleavage from host rocks to the Goldboro saddle reef Au-quartz vein deposit, Goldenville Formation, Meguma Supergroup, eastern Nova Scotia, exhibit demonstrable macroscopic color and modal mineralogy changes proximal to Au-bearing veins. These consist largely of purple coloration due to increases in the biotite mode, and

the presence of disseminated sulphide minerals and organic carbon. However, these samples exhibit little geochemical evidence of hydrothermal alteration on conventional geochemical scatterplots. Although the observed hydrothermal alteration is relatively subtle, the lack of geochemical expression of metasomatism is most likely due to the lack of power of conventional geochemical diagrams (major and trace element scatterplots) to discriminate the effects of hydrothermal alteration.

Consequently, matrix algebra has been used to design molar element ratio (MER) diagrams (scatterplots) that are special projections of the 8 dimensional geochemical space (SiO_2-Al_2O_3-FeO-MgO-CaO-Na_2O-K_2O-H_2O) in which the host rocks reside. These projections consider the modal mineralogy of the unaltered host rocks (quartz-plagioclase-chlorite-biotite-muscovite), and view the geochemical data from specific locations in the geochemical space that maximize the geochemical contrast between unaltered and altered samples.

Results demonstrate significantly enhanced graphical differences between hydrothermally altered and unaltered samples. This allows geochemical identification of and accurate quantification of the extent of hydrothermal alteration in all samples. Samples identified as significantly altered by this means exhibit consistently anomalous Au, As, and S concentrations, despite nugget effect variations. Thus, geochemical discrimination of hydrothermally altered rocks using MER diagrams can be used in exploration to reliably explore for hydrothermal alteration zones about saddle reef Au-quartz veins in the Goldboro region. Potential exploration applications are also possible in other saddle reef Au-quartz vein camps at similar metamorphic grade within the Meguma Supergroup.

Construction of a Radarsat mosaic of Nova Scotia and integration of elevation data

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The province of Nova Scotia acquired 17 Radarsat 1 Synthetic Aperture Radar (SAR) images in the fall of 1996 covering the province. These data have been processed at the Centre of Geographic Sciences (COGS) and used to construct a provincial radar mosaic. The processing involved orthorectification of the imagery, which translates the orientation of the image from the path of the satellite orbit to a map projection, also the various geometric distortions and relief displacements that are inherent in radar imagery as a result of the side looking geometry have been corrected utilizing a Digital Elevation Model (DEM) constructed from 1:50,000 topographic maps. Once the imagery was in a proper map projection the seventeen scenes were scaled from 16 bit to an 8 bit (256 grey scale) representation. The 8 bit images were radiometrically adjusted to ensure a seamless image mosaic. The SAR data were processed to a 30 m pixel. For provincial scale processing the data were averaged up to a 120 m pixel. A 1:50,000 based DEM was used to construct a shaded relief image with illumination from an azimuth of 188° and a zenith of 45° to compliment the natural illumination of the SAR data which is 98°. The DEM was also used to construct a colour elevation map of 256 colours, coded to optimize chroma-stereoscopy. The SAR mosaic, shaded relief and colourized elevation data were merged to produce a hybrid value-added provincial mosaic. The weighting factors for the three input layers were: 40% SAR, 30% shaded relief, 30% colour elevation. The DEM used in this study did not have the lakes coded. The SAR image was used to code the lakes and incorporate them into the final mosaic. The SAR image of standard mode 7 provides information related to the landcover, for example the forest is grey, while cleared areas such as agriculture lands are darker in tone and water is very dark. Major roads, airports and landcover can be identified in the final image. The final mosaic was then merged with a generalized regional land and bathymetric dataset. The image can be readily used within a GIS since it is georeferenced. Geologists can use the image and interpret it in terms of the topographic expression and drainage and lancover patterns, as well observe the data in 3-D through the use of Chromadepth™ glasses. Other layers, for example geophysics, can be used to colour code the SAR/DEM combination to correlate surface topography with subsurface characteristics.

Preliminary geological map of the Digby area, Nova Scotia

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Lower to middle Palaeozoic units in the Digby area, southwest Nova Scotia, include the Goldenville and Halifax formations of the Meguma Group and the overlying White Rock and Torbrook formations. The Goldenville Formation consists of metasandstone with lesser, although variable amounts of, slate and metasiltstone. The Halifax Formation has been subdivided into three members, including (from bottom to top); (1) the Bloomfield member, consisting of distinct maroon and green (locally variegated), laminated metasiltstone; (2) the Acacia Brook member, consisting grey laminated metasiltstone and; (3) the Bear River member, consisting of slate and silty slate characterized by thin cross-

laminated metasiltstone. This unit typically has abundant trace fossils and local graptolites. The White Rock Formation consists of cleaved, dark, silty slate, similar to the Bear River member, and local thick (25-30 m) quartzite beds. Trace fossils are common. An apparent disconformity or angular unconformity occurs with the underlying Halifax Formation. The Torbrook Formation conformably overlies the White Rock Formation and consists of mainly dark silty, locally fossiliferous shale, black siltstone and minor ironstone. The Lower to middle Palaeozoic rocks are cut by abundant mafic sills, including early (syndepositional?) fine-grained folded sills restricted to the Halifax Formation, gabbroic sills that post-date the Halifax Formation but predate the South Mountain Batholith, and younger undeformed sills related to the North Mountain Formation.

Lower to middle Palaeozoic units are folded into regional, northeast-trending F_1 folds; however, at a regional scale these units systematically young to the east with no map-scale repetition of units. This implies a regional-scale monocline with the Goldenville Formation and Bloomfield and Acacia Brook members defining an east-dipping limb in the west, the Bear River member representing a shallow limb in the central part, and the White Rock and Torbrook formations forming an east-dipping limb in the east. Post F_1 deformation includes kink folds throughout the area and crenulation cleavage developed in the west part of the area, particularly within the Acacia Brook and Bloomfield units. Several minor steep north- to northwest-trending faults cut the area.

The ca. 370 Ma South Mountain Batholith and Ellison Lake Pluton intruded the Lower to middle Palaeozoic units and produced contact metamorphic aureoles characterized by hornfels with cordierite, biotite and andalusite porphyroblasts.

To the north a conformable sequence of Triassic to Jurassic sedimentary rocks (Wolfville and Blomidon formations) and basalt (North Mountain Formation) unconformably overlie the older units.

Experimental evaluation of subaqueous disposal of acid generating rocks of the Meguma Supergroup, southern Nova Scotia

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Municipal and regional development in Halifax and southern Nova Scotia involves the disturbance and excavation of sulphide rich bedrock and produces large quantities of waste rock material. This material poses a high risk potential for acid rock drainage (ARD), a commonly known geoenvironmental issue in Nova Scotia. An economically feasible disposal technique and management option would be to discard acid generating waste rock in natural lake waters and coastal marine settings. This concept is based on the premise that acid generation is chemically suppressed in low oxygen conditions under water cover. Subaqueous disposal of mine tailings is presently a standard practice employed by the mining industry, but this method has yet been evaluated with regards to sulphidic slates of the Meguma Supergroup.

We have evaluated the subaqueous disposal of sulphide-bearing slates in seawater compared to fresh water in laboratory experiments. Polished thin sections were prepared from a drill core sample from the Meguma Supergroup near the Halifax International Airport. The experiment was conducted using distilled water, seawater from the Northwest Arm, and freshwater from Lake Banook in Dartmouth. One thin section was submerged in 500 mL of each of the three water samples at a depth of 32 cm in graduated cylinders exposed to the atmosphere at room temperature (~21°C). Mineral surfaces were observed microscopically under reflected light for tarnished regions, which were used as an indication of sulphide mineral oxidation. Preliminary results at six days show that the rate of sulphide oxidation is higher in seawater compared to freshwater and distilled water. These results will be discussed in terms of the differences in the chemistry of the solutions.

Maritimes Basin studies: GSC Atlantic

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The GSC Atlantic is conducting a comprehensive study of the origin, evolution, basin fill and petroleum prospectivity of the Maritimes Basin, onshore and offshore Gulf of St. Lawrence. Building on several decades of regionally based geological and geophysical mapping and syntheses, the project has three scientific and one reporting thrusts.

1. **Basin Framework Studies** — Regional crustal scale seismic refraction studies, together with mapping and interpretation of potential fields data, provide the essential geological context within which the geodynamic and thermal subsidence, and infill history of the basin can be considered.

2. **Stratigraphic Studies** — New biostratigraphic data, and a reappraisal of the lithostratigraphic framework have resulted in significant changes to perceptions of the stratigraphic character of the basins and regional correlations. One key element of the stratigraphic definitions has been the number of unconformities of regional significance which in turn may directly influence the distribution of source rocks and reservoirs in the deep basin.

3. **Petroleum System Studies** — The crustal and stratigraphic studies are an essential underpinning to considerations of the petroleum systems operating in the Basin

which in turn influences the basin petroleum prospectivity. Regional and site-specific studies of Late Devonian to Permian strata of the western Maritimes Basin provide evidence that all the geological prerequisites that influence the generation, expulsion, and migration of petroleum have been satisfied but that significant geological risks remain. Source, reservoir and trap/structuration studies are being conducted to assess the nature and degree of these risks.

4. **Maritimes Basin Geoscience Compilation** — A key component of the project is to ensure that elements of the data, information and knowledge generated through the project are made widely available through the use of web-enabling technologies.

Revised stratigraphic nomenclature for the Bathurst Mining Camp, northern New Brunswick

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Volcanic and sedimentary rocks in the Bathurst Camp were emplaced in an ensialic back-arc basin built on the Gander passive margin of the Avalon composite terrane. During closure of the back-arc basin (ca. 445-425 Ma), the volcano-sedimentary pile was incorporated into an accretionary complex ("Brunswick subduction complex") that was thrust over the Avalon margin as a series of imbricate sheets or nappes. Volcanism occurred in at least three, probably widely-separated, sub-basins that are now tectonically juxtaposed. The rocks in the respective sub-basins/nappes have been assigned to the California Lake Group, Tetagouche Group, and Sheephouse Brook Group, each of which consists, essentially, of a dominantly felsic volcanic sequence overlain by mafic volcanic and sedimentary rocks.

The California Lake Group includes the Canoe Landing Lake, Spruce Lake, Mount Brittain and Boucher Brook formations. The Canoe Landing Lake Formation (ca. 470 Ma) consists of alkalic to tholeiitic basalts and minor sedimentary rocks, whereas the Spruce Lake Formation (ca. 471 Ma) comprises feldspar-phyric rhyolite, local quartz-feldspar-phyric rhyolite or crystal tuff, and sedimentary rocks. The Mount Brittain Formation (ca. 468 Ma) consists of lithic-crystal tuff, feldspar-phyric to aphyric rhyolite, and fine-grained sedimentary rocks containing thin tuff beds. The Boucher Brook Formation is composed mainly of shale and siltstone, with locally abundant alkalic basalt, minor comendite and rare limestone lenses containing Caradocian fossils.

The Tetagouche Group, in the core of the Bathurst Camp, includes the Nepisiguit Falls, Flat Landing Brook, and Little River formations. The Nepisiguit Falls Formation (ca. 469-471 Ma), spatially associated with many of the VMS deposits in the Bathurst Camp, consists of quartz-feldspar crystal tuff/tuffite, and local quartz-feldspar-phyric rhyolite and porphyry. Calcareous sandstone, siltstone, and minor conglomerate at the base of the Nepisiguit Falls Formation are assigned to the Vallée Lourdes Member, whereas the Little Falls Member consists of shale, locally tuffaceous siltstone, sandstone, volcaniclastic rocks, and minor crystal tuff. The Flat Landing Brook Formation (ca. 465-466 Ma) consists of aphyric to feldspar-phyric rhyolite and associated hyaloclastites, felsic tuffs, tholeiitic to transitional basalt, and local sedimentary rocks. The Little River Formation comprises alkalic basalt (ca. 457-464 Ma), locally graphitic shale, siltstone, feldspathic wacke and chert.

The Sheephouse Brook Group in the southern part of the Bathurst Camp, includes the Clearwater Stream, Sevogle River and Slacks Lake formations. The Clearwater Stream Formation consists of plagioclase-phyric dacitic tuffs, which, at ca. 478 Ma, constitute the oldest volcanic rocks in the Bathurst Camp, suggesting that they are related to the earliest stages of intra-arc extension. The Sevogle River Formation (ca. 466 Ma) comprises aphyric to feldspar-phyric rhyolite and minor sedimentary rocks, whereas the Slacks Lake Formation consists of alkalic to tholeiitic basalt, and dark grey, locally graphitic shale, chert, and comendite.

Pyrite development within volcanic hosted petroleum reservoirs

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Within petroleum systems pyrite framboids are commonly found in the organic-rich source rocks, where they are interpreted as having formed during diagenesis, through biogenic reduction of pore-water sulphate. In the course of the study of a sequence of volcanic and sedimentary rocks of the Early Cretaceous back-arc basin of central Chile, I have documented the presence of abundant pyrite framboids associated dominantly with a degraded petroleum reservoir. The pyrite-rich petroleum, now bitumen, occupies primary and fracture porosity in volcanic reservoir rocks, rather than in the underlying sedimentary source rocks.

The petrology of the rocks and sulphur isotope data indicate that the pyrite framboids developed within the petroleum reservoir as a result of sub-surface biodegradation

of the, then migrating and accumulating, petroleum, circulating through primary and secondary porosity and basinal normal (probably growth) faults. It is suggested that the Fe-rich andesite volcanic reservoir rocks supplied Fe, which reacted with bacterially generated H_2S from sulphate within the migrating petroleum fluids. This reduction led to the precipitation of pyrite (with very minor sphalerite and chalcopyrite) within primary and secondary porosity of the reservoir rocks. The solidified petroleum (bitumen) still contains up to 2 wt. % sulphur.

Therefore, bacterial degradation of petroleum reservoirs can lead to the development of an authigenic assemblage of metal sulphides within the reservoir, thus fouling of the reservoir, and imparting it significantly different physical and chemical properties. The Fe-rich chemical character of the reservoir rocks may be a factor in determining the growth of pyrite.