# Atlantic Geoscience Society & Environmental Earth Sciences Division of the Geological Association of Canada

## ABSTRACTS

## 2000 JOINT MEETING & CONFERENCE

The 2000 Colloquium of the Atlantic Geoscience Society was held at the Fredericton Inn, Fredericton, New Brunswick, on February 11 and 12, 2000, in conjunction with the Environmental Earth Science Division of the Geological Association of Canada. On behalf of the societies, we thank Tom Al and Bruce Broster, meeting chairmen, and their organizing committee for providing an excellent meeting. We also wish to thank New Brunswick Department of the Environment, Noranda Mining and Exploration Brunswick Mining Division, Three-D Consultants Limited, and Universal Systems Limited for their sponsorship.

In the following pages we are pleased to publish abstracts of talks and posters of the joint meeting.

The Editors

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# THE ENVIRONMENTAL EARTH SCIENCES DIVISION (EESD) OF THE GEOLOGICAL ASSOCIATION OF CANADA

*CURRENT ENVIRONMENTAL RESEARCH and FOCI FOR THE NEXT CENTURY*

## Assessment of earthquake hazard for major engineering projects: the probable versus the determinable

Bruce E. Broster

*Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada*

Major engineering projects are often faced with the challenge of developing rational seismic design criteria for proposed high-risk structures and site activities. Criteria depend on the apparent seismic potential for the specific site and the consequences of failure for different project components. Often geological contributions consist of minor field reconnaissance, collection and assessment of published literature on structural geology, and installation of a microseismic station.

Seismic records are examined probabilistically and extrapolated to obtain estimates of ground motion design parameters covering a range of recurrence for specific magnitude events. This method is often favoured to establish seismotectonic zones when events are attributed to a broad class of features over a large area, rather than an individual lineament. While probabilistic analysis is useful when supported by several centuries of recorded earthquake data, inaccuracies occur in determination of events of low probability or of long return periods. Unfortunately, these are often the higher magnitude events.

Determinations of vertical or horizontal displacement of a specific fault, is often considered the best indication of seismic potential and indication of a maximum capable fault. Even when the fault is buried, ground mapping and the examination of deformation structures occurring in surficial sediments can identify underlying active faults, and can be crucial in dating movement and estimating event recurrence. Other than drilling and repeated seismic occurrences, identification of deformation structures in surficial sediments can indicate underlying blind faults; and is the only method to distinguish long return, large magnitude events. While seldom conducted, geological mapping is also crucial to determining the susceptibility of geological materials to seismic focussing; as experienced in the Mexico City, 1985 event.

## Historical seismicity in New Brunswick - one key to future earthquake activity

Kenneth B.S. Burke

*Quaternary and Environmental Studies Group, Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 3A5, Canada*

Most of New Brunswick lies within the Northern Appalachian earthquake source zone with a moderate level of seismicity and potentially damaging earthquakes (>magnitude 5) occurring from time to time. Historical seismicity investigations can therefore provide a guide to the identification of zones of enhanced earthquake activity, which can then be used in the assessment of future earthquake risk. A study of the historical seismicity of New Brunswick has been made using various earthquake catalogues and by scanning selected weekly local newspapers on an-issue-to-issue basis from the early 1800s for references to earthquakes. Lateral searches of other newspapers and diaries at the dates of newly found events and previously listed earthquakes were also made.

Three regions of enhanced activity have been identified in the study: the Central Highlands (Miramichi) region, the Passamaquoddy Bay region and the Moncton region. More than 600 events are listed for the Central Highlands region in the Canadian National Earthquake Database (CNED), the vast majority of them being earthquakes recorded since the installation of local seismograph stations in the 1980s. Most of the events since 1982 have been identified as aftershocks of the 1982 Miramichi earthquake. From the scanning process, 14 previously unlisted events were found in this region for the period 1826 to1943. In the Passamaquoddy Bay region, more than 75 events are listed in the CNED, with an additional 12 previously unlisted events found by the scanning process for the period 1811 to 1961. The Moncton region shows the least activity, with 25 events being listed in the CNED and two additional unlisted events being found by the scanning process. The study has also shown that some of the earthquakes listed in the catalogue had been mis-located and other events, listed as earthquakes, were actually explosions or meteorological effects, such as cryoseisms. However, all three regions have experienced at least one earthquake with a magnitude larger than 5 and present day seismograph recordings show continuing activity in each region.

## Geophysical imaging of a shallow aquifer: initial field tests at Fredericton

K.E. Butler
*Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada*

Advances in near-surface geophysical instrumentation and techniques over the past 10-15 years present new opportunities to improve our understanding of aquifer systems through the application of non-invasive geophysical imaging. The sand and gravel aquifer underlying the City of Fredericton, New Brunswick in the St. John River valley is a well-characterized and socially important example that could benefit from such technology. To date, the structure and stratigraphy of the aquifer, its overlying aquitard, and underlying bedrock have been determined almost exclusively by drilling. In November 1999, experimental field surveys were carried out in Fredericton comparing ground penetrating radar (GPR) and seismic methods. The main objectives were to evaluate the suitability of those techniques for (i) detecting breaks or 'windows' in the clay/silt aquitard, and (ii) mapping topography on the aquitard's upper surface. The identification of windows is important as they represent potential pathways through which contaminants spilled on surface could percolate into the aquifer. The surface topography of the aquitard is of interest because it influences contaminant flow paths.

Test surveys were carried out in the Wilmot Park and Smythe St. School areas of downtown Fredericton where the clay is covered by 5– 7 metres of surficial sands, and windows are known to exist. Preliminary results indicate that GPR is capable of mapping both the aquitard surface and the windows. Because radar signals are unable to penetrate through conductive clay layers, the window boundaries are marked by abrupt increases in the penetration depth of the radar signal. A paleochannel is visible in one of the radar sections, indicating that an erosional, channel scour process formed at least some of the windows. Seismic *P*-wave and *S*-wave refraction surveys carried out on either side of a suspected window boundary showed differences in arrival time patterns that correlate well with variations in GPR penetration depth.

The successful completion of the initial field trials encourages us to pursue further geophysical applications. Future plans include (i) field trials of resistivity, shallow electromagnetic, and streaming potential (SP) methods for window detection, and (ii) imaging of aquifer stratigraphy and bedrock topography using seismic reflection surveys. A promising, albeit limited, test of the latter has already revealed clear reflected arrivals originating from the top of bedrock at 60 m depth.

## GIS-based map modelling using the weights of evidence method applied to acid rock drainage prediction in the Meguma Supergroup, Nova Scotia

Don Fox
*Environmental Technology Department, New Brunswick Community College - Miramichi,*
*P.O. Box 1053, 80 University Avenue, Miramichi, New Brunswick E1N 3W4, Canada*

GIS-based map modelling involves the integration of input data layers (maps) by various techniques to derive a final output map showing either locations that satisfy a certain set of criteria, or areas of potential (generally ranked from high to low). The objective of this study is to produce a regional-scale output map of an area in the Meguma Supergroup of Nova Scotia that shows the potential to produce acid rock drainage (ARD) if the bedrock is exposed to surface oxidizing conditions. The integration method used is weights of evidence modelling which is an objective, data-driven technique that uses the location of known points (in this case, sulphide mineral occurrences) to calculate weights ($W^+$ and $W^-$) for each input map. The weights are then used to calculate an output map of posterior probability indicating ARD potential.

Five digital maps including geology, regional metamorphism, proximity to anticlines, proximity to the Goldenville-Halifax transition zone (GHT), and vertical gradient magnetics were used as input layers of evidence. Weights for each input map were calculated using the location of over one hundred sulphide mineral occurrences. Three of the input maps (proximity to anticlines, proximity to GHT, and vertical gradient magnetics) were optimized in order to maximize the spatial association between sulphide mineral occurrences and the predictor pattern of each map. The resulting output map shows areas most favourable and least favourable for the development of ARD. Such maps can be used as a "first pass" indication of possible ARD areas and would be particularly useful in the initial planning stages of major construction activities such as highway construction. Also, when the results of such maps are combined with the results of other ARD prediction techniques including acid base accounting and detailed mineralogical studies, areas where ARD is likely to occur can be accurately predicted.

## Differences in pyrrhotite and pyrite reactivity in acidic solutions and the possible influence on acid base accounting prediction techniques

Don Fox
*Environmental Technology Department, New Brunswick Community College - Miramichi, P.O. Box 1053, 80 University Avenue, Miramichi, New Brunswick E1N 3W4, Canada*

Traditionally, the focus of acid rock drainage (ARD) prediction has been on various types of chemical methods performed in the laboratory on crushed rock samples. These methods invariably involve some form of short-term (up to several hours) static acid-base accounting (ABA) where the acid consuming number is compared to the acid producing number and the overall net acid producing potential of a sample is determined. However, there is no single, universal approach to prediction by chemical methods and the interpretation of results from ABA typically is site specific. In an attempt to make ABA methods more accurate and applicable in the real world, some workers have developed longer-term procedures that require the acid consuming test be run over periods of 24 hours, 48 hours or even up to five days or more. However, the reactivity of specific sulphide minerals under these longer-term conditions is not well known.

Pyrrhotite and pyrite samples were collected from rocks of the Halifax Group in Nova Scotia. Separate, two gram samples of crushed pyrrhotite were reacted with 0.1N and 0.5N hydrochloric acid and sulphuric acid under two sets of conditions, one of weak mixing (grains of sample at bottom of vessel remained stationary), the other of strong mixing (grains of sample at bottom of vessel were in constant motion). In all cases, pH of the solution increased over time. In the case of pyrrhotite mixed with 0.1N hydrochloric acid under strong mixing conditions, the pH increased from approximately 2 to 4.3 within a 36-hour period. Only when the pH reached approximately 4.3 did the pH of solution begin to decrease. Comparatively, pH of solutions reacted with crushed pyrite under the same conditions remained relatively constant. The test conditions of this study are similar to those used in some static ABA prediction techniques. The results show that pyrrhotite (a well known acid producing mineral) is an acid consuming mineral under certain conditions and care should be taken when interpreting the results of ABA when pyrrhotite is a major sulphide mineral present.

## Hydrogeology, water quality and groundwater protection of the Miramichi East (former town of Chatham) aquifer, northeastern New Brunswick

Don Fox and Environmental Technology II Class of 1999-2000
*Environmental Technology Department, New Brunswick Community College - Miramichi, P.O. Box 1053, 80 University Avenue, Miramichi, New Brunswick E1N 3W4, Canada*

Miramichi East (the former town of Chatham which now forms part of the City of Miramichi) is located along the south side of the Miramichi River in northeastern New Brunswick and relies entirely on groundwater for its public water supply. Ten wells supply the population in the immediate vicinity of Miramichi East whereas those outside the former town limits rely on individual homeowner wells.

The Miramichi East aquifer is located in the Carboniferous Clifton Formation, which includes discontinuous, lenticular layers of shale, siltstone, sandstone, and conglomerate. Bedding thickness is variable and ranges from a few centimetres to many metres. Based on limited field observations, bedding strikes northeast-southwest and is shallow dipping either to the northwest or southeast. Bedding parallel fractures are common and well-developed in some beds but not in others. The variation in fracture development between beds may be, at least partially, responsible for the wide range of transmissivity values determined by previous workers.

Generally water quality of the Miramichi East aquifer is acceptable, however problems have occurred in the past due to chloride contamination and high levels of iron and/or manganese. In this study, iron and manganese were found to be above acceptable limits in one sample taken from a homeowners well located to the east of Miramichi East and in one sample taken from a spring located to the west of Miramichi East. Also, during the month of October, 1999 a boil order was issued for all residents of Miramichi East when two of the ten supply wells tested positive for total coliform bacteria including *Escherichia coli*. Regular flushing and chlorination were required to alleviate the problem.

Past and present problems of groundwater contamination in the Miramichi area indicate a strong need for the implementation of a Wellfield Protection Program. New Brunswick is currently implementing such programs throughout the province in areas that rely heavily on groundwater. The Miramichi area is one of the latest regions to have a study performed and is now in the process of implementing the results of the study. Further geological and geochemical studies can aid in this Wellfield Protection Program.

## Avalanches in Newfoundland

David Liverman[1], Martin Batterson[1], David Taylor[1], and Janice Ryan[2,1]
[1]*Geological Survey of Newfoundland and Labrador, Department of Mines and Energy*
*Government of Newfoundland and Labrador; P.O. Box 8700, St. John's, Newfoundland A1B 4J6, Canada*
[2]*Department of Geography, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3X7, Canada.*

Avalanches are a major natural hazard in the mountainous areas of western Canada, but generally are not perceived to be a risk in Newfoundland. Archival research (a systematic examination of newspapers, government files and other sources) was undertaken to document geological hazards in Newfoundland. The results indicated that avalanches are a frequent occurrence in the province. The dangerous combination of high snowfall events, steep slopes, and residential areas at the base of such slopes has resulted in at least 36 deaths over the last 150 years. Identification of this hazard has allowed a pro-active approach to be taken. The Eastern Canada Avalanche Project (ECAP) is an initiative of the Canadian Avalanche Association, based on the results of this research. And emphasizes avalanche awareness and training. In one case the archival research has led to installation of protective measures to control a severe, previously under-estimated, hazard.

## Episodes of rapid coastal change on the eastern shore of Nova Scotia: are they related to the North Atlantic oscillation?

G.K. Manson[1,2] and D.L. Forbes[2]
[1]*Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4J1, Canada*
[2]*Geological Survey of Canada (Atlantic), P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada*

Research along Nova Scotia's Eastern Shore has shown that decadal-scale coastal evolution is affected by varying relative sea-level rise, storminess, storm-surge frequency, and sediment supply. Some combination of these factors may cause a sudden shift in shoreline response from relative stability to rapid change. Two episodes of rapid coastal retreat are interpreted from historical charts and airphotos of McNab's Island at the entrance to Halifax Harbour. The first occurred sometime between about 1750 and 1850 and the second between 1954 and 1964. Other sites along the Eastern Shore show accelerated retreat after 1954, although the most rapid retreat in some places occurred in the late 1960s or 1970s as well as in the mid 1990s.

Relative sea level measured at Halifax has been rising since 1920 at a mean rate of 3.0 mm/a. The record shows significant decadal and multi-decadal variability. From 1920 to 1970, the mean rate of rise was 4.0 mm/a, declining to 0.8 mm/a after 1970 and increasing again in the 1990s. Winds measured at CFB Shearwater since 1953 show an anomalous period of storminess between 1954 and 1964. This period was characterized by increased frequency of storms with a southeasterly modal storm wind direction, in contrast to less frequent storms with a southwesterly mode from the 1970s to the early 1990s.

The North Atlantic Oscillation Index (NAOI), defined as the difference between mean normalized winter sea-level air pressures in the Azores and Iceland, has been correlated to a number of meteorological and oceanographic phenomena, including decadal-scale sea-level variability across the North Atlantic. Rapid sea-level rise at Halifax appears to occur during downward trends in the NAOI. The 1954-1964 stormy period occurred during the lowest point in the NAOI since 1864. Earlier episodes of storminess reflected in the sedimentological record of Halifax Harbour appear to correspond to minima in an extended NAOI constructed from a Greenland ice core.

It is important to recognize that geological factors, particularly sediment supply, also influence the shoreline response to varying environmental forcing. Coastal change occurs through non-linear interaction between storm waves, storm surge, sea level, and shore-zone morphology and sediments. Limitation of supply or a vulnerable self-organized morphology may render shorelines more susceptible to exceeding the threshold and change forced by storms and sea-level rise. Global climate change may affect the NAOI, thus storminess and sea-level rise, with a potential impact on rates of shoreline recession.

## A comparison of the internal and external biogeological structure of rusticles from the RMS Titanic

Jim McCarron[1], Henrietta Mann[2], and Frank Thomas[3]
[1]*Department of Biology, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada*
[2]*Department of Biological Engineering, DalTech, Dalhousie University, Halifax, Nova Scotia B3J 2X4, Canada*
[3]*Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada*

Few natural sources of iron occur in the deep ocean. Shipwrecks deposited in this environment introduce massive amounts of processed iron and iron derivatives unnatural to the deep ocean, providing a new source of nutrients. As a result, microorganisms normally present in low concentrations are provided with a new iron-rich environment in which they can flourish, thereby creating a unique ecosystem.

Studies show that both biological and mineralogical activities play a major role in the corrosive process that forms this unique ecosystem. Micro-organisms precipitate iron-rich minerals, which form the brittle skeleton of stalactite-like structures termed 'rusticles'. The skeleton supports the newly formed structures, preventing them from washing away in local currents. After more than 70 years of uninterrupted growth, rusticles now cover the hull of the *RMS Titanic.*

Little is known about the structure of rusticles or about the microorganisms involved in their formation. The internal and external surfaces of rusticles differ in their morphology and mineralogy, suggesting that different bacteria and/or physical-chemical conditions prevailed during their formation. It is believed that more than 20 different species of microorganisms can be found in these structures.

## Whose environment is it anyway? A search for environmental accountability over areas in the coastal zone and the offshore

David Monahan[1] and Sue Nichols[2]
[1]*Canadian Hydrographic Service, 615 Booth Street, Ottawa, Ontario K1A 0E6, Canada*
[2]*Geodesy and Geomatics Engineering, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada*

The new millennium will be one in which the United Nations Convention on Law of the Sea (UNCLOS), which came into force in November 1994, will form the basis for dividing up two thirds of the earth's surface. Jurisdiction over the seafloor is apportioned between Coastal States and the UN, with the authority of Coastal States diminishing seaward while that of the UN takes over. All ratifying Coastal States are automatically granted a Territorial Sea, a Contiguous Zone and an Exclusive Economic Zone, while some fifty countries, including Canada, will be able to claim a juridical Continental Shelf. Numerous references are made within the Convention to protection of the marine environment. National legislation has been written or adjusted by Coastal States before their ratification, and the early years of the new millennium will witness many measures for protection of the marine environment being introduced concerning the waters surrounding each State.

An International treaty like UNCLOS cannot make any rulings on jurisdictional subdivisions within the areas granted to or claimed by each state. Although individual States have authority over the sea floor, how that authority is apportioned between different authorities within the state remains the State's responsibly. In Canada, the offshore is an area where authorities are not as clearly understood as they might be, with differing federal/provincial jurisdictions overlain by issues as diverse as undefined aboriginal rights along the coast to determining which tidal datum property claims are measured from. Here we discuss the jurisdictional situation in Canada's coastal waters and provide a geospatial framework within which environmental research can be focussed.

## Ground penetrating radar and seismic methods applied to detection of 'windows' in the clay aquitard overlying the Fredericton Aquifer

J.A. Paasche[1], T. Gilman[1], and K.E. Butler[2]
[1]*Geological Engineering Program,* [2]*Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada*

Geophysical exploration is a non-invasive discipline that can be used to determine the subsurface features at a site. These methods utilize changes in material properties (e.g. density, velocity, dielectric constant) to enable imaging or inferences regarding the underlying geology.

The City of Fredericton's major source of potable water is a glaciofluvial sand and gravel aquifer that is overlain by a lacustrine clay/silt unit of variable thickness and a fluvial sand and gravel deposit. The sites chosen for this investigation are located near the Fredericton well field in the Wilmot Park area of the City's downtown. Through previous borehole data available for these locations, the confining clay/silt layer at 5-7 m depth is known to exhibit breaks or 'windows', where the underlying aquifer is vulnerable to contamination from above. Thus, it is important to locate these windows to guard against possible migration of hazardous material into the water supply

and to aid in city planning.

A project has been undertaken to determine the suitability of using geophysical methods to map the boundaries of the clay/silt windows. We present promising results from the ongoing interpretation of ground penetrating radar and seismic surveys selected for initial field trials.

## Glacigenic fault reactivation and enhanced groundwater flow: a previously unrecognized hazard to restoration of abandoned mine sites

Adrian F. Park and Bruce E. Broster
*Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada*

Glacitectonic reactivated bedrock faults and joints are common features encountered in open pit and underground mine workings in glaciated regions. Enhanced permeability leading to flooding and other ground control problems are associated with these fracture systems, which often act as high flow conduits for groundwater flow. As such, glacigenic fractures can be instrumental in the production and transport of acid mine waste, but are rarely considered in site restoration programs.

A detailed study of glacigenic fractures undertaken at the Stratmat and ACD zones at Heath Steele Mines, New Brunswick demonstrated the potential hazards associated with glacigenic fractures. During that study an encounter with groundwater flow in excess of 800 litres per minute, along a re-activated fault intersected by a tunnel thirty metres below ground, resulted in extensive flooding during the fall of 1992. For a period of one month, groundwater flow from this fracture system continued, due to re-opened jogs along a fault plane that provided connections to ground surface. Other conduits (possibly with fewer interconnections) were identified at depths 100 metres below ground, yielding groundwater flow of the order 10-30 litres per minute. The results indicated that flow along fractures was channelized and the quantity of discharge variable, due to the degree of fracture-interconnection.

Glacigenic fracture zones, causing enhanced permeability and contaminant migration, can be identified during field studies and from borehole data using several criteria, including: the presence of glacial sand and gravel in open fractures, RQD values, and losses of drill fluid during drilling. Data from such studies are essential in delineating contaminant transport at mine sites and should be addressed in every mine site reclamation plan.

## The use of regional geochemistry data in environmental assessment and planning: ignorance or missed opportunities?

A.G. Pronk
*Department of Natural Resources and Energy, Geological Surveys Branch, P.O. Box 6000, Fredericton, New Brunswick E3B 5H1, Canada*

Regional geochemical surveys have been carried out over large parts of Canada. The types of sample media used vary from recent sediments through Quaternary glacial deposits to bedrock. Generally, such surveys are designed with mineral exploration as the objective. Most of these surveys cover large areas and many different elements, and as such provide large databases that can be used as a background for epidemiological studies. Recent increases in lead and mercury in the environment, landslides, and climate change as a result of fossil fuel use, seem to be directly related with some of the changes we see in the biosphere. In these examples we know from historical records that many changes can at least partially be attributed to man's influence on the natural environment.

Several New Brunswick examples from both federal and provincial geochemical surveys will be used to identify possible uses of geoscience data in providing answers to environmental questions. The value of this data is often limited because the specific data required for the region under investigation are not available. In some cases the data is not available in sufficient detail to provide a meaningful answer (e.g. the data required is below detection limit of the methodology used, or sample density is too low). Many concerns or questions (e.g. drinking water issues) touch on the geoscience discipline and while geologists could help in providing the answers, they are not often consulted. This is likely because geological data is ignored in many cases where it could be helpful. However, it is incumbent upon the geoscience professions, to promote the existence and value of existing data.

## New Brunswick and water management

Darryl A. Pupek
*New Brunswick Department of the Environment, P.O. Box 6000, Fredericton, New Brunswick E3B 5H1, Canada*

Water is not only necessary for life, but it's also an important component for a strong and vibrant economy. The United Nations has identified water as the "issue of the new Millennium". In Canada, water management is a shared responsibility between the federal, provincial and municipal governments. Currently, the federal government's roles and responsibilities pertaining to the management of water are exercised primarily through *the Canadian Environmental Protection Act*, and the *Canada Water Act* amongst other related legislation. Several policies and strategies serve to assist in clarifying these responsibilities. In 1987, the federal government produced a *Federal Water Policy* in which commitments were made on several key water management issues. Unfortunately, many of these commitments have not yet materialized.

In New Brunswick, drinking water supplies can be categorized as follows; 40% of the population rely on municipal surface water, 20% on municipal groundwater and 40% of the population utilize domestic groundwater wells. Originally, provincial water responsibilities were handled by way of the *Water Resources and Pollution Control Act*. New Brunswick water related legislation continued to evolve with the advent of the *Water Act*: circa 1961 to 1975. This Act also included provisions for the *New Brunswick Water Authority*. Then in December 1971, the *Clean Environment Act* was passed in an effort to better regulate areas of water quality concerns. Although periodically amended, this Act is still in existence today.

Through the introduction of the *Petroleum Storage and Handling Regulation* in 1987 (under the *Clean Environment Act*), and the proclamation of the *Clean Water Act* in 1989, New Brunswick embarked on a new era of water management. Legislation now addressed sub-surface contamination as well as providing for potable water and water resource protection. Clean drinking water and public education were at the heart of this regulatory effort. The developments of three proactive water management programs were soon to follow as New Brunswick began to strategically piece together a sustainable approach. The areas of wellfield protection, watershed protection and water classification spearheaded program work within the department. In 1994, the *Potable Water Regulation* came into effect in an effort to monitor both municipal and domestic potable water qualities. The preservation of clean and plentiful drinking water, for present and future New Brunswickers, remains a critical objective of the New Brunswick Department of the Environment.

A recent Governments Roundtable on Water focussed on three key issues: Preventative Planning, Water Quality and Aquatic Ecosystems, Demand/Use and Management. New Brunswick is moving to address similar types of issues as well as Water Allocation and Bulk Water Export using various levels of participation, and would benefit through extended participation from the federal government by way of a renewed national management effort.

## Hurricane records on the South Carolina coast: patterns of periodicity over the last 5000 years

D.B.Scott[1], E. S. Collins[1], P.T. Gayes[2], and E. Wright[2]
[1]*Centre for Marine Geology, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada*
[2]*Center for Marine and Wetland Studies, Coastal Carolina University, Conway, South Carolina 29526, USA*

Singleton Swash on the South Carolina coast provides an extended record of storm events for this coast. Using experience gained by looking at traces of a known storm in the area, *Hugo,* which occurred in 1989, we were able to confidently pick out storm horizons from the sediments that have been accumulating in Singleton Swash since 5000 years ago. We found that although our record went back 5000 years the most intense storm activity occurred since 1800 years ago with major storm strikes on this location every 300-400 years. No storms were detected prior to that except two giant storms at about 5000 years ago. The storms were detected primarily by content of offshore foraminifera in marsh sediments at selected intervals except the two giant storms that had thick (10 cm) sand layers with offshore foraminifera. It has been suggested that the position of the Bermuda High plays a role in hurricane storm tracks in the Atlantic and our data combined with that of others appears to confirm this with most hurricanes before 2000 years hitting the Gulf Coast when the High was in a southerly position. After 2000 years ago when the Bermuda High moved up over Bermuda, we observe storms more frequently on the Atlantic coast.

## Holocene paleoproductivity in the Northwestern Pacific determined by foraminiferal assemblages in some fjords of Vancouver Island, British Columbia

T.M. Schell
*Centre for Marine Geology, Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3J 3J5, Canada*

Foraminiferal assemblages may be used as proxies for paleoclimatic and paleoceanographic conditions such as temperature, oxygen, salinity, and organic material production. Various combinations of those factors may indicate periods of enhanced and suppressed upwelling events, and associated productivity. Once the paleoceanography of a region is understood, the suitability of a paleohabitat for a particular pelagic fish species may be inferred. Little reliable research exists on the paleoproductivity of commercially and ecologically important Pacific pelagic fish such as salmon and herring.

Vancouver Island is located in the bifurcation region of the Subarctic Current and the West Wind Drift. The North-South shifting of this point determines whether the regional ocean climate will be dominated by the warm California Current or the cold Alaskan Current. Effingham Inlet (the first

study site selected) is a narrow 15 km-long double silled fjord, situated on the western side of Vancouver Island, British Columbia. It is located near the region of the northern extreme of the California Current. Several commercial and ecologically important species of pelagic fish, such as Pacific salmon and sardines are dependent on the extent of the California Current for a favourable habitat. Recent accounts of fishing history suggests a large scale expansion and contraction of this favourable habitat due to the large-scale changes in oceanic climate, *i.e.*, upwelling and El Nino.

The restricted nature of Effingham Inlet is an ideal primary study site with its deep basins and shallow sills, which provide excellent sedimentological and paleobiological records because of high sedimentation rates of low-oxygen bottom sediments that allow high resolution records and excellent preservation of fossils. Fjords are useful in paleoceanographic research because in many cases only the strong upwelling and ocean-climate events are felt in their inner basins, thus removing most of the "background" productivity. The correlation between paleoceanographic conditions inferred from foraminiferal evidence and changes in fish stocks is a particularly powerful analytical tool. This approach employs well-used micropaleontological concepts and applies them to environmental geology, oceanography and fisheries management problems.

A study of living and Recent foraminifera, both benthic and pelagic, thecamoebians and Sr-isotopes of fish bone material has been started to reconstruct the paleoceanographic conditions. Preliminary results suggest strong signals throughout one core sequence with cycles of the low oxygen indicator, *Fursenkoinia fusiformes*, showing several peaks that correspond to high productivity. In addition, this research will enhance the minor work done to date on recent to Late Quaternary Northwestern Pacific coastal foraminiferal faunas.

## Where's the science? Rethinking river restoration and enhancement

Ian S.Spooner[1], Michael Brylinsky[2], and Brooke Cook[3]
[1]*Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada*
[2]*Department of Biology,* [3]*Environmental Science Program, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada*

In Nova Scotia, many second and third order high gradient tributaries have been the focus of restoration and enhancement efforts in an attempt to re-establish Brook Trout (*Salvelinus fontinalis*) and Atlantic Salmon (*Salmo salar*) populations. We have re-evaluated both enhanced and unaltered tributaries with the intent of understanding the natural conditions that influence both habitat quality and enhancement efforts. We have found that a lack of understanding of watersheds as physical systems has, in some cases, led to ineffectual restoration and enhancement efforts.

Studies on Elderkin Brook and Mill Brook indicated that the pyrite-rich Kentville and Halifax Formation slates dominating the watershed geology do not govern the pH of the river water. The carbonaceous New Canaan Formation, which is a minor geological but major hydrological component of each watershed, buffers regional groundwater and has resulted in elevated pH levels (7.5-8.0). These conditions have resulted in the production of an iron precipitate. During the winter and spring increased discharge and dilution of the groundwater chemistry by precipitation combine to keep the iron in either solution or suspension. During low flow periods (primarily the summer and fall) flocculated accumulations develop coincident with the spawning of both target fish species. These conditions result in both temporally and spatially constrained habitat quality degradation that is difficult to recognise using the short term habitat evaluation techniques that are presently being employed by river management groups. Habitat enhancement efforts on Mill Brook, Elderkin Brook and the South Annapolis River have focussed on the application of restoration and enhancement techniques developed using low gradient, graded rivers as models. These models do not apply to the streams examined in this study and, as such, the in-stream structures that have been introduced have been largely ineffectual. Analysis of the natural distribution of in-stream features (e.g., spacing of pools and runs) has determined that their frequency is not consistent and is determined by a variety of physical conditions unique to each site. We conclude that, to be effective, restoration and enhancement protocol must be flexible and must include a rigorous evaluation of natural in-stream processes at each site.

These studies have shown that effective river restoration and enhancement must include an understanding of both the hydrodynamics of the river and the regional geology and hydrogeology of the watershed.

## The application of stratigraphic and mapping studies in delineation of landslide hazards: an example from British Columbia

Andrew J. Stumpf[1] and Bruce E. Broster[2]
[1]*Illinois State Geological Survey, Natural Resources Building,*
*615 East Peabody Drive, Champaign, Illinois 61820-6964, USA*
[2]*Quaternary and Environmental Studies Group, Department of Geology, University of New Brunswick*
*P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada*

In Canada, large bodies of water inundated areas along glacially-oversteepened U-shaped valleys and low-lying plateaus during the last glaciation. During the advance and retreat of glaciers, drainage was dammed in these areas and large proglacial water bodies served as sites for the deposition of thick deposits of fine-grained sediments, ranging from clay- to silt-sized.

In British Columbia, coastal regions, estuaries, shallow river systems, and fjords along the Pacific coast were flooded during marine transgression and experienced deposition of glaciomarine clay and silt deposits. The potential for mass movement is highest in coastal areas below 250 m asl (the elevation of maximum sea-level during deglaciation). However, in the interior of the province, thick deposits of proglacial lake sediments have been mapped to elevations as high as 1000 m asl. These deposits are often encountered unexpectedly during road construction and excavation of foundations.

As forestry operations have expanded into more remote areas and mountainous terrain, anthropogenic activities have accelerated slope failures. Nevertheless, areas of high risk to failure can easily be anticipated and avoided when the surface deposits are studied and the glacial stratigraphy is known. Where these sediments cannot be avoided, the surface deposits should be sampled and examined for mineralogical content and engineering properties. Proglacial lake deposits behave differently when disturbed due to differences in plasticity, stability and activity of the sediment. For example, the magnitude of damage or movement during initial retrogressive failures is commonly much larger in the Southern Interior sediments than those that occur in the Northern Interior clay units. However, long-term damage is significantly greater in Northern Interior clays, where failures tend to retrogress further over time. Variation in size and mode of failure can occur due to other natural factors such as; thickness of deposit, dip of strata, permeability and drainage, engineering properties of underlying units, topographic relief and slope.

## Extension of the St. Lawrence fault zone into, and beyond, western Lake Ontario

Joe Wallach[1] and Arsalan Mohajer[2]

[1]*Geosciences Incorporated, 2 Deguire Court, Russell, Ontario K4R lC1, Canada*

[2]*Seismican Geophysical Limited, 18 Restwell Crescent, Willowdale, Ontario M2K 2A3, Canada*

It had been suggested that the St. Lawrence fault zone extends upstream along the St. Lawrence Valley, through Lakes Ontario and Erie, toward New Madrid Missouri in the central USA. Seismic activity associated with this zone includes at least four magnitude 7 earthquakes in the Charlevoix region of Québec, as well as earthquakes of approximately magnitude 6 near Montreal and Cornwall. Thus, if the St. Lawrence fault zone extends into western Lake Ontario, its presence would add significantly to the risk of a major earthquake in the vicinity of the Darlington and Pickering Nuclear Generating Stations because that zone passes within about 30 km of both. The current seismic hazard assessment, however, implies that the St. Lawrence fault zone does not continue upstream beyond Cornwall, Ontario.

Numerous examples of mesoscopic-scale brittle faults, which are adjacent, and parallel, to the St. Lawrence River, occur in the rocks of the 1000 Islands region, southwest of Cornwall. The Hamilton-Presqu'ile Fault, which lies along the projection of the St. Lawrence, extends further to the southwest, from Prince Edward County almost into Hamilton Harbour. Finally elevation measurements of stratigraphic contacts in exposures on opposite sides of the Dundas Valley, west of Lake Ontario and aligned with the projection of the St. Lawrence fault zone, indicate evidence of vertical fault separation across the valley. That makes a compelling argument for the continuation of the St. Lawrence fault zone at least as far southwest as the Dundas Valley.

In addition to bedrock faulting, faulting has been recorded in unconsolidated sediments beneath Lake Ontario. Those young faults, with throws in the lake-bottom sediments of up to 22 m, lie in a 15 km-wide zone along the southern margin of the extension of the St. Lawrence fault zone. The foregoing argues that an earthquake of M=7, in the vicinity of the Pickering and Darlington Nuclear Generating Stations, should not be regarded as impossible.

## A damaging earthquake could occur in the western Lake Ontario area

Joe Wallach[1] and Arsalan Mohajer[2]

[1]*Geosciences Incorporated, 2 Deguire Court, Russell, Ontario K4R lC1, Canada*

[2]*Seismican Geophysical Limited, 18 Restwell Crescent, Willowdale, Ontario M2K 2A3, Canada*

The western Lake Ontario area is the most densely populated in Canada, and the home of mass transit, skyscrapers, industrial plants, waste disposal facilities and nuclear reactors. It is also an area about which there are ongoing debates regarding earthquake potential. Some consider that, because large-magnitude earthquakes have never been recorded there and that the locations of the small ones that have occurred there are poorly known, the seismic risk is low. Others argue just the opposite.

Seismicity results from movement along faults, thus knowledge of the characteristics of major faults in the western Lake Ontario area is essential in trying to estimate earthquake risk. As a result of geological fieldwork carried out in the last few years, it is known that at least five major faults pass into Lake Ontario. One is the Niagara-Pickering fault zone, which goes under the Pickering Nuclear Generating Station, the second is the Clarendon-Linden Fault, which crosses central Lake Ontario, and the third is the St. Lawrence fault zone, which extends upstream along the St. Lawrence valley into and, apparently, along the entire length of the lake. Both the

fourth and fifth faults traverse beneath the total width of western Lake Ontario and are associated with alignments of earthquake epicenters. One, the Georgian Bay fault zone, is marked by geophysically expressed lineaments, and geologically recent faulting, whereas the other, the Hamilton-Lake Erie Fault, also shows geophysical expression and is associated with subsurface faulting.

In late November 1999 a magnitude 3.8 earthquake occurred within 25 km of the Pickering Nuclear Generating Station, and is the largest to have been documented in that area. Though not large enough to cause damage, it was felt throughout the western Lake Ontario area and may be a harbinger of things to be expected.

## Radarsat: a tool for environmental monitoring and terrain evaluation

*Tim Webster*
*Centre of Geographic Sciences, Lawrencetown, Nova Scotia B0S 1M0, Canada <tim@cogs.ns.ca>*

The Radarsat satellite is equipped with steerable, multi-resolution synthetic aperture radar (SAR). The radar is an active system and is therefore independent on the sun illumination and operates in a wavelength that is not significantly effected by cloud, fog, or rain. These qualities make Radarsat a unique tool for monitoring environmental conditions for some regions. The system is sensitive to surface roughness and the dielectric properties of materials and local slope conditions. The ability of the system to highlight topographic variations has made it useful for structural and in some cases geological mapping. Natural oil slicks have been detected with Radarsat indicating natural seepage areas on the ocean floor associated with hydrocarbon deposits. The steerable beam allows a region to be imaged with several repeat passes, more frequently as one moves to high latitudes, allowing frequent monitoring during environmental disasters (e.g. flooding, oil spills, etc.). The steerable beam also allows for stereo coverage of an area, such that it is imaged twice at different incident angles. The stereo pair can be used to construct digital elevation models, which can further be used for environmental applications.

# ATLANTIC GEOSCIENCE SOCIETY COLLOQUIUM

## Dating alkali feldspar granites: revised age and tectonic interpretation of the Georgeville Granite, Antigonish Highlands, Nova Scotia

A.J. Anderson[1], J.B. Murphy[1], R.F. Cormier[1], and R.A. Creaser[2]
[1]*Department of Geology, St. Francis Xavier University, Antigonish, Nova Scotia B2G 2W5, Canada*
[2]*Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada*

The Georgeville Pluton is exposed along the Northumberland Strait in the northernmost Antigonish Highlands of Nova Scotia, where it intrudes Neoproterozoic (ca. 618-610 Ma) arc-related volcanic and sedimentary rocks of the Georgeville Group. The epizonal pluton consists of alkali feldspar granite and cogenetic pegmatitic intrusions. The age of intrusion of the pluton has proved particularly challenging to determine, and most of these difficulties are due to the extreme degree of fractionation. The granites contain above average $SiO_2$ (> 76%), Th, Nb, Y and Zr, very low CaO, $TiO_2$, MgO, FeO, MnO and Sr and most notably by a positive REE profiles generated by extreme LREE depletion. Tectonic discrimination diagrams suggest a within-plate environment, with many but not all geochemical features resembling A-type granites. The earliest attempt to date the pluton using Rb-Sr whole-rock geochronology was made difficult by the very high Rb/Sr (20-100) and $^{87}Rb/Sr^{86}$ (58-275) ratios. A reliable U-Pb age from zircons in the granite was precluded by extreme Pb loss caused by the metamict character of the zircons. $^{40}Ar/^{39}$ Analysis of a single white mica, 1.5 mm in length, from a pegmatite vein yielded an age of 579 ± 2.2 Ma. The undisturbed nature of the plateau, together with the epizonal nature of the pluton, and the sample location within a thin dyke led to the interpretation that the muscovite cooled rapidly and that this age represented the crystallization age of the pluton. This age suggested that the granite post-dated the main phase of arc-related magmatism in the Antigonish Highlands, and a petrogenetic model involving partial melting of a depleted, dehydrated crust following the cessation of arc activity was proposed. However, a preliminary Re-Os age of ca. 617 Ma obtained from molybdenite from within the granite has cast doubt on the crystallization age and the petrogenetic model. As a result, the intrusive age of the Georgeville Pluton is now re-interpreted to be coeval with the main phase of arc magmatism and with the adjacent ca. 610 Ma mafic Greendale Complex.

## The Parrsboro EdGEO Workshop

J.L. Bates[1], S. Baldwin[2], H.V. Donohoe, Jr.[3], R.A. Fensome[1], R. Grantham[4], L. Ham[3], I.A. Hardy[1], N. Koziel[1], H. Mann[5], J. Shimeld[1], K. Silverstein[6], and G.L. Williams[1]
[1] *Geological Survey of Canada (Atlantic), P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada*
[2] *Auburn Drive High School, 300 Auburn Drive, Dartmouth, Nova Scotia B2W 6E9, Canada*
[3] *Nova Scotia Department of Natural Resources, 1701 Hollis Street, Halifax, Nova Scotia B3J 1V8, Canada*
[4] *Nova Scotia Museum of Natural History, 1747 Summer Street, Halifax, Nova Scotia B3H 3A6, Canada*
[5] *Dalhousie University, Sexton Campus, Halifax, Nova Scotia B3J 2X4, Canada*
[6] *Queen Elizabeth High School, 1929 Robie Street, Halifax, Nova Scotia B3H 3G1, Canada*

The 1999 Nova Scotia EdGEO Workshop was held at the Fundy Museum in Parrsboro, 23-24 August. The committee, benefiting from experience with the previous five EdGEO Workshops, provided a full two days of hands-on activities plus field trips. The focus of the Monday morning sessions was on rocks, minerals and time, with emphasis on Nova Scotia. The highlight was the Chocolate Chip Cookie activity, an exercise which tests the resourcefulness of the players in developing a mine and returning the land to its natural state after exhaustion of the resources. Another activity was where do we find minerals in our everyday life? There were some interesting surprises, with few realizing that bread, toothpaste and wallboard all contain gypsum. The concept of geological time was explained by a time line comprising a series of cards. These illustrate when different animal and plant groups originated, helping teachers to remember both the order of appearance and the time. One intriguing discovery was that herbivorous dinosaurs did not eat grass.

Monday afternoon provided a change of pace with a field trip to Joggins and Jeffers Brook. This trip from Africa to North America included a stop at Kirkhill where the Cobequid-Chedabucto Fault is visible for miles as it parallels the Bay of Fundy coastline. The evening utilized the fascination of the Fundy Museum with a talk on the dinosaurs of Nova Scotia, followed by a tour of the preparation rooms and gallery displays.

The emphasis on Tuesday morning switched to the Net and Fossils, a somewhat eclectic mix. The advantages of the EarthNet website were readily apparent when teachers accessed lesson plans and activity sheets on such diverse topics as volcanoes, time and dinosaurs. The fossil session primarily reviewed plant and animal evolution, using where possible examples from Nova Scotia. Thus, it was possible to mention some of the reptiles found at Joggins, such as *Hylonomus* (the forest mouse).

For the first time, the Workshop did not conclude at noon on Tuesday. Instead there was a field trip to Wasson Bluff to view the Late Triassic-Early Jurassic rocks and to search for vertebrate bones.

Was the Parrsboro Workshop a success? The 26 teachers certainly thought so, judging from some of the comments on the evaluation sheets. These included the following:

"presenters excellent and informative", "great learning environment", "loved the blend of teaching/learning styles", "I have attended many workshops – this has been the best", "The material was exceptional". One of the most rewarding aspects of the workshop was that there was a waiting list, so that already there are several reservations for EdGEO 2000 in Antigonish.

## EarthNet: a Canadian education resource has its roots in the Maritimes

J.L. Bates[1], S. Baldwin[2], E. Frith[3], A. Henry[4], G. Nowlan[5], J. Shimeld[1], K. Silverstein[6], I. Spooner[7], P. Moir[1], C. Vodden[8], J. Waldron[9], and G.L. Williams[1]
[1]*Geological Survey of Canada (Atlantic), P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada*
[2]*Auburn Drive High School, 300 Auburn Drive, Dartmouth, Nova Scotia B2W 6E9, Canada*
[3]*Halifax, Nova Scotia, Canada,*
[4]*Ketch Harbour, Nova Scotia, Canada,*
[5]*Geological Survey of Canada (Calgary), 3301 33rd Street NW, Calgary, Alberta T2L 2A7, Canada*
[6]*Queen Elizabeth High School, 1929 Robie Street, Halifax, Nova Scotia B3H 3G1, Canada,*
[7]*Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada,*
[8]*Geological Survey of Canada (Ottawa), 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada*
[9]*Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada*

EarthNet is a unique website directed at the needs of Canadian earth science educators. These needs, expressed by teachers who have attended science teacher conferences and workshops, centre on the easy access to basic earth science information. This information must be reliable, accurate, and based on the Pan Canadian curriculum. If this information is produced by Canadians and includes Canadian examples, all the better. EarthNet aims to meet all these conditions.

To ensure the creation of an educational resource that is accurate and useful, input from and collaboration between the geoscience and education communities are essential. The EarthNet Committee is the group that leads this critical mechanism. The Committee includes most of the authors of this abstract. In addition, links with the nation-wide Canadian Geoscience Education Network allow the Committee to make connections with other established outreach groups across Canada. The EarthNet development team is located at Geological Survey of Canada (Atlantic). Without all these people and their knowledge, experience and steady enthusiasm for collaborative outreach products, EarthNet would simply not exist.

The educational materials and teaching resources on EarthNet can be accessed via eight main sections: "Activities", "Teaching Resources", "Geology in the Classroom" (a Q&A facility), "Earth Science Site of the Week", "Especially for Teachers"(a section facilitating communication among teachers), "Glossary", "Calendar of Events" and "Dynamic Earth" (mini-tutorials). The site is designed for ease of use by teachers in constructing lesson plans. Periodic reviews of the site by teachers throughout Canada will help to ensure a truly useful resource.

New initiatives entail the creation of new sections tentatively entitled "The Virtual Field Trip" and "Geology in Your Community", as well as continual expanding and updating of existing sections. To provide a means by which teachers can communicate to others within their community about like-minded topics and issues, the installation of a list server and/or chat room is planned.

Because EarthNet would not be possible without the many contributions of the geoscience community, we encourage anyone who is interested in the project to talk to any member of the Committee and become involved in the project. An enthusiastic interest in education outreach is the only requirement.

## Metal impact on benthic populations within the Baie des Chaleurs, New Brunswick: a reconnaissance review of marine geochemistry and species diversity

Ryan Campbell[1], David Scott[1], and Ray Cranston[2]
[1]*Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada*
[2]*Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A8, Canada*

Recently, the Restigouche esturarian system has been serving as both a transport and dispersal mechanism for base metals, trace elements (Cd, Hg, As), organic matter, and other suspended particulate within the Baie des Chaleurs. High frequency sampling within the bay produced representative gravity core, which were subsampled and processed to determine benthonic foraminiferal abundance and diversity together with associated geochemistry. Two cores, representing both inner and outer estuarine locations, divide and highlight a boundary zone of foraminiferal speciation, metal plumes, marine current and wind input, freshwater discharge, suspended particulate input, and organic matter. *Ammotium cassus, Ammobacu-lites dilitatus,* and *Eggerella advena,* are found in zones typical of high suspended particulate matter within the Baie des Chaleurs whereas the calcareous *Elphidium* group appear widespread and unaffected by variation in living environments. Geochemical data compiled through X-Ray Fluorescence (XRF) complements work done by the Bedford Institute of Oceanography on pore water analysis. Scanning Electron Micrographs analyze benthic species to outline any structures and deformation characteristics associated through nearby effluent dumps, airborne particulate input and other sources of organic matter (OM). Implications of metal influence, populational ecology, and verification of remediation practices are all potential results that may be reached from this ongoing study.

## Geochemical trends in a river receiving treated mine water, Bathurst, New Brunswick

Tracy A. Cochrane[1], Tom A. Al[1], and Robert A. Butler[2]
[1]*Department of Geology, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada*
[2]*Noranda Mining and Exploration Incorporated, Brunswick Mining Division, P.O. Box 3000, Bathurst, New Brunswick E2A 3Z8, Canada*

Effluent from the tailings ponds at the Brunswick No. 12 mine has been discharged into Little River since 1964. In 1993, a water treatment plant began operation, resulting in decreased metal concentrations and increased pH in the effluent released to Little River. Following implementation of the water treatment process, water sampling along the river indicated a decrease in pH downstream. This research examines the trend in pH and other geochemical parameters observed along the river. The mine is situated at the headwaters of the south branch of Little River. The discharge in the south branch is dominated by effluent from the water treatment plant. The length of the river from the mine to its discharge point in the Bathurst Basin is approximately 22 km. Aqueous geochemical and stream-sediment sampling were completed from June to August, 1998. Results of this sampling reveal a correlation between suspended and dissolved metal concentrations (Pb, Zn, S) in the upper reaches of the south branch of Little River, and elevated metal concentrations (Pb, Zn) in the river sediments (45-125μm fraction). Decreases in alkalinity, dissolved oxygen and pH were observed in the first 1-2 km downstream of the water treatment plant. Alkalinity and dissolved oxygen rise to background values within 2 km of their respective minimum, whereas the pH recovered to an average value of 6.3. This pattern is consistent with the release of low concentrations of acidity ($Fe^{(II)}$ or intermediate sulfur oxidation species) from the water treatment plant. In association with these trends in pH, metals transported in the stream are transferred between the aqueous phase and adsorption sites on suspended sediment particles.

## An assessment of in-stream restorative structures on tertiary streams in the Annapolis Valley, Nova Scotia

S. Brooke Cook[1], Ian S. Spooner[2], and Michael Brylinsky[3]
[1]*Environmental Science Program, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada*
[2]*Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada*
[3]*Department of Biology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada*

In Nova Scotia, many second and third order, high gradient tributaries have been the focus of restoration and enhancement efforts. Most community groups are interested in re-establishing Brook Trout (*Salvelinus fontinalis*) and Atlantic Salmon (*Salmo salar*) populations. In our evaluation of both enhanced and unaltered tributaries we have found that a lack of understanding of watersheds as physical systems has, in some cases, led to ineffectual restoration and enhancement efforts.

In this study, Elderkin Brook and the South Annapolis River were evaluated. Both of these rivers are located in the Annapolis Valley, Nova Scotia. Their headwaters originate on the South Mountain (elev. 260 m) and eventually drain into the Bay of Fundy. Both streams can be divided into three distinct reaches along their length: (1) an upper, ungraded, bedrock dominated reach consisting mainly of water falls and rapids, (2) a middle, ungraded reach with a bedrock bottom covered by a thin gravel veneer, and (3) a lower, graded, alluvial dominated reach. Analysis of the natural distribution of in-stream features (e.g., spacing of pools and runs) has determined that their frequency is not consistent and is determined by a variety of physical conditions unique to each site.

Habitat enhancement efforts on Elderkin Brook and the South Annapolis River have focussed on the application of restoration and enhancement techniques developed using low gradient, graded rivers as models. These models do not apply to the streams examined in this study and, as such, the in-stream structures that have been introduced have been largely ineffectual. For example, some digger logs are placed so they focus flow into tributaries while others focus flow into bedrock banks.

In our opinion, debris jams are the most effective in-stream structures for enhancing habitat in second order, high gradient streams. These debris jams (e.g., large root balls, log jams, and even large rocks) occur naturally but can also be constructed and create long lived pools at naturally stressed locations. We conclude that, to be effective, restoration and enhancement protocol must be flexible and must include a rigorous evaluation of natural in-stream processes at each site.

## Stratigraphic analysis and possible tidal influence in the Stellarton Basin, Nova Scotia

Tanya Costain
*Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada*

The Late Carboniferous Stellarton Basin, located in central Nova Scotia, formed as a pull-apart basin resulting from dextral movement on the Cobequid and Hollow faults. These bound the basin to the north and south, respectively. The 6 km by 8 km basin contains the approximately 2600 m of strata of the Stellarton Formation. The upper portion of the Stellarton Formation was deposited during the Westphalian C/D and is composed of the Coal Brook Member and the overlying Thorburn Member.

Two oil shale-bounded intervals from the upper Stellarton Formation were studied in order to observe a full spectrum of lithological facies in the area. An interval from the Coal Brook Member bounded by oil shales 21 and 22 exhibits a lateral thickness variation of 20 m to 10 m from east to west. The interval represents a distal facies association consisting of oil shale grading into mudstones (both laminated and massive), and a fine-grained sandstone element, which decreases in proportion with interval thickness. An interval from the Thorburn Member between oil shales 7 and 8 displays an increased proximal component to the facies association. This approximately 60-metre interval includes oil shales, mudstones, and fine-grained sandstones as well as coarser-grained sandstones, rooted paleosol horizons, and thin coals. Both intervals show flaser and lenticular bedding associated with small-scale cross-bedding as well as localized burrowing. The spectrum of facies observed suggest river-fed deltas advancing into standing-water bodies with low-energy hydrodynamic conditions.

The Stellarton Formation has traditionally been interpreted as lacustrine in origin. However, research is ongoing into the possibility of tidal influence in the Stellarton Basin. Paired mud drapes have been discovered in laminated mudstones and sandstones of the studied intervals. Although the lack of marine fossils and the low-sulphur coals of the area argue against marine influence, paired mud drapes are considered characteristic of tidally affected environments. Further study of the abundance and distribution of the paired mud drapes within the studied intervals is underway. Marine influence has been documented in the coeval Malagash Formation north of the Cobequid and Hollow faults, and incursions could have generated periodic restricted marine conditions in the Stellarton Basin.

## Structural and geometrical analysis of saddle reef folds at the mesothermal gold deposit, Port Dufferin, Halifax County, Nova Scotia: implications for future exploration and resource assessment

Ian A. DeWolfe
*Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada <idewolfe@glinx.com>*

The Port Dufferin gold deposit contains high-grade, low tonnage, nugget gold-bearing quartz-pyrite-arsenopyrite vein mineralization within a complex structural setting. Veins occur in a series of ten stacked saddle reefs along a parasitic anticline adjacent to (immediately south of) the regional Crown Pillar Anticline. Host rocks consist predominantly of massive greywacke interbedded with thinner, laminated argillite of the Goldenville Group, Meguma Supergroup. Strong fracture and slaty cleavages occur in these units, and exhibit a radiating fan pattern. Muscovite, chlorite, calcite and ankerite alteration occurs disseminated within the host rocks adjacent to the veins and along fracture cleavage within the greywacke. The saddle reefs are restricted to the argillite horizons, and filled open spaces that formed as a consequence of the different rheological behaviour of the slate and greywacke during folding.

Geometrical analysis of the form of the folds in both the greywacke and slate beds was undertaken to assess the differences in how the slate and greywacke deformed during compression on several cross sections. Polynomial regressions were fit through the locations of diamond drill core intersections of the various correlatable bed contacts to obtain best-fit macroscopic models of the fold forms. Both intersection and dip constraints were used in the regressions, and produced reasonable and consistent fold geometries. Bulk parameters describing the overall geometry of each fold surface (amplitude, wavelength, tightness, sharpness, inclination and asymmetry) were compared and exhibit consistent trends with depth. Isogon and quantitative analysis of fold limb thicknesses were also undertaken to investigate variations in fold form with depth. These results document changes in fold geometry with depth and should provide substantial guidance in future drilling programs.

Using these macroscopic fold models, distances between the fold hinges and each associated vein intersection were computed. This allows comparison of gold grade and vein thickness with distance from the fold hinge, and provides a quantitative model for proper interpolation and extrapolation of gold grade and vein thickness on each cross-section investigated. This will undoubtedly assist future geostatistical reserve estimation efforts by reducing the uncertainty created by the nugget effect.

## Geological investigation of the Coxheath Cu-Mo-Au System, Cape Breton Island, Nova Scotia: structurally controlled porphyry-type mineralization

J. DeWolfe[1] and D.J. Kontak[2]
[1]*Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada*
[2]*Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia B3J 2T9, Canada*

The Coxheath Cu-Mo-Au porphyry-type deposit, located in the Coxheath Hills southwest of Sydney, occurs within a Late Precambrian (~620 Ma) volcanic-plutonic complex. High-grade (ca. 10%) mineralization was mined in the early 1900's and more recently its potential as a low-grade Cu-Au system has been realized. The deposit has generally been regarded as anomalous in the Canadian Appalachians, as porphyry-type mineralization of pre-Mesozoic age is relatively rare in the geological record.

Previous geological studies of the Coxheath area include regional and detailed mapping, geochemical studies and mineralogical investigations. This study integrates previous work with ongoing investigations of vein structure, mineral paragenesis and geochemical studies of both host rocks and alteration. During the past summer, field work on the main mineralized zone focused on structure, alteration, and mineralization and the inter-relationships of these features. In addition, drill core of the deposit was logged.

Mineralization-related alteration of the host hornblende diorite and plagioclase-phyric andesite at Coxheath includes zones of potassic, phyllic, argillic, tourmaline, and propylitic assemblages; however, within the study area only potassic, tourmaline, and propylitic alteration occur. Ore mineralization consists of chalcopyrite, molybdenite, minor bornite, and gold, while the most abundant sulphide mineral in the system is pyrite. Based on our investigations there is a strong structural control for both the alteration and mineralization at Coxheath. Mineralization is associated with two distinct structural features; shear zones and sheeted veins. The shear zones dip steeply and strike southeast, and are typically several metres thick. These shear zones form a stockwork of massive tourmaline veins bordered by pervasive alteration halos of pink K-feldspar. Chalcopyrite is abundant in the stockwork, occurring as discontinuous veinlets and blebs. Sheeted vein networks 10-20 m wide consist of hundreds of subparallel veins per metre. These sheeted veins, typically a few millimetre to several centimetres thick, consist of quartz and chalcopyrite fill, with localized occurrences of molybdenite. Silicification and potassic alteration associated with the sheeted veins is very intense, completely overprinting the primary features of the host rock.

Mineralization is considered to reflect the focusing of late-stage magmatic fluids into a volcanic-plutonic complex located within a zone of active deformation. The widespread development of alteration reflects the interplay of both magmatic and non-magmatic fluids and favourable structural conditions.

## Documentation of abundant intergranular felsic mesostasis in the Jurassic North Mountain Basalt, Annapolis Valley, Nova Scotia: product of silicate liquid immiscibility

Michelle DeYoung[1], Daniel J. Kontak[2], and Jarda Dostal[1]
[1]*Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada*
[2]*Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia B3J 2T9, Canada*

The presence of liquid immiscibility has been recognized as an important phenomenon in igneous petrology from several decades of field and laboratory studies; however, the extent of this process remains poorly understood. In some cases there are obvious field relationships that suggest immiscibility, whereas in other cases the evidence is relatively ambiguous - the Jurassic (ca. 200 Ma) North Mountain basalts of southern Nova Scotia represent such a case. Previous work indicates that rare occurrences of thin, felsic bands within thick basalt sequences are products of silicate liquid immiscibility rather than crystal fractionation. Here we report the occurrence of pervasive development of silicate liquid immiscibility based on detailed imaging and electron microprobe analysis of fresh, in part glassy, phyric to aphyric basalts from several localities of the North Mountain Basalt. The fine- to medium-grained basalts consist of variable amounts (≤20%) of phenocrystic plagioclase ($An_{50-70}$), augitic pyroxene ($En_{40-50}Wo_{30-40}Fs_{15-40}$) and Fe-Ti oxide phases within a fine-grained matrix of plagioclase microlites, equant clinopyroxene, and skeletal to equant Fe-Ti oxide phases. In plane-polarized light, a dark brown to black material (glass) forms a mesostasis in many of the samples, at times up 25-30 volume %. Imaging of the glassy phase indicates variable degrees of crystallization (feldspars, quartz, Fe-Ti oxide phases, Fe-rich pyroxene) and complex textures (granophyric, symplectic), but in some cases remnant globules are preserved. Analysis of the globules indicates two contrasting compositions, one enriched in Si, Al and alkalis and the other relatively enriched in Fe, Ti, and P. Where clinopyroxene is in contact with the matrix glass, an Fe-rich overgrowth (to $En_{10}Wo_{40}Fs_{50}$) is present. This Fe-enrichment is similar compositionally to pyroxene in mafic pegmatite at McKay Head, where immiscibility has been demonstrated in the basalts, and also coincides with the extreme Fe-rich trend in Skaergaard pyroxenes. Based on petrographic observations, imaging and microprobe analysis it is apparent that silicate liquid immiscibility was a significant process in the crystallization history of the North Mountain Basalt.

## Delineation of glacial dispersal patterns in areas of thick overburden and multiple ice-flow events, northeastern New Brunswick

M.L. Dickson[1], B.E. Broster[1], and M.A. Parkhill[2]
[1]*Quaternary and Environmental Studies Group (QUEST), Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada*
[2]*New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch, P.O. Box 50, Bathurst, New Brunswick E2A 3Z1, Canada*

Drift prospecting is often the best tool for mineral exploration in areas where mineralized bedrock is concealed by thick overburden. However, the data can sometimes be misleading where a region has experienced multiple ice-flow events. In these areas, dispersal of a particular lithology or mineralogy from a known occurrence can be used to model dispersal patterns for comparison with anomalous concentrations of mineralized till clasts or matrix geochemical content from unknown sources. These results must be assessed with a competent understanding of local bedrock geology, Quaternary stratigraphy and glacial movements.

Cu-Mo skarn occurrences have previously been identified in the Popelogan Lake area of northeastern New Brunswick by geophysical surveys and diamond drilling programs. Bedrock exposure in the area is minimal due to the thick (>2 m) covering of basal till, but the skarn deposits were considered to represent distinctive targets for studying glacial dispersal. Approximately 328 till matrix geochemical samples and 171 till clast samples were analyzed for the study area; obtained from archival samples and from field sampling during surficial mapping. The boundary of the study area and sample spacing were based on the location of the skarn occurrences and the direction of ice flow. Sampling of clasts and matrix was conducted on a detailed 100 m grid in the area of the largest skarn occurrence, and on a 2 km grid in other areas.

Our results infer that the area experienced a complex style of glaciation during the Late Wisconsinan. Glacial landform orientation and striae data indicate three major directions of ice movement in the area: (1) southeast, (2) east, and (3) northeast. However, dispersal patterns of till clasts and matrix geochemistry only reflect movement to the northeast. Anomalous concentrations of mineralized clasts and Cu-Mo geochemistry indicate the presence of other, previously unknown, buried sources of mineralization in the area. Clast dispersal trains 2 km in length and geochemical dispersal trains extending 1 km, indicate that source areas for the buried anomalies are likely within 2 kms to the west-southwest.

## A high resolution stratigraphic and petrological investigation of the Braeburn Member, Charlie Lake Formation, Peace River Arch, northwestern Alberta: reservoir implications?

Christie Dyble
*Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada*
*Gascan Resources Limited, Calgary, Alberta T2P 3W2, Canada*

The Middle Triassic Braeburn Member (Western Canadian Sedimentary Basin) is a relatively thin dolomitic sandstone/dolomite, formed in a sabkha environment. It is a part of the Charlie Lake Formation, which conformably overlies the Halfway Formation and is, in turn, conformably overlain by the Baldonnel Formation. Its structure and distribution have been influenced by activity along the Peace River Arch. The Braeburn Member has not been the subject of many studies but is now being re-evaluated as a potential oil producer. Location of potential reservoir facies has been problematic due to the variability in lithology, thickness and porosity over short distances. In this study a high-resolution evaluation of the Braeburn Member has been attempted to help determine the sedimentary and diagenetic conditions that might enhance porosity development.

Core specimens, thin sections and geophysical logs comprise the database used in this study. Image analysis techniques were used to calculate thin section porosity. Core analysis revealed some bedding development and vuggy porosity. Anhydrite commonly occurs as nodules but also as infills in fractures. Preliminary petrological analyses indicated significant alteration. Most samples are dolomitic and exhibit early secondary porosity development; significant amounts of detrital quartz are present in all samples. Anhydrite appears in fractures and is common near the base of the Braeburn Member. Initial porosity results ranged from 8% to 17%. Porosity appears to be significantly enhanced in those samples located along the Braeburn Member subcrop edge and the up-dip (NE) edge of erosional outliers. These data will be used to re-evaluate the economic potential of recently discovered erosional outliers of the Braeburn Member.

## "The Last Billion Years"

R.A. Fensome, G.L. Williams, and the AGS Book Committee
*Geological Survey of Canada (Atlantic), P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada*

The book, "The Last Billion Years" highlights the geological history of the three Maritime Provinces, namely

New Brunswick, Nova Scotia and Prince Edward Island. The title is derived from the approximate age of the oldest suite of rocks known from the region, the Blair River Complex of northern Cape Breton. The three main threads in the story of the Maritimes are: plate tectonics, climatic change, and evolution. These are discussed generally in the first three chapters, which serve as an introduction. Chapter 1, The Dynamic Earth, focuses on dynamic earth systems including plate tectonics, the rock cycle and changing climates. The Fourth Dimension, Chapter 2, discusses time, the age of rocks and correlation. Tales of Trails and Ancient Bodies, Chapter 3, highlights the fascinating evolution of fossil plants and animals. All three chapters emphasize Maritimes examples.

The succeeding chapters relate directly to the regional geology, starting with the Precambrian in Chapter 4, Into Deepest Time. Chapter 5, The Pieces Come Together, outlines how fragments of crust from as far a field as the Southern Hemisphere came together in the Early Paleozoic to form the geological collage that is the Maritimes. This was also the time of the Iapetus Ocean, precursor of the present day Atlantic Ocean. Chapter 6, Basins and Ranges introduces the Late Paleozoic, which is of vital importance to our economic history because of the wide spread coal deposits. An Ocean is Born, Chapter 7, starts to bring us into the modern world, with formation growth of the Atlantic Ocean.

The saga pauses with Chapter 8, From Rocks to Riches, which relates the importance of natural resources in this region. Finally in Chapter 9, The Ice Age and Beyond, the book concludes with a discussion of the last million years and a glimpse into the future.

One of the highlights of the book is the series of boxes throughout the text. Topics include the structure of the Earth, minerals, turbidites, soils and coastlines. Throughout the book, there are numerous superb illustrations, both in colour and black and white.

When can you purchase your copy of "The Last Billion Years"? We are planning for publication in 2001, a not unrealistic target in view of the remarkable progress of the last twelve months.

## Recognition of a modern sediment oscillation in Loon Lake, Halifax County, Nova Scotia: implications for paleoclimate and environmental research

Janet Fownes and Ian Spooner
*Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada*

In this study the physical properties of Loon Lake near Halifax were studied with the intent of understanding the processes that influence sedimentation and sediment mobility in small, shallow, organic-dominated lakes. Organic lakes are of interest as productivity shifts resulting from climate change events are often preserved within the lake sediments. As well, remediation of contaminated organic lakes is often hampered by a lack of understanding of the physical processes that govern sedimentation and sediment mobility.

Loon Lake was chosen for this study on the basis of size, shape, depth and location. Loon Lake is located along the path of a recent hurricane. We hypothesised that hurricanes may be significant in the mobilization of lake bottom and watershed sediments. Sonar profiling was carried out to determine basin stratigraphy, using a King 1570 sonar unit. Lake sediment sampling was accomplished with a Glew gravity sediment corer. Sediment traps and thermistor strings were employed to ascertain the lakes present trophic state. 3-D reconstruction of sediment distribution was accomplished using the Rockworks 99 program. Loss on ignition and thin section analyses were carried out on core sediment. Wind speed and precipitation data were used to model basin and watershed dynamics. Loon Lake is highly productive and exhibited very high organic sedimentation rates and much of the organic sediment is algae. A clastic sediment oscillation was evident near the top of all cores recovered. The sediment oscillation is characterized by an increase in the clay content within the lake sediment core and a decrease in L.O.I. The clastic oscillation is asymmetrically distributed, with thickest accumulations in the north end of the lake. The lack of any ice rafted silt or sand within the oscillation indicates that the sediment was deposited during ice-free conditions. Wind speeds associated with recent hurricanes were sufficient enough to produce turbulent conditions and re-suspend previously deposited organic sediment within the lake basin. Rainfall amounts were sufficient and of short enough duration that saturated conditions and overland flow likely existed. We conclude that the oscillation is a product of the transfer of surface sediment (made available in part by physical disturbance) into the lake basin and the transfer within the basin of this sediment by turbulent suspension. These results indicate that shallow organic lakes are susceptible to hurricane induced mixing and sediment redistribution. They also illustrate that significant sediment oscillations can be produced by very short term, catastrophic events and do not necessarily need to be a product of a period of climate change.

## Structure of the San Miguel ultramafic body and its host rock, the Acatlan Complex, southern Mexico: a fragment of the Iapetus or Rheic oceans

D. Fox[1], J.D. Keppie[2], J. Dostal[1], and F. Ortega-Gutierrez[2]
[1]*Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada*
[2]*Instituto de Geologia, Universidad Nacional Autonoma De Mexico, 04510 Mexico D.F., Mexico*

The San Miguel ultramafic body appears to represent a slice of oceanic lithosphere that was thrust onto a thick psammitic-pelitic sequence (Chazumba Formation) during the Paleozoic. These units form part of the Acatlan Complex that lies west of the 1 Ga Oaxacan Complex that is inferred to represent part of the Amazon craton. The structural sequence consists of the following: (1) a foliation, $S_E$, defined by mica which appears to be associated with the thrust at the base of the ultramafic body; (2) a micaceous, crenulation cleavage axial planar to the main folds, $F_M$, which are generally isoclinal and recumbent with curvilinear fold axes that appear to represent segments of sheath folds with long limbs generally trending NNW-SSE – $S_M$ is strongly developed at the base of the ultramafic body suggesting further thrust movement during this phase of deformation; (3) late, upright, open-tight, gently N-plunging, N-S (and some conjugate) folds, $F_L$, which vary from cylindrical to conical; (4) moderately NW-dipping, NE-trending kink bands; and (5) variably oriented faults.

The outcrop pattern is a mushroom-shaped interference pattern produced by superimposition of $F_L$ on $F_M$. The general NNW-SSE orientation of the FM fold axes is probably parallel to the direction of thrusting. The $F_M$ and $F_L$ structures are cut by granitic sheets that have been dated at 172 ± 1 Ma (Sm-Nd garnet-whole rock age) and 175 ± 3 Ma (Rb-Sr muscovite-whole rock age). Several kilometres to the north, structures geometrically correlated with $F_M$ show top-to-the-south kinematics during which the 287 ± 2 Ma Totoltepec pluton was thrust over the (?)Devonian Tecomate Formation. The Totoltepec pluton is unconformably overlain by Middle Jurassic rocks. This appears to bracket the $F_M$ and $F_L$ deformation in the Permo-Triassic, however, elsewhere Mississippian rocks are reported to unconformably overlie N-S trending folds, suggesting that $F_M$ and $F_L$ fold are pre-Carboniferous, post-Devonian(?). Thus, the main and late structures may relate to the Permian amalgamation of Pangea and Triassic opening of the Gulf of Mexico. Alternatively, they may record the Devonian transpressive collision between Laurentia and Gondwana during the closure of Iapetus, or convergent tectonic events on the margin of Gondwana adjacent to the Rheic ocean. Correlatives of the $F_E$ folds farther north do not affect the (?)Devonian Tecomate Formation and may be related to the Late Ordovician-Early Silurian Acatecan Orogeny, which is inferred to record either the collision between Laurentia and Gondwana or active tectonics on the southern, Amazonian margin of the Rheic Ocean.

## Stratigraphy, structure, and mafic sills in a section through the Halifax Group, Black River area, Kings County, Nova Scotia

K. Gladwin, S.M. Barr, and A.S. Macdonald
*Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada*

A recently constructed canal adjacent to Black River has provided an excellent opportunity to examine the upper part of the Halifax Group in a section of continuous exposure over one kilometre in length. The canal has vertical walls ca. 5–10 metres in height, and is part of the Black River hydroelectric system. It trends north-south, nearly perpendicular to the strike of the rocks. More intermittent exposures in Black River and adjacent roadcuts continue the section northwest 500 metres to the quartzite that marks the base of the White Rock Group. Similarly, roadside and stream outcrops continue the section an additional 1500 metres to the southeast, to the contact of the Halifax Group with the underlying Goldenville Group, near the middle of Lumsden Pond. This essentially complete section through the Halifax Group affords an opportunity to examine and subdivide the group, compare it to sections recognized elsewhere in southern Nova Scotia, and hence provide insight to the lateral continuity of formations proposed within the group. Preliminary examination indicates that four distinct lithologic units are present in the Black River area, varying in their sand/silt/mud ratios and overall appearance such as bed thickness and nature of layering. Contacts between units appear to be conformable and gradational, although none of the contacts is well exposed. Three of the units correspond well with the Feltzen, Delanceys, and Rockville Notch formations recognized elsewhere in the Halifax Group.

Throughout the study area, cleavage dips steeply to the south, and bedding dips steeply to the north, consistent with an unfolded stratigraphic section. Minor strike-slip and oblique-slip faults are evident, particularly in exposures along the canal, where striations and release steps provide a sense of motion on many faulted surfaces. It is not possible to measure amounts of offset, as the lithology in this section is monotonous and there are few distinct marker beds. The lack of repetition of the marker units that do occur, such as mafic sills and rare quartzite beds, suggests that movement was limited.

The section contains at least 12 highly altered mafic sills that vary in width from less than 1 m to 6 m, except one larger sill that is 65 m wide. Preliminary interpretation of

geochemical data from the sills indicates that they are alkalic, and formed in a within-plate tectonic setting. Quartz and quartz-carbonate veins and lenses are abundant in the section, mainly occurring in proximity to sills.

## Determination of protoliths and pressure-temperature conditions of metamorphic rocks in the "Pocologan mylonite zone", southern New Brunswick

Elizabeth M. Grace and Sandra M. Barr
*Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada*

Southwest of the city of Saint John in southern New Brunswick, a belt of metamorphic and deformed granitoid rocks occurs between rocks that are definitively part of the Kingston terrane to the north and those that are part of the Brookville terrane to the south. Previously, this belt of rocks, herein termed the Pocologan belt, was included mainly in the Pocologan Mylonite Zone, but most of the components of the belt are not mylonites. They include metatuff, metasiltstone, schist, amphibolite, calc-silicate rocks, and minor marble, with sheets of granite and diorite. On their northern margin, these distinctive rocks are in sharp, faulted contact with equally distinctive Silurian felsic volcanic rocks, granitic plutons, and amphibolitic sheets of the Kingston terrane. On its southern margin, the belt is in sharp faulted contact with variably deformed composite dioritic to granitic plutons of the Red Head granitoid suite. The Red Head granitoid suite is likely to be part of the varied suite of ca. 555 to 530 Ma plutons that comprise much of the Brookville terrane. However, it is not yet clear whether or not the metamorphic rocks of the Pocologan belt are equivalent to or part of the metasedimentary Green Head Group of the Brookville terrane.

The mineral assemblage in metasiltstone and schist includes biotite, muscovite, plagioclase, garnet, and staurolite. Calc-silicate rocks contain abundant amphibole, epidote, and garnet, and host magnetite deposits in the New River - Lepreau area. Preliminary analysis based on mineral assemblages and compositions indicates that metamorphism occurred at temperatures of ca. 600°C, with pressures of 6-7 kPa. The determination of the pressure-temperature conditions of these rocks during metamorphism, and the determination of the protoliths of these rocks may provide insight into the relationship between the Kingston and Brookville terranes.

Deformation in the area is attributed to mid-Paleozoic strike-slip movement, associated with the accretion of terranes in southern New Brunswick. The deformation associated with the rocks of the Pocologan belt included development of mylonitic zones that do not occur in the adjacent Kingston terrane.

## Geology of the lower to middle Paleozoic metamorphic rocks in the Digby-Weymouth area, southwestern Nova Scotia

Rick Horne[1], Chris White[1], Catherine Muir[2], and Mike Young[2]
[1]*Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia B3J 2T9, Canada*
[2]*Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada*

Systematic regional (1:10 000 scale) mapping of lower to middle Paleozoic metamorphic rocks, including the Meguma Group (Goldenville and Halifax formations), White Rock Formation and Torbrook Formation, was conducted in the Digby-Weymouth area. Results indicate significant revisions to previous maps, including subdivision and re-assignment of stratigraphy, re-interpretation of regional fold geometries, recognition of a regional-scale shear zone, and identification of new mineral occurrences.

The Goldenville Formation consists of medium- to thickly-bedded metasandstone with variable amounts of laminated metasiltstone. Coarse metasandstone to fine metaconglometate beds occur locally. Concretions, locally metamorphosed to calc-silicate, are abundant within the metasandstone beds. The Halifax Formation conformably overlies the Goldenville Formation and has been subdivided into four lithologic units (members). The Bloomfield member, the lowest unit, consists of distinct green and maroon, locally variegated, laminated metasiltstone. The Acacia Brook member, overlying the Bloomfield unit in the northern part of the area, consists of medium- to dark-grey, well-laminated, slate-metasiltstone. The Cunard member consists of dark, finely laminated, locally sulphide-rich, slate and minor metasandstone, and overlies the Bloomfield member in the southern part of the area. The Bear River member (Tremadocian) represents the upper Halifax Formation in the Bear River area and consists of silty slate, metasiltstone and minor metasandstone. In the south part of the area the upper Halifax Formation is referred to as the Sissiboo member, and consists of well-laminated and distinctly colour-banded slate-metasiltstone. The White Rock Formation (Silurian), consists mainly of dark slate with minor metasiltstone, marly metasiltstone and local, thickly bedded quartzite, conformably to disconformably overlying the Halifax Formation. The Torbrook Formation (Early Devonian) conformably overlies the White Rock Formation and consists of slate and metasiltstone, locally with abundant macrofossils.

The lower to middle Paleozoic metamorphic sequence is folded into regional-scale northeast-southwest to north-south, moderately plunging folds. Axial planar cleavage is strongly developed in the Goldenville and Halifax formations, however, only moderately developed in the White Rock and Torbrook formations. The variation in strain may be related to the disconformity between the Halifax and White Rock formations. Concretion shapes and stretched clasts in coarse metasandstone and conglomerate of the Goldenville Formation indicate significant extension parallel to fold hinges. Regional metamorphism is greenschist facies (up to biotite). Contact metamorphism is defined by biotite ± cordierite ± andalusite hornfels adjacent to granite intrusions and locally in areas away from exposed intrusions, implying buried intrusions in these areas. A regional-scale, dextral shear zone reflecting Carboniferous reworking of the fold belt overlaps the Goldenville-Halifax boundary and several late brittle faults occur.

Several new mineral occurrences were found, including Cu-Mo in quartz veins associated with the Clayton Hill pluton and Cu-Sn-Ag-Zn associated with skarn developed from concretions in the Goldenville Formation in areas of contact metamorphism.

## Gravity models over the Shubenacadie-Stewiacke Carboniferous subbasin, Colchester and Hants counties, Nova Scotia

Ken Howells[1] and Alan Ruffman[2]
[1]*Ken Howells Geoscience, 27 John Cross Drive, Dartmouth, Nova Scotia B2W 1X1, Canada*
[2]*Geomarine Associates Limited, P.O. Box 41, Station M, Halifax, Nova Scotia B3J 2L4, Canada*

The gravity compilation over the low density evaporite (salt) deposits in the Shubenacadie-Stewiacke Carboniferous sedimentary subbasin of south central Nova Scotia has been expanded to cover the area 45°00' to 45°15'N and 63°15' to 63°36'W at a standardized scale of 1:35 000. The compilation now involves almost 1975 historic and modern gravity stations. These data have now been contoured with the "Surfer" contouring package to produce a more accurate contoured representation of the gravity data. The addition of 235 stations to the west has allowed better definition of the area of more positive Bouguer gravity anomaly values to the northwest and to extend the main negative anomaly to the southwest. This work has been sponsored by CanEnerco Limited in support of exploration for possible underground storage of natural gas in salt caverns.

Three geological cross-sectional models have been constructed across the axis of the basin along with one longitudinal model tied to two deep drillholes drilled in the mid-1970's. These two boreholes provide the only calibration to the models to date. Geological sections produced by Giles and Boehner in their early 1980s mapping and Boehner's major 1986 *Salt and Potash Resources in Nova Scotia*, Bulletin No. 5, provided the necessary background information. The gravity models have led to some significantly different interpretations from the earlier work. a) The Stewiacke Formation (salt) is continuous along the axis of the basin but does not appear to extend northwest of the Otter Brook and Roulston Corner faults or southeast of the Milford Station-Meadowvale fault system. It may be terminated by a steeply dipping fault to the southwest. b) To the northwest of the Otter Brook and Roulston Corner faults the Horton Group sedimentary rocks become much thinner. c) The Admiral Rock Anticline is a salt-cored anticline and there is no evidence for the northeasterly extension at the basement ridge of higher density Meguma Group metasedimentary rocks in the core of the anticline. d) There is a suggestion of a buried granite basement body in the Meguma Group metasedimentary rocks in the southeast part of this area or alternatively there is a large area of lower density Goldenville Formation quartzite.

## Isotope and chemical hydrogeology of the Avon River drainage basin, Nova Scotia

Duncan Johannessen[1], Dorothy Godfrey-Smith[1], Joel Kronfeld[2], and Marcos Zentilli[1]
[1]*Earth Sciences Department, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada,*
*<djohanne@is2.dal.ca>*
[2]*Department of Geophysics and Planetary Sciences, Tel Aviv University, Tel-Aviv 69978, Israel*

Recent dry summers in Nova Scotia have underlined the increasing importance of clean, available surface water and groundwater. Such resources cannot be properly managed without a clear and detailed understanding of the terrestrial water cycle including geological and anthropogenic effects. This study investigates the applicability of isotopic analyses in conjunction with standard water chemistry to gain insight into the water cycle in a single catchment basin. Samples of lake, stream, and well water were taken along the south branch of the Avon River during the summer of 1998 with some follow-up sampling in 1999.

Beginning at Card Lake in the south, the Avon River flows through a chain of lakes in the tree covered granite highlands of the South Mountain Batholith following the number 14 highway. It then drops down to the fairly flat farmlands overlying sedimentary rocks of the Carboniferous Windsor and Horton groups, where its southwest branch joins it before flowing into the Minas Basin at Windsor, Nova Scotia. It was expected that the groundwater chemistry would reflect the change in geology between the granite highlands, and the down stream lowlands containing limestone and gypsum. Instead, the groundwater samples are clearly divided based on their stage in the water cycle. The surface waters are acidic (pH 3.9-5.9), with extremely low TDS (10-20 ppm). The surface waters have a clear sea salt signature. The groundwater is dominated by calcium carbonate chemistry. The pH values are mostly neutral to slightly basic (5.2-8.0). The groundwater also exhibits appreciably higher concentrations of dissolved salts (40-740 ppm).

These data, combined with trends in the isotopic data, suggest a hydrologic system that is rapidly flushed. The surface waters are essentially rainwater, while the groundwater rarely reaches equilibrium with the bedrock or the till through which it flows. The oxygen isotopes demonstrate that groundwater in the source area, ($\delta O^{18}$ –7.5 to –8.5‰) is derived dominantly from seasonal rainfall recharge. The oxygen isotopic composition of the groundwater becomes systematically more depleted in the downstream direction ($\delta O^{18} \approx$ -10‰). This suggests increasing inputs downstream of meltwater drainage from the winter season, when precipitation is primarily in the form of snow, which is isotopically depleted compared to rainfall. The strontium isotopes suggest interaction with granite in the source area, which is subsequently overprinted by interaction with sedimentary rocks.

## Sequence-stratigraphic interpretations of alluvial-lacustrine basins: Uinta Basin, Utah, as an analogue of the Moncton Basin, New Brunswick

Dave Keighley[1*], Stephen Flint[1], and Andrea Moscariello[2]
[1]*STRAT Group, Department of Earth Sciences, University of Liverpool, Liverpool, England*
[2]*Shell UK Expro, P.O. Box 4, Lothing Depot, North Quay, Lowestoft, England*
[*]*present address: 219 York Street, Fredericton, New Brunswick E3B 3N9, Canada*

Sequence stratigraphy has proved to be a powerful approach to the modeling of stratal successions in increasingly diverse types of sedimentary basins. However, only limited work has yet been done in lacustrine basins. Models are of low resolution, and case studies are rare. New data from the recent Shell Canada drilling program in the Mississippian of the Moncton Basin will provide an opportunity to apply a sequence stratigraphy to the Albert and associated formations and to aid in the development of higher resolution models. Of interest is how the succession might compare to the analogous Uinta Basin of Utah.

Both basins have the typical five-part succession that spans the entire lifespan of intermontane lacustrine basins and which reflects the general tectonic control over basin initiation and fill. Alluvial strata associated with basin initiation is followed by a sediment starved, lacustrine dominated succession where tectonism is deepening the basin faster than sediment is infilling. Changing tectonic controls and, or, increased sediment supply causes sediment to accumulate as deltaic and ultimately fluvial successions before the basin itself is filled and bypassed.

The three-dimensional facies distributions developed at each stage are controlled by the long term climatic belt the basin was situated in. Both basins have lithofacies associations indicative of a wet to seasonally dry climate, the Moncton Basin being the wetter (the Gautreau evaporite being very localized). Wet climates maintain high lake levels and high relief, highstand deltas, whereas more seasonal climates produce highly fluctuating lake levels containing deltas with low preserved relief, and some evaporites toward the basin centre.

Work in the Uinta Basin is further advanced and may indicate what the Moncton Basin study might reveal. A cyclic climatic control and irregular tectonic control on higher frequency, low relief sequences has been identified in the lower Green River Formation (Dawson Settlement Member equivalent). An overriding climatic control influences the high relief sequence of the Uinta Formation (Hiram Brook Member equivalent).

## Application of combined enhanced aeromagnetic and digital elevation data in the geological interpretation of the eastern Meguma Terrane of Nova Scotia

M. S. King[1] and R. J. Horne[2]
[1]*72 Johnstone Avenue, Dartmouth, Nova Scotia B2Y 2K5, Canada*
[2]*Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia B3J 2T9, Canada*

Aeromagnetic and digital elevation data are useful for regional geological interpretation. Combination of these data can further enhance geological features, allowing for interpretation beyond that of the individual data sets. Enhanced aeromagnetic data, consisting of calculated second vertical derivative data, have been overlain on a detailed digital elevation model (DEM), generated from 1:10 000 scale topographic information, to create a single map image for the eastern Meguma Terrane. The aeromagnetic data were gridded to 75 m and the digital elevation data were gridded to 40 m. Colour contour information was generated from the magnetic data, whereas the digital elevation data are presented as shaded relief.

These combined data sets reveal useful and interesting features that enhance geological interpretation of the eastern Meguma Terrane, locally revealing previously unrecognized features. For example, the combined data indicate a more complex, composite nature for northwest-trending faults than is obvious from the offset of aeromagnetic data alone. In addition, the DEM illustrates the presence of countless, parallel, northwest-trending linear features, resulting in a penetrative fabric at 1:250 000 scale. Several previously undocumented, regional-scale northeast-trending linear features are defined by the DEM. These linear features are locally coincident with abrupt changes in aeromagnetic data or geological contacts, implying that they represent faults. In the

Carboniferous Musquodoboit Basin, these northeast-trending linear features locally correspond to mapped basin margins. In one area, significant attenuation of the aeromagnetic response from the underlying Meguma Group, resulting from overlying Carboniferous strata, is bounded by two northeast-trending features. This implies that these structures may influence basin geometry. Attenuation of the magnetic signal within this block indicates significant vertical displacement associated with an increase in the thickness of non-magnetic (e.g. Carboniferous) strata. Locally, linear features in the DEM define bedding-parallel ridges in the Meguma Group, providing detailed structural information for folds in areas with little or no magnetic relief. Aeromagnetic and (or) DEM data have distinct patterns over areas of known intrusions (e.g. Musquodoboit Batholith) that can be useful in defining pluton boundaries in areas with little geological control. Linear features defined in the DEM cut plutons or are coincident with the pluton boundaries, constraining the relative age of these faults. The combination of aeromagnetic and DEM data are a useful tool in interpreting the bedrock geology in the eastern Meguma Terrane.

## New insights into the classification and formation of zeolites hosted by the North Mountain Basalt, Annapolis Valley, southern Nova Scotia

Daniel J. Kontak
*Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia B3J 2T9, Canada*

The Jurassic North Mountain Basalt of southern Nova Scotia constitutes a thick sequence of massive, variably porphyritic [clinopyroxene ($En_{40-50}Wo_{30-40}Fs_{15-40}$, plagioclase ($An_{50-70}$)] and vesicular tholeiites that outcrop along the Bay of Fundy for 100's of km, thus providing excellent exposure. The ubiquity of zeolites in the basalts has been known for ca. 150 years, however, detailed macro- and micro-scale studies of their occurrence remain scarce. Recent field studies and subsequent detailed electron microprobe analysis (EMPA) in conjunction with back scattered electron (BSE) imaging have provided new and insightful information regarding factors controlling zeolite distribution within basalt flows and processes responsible for their formation. Field studies indicate that a 4-part zonation occurs, continuous laterally for 100's m, for zeolite-filled amygdules within individual amygdaloidal flows. From bottom to top these zones are: (1) a basal zone of ca. 1 m containing two types of amygdules, namely (i) oriented (vertical to steeply dipping), cigar-shaped ($\leq$10 cm) amygdules, and (ii) disseminated $\leq$5%, $\leq$1-2 cm) amygdules; (2) bubble-train zone of 2-4 m containing vertical, cigar-shaped, amygdule-rich pipes of 10-20 cm diameter; (3) net-textured zone of 1-2 m in which the bubble-train zone coalesces with disseminated amygdules of $\leq$3 cm; and (4) a disseminated zone (1 m) at the top representing the frothy, oxidized top of the flow with abundant amygdules of highly variable shape and size ($\leq$4-6 cm). The 4 zones are continuous except for a gap of 1-2 m between zones 1 and 2 where massive, non-vesicular basalt occurs. Imaging (BSE) analysis integrated with EMPA indicate the following features: (1) a variety of Ca-Na zeolites occur in filling amygdules along with abundant Fe-, Mg- and Ca-rich micas, minor K-feldspar ($Or_{90-98}$), and rarely riebeckitic amphibole. The zeolites are relatively late paragenetically compared to other silicates; (2) abundant matrix zeolite occurs, most commonly replacing albitized plagioclase; (3) remnant patches of variably altered and crystallized intergranular glass are common. Field and laboratory data suggest zeolite formation relates to: (1) degassing of volatile-rich flows resulting in a 4 part zonation of vesicles; (2) leaching of elements from intergranular glass via migration of hot (initially ca. 350°C) fluids; and (3) deposition of a variety of silicate phases with zeolites generally late paragenetically.

## Observations on the nature of aplite-pegmatite sheets in the Peggy's Cove area, Halifax County, Nova Scotia

Daniel J. Kontak[1] and Jarda Dostal[2]
[1]*Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia B3J 2T9, Canada*
[2]*Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada*

The Peggy's Cove area is underlain by compositionally uniform, but texturally variable biotite monzogranite of the 370 Ma peraluminous South Mountain Batholith (SMB) of southern Nova Scotia. Extensive coastal outcrop provides an opportunity to examine the nature and origin of pegmatite-aplite sheets. In this study, an area north of Peggy's Cove southwards to East Dover was mapped at 1:2000 scale on expanded aerial photographs and all pegmatite-aplite occurrences were noted. In several cases, detailed mapping of pegmatite-aplite sheets was done as a basis for geochemical studies. Observations of the coastal exposures reveal: (1) a generally uniform texture for the monzogranite, but with local variations in the size (±10-12 cm) and abundance (±30-40%) of K-feldspar megacrysts; (2) large variation in abundance, size and texture of xenoliths; (3) occurrence of K-feldspar - rich pegmatite zones about xenoliths; (4) local development of magmatic layering; and (5) a concentration of pegmatite-aplite sheets in zones subparallel to coast. Examination of the pegmatite-aplite sheets reveal: (1) extreme vertical and lateral variability in evolution of pegmatites and aplites; (2) welded

contacts versus structural contacts, but at one locality tourmaline fibres occur at the contact; (3) general zonation of line rock with contorted texture in the bottom half and coarsening of the leucocratic material and development of monomineralic K-feldspar layers in the upper part; (4) development of qtz-ms-tourmaline - rich pockets on variable scales; (5) generally flat dips, which contrast with steep dips for fractures; (6) wedge-shaped terminations to sheets that define en echelon arrays on both a small and large scale. Geochemistry indicates the following: (1) aplites are silica rich (75-78 wt. % $SiO_2$) with $K_2O/Na_2O \geq 1$, Rb=180 to 260 ppm, Sr≤30 ppm, Nb≤5 ppm, Sn≤8 ppm; (2) bulk K-feldspar is $Or_{72-80}$ with 250-350 ppm Rb and 120-190 ppm Ba; (3) perthitic feldspars consist of $Or_{86-95}$ with <0.5 wt. % $P_2O_5$ and $Ab_{96-100}$; (4) muscovite contains ca. 1-2 wt. % FeO and 0.4-1.0 wt. % MgO with F not detected; (5) tourmaline is Fe-rich with Fe:Mg of 2:1 to 5:1. These chemical indices indicate that the pegmatites are not extreme fractionates, but instead represent local segregations of the host monzogranites. We tentatively suggest that the pegmatite-aplite sheets formed due to infiltration of fluids derived from devolitization of either the Meguma Group country rock or xenoliths. Stable isotope analysis and fluid inclusion work in progress will address the validity of this hypothesis.

## A Cambrian carbonate platform in the Québec Reentrant: new insights from in situ platform core data and slope conglomerates

Denis Lavoie[1] and Osman Salad Hersi[2]
[1]*Geological Survey of Canada, Centre Géoscientifique de Québec, 2535 Laurier Boulevard, P.O. Box 7500, Ste-Foy, Québec G1V 4C7, Canada*
[2]*INRS-Géoressources, Québec Geoscience Centre, Ste-Foy, Québec G1V 4C7, Canada*

The passive margin platform record in Western Newfoundland at the St. Lawrence Promontory consists of an initial Lower Cambrian mixed siliciclastic – carbonate fluvial to shallow marine succession (the Labrador Group) followed by a well developed, extensive but narrow Middle to Upper Cambrian carbonate high energy platform (the Port au Port Group) and capped by a Lower Ordovician extensive and wide low energy carbonate platform (the St. George Group). More than two decades of detailed stratigraphic, paleontologic and sedimentologic studies resulted in a comprehensive evolution framework for this passive margin evolution.

The passive margin platform record in southern Québec in the Québec Reentrant is significantly different. Unconformably overlying the Precambrian basement, the preserved outcrop record consists of an initial Upper (?) Cambrian fluvial to marginal marine succession (the Potsdam Group) overlain by a Lower Ordovician low energy peritidal carbonate platform (the Beekmantown Group) which marks the end of the passive margin stage of the Sauk Sequence. Interestingly, the Beekmantown Group in southern Québec as well as its time equivalent Romaine Formation in Anticosti Island are both, facies-wise, similar to the upper part of the St. George Group in Western Newfoundland.

The presence of an enigmatic and unexposed Cambrian carbonate platform in the Québec Reentrant has long been known through the documentation of Lower to Upper Cambrian shallow marine carbonate clasts in conglomerates found in the Appalachian Humber Zone which preserved the passive margin slope record. Lithologies documented in these clasts argue for a highly facies-diversified platform (thrombolites, laminites, bioclastic-intraclastic-oolitic grainstones and packstones). Detailed examination of cores from the St Lawrence Platform in southern Québec revealed the presence within the Upper (?) Cambrian Potsdam Group of a previously unreported 10-20 m thick interval of mixed siliciclastics and marine carbonates. These carbonates (impure bioclastic and intraclastic dolomitic grainstones) represent the *in situ* nearshore expression of a Cambrian carbonate platform that existed in the Québec Reentrant. This finding has significant implication for the overall reconstruction of Laurentia passive margin.

## Appalachian foreland and platform architecture in Québec, New Brunswick and Newfoundland: an up-to-date NATMAP contribution to the Geological Bridges of Eastern Canada

D. Lavoie[1], D. Lebel[1], S.R. McCutcheon[2], S. Colman-Sadd[3], A. Tremblay[4], O. Salad Hersi[4], S. Castonguay[1], M. Rocher[4], K. Lauzière[1], L. Nadeau[1], Y. Lemieux[4], and J. Gagnon[4]
[1]*Geological Survey of Canada, Centre Géoscientifique de Québec, 2535 Laurier Boulevard, P.O. Box 7500, Ste-Foy, Québec G1V 4C7, Canada*
[2]*New Brunswick Geological Surveys Branch, P.O. Box 50, Bathurst, New Brunswick E2A 3Z1, Canada*
[3]*Geological Survey of Newfoundland and Labrador, P.O. Box 8700, St. John's, Newfoundland A1B 4J6, Canada*
[4]*INRS-Géoressources, Québec Geoscience Centre, Ste-Foy, Québec G1V 4C7, Canada*

The Appalachian Foreland and Platform project is the NATMAP funded component of a multi-disciplinary and multi-agency collaborative endeavour called the Geological Bridges of Eastern Canada. The Bridges traverse critical geological segments of southeastern Québec, northwestern New Brunswick, and western Newfoundland. The objective of

the Bridges is to use five narrow geological transects to bridge the knowledge gaps that exist between the crystalline basement, the St. Lawrence platform, the Appalachian foreland thrust-fold belt and successor basins, from the Neoproterozoic to the Quaternary. Bridge segments are regularly spaced, and were chosen to elucidate in 4D (from surface to depth, and through geological time) the complex, multi-phased history of basin formation, infilling, deformation and erosion that formed the outer parts of the Appalachians.

The NATMAP component consists of new bedrock and surficial mapping in conjunction with planned provincial geological mapping projects, and a series of thematic studies to complement the mapping. Surface and subsurface thematic studies focus on: (1) stratigraphy (litho-, bio, chemo- and chrono-) and sedimentology of Neoproterozoic to Quaternary sections; (2) documenting structural styles through mapping, geochronology, remote sensing, geophysics and bathymetric data, both onshore and offshore; and (3) diagenetic, petrographic, geochemical and thermal maturation studies, in order to help assess the mineral, petroleum and groundwater potential of these areas and so generate new exploration models for the resource exploration industry.

For the first year of the project, new field work (maps and thematic studies) and compilation of existing data were made for the Montreal-Appalachians transect (#1), for the Québec City-Appalachians transect (#2), for the Matane-New Brunswick transect (#3) and for the Western Newfoundland transect (#5). A total of 12 new maps were produced as well as a major 1:100 000 compilation map for transect #1.

## Holocene paleoceanography: marine palynology records from Atlantic Canada

Elisabeth Levac[1], Andre Rochon[2], and Peta J. Mudie[2]
[1]*Center for Marine Geology, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada*
[2]*Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada*

New transfer functions, using a database of more than 500 modern reference sites, have been used to reconstruct sea surface conditions on the Atlantic margin of Canada. They were applied to palynological records from the La Have, Emerald and Bedford Basins. The interval from 10 to 6 ka B.P. was characterized by stable sea surface conditions similar as today. More frequent and greater variations are found after 6 ka: two episodes with colder sea surface temperature and lower salinity occur around 5,500 and 2,500 ka.

Cysts of *Alexandrium excavatum*, a dinoflagellate species responsible for paralytic shellfish poisoning (PSP) show a peak at Bedford Basin during the 6 ka thermal maximum, and at about 7,500-10,000 years B.P. in La Have and Emerald basins. Blooms of PSP causing dinoflagellates are a major concern for the shellfish industry and have shown an increase in the past 50 years on the Altantic coast. Laboratory and field observations over the past 20 years show that blooms of PSP dinoflagellates are often triggered by warm sea surface temperature, high runoff and storm resuspension of resting cysts. Our results do not show a strong correlation between PSP cyst abundance and summer sea surface temperature, salinity or sea ice cover over the Scotian Shelf. However, a correlation between peaks in cyst abundance and intervals of silt/sand beds suggests that storm resuspension plays a greater role in triggering harmful algea blooms. This observation has important implications for the Atlantic Provinces because of the increased frequency and intensity of storms apparently associated with global warming.

## The Willett Cu-rich massive-sulphide deposit, Bathurst Mining Camp, New Brunswick: general geology, deposit characteristics, and felsic volcanic chemostratigraphy

Chris D. MacDonald
*Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada*

The Willett property is located in the Bathurst Mining Camp in northern New Brunswick. It is underlain by the volcano-sedimentary rocks of the Middle Ordovician California Lake Group, which hosts several other significant massive-sulphide deposits, in particular the Caribou, Orvan Brook, Wedge, and Nepisiguit deposits. Similar to the Tetagouche Group, this newly defined group has experienced variable degrees of hydrothermal alteration related to the genesis of massive-sulphide deposits, regional greenschist-grade metamorphism, and metasomatism-related polyphase deformation. This area, like many other massive-sulphide deposits in the Camp, is intimately related to felsic volcanism and coeval sedimentation.

The Willett massive-sulphide showing (< 50 000t grading up to 6.35% Cu, 8.50% Zn, 3.24% Pb, 246 g/t Ag, and 1.00 g/t Au) is hosted in intensely deformed argillaceous sedimentary rocks of the Boucher Brook Formation. Based on field observations and diamond drill core logging, the sulphides are interpreted to be boudinaged rafts in a tectonic melange that has been transported some unknown distance from its original stratigraphic location. Like the Wedge deposit, the Willett deposit is very Cu-rich indicative of an original proximal association to its stockwork system and host volcanic package. The occurrence of numerous, variably sized aphyric to feldspar-phyric rhyolitic blocks in the melange proximal to the massive sulphides suggests an intimate association with the

Spruce Lake Formation felsic volcanic rocks that occur to the north and south of the showing and (possibly) the quartz-feldspar-phyric and quartz-phyric felsic pyroclastic rocks of the Shellalagh Hill Brook Member of the Spruce Lake Formation located to the south, preceding deformation. Therefore, it was important to ascertain which autochthonous Spruce Lake felsic package these volcanic rocks were most closely associated.

A lithogeochemical study of selected Spruce Lake felsic volcanic rock samples representing roughly a cross section through the northern unit in the Willett area suggests that there may be two distinct rhyodacitic volcanic packages in this unit. This interpretation is based on two separate $Zr/TiO_2$ populations; the lower ratios ($Zr/TiO_2$= 0.060-0.068) occur near the outer margins (to the north and the south) of the Spruce Lake felsic volcanic unit and higher ratios ($Zr/TiO_2$ = 0.086-0.089) occur predominantly in the inner portions or core of the unit; this is consistent with increasing fractionation of the package. Other chemical differences between the core (c) and margins (m) of the unit (based on 10 averaged sample analysis) include: $K_2O$ (wt.%), 7.91(c) to 4.17(m); Ba (ppm), 805(c) to 418(m); Zr (ppm), 234(c) to 167(m); Y (ppm), 54(c) to 34(m) and Nb (ppm) 16(c) to 12(m). Zr/Y values of 3.5 to 4.7 (avg. 4.3) for both core and margin indicate that the Spruce Lake felsic volcanic rocks are transitional with tholeiitic affinities. A plot of Nb versus Y reveals that the samples straddle the volcanic-arc and within-plate fields with respect to tectonic setting. Considering the local synclinal fold geometry, the two separate $Zr/TiO_2$ populations may be indicative of vertical chemostratigraphic differences within the Spruce Lake felsic volcanic sequence. These geochemical attributes may be significant for both local chemostratigraphic correlation, as well as empirically identifying similar felsic volcanic packages hosting deposits elsewhere in the Spruce Lake Formation.

## Stratigraphy, geochemistry and age of the White Rock Formation in the Yarmouth area, Nova Scotia

Lisa A. MacDonald[1], Sandra M. Barr[1], Chris E. White[2], and John W.F. Ketchum[3]
[1]*Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada*
[2]*Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia B3J 2T9 Canada*
[3]*Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3X5, Canada*

The White Rock Formation in the Yarmouth area occurs in a faulted synclinal structure underlain by slate and phyllite of the Halifax Formation. The formation is divided into 7 stratigraphic units based on field mapping, petrographic study and published geophysical maps. The stratigraphically lowest unit consists of mainly metapelitic rocks that are schistose on the eastern limb near the faulted contact with the Brenton Pluton. The unit grades into a quartzite unit which becomes fine-grained near the top. The third unit consists of metavolcanic and metasedimentary rocks near the base and mafic metavolcanic rocks in the upper part. On the eastern limb, the upper metavolcanic rocks are felsic. Unit four is a sequence of mafic metavolcanic and metasedimentary rocks, which include conglomerate near the top. The fifth unit is a predominantly mafic metavolcanic unit with minor metasedimetary rocks. Metavolcanic rocks include pillow basalt and towards the top, felsic and intermediate tuffaceous rocks (including ignimbrite). The sixth unit consists of intermediate and mafic metavolcanic rocks (with pillows) with minor metasedimentary rocks, grading upwards into slate near the top. The stratigraphically highest unit preserved in the syncline is predominantly mafic tuff and flows. All units are commonly intruded by mafic dykes and/or sills, which also occur in the adjacent Halifax Formation. Metamorphic grade increases from greenschist facies in the south to amphibolite facies in the north.

The Brenton Pluton occurs on the eastern limb of the syncline and appears to be in faulted contact with unit 1 of the White Rock Formation to the west, and slate of the Halifax Formation to the east.

Mafic volcanic rocks of the White Rock Formation have chemical features indicating alkalic affinity and within-plate tectonic setting. The felsic volcanic rocks are chemically similar to the Brenton Pluton and both have characteristics of within-plate A-type granites. Preliminary results of U-Pb dating of zircon from ignimbrite in unit 5 yield an age of 438 +31/-35 Ma. This supports the Silurian age of the White Rock Formation, based on fossil evidence from the formation elsewhere in southern Nova Scotia.

## A forensic petrological study of granite blocks from the Sambro Lighthouse

Michael A. MacDonald[1] and Alan Ruffman[2]
[1]*Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia B3J 2T9, Canada*
[2]*Geomarine Associates Limited, P.O. Box 41, Station. 'M', Halifax, Nova Scotia B3J 2L4, Canada*

The Sambro Island Lighthouse was built in 1758-60 and is the oldest operating lighthouse in North America. The lighthouse was the focus of a major restoration program by the Canadian Coast Guard in 1998. The lower part (13.1 m) of the lighthouse, representing the original construction, was built with granite blocks of uncertain origin. Several sources for these blocks have been postulated, including: ballast from a vessel from Massachusetts; one of the five granite quarries on early geological maps of the Halifax area; a quarry in the Duncan's Cove-Chebucto Head area; or possibly from Sambro Island itself. Another suggestion was that the granite blocks were salvaged from the fortress of Louisbourg after the defeat of the French army; however, Louisbourg was constructed from sandstone and is not a possible source. In 1998, the authors began a forensic petrological study of the granite blocks to establish their origin with field assistance from the Nova Scotia Lighthouse Preservation Society.

Granitic rocks of the Halifax area were studied extensively in 1985, as part of a mapping project under the 1984-1989 Canada-Nova Scotia Mineral Development Agreement. Specifically, work included 1:10 000 scale geological mapping, whole-rock geochemical analysis, and mineral chemistry studies to establish compositional variations within the granitic rocks. The database generated during this study provides an excellent framework for forensic petrological work on the Sambro Lighthouse granite blocks.

Three chips were collected from separate granite blocks in the Sambro Lighthouse along with a large representative sample of granitic outcrop on the island and representative samples from coastal exposures between Sambro and Chebucto Head. Petrographic inspection and microprobe analysis of biotite grains from these samples were compared to data from the major granitic rock types of the Halifax Pluton. The petrographic work reveals that the Sambro Lighthouse granitic blocks show mineralogical features consistent with some granitic rocks of the Halifax Pluton. Consequently, these blocks: (1) are not considered to have originated as ship ballast from New England; (2) were not quarried from the biotite monzogranite on Sambro Island; (3) do not resemble fine- or coarse-grained leucomonzogranite of the Halifax Pluton and, therefore, did not originate from the Brookfield quarry on Terrence Bay; and (4) were probably quarried from either the Harrietsfield or Sandy Lake monzogranite units. The exact location of the quarry site has not yet been confirmed; however, the forensic petrology supports the documented quarry in the Chebucto Head area as a possible source for the Sambro Lighthouse granite.

## Detailed structural analysis of a transpressional terrane boundary, Minas fault system, Nova Scotia

Ellie MacInnes and J.C. White
*Department of Geology, University of New Brunswick,*
*P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada <c2u63@unb.ca>*

The Minas fault zone, an east trending Paleozoic Appalachian terrane boundary, is an excellent example of a long lived zone of intense deformation of low metamorphic grade and significant displacement. Dextral transpression was dominant during the Acadian Orogeny as Meguma docked against Avalon. This transpressive fault zone was later reactivated and acted as the loci for the opening of the Fundy and Minas basins during the initial fragmentation of Pangea in the Triassic. The reversal of deformation environments created a convenient site for examination of basin inversion and subsequent redevelopment.

The principal rock unit within the fault zone is the Late Devonian-Early Carboniferous Horton Group (low grade facies Greville River and Rapid Brook formations respectively represent the products of distal and proximal facies of a single alluvial fan-fluviatile-lacustrine unit). Study of these sediments, which preserve a wide range of deformation intensities, (from relatively undeformed large-scale folds to high strain phyllonites), allows for a detailed microstructural examination within a large scale tectonic framework.

Through detailed structural mapping of this well exposed fault zone the complex overprinting and geometric relationships associated with protracted deformation can be ascertained. Distinctive variations in the styles of deformation are evident through a cross section of the shear zone. Strain partitioning played a crucial role in the development of the transpressive fault zone. Transcurrent motion was concentrated within the central portion of the zone. Within this zone intense deformation has accommodated high displacements and produced a wide range of fault rocks, including well developed sheath folds, S-C', fault gouge, breccias, phyllonites and intense repeated veining. There is a clear overprinting relationship between ductile and brittle regimes. Stretching lineations plunge moderately to the SW. A distinct boundary exists between the high strain central zone and the inbound portion, which displays low level deformation and very low-grade metamorphism. Large scale open folding and bedding plane thrusts are typical of this compression dominated area.

## Gold environments in New Brunswick

M.J. McLeod[1] and S.R. McCutcheon[2]
[1]*New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch,*
*P.O. Box 5040, Sussex, New Brunswick E4E 5L2, Canada*
[2]*New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch,*
*P.O. Box, 50, Bathurst, New Brunswick E2A 3Z1, Canada*

Exploration in the vicinity of recently discovered gold occurrences, and additional exploration in areas containing known gold mineralization, has highlighted the potential for economic precious metal deposits in New Brunswick. Gold has been documented in nearly all the main tectonostratigraphic zones in the province in units ranging in

age from Neoproterozoic to Carboniferous. Although research on most occurrences is limited, generalized unifying models depicting gold environments in some regions of the province can be established utilizing available information. The majority of occurrences are either directly or indirectly related to magmatism in plutonic and volcanic environments; some are strictly structurally controlled (metamorphic), and others are associated with volcanic-hosted massive sulphide deposits.

In southwestern regions of the province, Lower Devonian, intermediate to felsic intrusions that produce contact metasomatic (skarn?) and porphyry mineralization are also likely source rocks for numerous, mesothermal, quartz/carbonate vein systems. The latter probably represent eroded high sulphidation-type epithermal deposits. In central and northeastern regions, gold in similar environments is associated with Siluro-Devonian and Ordovician, felsic to mafic intrusions. These intrusions may have also generated the base-metal sulphide- and gold-bearing occurrences that are present in the Siluro-Devonian, shallow subaqueous volcanic sequences in these regions. The structurally-controlled types, without any obvious magmatic source, are most prevalent in, but not restricted to, Neoproterozoic to Cambrian units along the Bay of Fundy shore. Like the occurrences in the southwestern region, these may also be the roots of high sulphidation, epithermal systems. Gold occurrences associated with deep subaqueous exhalite and stringer zone sulphides are restricted to northeastern regions, i.e. the Ordovician Bathurst Mining Camp.

Several other types of gold environments are represented in the southern part of the province. Intrusion-related hydrothermal breccias appear to be associated with Late Devonian, high-silica granite and may represent low sulphidation epithermal systems. Paleoplacers and possible subareal geothermal systems are associated with Carboniferous fluvial sedimentary sequences. Gold enrichment has been documented in recent peat bogs overlying these Carboniferous rocks.

Currently, the most intensive exploration is focused on promising occurrences intimately associated with the Lower Devonian and Ordovician (?) intrusions in southwestern and central regions. The exploration potential of extensive Carboniferous sedimentary basins is just beginning to be evaluated and the Neoproterozoic terranes of southern New Brunswick should have similar potential to those in Newfoundland and to the gold districts in the Carolina Slate Belt.

## BASIN: a hydrocarbon exploration database and model for data distribution

P.N. Moir and P.B. Lake
*Geological Survey of Canada (Atlantic), P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada*

Creation and maintenance of digital databases is a valuable product of the Geological Survey of Canada's Atlantic Division petroleum geoscience research program. Historically, access to such databases has been cumbersome, often requiring the help of skilled data extraction experts, who access data from several dispersed and unrelated database architectures. The GSC's own need for simplified access and better archiving of the data, coupled to the dramatic increase in demand for external access by clients prompted change. The unique solution was to use the Internet and World Wide Web in conjunction with a relational database system to create easy to use graphical user interfaces that extract and display data quickly and effectively. This poster highlights the development of the BASIN database and its Web interface as an important science knowledge archive centre and distribution media. It presents examples of completed database interfaces and presents a successful model for cost effective data distribution to clients.

## Spatial distribution and grades of conjugate veins associated with mesothermal saddle reef gold mineralization, The Ovens, Nova Scotia: implications for an open pit resource

Donnette M., Mugridge
*Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada <prende@hotmail.com>*

A 228 m long E-W oriented cliff section of continuous exposure along the north shore of Rose Bay, The Ovens, Nova Scotia, was measured along a reference line to determine the locations and attitudes of conjugate, thrust-related and bedding parallel (saddle reef) Au-quartz-sulphide veins within the Cunard Formation, Halifax Group, Meguma Supergroup. Over 1700 veins ranging from less than 1 mm to 173 mm wide were observed. A variety of statistical tests were performed to determine whether these veins are randomly located in space. All results indicate that these veins exhibit a non-random distribution. Studies presently underway are examining the spatial periodicity of the vein locations.

Net lateral dilation accommodated by west dipping conjugate veins does not exhibit a significant trend; however, east dipping conjugate veins become sparser but exhibit more net dilatancy to the west and down-section toward a basal thrust.

Metallic gold grade results from 0.5 to 3 kg of vein material exhibit a high, positively skewed distribution with concentrations ranging from 0.016 to 60.911 grams per tonne. Using an ideal Poisson grade distribution with identical mean (2.742 grams per tonne), the observed vein width distributions and the observed vein frequency distributions, a Monte Carlo simulation using 5700 1 $m^3$ block realizations was undertaken to produce a hypothetical model for tonnage, grade and dilution curves for this mineralization. Results provide insight into the potential open pit economic feasibility of Au-bearing quartz-sulphide vein saddle reef stockworks associated with anticlines within the Meguma Supergroup.

## Petrology of the San Miguel ultramafic body, Acatlan Complex, southern Mexico: an oceanic fragment of the Iapetus or Rheic oceans?

J. Muise[1], J. Dostal[1], J.D. Keppie[2], and F. Ortega-Gutierrez[2]
[1]*Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada*
[2]*Instituto de Geologia, Universidad Nacional Autonoma De Mexico, 04510 Mexico D.F., Mexico*

The San Miguel ultramafic body represents a thrust slice emplaced above a thick clastic sequence (Chazumba Formation) in the Acatlan Complex of southern Mexico. The ultramafic rocks consist of pyroxene, amphibole and olivine that are extensively altered to talc, chlorite and serpentine. Minor mafic components occurring as layers within the ultramafic body and as dykes are made up of plagioclase, K-feldspar, pyroxene and amphibole altered to chlorite. The ultramafic rocks have $SiO_2$ contents ranging from 39 to 47%, whereas in the mafic rocks it varies from 46 to 54%. Microprobe and trace element analyses are currently underway and will be presented at the conference. A younger limit for the age of the body is given by the published 175-170 Ma ages on granitic sheets that cut across the ultramafic rocks and most of the structures affecting the unit. The San Miguel ultramafic body is inferred to be a fragment of oceanic lithosphere, and current models indicate that this could have been part of either the Iapetus or Rheic oceans.

## Evolution of Proto-Avalonia: a 1.0 Ga tectonothermal event and geodynamic linkage to the breakup of Rodinia?

J.B. Murphy[1], R.A. Strachan[2], R.D. Nance[3], D.K. Parker[2], and M.B. Fowler[2]
[1]*Department of Geology, St. Francis Xavier University, Antigonish, Nova Scotia B2G 2W5, Canada,* *<bmurphy@stfx.ca>*
[2]*School of Earth and Construction Sciences, Oxford Brookes University, Oxford OX3 OBP, United Kingdom*
[3]*Department of Geology, Ohio University, Athens, Ohio 45701, USA <dnance1@ohiou.edu>*

Avalonia, the largest suspect terrane in the Canadian Appalachians, originated along the Neoproterozoic margin of Gondwana and was accreted to Laurentia by the late Ordovician. The age and character of Avalonian basement is key to identifying the portion of the Gondwanan margin from which the terrane was derived and provides important constraints for Neoproterozoic paleocontinental reconstructions. Since this basement is not exposed, it must be characterized indirectly by isotopic analyses. Nd-Sm data from ca. crustally derived, 630-430 Ma felsic rocks typically record initial $e_{Nd}$ values between 0 and +5.0 and model ages ($T_{DM}$) between 0.8 to 1.1 Ga, but the origin of this isotopic signature is unclear. Two early Avalonian igneous complexes that were emplaced prior to the main (630-570 Ma) cycle of Neoproterozoic magmatism; the ca. 734 Ma Economy River Gneiss of mainland Nova Scotia and the ca. 675 Ma Malverns Plutonic Complex of the British Isles show non-overlapping $e_{Nd^t}$ values of +1.29 to +4.09, and -0.11 to -2.03, respectively. Yet their $T_{DM}$ (998 -1194 Ma and 1043- 1147 Ma) are almost identical and are similar to those of the main 630-570 Ma arc phase and subsequent Paleozoic tectonothermal events. This indicates that the isotopic signature is a characteristic feature of Avalonian basement and that felsic magmatism produced by peak arc activity was predominantly generated by recycling pre-existing crust.

The $T_{DM}$ ages are interpreted to record a ca. 1.0 to 1.2 Ga tectonothermal event that formed much of the basement upon which subsequent Neoproterozoic and Paleozoic tectonothermal activity developed. This interpretation is supported by U-Pb detrital zircon ages of 977-1223 Ma obtained from Avalonian sedimentary rocks in Nova Scotia that are coeval with the main arc phase. This tectonothermal event is interpreted to reflect western-Pacific-type arc-back arc complexes formed coevally with the Tocantins province of central Brazil. The transition to eastern Pacific-type arc activity may be related to the ca. 760 breakup of Rodinia in a manner analogous to effect of the breakup of Pangea on the tectonothermal evolution of western North America.

## Investigation of integrated geologic and geophysical data using GIS: Crooked Creek and Decaturville impact structures, Missouri

G.A.J. Nickerson[1], J.G. Spray[1], and L.A.Mayer[2]
[1]*Impact Geology Group, Department of Geology, University of New Brunswick, 2 Bailey Drive, Fredericton, New Brunswick E3B 5A3, Canada*
[2]*Department of Geodesy and Geomatics, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada*

The morphometry and geology of structures formed by the impact of extraterrestrial objects with the earth are systematic by nature. The processes involved in the formation of impact structures however are not completely understood.

The general morphometry of impact structures is known from observations of the moon, other planets and the detonation of explosives. Modification of impact structures by erosion often makes identification of structural features difficult and adds ambiguity to the geologic record at the earth's surface. Thorough investigation of highly eroded structures may require supplemental information via drilling and geophysics.

An investigation of the Crooked Creek and Decaturville impact structures of Missouri, U.S.A., was conducted using three-dimensional interactive visualization technology. Topographic data and drill core logs were obtained from government sources. Geophysical data from the Crooked Creek structure was also obtained. The data was digitized for use with GIS. Topographic and geophysical data were gridded to form three-dimensional surfaces. Drill core data was converted into two-dimensional vectors. GIS software was used to integrate the data in a geospatial reference system.

The data was investigated in three dimensions using UNB's Fledermaus software. Fledermaus can integrate and display both raster and vector data in three dimensions. Fledermaus offers several data manipulation tools, to enhance viewing of subtle topographic and subsurface features, as well as geophysical data. Fledermaus provides tools to measure and export profiles of continuous surfaces for construction of geologic cross sections. Fledermaus facilitates the output of cartographic media in soft copy, hard copy maps or animations.

The ability to visualize and interact with spatial data allows the user to inspect data in three dimensions and to move about the data in real time. The integration of several data sets allows for the construction of a multidimensional model. The manipulation of digital data also makes it possible to reconstruct the morphometry of the impact structure as it may have appeared at the time of impact.

## Haughton-Mars Project 1999: geology of the Haughton impact structure, Devon Island, Nunavut, Canada

G. R. Osinski[1], J. G. Spray[1], and P. Lee[2]
[1]*Impact Geology Group, Geology Department, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada <f532b@unb.ca>*
[2]*NASA Ames Research Center, Moffet Field, California 94035-1000, USA*

It is now widely recognized that impact cratering is a ubiquitous process that affects all the terrestrial planets. The surface of the Moon, where other geological processes stopped millions of years ago, records this process clearly. On Earth, however, impact craters are continually erased by erosion, volcanic resurfacing, and tectonic activity.

The relatively uneroded 23 Ma old Haughton impact structure, situated near the western end of Devon Island in the Canadian Arctic Archipelago, is the highest latitude terrestrial impact crater known on land (75° 22' N, 89° 41' W). Estimates of the original rim diameter range from ~20 km to ~24 km. The target sequence comprises a ~1750 m thick series of predominantly carbonate rocks, of Lower Paleozoic age, underlain by Precambrian metamorphic basement. Geological mapping indicates that the oldest rocks are exposed in the centre and are surrounded by concentrically arranged fault-bounded blocks of progressively younger Paleozoic formations (faulted annulus). Polymict impact breccias form a more or less continuous deposit covering ~56 km$^2$ within the central area of the structure and extend out into a ring of hills. Discontinuous deposits of breccia occur up to a radial distance of ~7.5 km in the east of the structure. The light grey-weathering breccias comprise a finely comminuted, friable matrix containing variably shocked lithic and mineral clasts, indicating a maximum depth of excavation of ~ 2000 m (i.e., ~250 m into the metamorphic basement). Well-developed shatter cones occur in carbonate clasts in the impact breccia, and in-situ within the central uplift area.

Appraisal of a predominantly sedimentary rock target provides for assessing the role of hypervelocity impact in liberating carbonates, water vapour and sulphates into the Earth's atmosphere. Haughton is also currently the focus of scientific attention as a Mars analogue site. The goal of the Haughton-Mars Project is to identify those aspects of the Haughton impact structure's history and present features that may shed light on Mars's geological, hydrological and possibly biological evolution.

## Quaternary mapping and till, stream-sediment, and water geochemical surveys in northern New Brunswick: a NATMAP contribution to the Geological Bridges of Eastern Canada

Michael Parkhill[1], Toon Pronk[2], Rex Boldon[2], Marni Lynne Dickson[3], Peter Friske[4], and Stephen Day[4]
[1]*New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch, P.O. Box 50, Bathurst, New Brunswick E2A 3Z1, Canada <mparhhill@gov.nb.ca>*
[2]*New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch, P.O. Box 6000, Fredericton, New Brunswick E3B 5H1, Canada <tgpronk@gov.nb.ca>*
[3]*Quaternary and Environmental Studies Group (QUEST), Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada*
[4]*Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada <pfriske@gsc.nrcan.gc.ca; sday@gsc.nrcan.gc.ca>*

In 1997, multimedia National Geochemical Reconnaissance and multiparameter airborne geophysical surveys, with the objective of locating Cu-skarn, Carlin-type, and other mineral deposit types in central Restigouche County were completed. The regional stream sediment and water survey covered an area of approximately 4000 km$^2$ (1075 sample sites). These surveys were a pre-cursor to the NATMAP Project "Geological Bridges of Eastern Canada" (1999-2004). During 1999, airborne geophysical and NGR geochemical surveys (800 sample sites) were conducted in western Restigouche County. Analysis of: the airborne geophysics; geochemical data; radiometric maps; bedrock mapping; Quaternary mapping and sampling (800 basal till samples in the Charlo, Kedgwick and Menneval map areas); follow-up humus, stream-sediment and water geochemical surveys; and mineral deposit investigations, are ongoing in both survey areas. In the process, anomalies may prove to be related to mineral occurrences and/or larger bedrock diversity than is currently known. For example, a large As, Sb ± Au stream-sediment anomaly south of the Patapedia occurrence suggests a much wider extent of felsic intrusive rocks and associated mineralization in the area. Several of the As-Sb stream sediment anomalies have been confirmed by field checking.

The resulting geochemical patterns confirmed many of the known mineral occurrences (e.g. Legacy, Burntland Bk., Popelogan, Squaw Cap, Patapedia), and also indicated new areas of mineral potential. An aerially extensive (approximately 80 km$^2$) Ni (up to 685 ppm), Co (up to 58 ppm), ± Cu (up to 62 ppm) anomaly in the 1997 stream sediment survey initiated follow-up till and stream-sediment sampling in the Boland Brook area that confirmed the original anomaly. Results from 21 basal till samples collected over the northern part of this Ni-Co anomaly show elevated levels of Ni (>100 ppm) and Co (generally > 15 ppm). Normal background levels for the Restigouche survey area are <75 ppm Ni and 8-13 ppm Co. The only known Ni occurrence in the area is a float occurrence along the Upsalquitch River to the east. This suggests that the anomaly is a result of unique chemical characteristics of the surface rocks of this area, or alternatively that glacial erosion has moved mafic material out of the deeply incised valleys onto the plateau surface. Glacial history of the area and the basal glacial physics favor the former. The airborne survey of the area also indicates the presence of a large magnetic anomaly in the subsurface, coinciding with the geochemical anomaly.

Detailed surficial mapping and sampling in the vicinity of the Popelogan skarn occurrences were carried out during the summer of 1998 to follow-up a detailed multimedia geochemical survey done at the Legacy skarn deposit in 1997. The skarn-type mineralization occurs in calcareous sedimentary rocks of the Silurian LaVieille Formation and the Upper Ordovician–Lower Silurian Matapedia Group, within the contact aureole of a Devonian granodiorite stock. Geochemical results (INAA and ICP) indicate glacial dispersion distances to be less than 2 km.

## New 1:50 000 geological maps of the Cobequid Highlands, Nova Scotia

Georgia Pe-Piper[1] and David J.W. Piper[2]
[1]*Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada*
[2]*Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada*

The Cobequid Highlands are a block of Avalonian Neoproterozoic and Silurian rocks with widespread latest Devonian to earliest Carboniferous plutons and volcanic rocks. The Highlands lie within a major late Paleozoic strike-slip fault zone between the Avalon and Meguma terranes. The Cobequid Fault, which marks the southern margin of the Highlands, was reactivated as a basin-margin fault in the Triassic. The Rockland Brook Fault separates two contrasting blocks of Neoproterozoic rocks, the Bass River block to the south and the Jeffers Block to the north. The northern margin of the Cobequid Highlands is largely fault-bound, with minor overstep of upper Carboniferous rocks of the Cumberland Basin. A series of E-W striking faults have been mapped between the Rockland Brook and the northern margin of the Cobequid Highlands, resulting in E-W trending outcrop belts of Neoproterozoic, Silurian and Devonian-Carboniferous rocks.

Principal results of the new mapping have been largely reported in the literature. In the Bass River block between

Londonderry and Mount Thom, late Paleozoic plutonic rocks are of very limited extent and most plutonic rocks are Neoproterozoic in age. Neoproterozoic granite outcrops northeast of Earltown and slivers of granodiorite outcrop north of Dalhousie Mountain. A complex thrust sheet is recognized in the area south of New Annan, deforming rocks as young as earliest Carboniferous. In the area west of the Cobequid Pass highway, the geology is dominated by E-W striking belts of Neoproterozoic Jeffers Group, late Paleozoic Fountain Lake Group, and late Paleozoic plutonic rocks. North of Five Islands, late Paleozoic plutonic rocks intrude Nuttby Formation (Horton Group). North of Parrsboro, Silurian rocks are much less widespread than previously mapped. The relationship between the Fountain Lake Group in the western and eastern Cobequid Highlands has been clarified.

Three phases of late Paleozoic pluton emplacement are recognised. (1) The granite plutons of the western Cobequid Highlands and their associated gabbro, the mafic Wyvern pluton, and the granites in the northern part of the Wentworth pluton have yielded ages of 362 to 358 Ma by U-Pb on zircon and $^{40}Ar/^{39}Ar$ on amphiboles and thus span the Devonian-Carboniferous boundary. (2) A complex intrusion of fine-grained granite and diabase along the northeastern margin of the Wentworth pluton corresponds to the top of the Byers Brook Formation and is of earliest Carboniferous age. (3) Gabbro/diorite and associated granites of the southwestern Wentworth Pluton (the Folly Lake gabbro) consistently yield $^{40}Ar/^{39}Ar$ ages on amphibole and biotite of 350-354 Ma, synchronous with the extrusion of the voluminous basalt of the Diamond Brook Formation, and are thus of earliest Carboniferous age.

## Emplacement style of the Wentworth plutonic complex, Cobequid Highlands

David J.W. Piper[1], Georgia Pe-Piper[2], and Ioannis Koukouvelas[3]
[1]*Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada*
[2]*Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada*
[3]*Department of Geology, University of Patras, Patras 26110, Greece*

The 363 - 350 Ma Wentworth plutonic complex in the Cobequid shear zone of the Appalachians is coeval with an up to 5 km thick pile of volcanic rocks of the Fountain Lake Group. The magmatic evolution of the Wentworth plutonic complex through time can be constrained by the cyclic eruption of the co-magmatic volcanic rocks. Two cycles of eruption of rhyolites with minor basalts (Byers Brook Formation) correspond to emplacement of the Hart Lake - Byers Lake alkali granite. Three cycles of eruption of tholeiitic basalts (Diamond Brook Formation) correspond to emplacement of the Folly Lake gabbro. The gabbro melted the granite into which it was intruded and a felsic and a mafic magma co-existed and cooled together. Larger late granite intrusions appear to be felsic differentiates of a deeper magma created by mixing or assimilation of granite (or granitic magma) by the gabbroic magma.

The Wentworth plutonic complex lies on the north side of the dextral Rockland Brook Fault, near the western tip of a wedge-shaped basement block (Bass River Block) of the Avalon terrane. Field observations of mesoscopic structures and map contacts show that the plutonic bodies at all structural levels are related to transpressive strike-slip faults. Dykes parallel to the mylonitic foliation in the Rockland Brook fault zone and at the contacts between igneous phases suggest that the plutons developed largely through dyke to pluton construction. However, structures within the gabbro pluton suggest that it may have risen as a diapir.

In the Cobequid Highlands, dyke-to-pluton construction and diapirism are related processes. Dyking of a series of magmatic pulses overcame compressional tectonic forces and set up the system. Magmatic-partitioned transpression and diapirism extended the magmatic activity over at least a 10 My period. Magmatic-partitioned transpression was the emplacement mechanism that enabled mafic magma to intrude at higher structural levels by thermomechanically softening the crust, which facilitated the dyke-to-pluton construction of the Hart Lake-Byers Lake pluton and triggered the formation of the Folly Lake diapir. The localization of voluminous magmatic activity over 10 My in the western part of the Wentworth plutonic complex, compared with the short-term magmatism elsewhere in the Cobequid Highlands, was a consequence of eastward extrusion of the Bass River block and the magmatically-partitioned transpression.

## Pleistocene glacial history of the Petitcodiac area, southeastern New Brunswick

A. G. Pronk[1], G. M. Allaby[2], and B. E. Broster[2]
[1]*New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch, P. O. Box 6000, Fredericton, New Brunswick E3B 5H1, Canada*
[2]*Quaternary and Environmental Studies Group (QUEST), Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada*

Regional scale surficial mapping and till dispersion studies have helped increase the understanding of Late Wisconsinan stratigraphy and direction of ice movement in southeastern New Brunswick. Clast and matrix samples were collected from basal till at 2-km intervals across the Petitcodiac map area. Only one till unit was recognized, suggesting that glacial sediments were deposited by a regional ice sheet during the Late Wisconsinan glaciation. Ice-flow directions were inferred from the till matrix geochemistry, till clast provenance, and the orientation of glacial landforms and striae.

Ice-flow data and dispersal patterns indicate that the dominant ice flow direction fluctuated between south-southwest and southeast over the map area. No evidence supporting a previously suggested northward flow event was found, although multiple ice flow directions were recorded in the northern half of the map area.

In the northeastern part of the study area drumlinoid features, rat-tail and nail head striations, and dispersal patterns record a late easterly flow event. It is likely that ice flow shifted toward a more easterly direction during deglaciation. As the ice sheet thinned it became confined by the regional topography and an ice divide developed in the study area as ice streamed around the eastern border of the Caledonian Highlands.

## Late Quaternary relative sea-level variations in the North Atlantic: comparison of mid-Holocene highstands to the last interglacial (isotope stage 5e) highstands

D.B. Scott[1] and R.R. Stea[2]

[1]*Centre for Marine Geology, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada <dbscott@is.dal.ca>*

[2]*Nova Scotia Department of Natural Resources, Halifax, Nova Scotia B3J 2T9, Canada <stear@is.dal.ca>*

We have sea-level curves covering the last 16,000 years from several locations in Maritime Canada but the most interesting part of the record is the last 8000 years when there is a combination of water level and land level changes that interact to produce some complex sea-level records. From Texas to Nova Scotia we have accelerated sea-level rise between about 6000 to 4000ybp and in South Carolina we are able to see a drop after 4200ybp. In most places in the North Atlantic there are no higher than present Holocene sea levels except perhaps Texas. However we do see, especially in Nova Scotia, what have been called "stage 5e" shorelines which predate the last glacial and are 5-10m above present sea level. These have been discussed in the past as correlative with the worldwide stage 5e highstands of sea level, but are they really time correlative? Sea level is presently rising all along the Atlantic coast of North America and nowhere is it rising faster than in Nova Scotia. This rise has been going on for at least the last 7000 years at a rate of 20-30cm/century with an acceleration between 5000 and 4000 ybp where rates of rise were up to a metre/century. With the exception of the rapid acceleration, we believe this rise is a result of crustal adjustment following deglaciation and it if the present is the key to the past this would have happened in the last interglacial also. Most of the mid-Holocene highstands that are above present sea level are in South America or Africa where there was no glacial-isostatic adjustment-these levels are comparable to the stage 5e shorelines in the same areas. However in the North Atlantic we have not attained the highstand yet and hence probably the "stage 5e" shorelines in Nova Scotia are not really time correlative with other stage 5e shorelines. They also do not represent the climatic optimum but some time after related to when either another glacial (stage 4) commenced or the earth finally adjusted isostatically. Judging by the Holocene experience that would be at least 4000 to 5000 years AFTER the climatic optimum of stage 5e. This same relationship must also be true for many other North Atlantic shorelines, especially in the UK where the sea-level history is similar to Nova Scotia.

## Glacial dispersal in west-central New Brunswick

Allen A. Seaman

*New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch, P.O. Box 6000, Fredericton, New Brunswick E3B 5H1, Canada*

The glacial erosion record for west-central New Brunswick reveals a complex sequence of erosional events with trends ranging from east-northeastward clockwise through to southwestward. Cross-cutting relationships suggest an early east-southeast ice flow, followed by flows gradually shifting clockwise through to southwestward and then counter-clockwise through to east-northeastward.

In contrast, evidence collected during regional till sampling (2-km grid) reveals a comparatively simple glacial dispersal pattern. Early dispersal toward the east-southeast is indicated by scattered small areas of reddish-coloured basal till, and pebbles of this till encountered as clasts in the regional yellowish-brown till, in the area to the east-southeast of the red clastic sedimentary rocks of the Carboniferous Carlisle Formation. However, seven lines of evidence indicate that the dominant glacial dispersal direction in the area was toward the south-southeast. These are: 1) a 23 km long dispersal train of detectable gold (2 ppb or greater) extending from the Poplar Mountain deposit; 2) a dispersal train of mafic to intermediate volcanic clasts extending 20 km from the Oak Mountain volcanic complex; 3) a fossiliferous limestone boulder from the Scott Siding area found 33 km to the south-southeast; 4) a dispersal train of reddish-coloured till (7.5 YR or redder) extending 27 km from the southern margin of the Carlisle Formation; 5) an antimony and arsenic dispersal train lying within the above reddish till dispersal train, and extending at least 13 km from an unknown source; 6) discontinuous dispersal trains of anomalous antimony and arsenic extending up to 15 km from known occurrences in the Gravel Hill – Howland Ridge – Taffy Lake area; and 7) a dispersal train of anomalous antimony extending at least 7 km from the Lake George mine.

The ice flow responsible for the glacial dispersal and till deposition is deduced to have occurred early in the sequence of glacial erosion events. A flow event sufficiently powerful to entrain and transport material over several tens of kilometres would be expected to erode most pre-existing glacial erosion marks. The preservation of up to a dozen sets of striae on a single bedrock surface indicates that actual bedrock erosion was minimal throughout much of the area subsequent to the early southeast to east-southeast ice flow events. It is suggested that the later flow events shifted the previously deposited till only enough to generate new erosion marks, but not enough to obliterate most earlier erosion marks, or to significantly alter the glacial dispersal trend.

## Sequence stratigraphic interpretation of regional Upper Cretaceous limestone units, offshore eastern Canada

John W. Shimeld and R. Andrew MacRae
*Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada*

Regionally widespread, Upper Cretaceous limestone units are recognized beneath the Scotian Shelf and Grand Banks, both as lithostratigraphic units and as important seismic markers. The Late Turonian-Coniacian Petrel Member of the Dawson Canyon Formation and the Late Santonian-Maastrichtian Wyandot Formation are typically composed of intensely bioturbated, fine-grained, coccolith-dominated limestone (chalk) with minor amounts of sandstone, calcareous mudstone, wackestone, and packstone. These units range from a few metres up to 400 metres in thickness, but are thin or absent along the southernmost portion of the Scotian Shelf and beneath much of the southern Grand Banks. The hydrocarbon reservoir potential of these units should not be overlooked given the significance of similarly aged chalk reservoirs worldwide (e.g., Gulf of Mexico and North Sea) and the gas discoveries at the Primrose and Eagle structures in the Wyandot Formation. Heavy oil was also encountered in the Petrel Member at Heron H-73.

Information about the Petrel Member and Wyandot Formation comes primarily from drill cuttings and from interpretation of seismic and wireline data. Cores are available only from four wells drilled on the Scotian Shelf (Wyandot Formation) and one well drilled on the southern Grand Banks (Petrel Member). Despite the level of exploration activity in recent years, no cores are available in the Jeanne d'Arc Basin. From this limited dataset, these limestone units appear to have been deposited in a deep shelf environment below storm wave-base. Trace fossil assemblages are dominated by *Zoophycos*, *Thalassinoides*, and *Chondrites* of the *Cruziana* ichnofacies. Inoceramid bivalves are also present.

Like many Upper Cretaceous chalk-rich units around the world, the Petrel Member and Wyandot Formation are interpreted as the product of pelagic carbonate sedimentation during stages of maximum transgression and minimal siliciclastic input to a shelf environment. While much of our data are consistent with this interpretation, lateral variations in thickness and lithofacies from well and seismic interpretation suggest the development of significant unconformities during and immediately after deposition of the limestone units. Depending upon location within the basins, mappable seismic horizons may correspond either to the maximum flooding surface, the erosional surface developed during relative sea-level lowstands, or the amalgamation of both when the thickness falls below the limit of seismic resolution. This situation greatly complicates the use of the Upper Cretaceous limestone units for regional correlation.

## Pock marks in the nearshore and their relationship to forcing conditions and lunate megaripple genesis

Rachel Speller and Alex Hay
*Department of Earth Science and Oceanography, Dalhousie University, Halifax, Nova Scotia B3H 4H6, Canada*

Previous bedform research has described different ripple types forming in varying hydrodynamic conditions, providing a partial basis for using ripple geometry within sedimentary rocks to infer the paleoenvironmental conditions during the ripple formation. However, real-time observations of ripple characteristics during active transport conditions associated with storm events are lacking. During the 1997 SandyDuck'97 nearshore dynamics experiment at the U. S. Army Engineers Waterways Experiment station's field research facility at Duck, North Carolina, rotary fan beam sonars were used to collect centimetre-resolution images of the sea floor within and near the surf zone. In these images, curious depressions were observed to form in the seabed during storm growth and decay. These "pock marks" have horizontal scales of 10-30 cm and appear to form in a specific range of wave orbital velocity amplitudes. The purpose of this project is to determine the relationship between pock marks and their hydrodynamic forcing conditions. This was accomplished by studying their physical and time characteristics such as size, shape, and duration of existence, and relating these to flow energy and bottom shear stress. Also studied is the mode of formation of the pock marks (i.e. shell/pebble nucleus) and their connection to lunate megaripple genesis.

## Advancements in the lithostratigraphy, palynology and boundary relationship of the Upper Carboniferous Cumberland and Pictou groups in southeastern New Brunswick

Clint St. Peter[1], Susan C. Johnson[2], and Graham Dolby[3]
[1]*New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch, P.O. Box 6000, Fredericton, New Brunswick E3B 5H1, Canada*
[2]*New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch, 207 Picadilly Road, P.O. Box 5040, Sussex, New Brunswick E4E 5L2, Canada*
[3]*Consultant Palynologist, 6719 Leaside Drive, S. W. Calgary, Alberta T3E 6H6, Canada*

In southeastern New Brunswick, the Upper Carboniferous Cumberland Group and overlying Pictou Group comprise repetitive fining-upwards sequences of fluvial and minor paludal strata. Prior to this study the Cumberland Group north of the Hastings Uplift was undivided and entirely assigned to the Boss Point Formation. New palynological assemblages and refined spore zonations have allowed subdivision of the Cumberland Group into the basal Boss Point and overlying Grande Anse formations. The Grande Anse Formation was previously known only on the Hastings Uplift. South of the Uplift in the Cumberland Subbasin of Nova Scotia the Boss Point Formation is overlain by the Joggins Formation.

The Boss Point Formation in New Brunswick is now restricted to the lowermost fining-upwards megasequence of the Cumberland Group. It comprises grey quartz-pebble conglomerates, grey to olive green quartzose arenites and grey to locally red-brown mudstones. Several new spore collections include key species such as *Kraeuselisporites echinatus, Ahrensisporites beeleyensis* and *Spelaeotriletes arenaceus* but lack the smaller species of *Florinites* and indicate a Namurian B (Kinderscoutian) to early Namurian C (Yeadonian) age for the Boss Point Formation. The overlying Grande Anse Formation is dominated by multistory buff to light pinkish-grey, feldspathic, quartzose arenite, quartz arenite, and pebbly quartzose sandstones with lesser overbank grey or red-brown mudstones and thin coal seams. Palynological assemblages in the Grande Anse comprise key species such as *Florinites mediapudens, F. junior, Cannanoropollis mehtae, Wilsonites* spp., and striate bisaccates and indicate an age no older than mid-Namurian C (Yeadonian) to probably early Westphalian B (Duckmantian).

The Salisbury Formation, the basal unit of the Pictou Group, comprises a regionally distributed 'red facies' and a locally developed basal 'grey facies'. The grey facies consists of grey to pinkish grey feldspathic quartzose arenites, pebbly sandstones and minor red (rarely grey) mudstones. The grey facies was previously included in the undivided Boss Point Formation. The red facies is dominated by red mudstone and fine-grained sandstone with lesser red to grey coarse feldspathic and lithic sandstones and quartz arenite. Rare grey mudstone beds in both the grey and red facies yield late Westphalian B – Westphalian C (late Duckmantian – Bolsovian) spore assemblages. The chronologically significant spores in the Salisbury include *Vestispora magna, V. pseudoreticulata, V. foveata, Illinites unicus* and *Protohaploxypinus* spp.

The Salisbury Formation (basal Pictou Group) disconformably overlies the Grande Anse Formation (upper Cumberland Group). Contrasting spore assemblages and spore ranges in the two formations indicate the disconformity is probably a middle Westphalian B (Duckmantian) event.

## Using whole rock geochemistry to locate the source of igneous erratics from drumlins on the Atlantic coast of Nova Scotia

Rudolph R. Stea[1] and Georgia Pe-Piper[2]
[1]*Nova Scotia Department of Natural Resources, Halifax, Nova Scotia B3J 2T9, Canada <stear@is.dal.ca>*
[2]*Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada*

Whole rock geochemistry has been determined for erratics from the surface Lawrencetown Till in two drumlins on the Atlantic coast of Nova Scotia. The geochemical data, particularly trace element composition, allows source rocks to be identified more precisely than by visual identification or petrographic microscopy. A drumlin near Lunenburg contains erratics of Neoproterozoic arc-related plutonic rocks and basalts that outcrop only in a small area near Parrsboro in the Cobequid Highlands. Some associated erratics of granite precisely match a small late Devonian pluton in the same area and other granites and rhyolite could also be derived from late Devonian rocks in the same area. The type section of the Lawrencetown Till contains different Neoproterozoic plutonic rocks of a type found in the eastern Cobequid Highlands, together with a distinctive late Devonian granite with sodic amphiboles that is restricted to a small area near the Debert River. Both these source areas indicate a southward flow of ice (Escuminac Phase) from an ice centre in the vicinity of Prince Edward Island (Escuminac Ice Centre), which deposited the Lawrencetown Till from fast-flowing ice streams that terminated at the edge of the continental shelf. Earlier southeastward-flowing ice (Caledonia Phase) deposited the Hartlen Till that forms the core of the drumlin. Drumlins in Nova Scotia are complex palimpsest landforms that formed by till-accretion, and evolved in surface form throughout multiple flow events.

## The geological history of the Brunswick subduction complex in Bathurst, northern New Brunswick – an important clue to understanding the tectonic evolution of the Northern Appalachian Orogen

C.R. van Staal
*Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A OE8, Canada*

Critical to understanding the tectonic history of the Gondwanan Gander margin of the Northern Appalachians are the geological relationships preserved in the polyphase deformed rocks of the Brunswick complex near Bathurst in north-central New Brunswick.

A combination of stratigraphic, structural, geochemical, radiometric and isotopic data of the Lower Paleozoic rocks shows development of a magmatic arc (Popelogan arc) during the Arenig (479-473 Ma) on the Gander margin. Subsequently the Popelogan arc rifted and migrated towards the west due to slab-rollback, which opened a wide, Japan-Sea style back-arc basin (Tetagouche basin) during the Middle Ordovician (c. 473-460 Ma). Rifting appears to have taken place in stages, which led to development of several oceanic subbasins, separated by small semi-continental fragments.

The Popelogan arc collided with the Laurentian margin during the Caradoc (c. 455 Ma) and was subsequently unconformably overlain by Ashgill rocks of the Matapedia overstep sequence; hence the Popelogan arc is the obvious equivalent of the Bronson Hill arc in New England, with which it also lies on strike. Stratigraphic and radiometric evidence constrain closure of the Tetagouche basin between 450 and 420 Ma; thus during deposition of the adjacent Matapedia sequence above the now accreted and shut-off Popelogan arc. Closure of the Tetagouche basin led to underplating and incorporation into the Brunswick complex. Underplating was achieved mainly by imbrication ($D_1$) into numerous thrust-bounded nappes. D1 took place at conditions of c. 8-6 kb, 330-400°C (epidote-blueschist to greenschist facies). Removal of the effects of the deformation ($D_2$-$D_4$) that postdated underplating shows that the stratigraphy in each nappe has an overall northward younging, while the sedimentary cover of the volcanic rocks becomes progressively younger towards the south. This suggests that underplating progressed from north to south, and formed a series of southward propagating duplexes.

The major thrusts that separate nappes with different volcanic stratigraphies also coincide with minor, but consistent jumps in metamorphic grade such that it created a partially inverted sequence with higher pressure rocks overlying lower pressure rocks. Hence, the major thrust faults must have continued moving after peak metamorphism, which is consistent with the observation that the thrust-related deformation ($D_1$) comprises at least two generations of shear zones. $D_1$ also included steeply inclined, s-shaped isoclinal folds that folded the earliest thrusts and rotated them into steeper attitudes. The overall geometry and kinematics of the nappe sequence with ophiolite at the highest structural level, underlain by progressively less oceanic rocks, combined with the presence of large ophiolitic melanges and blueschists is difficult, if not impossible, to explain in any other way than by northwest-directed subduction. Deformation in the subduction complex is coeval with deposition of the Late Ordovician-Early Silurian Fredericton trough foredeep, which is linked to the Ordovician rocks of the subduction complex by detritus and age of deformation. The excellent preservation of the HP-assemblages indicates that refrigeration of the Brunswick Complex, and hence subduction of cold lithosphere, continued while the rocks were exhumed during the Silurian. The Brunswick Complex is the best preserved Silurian subduction complex in the Northern Appalachians and can be traced along strike into other parts of the orogen. Its preservation is the best evidence that the Laurentian margin was active during this time.

The subduction related structures ($D_1$) were overprinted into complex fold structures during the Devonian. These structures are related to extensional collapse and transpression and are coeval with bimodal magmatism. Terminal collision, slab-breakoff and oblique accretion of Meguma were probably responsible for this deformation.

## $\Delta^{18}$O prediction from corelog data – high-resolution paleoclimate proxy generation

M.E Weber
*Ocean Mapping Group, Department of Geodesy and Geomatics Engineering, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada <mweber@unb.ca>*

As part of the Canadian Climate System and Dynamics History Project (CSHD), we studied sediment cores retrieved with RV Marion Dufresne in 1995 and 1999 during IMAGES cruises MD101 and MD99, respectively. Our major goal was to predict the downcore variation of $\Delta^{18}$O values (measured in N. *pachyderma*, left-coiled) from log data sets of density, velocity, magnetic susceptibility, and color, in order to collect important paleoceanographic and paleoclimatic data rapidly and at very high resolution. The 27 "Canadian" piston cores originate from the shelf and slope off Atlantic Canada.

Sediments are primarily composed of terrigenous components (with minor proportions of carbonate and opal) and mostly reflect varying grain sizes from fine-grained hemipelagic (e.g., cores 2028, 2029) to sandy (e.g., core 2031) and coarse-grained terrigenous sediments (e.g., core 2026). For core MD2024, a comprehensive data set exists (4) for discrete sample data (collected at Geotop, Montreal) and log data (collected at Bedford Insitute of Oceanography, Halifax). Therefore, we applied the $\Delta^{18}$O prediction to this core first. All corelog data sets were normalized to variance before a multiple linear regression determined the correlation between $\Delta^{18}O$ and the corelog. Accordingly, velocity and color provide the substantial portion of the correlation (35% each), followed by susceptibility (20%) and density (9%). The correlation coefficient is up to 0.9 for younger intervals of the last glacial, where fluctuations of $\Delta^{18}O$ are related to Heinrich events and Daansgaard-Oeschger cycles and are undeniably mimicked by variations in corelog parameters. During the Holocene, both $\Delta^{18}O$ and corelog values are decoupled, pointing most likely to a change in water mass structure.

## Applied geomatics research at the Centre of Geographic Sciences (COGS)

Tim Webster
*Centre of Geographic Sciences, Lawrencetown, Nova Scotia B0S 1M0, Canada <tim@cogs.ns.ca>*

COGS on behalf of the Nova Scotia Community College was awarded a research infrastructure grant from the Canadian Foundation for Innovation and the Canada-Nova Scotia agreement on Economic Development. The grant was on the order of $1.3M in order to conduct geomatics research along the coastal zone. The centre has been carrying out applied research for many years including the construction of a provincial Radarsat mosaic which has been merged with other geoscience data including: elevation, magnetic field and Bouguer gravity. The Radar/Elevation product when viewed with Chromadepth ™ glasses appears in 3-D adding to the interpretive value of the product for geoscientists. As part of the new research initiatives under way at COGS a simulation of Radarsat 2 was undertaken in November 1999. This involved the Convair 580 aircraft utilizing a C-band polarimetric synthetic aperture radar, similar to what is planned for Radarsat 2 scheduled for launch in 2002. Three flight lines were acquired parallel to the Annapolis Valley with the intended applications including: geoscience, landcover mapping, and coastal mapping. An additional set of lines were flown in the Minas Basin at low tide for similar applications. The system is equipped with two radar antennas to allow across-track interferometry. Data from this system can be used to construct very high resolution Digital Elevation Models (DEM). This mode was flown for one line along the Bay of Fundy coast. The high resolution of this sensor and the multipolarimetric signatures will allow more detailed mapping and feature extract from the imagery. Several topographic features have been identified along the North Mountain and along the Meguma Group rocks of the South Mountain. The folds within the Carboniferous rocks along the Walton shore are also evident in the imagery that was acquired during low tide. Additional data is planned for this test site (Annapolis and Minas Basins) in the spring/summer period including: laser altimetry data, CASI hyperspectral data as well as a full suit of available high-resolution satellite data. The application areas include the construction and validation of DEMs, detailed landcover and coastal mapping. The applications of such a dataset include: geoscience mapping, disaster management (flood risk maps, sea level rise risk maps), soil erosion mapping etc.

## The Hammondvale metamorphic suite: part of an exhumed Neoproterozoic convergent margin in the Avalon Terrane, southern New Brunswick

C.E. White[1], S.M. Barr[2], R.A. Jamieson[3], and P.H. Reynolds[3]
[1]*Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia B3J 2T9, Canada, <whitece@gov.ns.ca>*
[2]*Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada*
[3]*Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada*

The Hammondvale metamorphic suite consists of relatively high-pressure/low-temperature metamorphic rocks located at the northwestern margin of the Caledonian Highlands near Hammondvale (NTS 21H/11,12). It is in faulted contact along its southeastern margin with the ca. 560-550 Ma volcanic and sedimentary rocks of the Coldbrook Group and associated plutonic units. On its northwestern margin the suite is unconformably overlain by sedimentary rocks of the Carboniferous Windsor Group, but drill cores show that the suite extends under the Carboniferous cover to the northwest toward the Caledonia-Clover Hill Fault.

The Hammondvale metamorphic suite consists dominantly of albite- and garnet-porphyroblastic mica schist with a prominent foliation defined by alternating albite- and muscovite ± biotite- rich layers. A strong mineral lineation is locally developed and defined by recrystallized quartz ribbons and asymmetric porphyroblasts. Minor marble and calc-silicate layers are typically banded with thin muscovite-rich layers. Amphibolite and quartzite layers and felsic sills/dykes occur rarely. Pressure and temperature estimates from mineral assemblages in the mica schist, marble, and calc-silicate rocks indicate that metamorphic conditions of 8.5-9.8 kbar and 500-590°C were achieved. Three $^{40}Ar/^{39}Ar$ muscovite dates range from 617-603 Ma and provide minimum ages for the high-pressure metamorphism in this unit. These argon ages are similar to those obtained from detrital muscovite in the Cambrian Saint John Group, suggesting that the Hammondvale metamorphic suite was exposed by Early Cambrian time.

The Hammondvale metamorphic suite has traditionally been interpreted to be a metamorphic equivalent of part of the Green Head Group. However, the composition of the suite, the style of metamorphism and deformation, and muscovite ages are significantly different from those in the Green Head Group. The muscovite cooling ages suggest a more plausible relationship with the ca. 620 Ma metavolcanic and metasedimentary rocks of the Broad River Group exposed farther to the southeast. We interpret the Hammondvale metamorphic suite to represent an isolated fragment of part of an accreted subduction complex, hence confirming the presence of a major suture between the Avalon terrane and now-adjacent inboard terranes previously included in the Avalon terrane. Based on the present configuration of units, subduction was to the present southeast, under the Broad River Group.

## The search for the Fredericton Fault: new exposures along the Longs Creek to Fredericton section of the (toll-free) Trans-Canada Highway

J. Whitehead and A.F. Park

*Department of Geology, University of New Brunswick, 2 Bailey Drive, Fredericton, New Brunswick E3B 5A3, Canada*

New exposures along the 23 km stretch of the Longs Creek (Kings Landing) to Fredericton section of the Trans Canada Highway provide a transect through all the major lithological units of the Fredericton area, including: multi-deformed Silurian Kingsclear Formation turbidites; post-Silurian mafic dykes and Pennsylvanian sandstones, conglomerates and red siltstones.

Two generations of macroscopic structures and related fabrics dominate most of the Silurian outcrops. $F_2$ folds are open to tight upright structures, often approximating a chevron profile heavily modified by accommodation structures in the form of minor faults. The $F_2$ fold axes vary from horizontal to a moderate plunge towards the northeast or southwest. An axial planar cleavage ($S_2$) is locally developed in the more pelitic lithologies. Intersection of $S_2$ with bedding usually creates a prominent crenulation lineation ($L_{1/2}$), and an earlier fabric ($S_1$) is generally bedding-parallel or sub-parallel. Locally, $F_1$ closures can be identified, and here a discrete $S_1$ cleavage occurs oblique to bedding. In such closure areas bedding can be inverted. At least two sets of post-$F_2$ kink bands are present, and very locally a set of $F_3$ folds with horizontal axial planes, horizontal axes, and chevron profiles are present.

The southwestern-most unconformable contact between the Kingsclear Formation and the overlying shallowly dipping Pennsylvanian sedimentary rocks is located near Mountain Road, at the southern extent of Longs Creek, but is not exposed. The northeastern-most contact of the Pennsylvanian and Silurian rocks is defined to within 20 m along the southwest-bound carriageway, 4.3 km northeast of Mazzerole Settlement Road. Here the Pennsylvanian beds are vertical and even locally overturned, though curiously, the structures in the adjacent Silurian rocks indicate that they have not been rotated relative to their correlatives to the southwest of the Carboniferous cover.

The Fredericton Fault, a major fault zone that extends into New England, is not exposed in the new exposures. However, we have defined its position to within a few metres in a stream gully 100 m to the northeast of the bridge at Deerwood Drive.

## Geological Bridges of Eastern Canada NATMAP Project: bedrock mapping in Restigouche County, New Brunswick

R.A. Wilson, J.P. Langton, and J.I. Carroll

*New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch, P.O. Box 50, Bathurst, New Brunswick E2A 3Z1, Canada <rawilson@gov.nb.ca>*

Geological Bridges of Eastern Canada is a multi-agency NATMAP program focussing on the Laurentian Margin and Appalachian Foreland. The "bridges" consist of several geo-traverses, two of which transect the Restigouche area of northern New Brunswick, which is underlain by Late Ordovician to Middle Devonian rocks of the Gaspé Belt. In 1997 and 1999, regional multi-parameter airborne geophysical surveys were followed by stream and till geochemical surveys in order to stimulate exploration for potential porphyry and skarn mineralization in this area. Geological mapping began in 1999 in the Popelogan-Charlo River and Kedgwick areas.

The oldest rocks in the area are arc-related mafic volcanic rocks of the Mid to Late Ordovician Goulette Brook Formation, and overlying Caradocian black slates and cherts of the Popelogan Formation. Together, these constitute the Balmoral Group, an inlier of Dunnage Zone rocks exposed in the core of the Popelogan Anticline. In the Popelogan area, the Balmoral Group is disconformably overlain by Upper Ordovician to Early Silurian rocks of the Matapedia Group, which consists of interbedded calcilutite, calcareous shale and minor calcarenite deposited as turbidites on a submarine slope.

The Matapedia Group is conformably overlain by the Silurian Chaleurs Group, which comprises, from oldest to youngest, the Upsalquitch, LaVieille (locally), Bryant Point and Benjamin formations. West of the Popelogan Anticline, the Upsalquitch Formation consists dominantly of thin-bedded, fine-grained calcarenite, calcilutite and calcareous siltstone, whereas east of the anticline, it consists mainly of thin-bedded, micaceous, weakly calcareous siltstone and fine-grained sandstone. The Upsalquitch Formation is commonly bioturbated and fossiliferous, and is interpreted to have been deposited in an outer shelf environment. The LaVieille Formation consists of nodular to massive fossiliferous limestone and minor calcareous fossiliferous siltstone. The

Bryant Point Formation is mainly composed of porphyritic, amygdaloidal mafic volcanic rocks, and the Benjamin Formation comprises maroon to red, commonly flow banded rhyolite.

The Kedgwick area is divisible into eastern and western domains separated by the northeasterly striking McKenzie Gulch Fault. West of the fault, the area is underlain by the Late Ordovician Grog Brook Group, which can be divided into a sandstone-dominated facies to the west, and a mudstone-dominated facies to the east. Grog Brook sandstones are fine to medium grained, light to medium-grey, generally weakly calcareous, and display bedforms typical of turbidite deposits. The mudstone-dominated facies is composed of thinly bedded siltstone and local shale, including a distinctive thin unit of carbonaceous, pyritiferous shale near the top of the sequence.

East of the McKenzie Gulch Fault, the area is underlain by the Balmoral Group, Matapedia Group and Upsalquitch Formation, in ascending order. The Balmoral Group is represented by the Popelogan Formation (chert and slate), and overlying siltstones and fine grained sandstones ("Pat Brook beds") that are stratigraphically equivalent to, but lithologically unlike the Grog Brook Group. The gradationally overlying Matapedia Group consists of interbedded calcilutite, calcareous shale and local calcarenite. The Upsalquitch Formation is composed of thin- to medium-bedded, micaceous, calcareous sandstone, siltstone and weakly calcareous shale, overlain by thin-bedded, bioturbated, fossiliferous, calcareous siltstone and sandstone.

## Post-Horton Group, pre-Windsor Group recumbent folding and cleavage deformation in the St. Peters area, Nova Scotia

Thomas O. Wright
*National Science Foundation, Arlington, Virginia 22230, U.S.A.*

The Carboniferous Horton Group and overlying strata overlap the Avalon-Meguma boundary, so their deposition post-dates deformation associated with the primary terrane suturing, however subsequent periods of deformation have variably affected these cover rocks. Preliminary structural mapping and microfabric data in the St. Peters area indicates that a remarkably strong pulse of deformation has produced a map scale recumbent fold with associated shallow northwest dipping cleavage in the Horton Group. Finer-grained rocks exhibit a complex cleavage consisting of spaced, dark selvages and very fine-grained, moderately well-oriented muscovite fabric parallel to selvages. In one example, interlithons between selvages display an earlier, fine muscovite cleavage at a high angle to the regional, shallow cleavage. Coarser rocks, including conglomerate, display clast interpenetration by pressure solution with accompanying insoluble selvages. Buckled pre-cleavage veins and bed thickness changes around an outcrop scale recumbent fold indicate 30-40% flattening strain due to cleavage development. This deformation is consistent in orientation and intensity across strike for at least 7 kilometres within the regionally overturned, lower limb of the recumbent fold. However, the basal Windsor Group impure limestone exposed immediately north of the Horton Group has no detectable cleavage and fossils show original textures. These outcrops show large kinks in steep bedding but only brittle features were noted.

These observations are consistent with a localized but intense compressional event followed by uplift and erosion after Horton Group deposition but prior to Windsor Group deposition. One possibility is that this area was in a compressional jog in the dextral terrane boundary fault that was briefly reactivated at this time. Elsewhere, such reactivation would produce more subtle effects across the Horton Group-Windsor Group contact.

## Minor folds and their relationship to regional fold evolution, central Meguma Terrane, Nova Scotia

Michael Young[1], Richard Horne[2], and Nicholas Culshaw[1]
[1]*Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada*
[2]*Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia B3J 2T9, Canada*

The highly anisotropic turbidite sequences of the Meguma Group are folded into upright, noncylindrical, northeast-southwest trending box and chevron folds. Minor folds are well developed in coticule layers in the Beaverbank member, the basal unit of the Halifax Formation in central Nova Scotia. Classical interpretations for the development of minor folds involve layer-parallel shortening predating regional fold development, with minor folds becoming asymmetric as regional folds develop. This interpretation has been used for the origin of buckled bedding-parallel veins in the Meguma Group.

Minor folds in coticule layers display ptygmatic, sinusoidal, box, and chevron fold geometries, and all folds are moderately noncylindrical. Fold geometry is mainly ptygmatic in regional fold hinges whereas minor folds are more open and commonly display a box fold geometry on regional fold limbs. Some minor folds on regional fold limbs are asymmetric, consistent with flexural flow folding, whereas others are symmetric with axial planes and cleavage at high angles to bedding. Folding of coticule layers record significantly more shortening in regional fold hinges than on regional fold limbs. Coticule layers are always folded in regional fold hinges, however, coticule layers are locally non-folded on regional fold limbs. In thin section, outer arc extension is common in folded coticule layers, recording tangential longitudinal strain. Cleavage exhibits a divergent fan pattern around the outer arc reflecting inverse tangential longitudinal strain. Extensional fractures occur along garnet grain boundaries indicating that fold initiation postdates garnet formation. Coticule layers display boudinage parallel to regional cleavage which records significant vertical and hinge-parallel extension.

The observed minor fold geometries, in particular box folds, support development during layer-parallel shortening. However, the lack of minor folds in coticule layers on some regional fold limbs, the contrast in the degree of shortening recorded by minor folds in regional fold hinges compared with limbs, and the variation in symmetry of minor folds and associated cleavage on fold limbs suggest minor folds record additional strain during progressive development regional folds. We suggest the observed features of minor folds can be explained by layer-parallel shortening in the flat segments of early formed regional box folds followed by hinge migration, resulting in redistribution of minor folds, and continued shortening in fold hinges during progressive fold development. This interpretation is consistent with the box and chevron fold character of regional folds; such folds typically initiate with little layer-parallel shortening and involve considerable hinge migration during development.