

ATLANTIC GEOSCIENCE SOCIETY

ABSTRACTS

1994 COLLOQUIUM "CURRENT RESEARCH IN THE ATLANTIC PROVINCES"

AMHERST, NOVA SCOTIA

The 1994 Colloquium of the Atlantic Geoscience Society was held at the Wandlyn Inn, Amherst, Nova Scotia, on February 4 to 5, 1994. On behalf of the Society, we thank David Mossman and Laing Ferguson of Mount Allison University, and all others involved in the organization of this excellent meeting.

In the following pages we publish the abstracts of talks and poster sessions given at the Colloquium.

The Editors

Absolute timing of thrust faulting - a thermochronological approach

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The absolute timing of movement across thrust faults has important implications for both the tectonic and kinematic evolution of thrust belts. Absolute timing constraints provide a link between regional tectonics and structural development at a local scale, while kinematic models for fold and thrust belts often assume a particular chronology for the formation of structures. Apatite fission track thermochronology has the potential to provide absolute timing constraints at shallow erosional levels in fold and thrust belts if it accepted that distinct breaks in cooling history across discrete structures are related to the denudation of

actively thrusting plates. In practice, fold and thrust belts are often deeply eroded, such that low-temperature thermochronometers often only provide evidence for regional cooling. An approach involving the integration of vitrinite reflectance data and apatite fission track thermochronology is proposed to assess this potential limitation. General principles will be illustrated using case studies from southwest Alberta (Rocky Mountain Main Ranges and Foothills) and western Sichuan Province, China (Longmen Mountains Thrust-Nappe Belt).

Devono-Carboniferous volcanic and plutonic rocks of Cape Breton Island, Nova Scotia

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Volcanic and interlayered sedimentary rocks of known or inferred Devono-Carboniferous age in Cape Breton Island are assigned generally to the Fisset Brook Formation, but in most areas stratigraphic relations and age range are uncertain. In addition, the relationship of possibly contemporaneous gabbroic and granitic plutons to the volcanic rocks has not been investigated. In the Gillanders Mountain area east of Lake Ainslie, our mapping shows that the Fisset Brook Formation is more extensive than previously recognized, and consists of a conglomeratic unit, overlain by basalt (with some interlayered clastic sedimentary rocks), rhyolite, and a red clastic sedimentary unit. The basalt is mainly amygdaloidal and contains well preserved peperitic structures. Spatially associated gabbroic dykes and small plutons appear to have been co-genetic with the basaltic flows, and the Gillanders Mountain syenogranitic pluton is inferred to be co-genetic with the rhyolite.

In the geologically complex area around the southern and western margins of the Creignish Hills, amygdaloidal and locally scoriaceous basalt occurs only in the southernmost part, and rhyolite forms a small dome in the northwest. A body of mixed fine- and coarse-grained gabbro is located east of the basalt, and mafic dykes are common. Associated units include felsic tuffs and varied clastic sedimentary rocks. Older quartzite, marble, phyllite, slate, and granitoid rocks occur in windows or faulted slivers throughout the area.

Petrological studies show that the mafic rocks in both the Gillanders Mountain and Creignish areas are tholeiitic transitional to alkalic, and have petrochemical signatures most likely indicative of a continental extensional setting. The felsic rocks formed in a within-plate setting, and are coeval but not comagmatic with the mafic rocks.

Devono-Carboniferous volcanic and plutonic rocks of the Guysborough area, northern Nova Scotia

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Mapping and petrological studies of inferred Devono-Carboniferous volcanic, sedimentary, and plutonic rocks in the Guysborough area have resulted in new understanding of their stratigraphy and palaeotectonic setting. Volcanic rocks occur widely throughout the area and appear to form the basal part of the stratigraphic sequence. They are dominantly basaltic amygdaloidal flows (locally with peperitic structures) and tuffs, with minor rhyolite. The rhyolite varies from aphyric and eutaxitic to porphyritic with quartz and feldspar phenocrysts, and appears to form domes of limited extent. Although field relations are not certain, the volcanic rocks are probably overlain conformably by clastic sedimentary rocks divided into three units (from oldest to youngest):

(1) red conglomerate and sandstone; (2) green-grey siltstone, blue-grey quartz arenite, and minor conglomerate; and (3) grey siltstone with minor shale and conglomerate, and red shale and siltstone. Dykes, sills, and small plutons of gabbro of uncertain age are common in all of these units. The volcanic and sedimentary rocks occur in faulted contact with rocks of the Meguma Terrane on the south and are overlain by younger Carboniferous rocks on the north and west.

Petrological studies show that the mafic rocks are tholeiitic, whereas the felsic rocks are alkalic. Both mafic and felsic rocks are characterized by high zirconium contents. They appear to have formed in a continental within-plate tectonic setting.

A shear system in the Meguma Group and Whiterock Formation - Yarmouth to Meteghan, southwest Nova Scotia

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Second-phase (D_2) structures define a 30 km wide, north-northeast-striking corridor containing two steeply southeast-dipping reverse-sense shear zones (Cranberry Point and Cape St. Marys), a third (Chebogue Point) with more complex kinematics, and regional (D_1) folds moderately overturned northwest during D_2 . D_1 and D_2 folds are coaxial, plunging gently south-southwest; however, first phase stretching lineations (L_1 ; strike-parallel, locally occurring within sinistral, north-northeast-striking ductile shear zones) are orthogonal to L_2 .

The D_2 shear zones contain combinations of the following characteristic structures: folds with hinges parallel to the tectonic transport direction, folds with strongly curved hinges and sheared limbs, downward-facing folds, intrafolial isoclinal folds, layering transposition, crenulation cleavage (S_2), boudinage of quartz veins, zones of brittle-ductile disruption of layering and cleavage, and shear bands.

Formation of most quartz veins accompanied D_2 . They are particularly abundant in the footwall, northwest of the shear zones, where S_{2b} crenulation and related northwest-verging outcrop-scale folds, minor brittle, southeast-dipping, thrust- and reverse faults affect the west-dipping limb of a major F_1 fold.

The shear zones, their footwall and the overturned folds may be part of a single, thin-skinned system accommodating northwest-transport. The brittle-ductile Cape St. Marys and Cranberry Point shear zones are envisaged to have listric geometry and to merge at the level (6-8 km) inferred for fold detachment. The footwall structures appear to record a coaxial higher-level deformation.

The shear system so defined may be extrapolated northeast on the basis of regional magnetic patterns. The South Mountain Batholith apparently deflects the extrapolated shear system; this suggests a syn- or post-intrusion age for D_2 .

Structural trends from seismic reflection data in St. Georges Bay, Nova Scotia

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Apparent and true strikes and dips were interpreted from high resolution single channel seismic reflection data in St. Georges Bay. These data were used in conjunction with bedding attitude and structural data from coastal outcrops of Upper Devonian-Upper Carboniferous rocks to make a formline contour map.

The formline map is characterised by northeast striking faults separated by synclinal troughs. Sub-parallel, northeast-trending anticlinal and synclinal fold axes have been mapped in the south-central part of the bay. Additional folds are also present on the western side of the bay offshore from Lakevale. Flexures are seen in the limbs of some of these folds. Directly north of Cape Jack, in the southeastern part of the bay, a number of short wavelength anticlinal and synclinal folds occur, the axes of which are approximately north-south. Some synclinal structures underlie depressions in the eroded bedrock surface. The depressions are filled with significant

thicknesses of surficial sediments. Some anticlinal folds are coincident with both bedrock and seabed topographic highs.

Industry seismic reflection data in the area indicates that the northeasterly striking faults extend across the bay and are probably intruded by salt. Along the southern margin of the bay, the Carboniferous strata are cut by north to northwest striking faults. Additional faults may be interpreted where narrow deep depressions occur in the eroded Carboniferous bedrock surface.

In the northern part of the bay, multi-channel high resolution and industry seismic data indicate that the Hollow Fault extends northeasterly along the Cape Breton Island coast only to the vicinity of Mabou Inlet. A major fault has been mapped on the shore line west of Mabou Inlet with the same trend as the offshore structure (P.S. Giles, personal communication). This fault may represent the onshore continuation of the Hollow Fault, or a splay of that major fault system.

The use of "sieve models" in introductory geological mapping

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The "sieve model" is an innovative device which demonstrates the interrelationships of surface topography and the outcrop patterns of subsurface geological contacts, and

greatly facilitates a student's understanding of "dip and strike" in rock layers.

Sieve models are constructed from simple eight inch

diameter kitchen sieves or strainers. The wire mesh surface represents the surface of an almost hemispherical hill. Contour lines can be represented on this surface by means of coloured threads sewn into the mesh.

The "strike lines" depicting contours on the surface of the rock layers are represented in the models by straight pieces of stout wire (cut from coat hangers) which are pushed through the sieve and protrude from each side of it. The wires are pushed through at the levels of the contours (and are thus essentially structure contours on the bed being represented). These strike lines can thus be seen running right through the model and appearing (in space) on the other side. The strike lines can be labelled with their elevation (as can the topographic contours). The addition of heavy card of Bristol Board can make the labelling of strike lines easier and aid in the visualizing of the bed surfaces or contacts, etc. The cards can be inside or outside the sieve.

The use of different coloured wires for the strike lines on the upper and lower surfaces of a bed will also help one visualize the bed of rock and can be easily correlated with

the map problems done in the laboratory. (Coloured vinyl-coated coat hangers provide suitable material for the strike lines.)

The orientation of the rock surface or contact in space is thus not only readily observed, but is measurable both with regard to the "dip" (amount of inclination from the horizontal) and with respect to the compass direction. (n.b. The sieve handle acts as a convenient, ready-made North Arrow, while the wire mesh itself can rotate through 360° within its frame demonstrating numerous problem options for any particular set of strike lines used.)

Used along with an overhead projector, the sieve model's contours and strike lines can be projected on a screen to represent the "map view" of the interrelationship of the strike lines and contours which the students can readily see in the three dimensions in the model itself. The sieve model is not restricted to the representation of a simple hill but can, if inverted, represent a hollow or depression and can be used to demonstrate the behaviour of geological surfaces intersecting a depression.

Depositional and economic aspects of Upper Carboniferous coal measures in the Gulf of St. Lawrence-Sydney Basin region

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A seismic facies related to Upper Carboniferous Coal Measures has been mapped over an area of more than 60,000 km² in the Gulf of St. Lawrence-Sydney Basin region of Atlantic Canada, including central and eastern Prince Edward Island. The depositional continuity indicated by this seismic facies is on the scale of cyclothem deposition in the Illinois Basin and Mid-Continent Basin region of the United States, and suggests an analogous stable cratonic shelf setting for the Gulf of St. Lawrence-Sydney Basin region. It also suggests that marine incursions occurred during the deposition of these Coal Measures. Evidence for such incursions, in the form of agglutinated foraminiferal assemblages, has been reported from coal-bearing strata of the

Sydney Basin, Cape Breton Island. Similar assemblages have recently been found in four offshore wells in the Gulf of St. Lawrence. This discovery supports arguments for cyclothem deposition and enhances the possibility of marine source rocks for hydrocarbon generation.

The Coal Measures generally are too deep to mine, but they contain a large resource of coalbed methane, and also may have charged deeper and shallower reservoirs with this natural gas. With the present outlook that gas will be the fuel of the twenty-first century, this indicated resource presents a potentially rewarding challenge to determine how it can be recovered and used.

Ichthyology of the Lower Devonian Wapske Formation, northwest New Brunswick

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The Lower Devonian (Helderbergian) Wapske Formation of the Tobique Group of northwestern New Brunswick comprises a siliciclastic sedimentary sequence with reduced proportions of mafic and felsic volcanics. Sedimentary facies consist mainly of grey, greenish grey or brown, thin- to thick-bedded coarse-grained siltstones; markedly laterally continuous, fine- to coarse-grained sandstones interbedded with dark grey mudstones or shales; and rare thick-bedded pebbly siltstones and conglomerates. The succession is interpreted as a relatively deep water turbiditic sequence de-

posited in a north-northeast - south-southwest oriented outer shelf/upper slope environment.

Little work has been done on the ichthyology of the Wapske Formation. The present work in northwestern New Brunswick has recorded a relatively diverse, abundant and well-preserved ichthyofauna comprising 20 ichthyogenera: *Arthraria*, *Bergaueria*, *Chondrites*, *Cosmorhapha*, *?Dendrotichnium*, *Didymaulichnus*, *Helminthopsis*, *?Hormosiroidea*, *Monomorphichnus*, *Neonereites*, *Palaeophycus*, *Paleodictyon*, *Phycodes*, *Protopalaeodictyon*, *Protovirgularia*, *Rusophycus*,

Skolithos, *Taenidium*, *Uchirites*, *Umfolozia*, and several unnamed arthropod tracks and scratch markings; 34 ichnospecies are identified, one of which (*Phycodes templus* isp. nov.) is new. The most common traces are *Helminthopsis* and *Palaeophycus*.

The association of ichnofaunas is characteristic of the *Nereites* ichnofacies, indicative of a deep water infaunal marine benthic community found below storm wave base.

The potential for surface subsidence related to crown pillar failure in abandoned mines at Goldenville, Nova Scotia

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Gold mining has been an integral part of the history of Nova Scotia since 1862, resulting in the creation of numerous near-surface underground openings in more than 60 abandoned mining districts in the Meguma Terrane. Very little is known about the problem of long-term stability of the surface crown pillars which cap these openings. Time domain reflectometry was used to investigate this problem in the Goldenville mining district between February 1991 and March 1993.

The Goldenville site lies on the southern limb of a major anticline. Abandoned near-surface stopes excavated in stratiform gold-bearing quartz veins are tabular in shape, strike east-west and generally dip steeply to the south. Surface crown pillars overlying these stopes are typically 1 to 2

m wide and as little as 1 to 3 m thick. Although recent surface subsidence is evident in several places, a direct causal relationship between crown pillar failure and subsidence has not been established.

The bedrock is characterized by tabular to wedge-shaped decimetre-scale blocks bounded mainly by cleavage planes, bedding planes and joints. Time domain reflectometry measurements indicate that the rock mass is deforming by pervasive shear and extension along numerous discrete discontinuities. These data imply that the wallrocks and crown pillars associated with near-surface openings in the Goldenville district are undergoing progressive gravity-controlled degradation. Continuation of this process will lead to eventual failure and surface caving.

A history of quartz veining, deformation and gold mineralization at the Ovens, southern Nova Scotia

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The Ovens Anticline is a kilometre-scale, northeast-trending (055°) chevron fold with an interlimb angle of $\leq 40^\circ$. Where the anticlinal structure has been examined the rocks consist of a mixed package of greenschist facies slate and metasandstone (70:30 ratio approximately) within the lowermost part of the Ordovician Halifax Formation of the Meguma Group. Folding occurred primarily by flexural shear and flexural slip. Preliminary investigation of the Ovens area indicates a history of pre- to syn-folding veining with related Au mineralization in the hinge zone. Three distinct sets of mineralized veins have been recognized:

- (i) Tightly buckled, pre-folding, bedding-concordant veins;
- (ii) A steep, conjugate vein set (strike sub-perpendicular to the fold hinge) and related subhorizontal veins;
- (iii) Flexural-slip, bedding-parallel veins which occur along bedding-parallel slip surfaces across which discordant veins (Type ii veins) are offset.

In terms of the chronology of vein emplacement, Type (ii) veins are observed to cross-cut Type (i). Although Type (iii) veins generally transect Type (ii) veins, mutually cross-

cutting relationships locally occur. These relationships imply that whereas Type (i) veins are clearly early relative to the other veins, Types (ii) and (iii) are more closely related in time.

The conjugate (Type ii) and flexural-slip bedding-parallel veins (Type iii) are volumetrically the most significant, whereas the early bedding-concordant veins (Type i) are relatively insignificant. Based on sightings of native gold the majority of the mineralization is noted to occur in vein Types (ii) and (iii). Therefore, based on the volume of vein types observed and the knowledge that previous mining focused on bedding-concordant veins, we speculate that previous mining at the Ovens was focused on flexural-slip bedding-parallel veins (i.e., Type iii versus Type i).

The distinction of an early set of buckled bedding-concordant veins from chronologically later flexural-slip bedding-concordant veins at the Ovens invites a reassessment of bedding-concordant veins at other Meguma-hosted Au occurrences where the bedding-concordant veins have been considered to be the dominant hosts for gold mineralization.

Gamma-gamma (density) calibrations using the EMR facility in Dartmouth, Nova Scotia

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Gamma-gamma (density) logging was a critical component in determining the depth and thickness of coal seams in the Nova Scotia Coal Inventory program. Both Long Spaced Density (LSD) Logs and Bed Resolution Density (BRD) Logs were measured inside the drill rods using the Nova Scotia Research Foundation Corporation Slimhole geophysical logging system.

This logging system and its density probes have been calibrated directly in density units at the EMR borehole logging calibration facility in Dartmouth, Nova Scotia. The calibration results are described and assessed. Their application to actual borehole logs, for which rock densities are available, is discussed.

Groundwater fluoride concentration levels in private water supply wells in the eastern Annapolis Valley region, Nova Scotia

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Fluoride (F^-) is a naturally occurring inorganic species in groundwaters which has significant health implications, particularly for children. It is an essential element in human nutrition as optimum development of teeth and bone depend on its availability. Children are most sensitive to fluorides during the first six years of life when their adult teeth and their bones are still forming. A strong correlation has long been established between low levels of F^- in drinking water (and no use of dietary supplements) and increased dental caries (tooth decay) in children. More recently, concerns have been raised over situations where and when the F^- intake of children is more than optimum because of the possibility of mild or even moderate fluorosis. Fluoride supplementation or removal from drinking water may therefore be necessary in some groundwater flow system regions.

No detailed inventory and mapping of F^- concentrations

in the groundwater flow systems of the eastern Annapolis Valley region currently exists. This preliminary study of the spatial and temporal F^- concentration levels in groundwaters utilized for drinking water purposes from private wells has been initiated to provide base level data for this region. Fluoride concentrations were analyzed with a solid state Orion No. 9609BN selective ion (combination) electrode (calibrated with TISAB standard solutions). Measurements of pH, Eh, electrical conductivity and temperature were made concurrently at each well site. Well owners were also questioned regarding: (1) their knowledge of the F^- concentration in their drinking water, (2) the number and ages of children consuming their well water, and (3) their knowledge of the daily F^- intake for children recommended by the Canadian Dental Association.

Evolving fluvial systems from the Mabou-Cumberland groups (Namurian-Westphalian A) of western Cape Breton Island, eastern Canada

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The middle megasequence of the Maritimes Basin in western Cape Breton Island consists of an overall coarsening-upward succession of clastic strata assigned to the Hastings Formation, the Pomquet Formation (both of the Mabou Group) and the Port Hood Formation (Cumberland Group). The Port Hood Formation is informally divided into lower and upper 'parts'. In the lower beds, primarily red-coloured mudstones are interbedded with sandstones that progressively thicken upsection; coal seams are essentially absent. Interbedded with the sandstones in the upper beds are thick successions of grey mudstones with numerous coal seams.

Fluvio-lacustrine strata predominate in the Cumberland Group, whereas strata of the Mabou Group are predominantly lacustrine in origin. Previous interpretations of fluvial strata from the uppermost Port Hood Formation suggest deposition by broad meandering rivers on an upper delta

plain. Incorporating both vertical and lateral profile analysis of outcropping fluvial sandstones, a more complex and evolving fluvial system can be shown to have existed.

The lowermost Port Hood Formation (and probably better reassigned lithostratigraphically to the Pomquet Formation) exhibits gravelly bedforms infilling channel scours and laminated sand sheets, enclosed by overbank fines. Fluvial style is characterized by poorly confined, shallow channels and suggests flashy discharge in an ephemeral, braided river. The typical lower Port Hood Formation contains numerous in-channel downstream and obliquely-accreting sandbars, dune trains, minor scour-channels and rare overbank deposits. Crevasse-splay, levée, and classic point bar deposits are absent. A lack of desiccation cracks, caliche development, or other evidence of subaerial exposure suggests variable, but perennial discharge in a relatively deep (5-10 m), low-

sinuosity, braided channel system. Higher up the succession, near the boundary with the upper part of the Port Hood Formation, large, distinctly fining-upwards, composite channel macroforms are developed, comparable to large, laterally-

accreting point-bars. Together with more variable palaeocurrent data derived from cross-beds, these macroforms suggest a higher sinuosity channel system traversing a wide flood-plain had developed.

The Late Carboniferous thermal history of the Meguma Terrane as revealed from $^{40}\text{Ar}/^{39}\text{Ar}$ dating at the east Kemptville and Gays River mineral deposits, Nova Scotia

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The Gays River carbonate-hosted Zn-Pb deposit and the East Kemptville granite-hosted Sn-base metal deposit represent two very different styles of mineralization and geological setting within the Meguma Terrane. However, detailed $^{40}\text{Ar}/^{39}\text{Ar}$ dating of the two deposit areas indicate that a thermal disturbance of similar magnitude affected both areas during the Late Carboniferous (i.e., ca. 300 Ma).

The Gays River deposit represents Mississippi Valley-Type (MVT) Zn-Pb mineralization occurring as a replacement of Viséan carbonates which developed as a buildup upon Meguma Group basement rocks. Hydrothermally altered Meguma Group fragments occur within a mineralized basal breccia unit that underlies part of the carbonate bank, and geothermometry (i.e., fluid inclusions, chlorite thermometry) indicates temperatures of ca. $\leq 300^\circ\text{C}$ attended alteration and mineralization. Whole rock $^{40}\text{Ar}/^{39}\text{Ar}$ dating of metasedimentary fragments ($n = 5$) from the basal breccia give very similar age spectra profiles: the low temperature gas fractions (first 10-15% gas liberated) indicate ages of ca. 300 Ma followed by plateau ages of ca. 380 to 400 Ma for the remaining gas fractions. Whereas the latter ages reflect regional metamorphism, the younger ages reflect thermal overprinting concurrent with mineralization. Model calculations of the age spectra suggest a reheating event of ca. 250 to 300°C of 1 to 6 Ma duration, consistent with geological constraints.

The East Kemptville deposit represents greisen-style Sn mineralization within a variably deformed topaz-muscovite leucogranite. Previous dating (Pb-Pb, U-Pb, Rb-Sr,

$^{40}\text{Ar}/^{39}\text{Ar}$) indicates granite emplacement and greisen formation at 365 Ma, with subsequent episodic thermal overprinting occurring to at least ca. 250 Ma. In the present study, seven size fractions (from -40 to +140 mesh) of muscovite from a sample of massive, barren leucogranite were analyzed by the $^{40}\text{Ar}/^{39}\text{Ar}$ incremental step-heating technique and compositions determined using the electron microprobe. Experimental results indicate no geochemical (e.g., Fe, Al, Si, F) distinction among the various size fractions and similar Turnerian-type diffusion profiles indicating resetting at ca. 300 Ma with quasi-plateau ages of 325 to 329 Ma. Therefore, since neither chemistry or grain size appear to have controlled argon diffusion, it is concluded that highly variable thermal gradients existed at East Kemptville. The presence of fault zones within the deposit area may have facilitated passage of heated fluids.

Results from the present study combined with previous geochronological dating in the Meguma Terrane, particularly in the southwestern area, indicate that thermal overprinting was a widespread phenomenon at ca. 300 Ma. The presence of mafic and felsic volcanic rocks of Carboniferous age throughout the Maritime region suggests that a persistent geothermal anomaly may have existed throughout the area for most of the Carboniferous. Thus, it is proposed that such an elevated geotherm contributed to the thermal overprinting recorded at East Kemptville and other areas and that it may have been an important factor in the generation of ore-forming fluids responsible for Pb-Zn(-Ba, -F) mineralization in the basal Windsor Group at places such as Gays River.

Preliminary geological map of the Little River, Tomogonops River map area (21 P/4 west), Bathurst Camp, northern New Brunswick

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The centre of the 21-P/4e,f map area is approximately 20 km southeast of the Heath Steele Mine and 33 km south of the Brunswick No. 12 Mine, in northern New Brunswick. Most of the map area is underlain by Early and Middle Ordovician rocks of the Miramichi and Tetagouche groups. These rocks were deposited in an ensialic, and later ensimatic, back-arc basin that developed on the eastern margin of the Iapetus Ocean. They were later incorporated into an accretionary wedge complex during closure of the basin in the Late Ordovician and Early Silurian. The map area is divis-

ible into three domains. The northwest domain comprises mainly Tetagouche Group volcanic rocks, and the southwest domain comprises mainly Miramichi and Tetagouche groups sedimentary and volcanoclastic rocks. The eastern domain is dominated by the Tomogonops formation and Carboniferous cover rocks. The contacts between the various groups and formations are typically conformable, but may be gradational, abrupt, or disconformable.

A new formation, informally named the Tomogonops formation, has been outlined in the southeastern part of the

study area. It comprises a coarsening-upward sequence of calcareous lithic- and quartz-wacke, grey slate, and autoclastic conglomerate. The conglomerate contains clasts of both the Tetagouche and Miramichi groups. The Tomogonops formation is believed to represent a Late Ordovician or Early Silurian flysch, deposited in front of a southward-advancing thrust-front associated with closure of the back-arc basin.

Five generations of folds, designated F_1 to F_5 on the basis of overprinting relationships, are recognized in the study area; however, it is mainly the F_1 , F_2 , and F_4 folds, as well as later brittle faults, that govern the macroscopic distribution of the rocks.

Thermal history of the Scotian Basin, offshore Nova Scotia, Canada: evidence from apatite fission track analysis

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Forty apatite samples of sandstone from ten exploration wells in the Scotian Basin, offshore Canada, are used for fission track analysis and thermal history reconstruction. The sample depths range from 1000 to 5500 m. Fission tracks in all apatite samples are at least partially annealed. Apatite fission track ages for samples from the Logan Canyon Formation are generally older than their stratigraphic ages. These data indicate a high degree of track retention and therefore record the time of cooling in the detrital source area. Samples from deeper formations (Missisauga, Mic Mac and Verrill Canyon) give apatite fission track ages younger than their stratigraphic ages (some give zero ages), indicating partial to total annealing of fission tracks in apatite.

Computer forward modelling of well-constrained data

indicates heating to palaeotemperatures of 80 to 110°C prior to cooling, at some time during the interval 110 to 60 Ma in the Scotian Basin. This thermal overprinting in apatite samples is common throughout the study area and coincides with the time at which peak oil generation began in some wells. Zircon fission track data from fifteen samples in four wells suggest that these samples have never experienced temperatures higher than $235 \pm 25^\circ\text{C}$ since deposition.

The causes of this thermal anomaly are very likely to be the high heat flow during 150 to 90 Ma and fluid migration related to the process of oil generation in the Scotian Basin, during which release of overpressured hot fluid is expected to have occurred.

Candidates for rocks of the Appalachian Central Mobile Belt in the Aspy Terrane of Cape Breton Island, Nova Scotia

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The four-fold division of pre-Carboniferous geology of Cape Breton Island implies that the Central Mobile Belt (CMB) of the Canadian Appalachians in the Cape Breton Highlands (CBH) is represented by the Aspy Terrane. The occurrence of rocks in the Aspy Terrane equivalent to those occurring in the CMB of southwest Newfoundland supports this interpretation.

The "Cape North Group", as exposed along the north shore of the CBH, can be divided into at least two distinct lithological assemblages. The western assemblage comprises marble that is tectonically interleaved with thinly-banded amphibolite, hornblende and kyanite-garnet schist, intruded by tonalite, diorite and gabbro. This assemblage resembles the highly deformed slivers of the Fleur de Lys Supergroup and associated plutons in the Notre Dame Subzone in southwest Newfoundland. The eastern assemblage comprises psammites, semipelites and felsic orthogneisses injected by abundant amphibolite, which together are intruded by granite and granodiorite. This assemblage is interpreted as an equivalent

of the Port aux Basques gneisses in southwest Newfoundland.

The Jumping Brook Metamorphic Suite (JBMS) in the western CBH mainly comprises the Faribault Brook pillow basalts and metaturbidites. The basalts are tholeiites with a transitional VAB/MORB geochemical composition. The JBMS is lithologically and geochemically distinct from dated Early Silurian units in the Aspy Terrane, but closely resembles the Middle Ordovician Bay du Nord and Harbour le Cou groups of the Exploits Subzone in southwest Newfoundland.

The Cheticamp Lake Gneiss in the Warren Brook area of the eastern CBH consists of meta-arkosic sandstone and conglomerate. It may lie unconformably on rocks of the Avalon Composite Terrane. The youngest detrital zircons in the gneiss are ca. 490 Ma and the detrital zircon population is similar to that in Gander Zone rocks in Newfoundland and New Brunswick. Hence, we tentatively consider the unit as an Ordovician member of the CMB.

Anisotropy of ore-stage fracture permeability in a porphyry copper system: a response to regional shear

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Within most porphyry copper systems disseminated mineralization occurs as stockworks and veins. Contrary to accepted thoughts on the homogeneity of porphyry copper deposits, the mineralized fractures and microfractures impart strong anisotropies of rock properties and ore grades, which record changing stress regimes during the hydrothermal systems evolution. The Domeyko Cordillera of northern Chile hosts several gigantic porphyry copper deposits. These porphyries have developed within active regional brittle shear systems during the Tertiary.

Detailed structural sampling of domains and subdomains within a major deposit, at scales from centimetres to tens of metres, identifies a relative timing sequence and consistency of orientation for independent vein sets. Vein sets compris-

ing the stockwork are characterized by consistent textures and mineralogies. Comparison of data derived from mining scale mapping (1:1000; 1:2000) with the detailed scales shows a correlation only if the relatively earliest formed veins are considered. Interpretation of vein set and fault orientations with respect to the master fault direction indicates an ore control by Riedel (synthetic and antithetic) fractures, at the various scales, formed by regional simple shear.

$^{40}\text{Ar}/^{39}\text{Ar}$ geochronology of alteration minerals from the different alteration phases impose restrictions on the relative and absolute timing of deformation and mineralization events.

This is a contribution to IGCP Project Number 342 "Age and Isotopes of South American Ores".

Experimental evaluation of the relative acid drainage potential of pyrite and pyrrhotite

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Iron sulphides have been recognised as a source for acid drainage for some time. For example, sulphidic black slates of the Halifax Formation of the Meguma Group occur under certain areas of the Halifax International Airport, Nova Scotia. Physical disturbance of the sulphidic slate during taxiway and hangar construction has resulted in acid runoff causing fish kills, as well as severely degraded water quality and aquatic habitat in receiving streams. Assessment of acid drainage risk is based on the potential production of sulphuric acid, based on the sulphur content and the neutralising capacity of the rock. Such assessment assumes that sulphur is present only in pyrite. However, the predominant sulphide is monoclinic pyrrhotite, not pyrite, in representative slates from the Halifax International Airport. Pyrite and marcasite are less abundant. Therefore, we have conducted simple experiments to determine the relative rates of pyrrhotite and pyrite oxidation, and hence the relative acid drainage risk.

Samples of pyrite and pyrrhotite were mounted together in epoxy and polished to 0.3 μm . Surface observations were made under reflected light. Samples were immersed in distilled water, acidified with HCl to pH 4.5 and pH 2 and effluent containing *Thiobacillus* bacteria from the Halifax International Airport. Within 6 days, pyrrhotite exhibited a thin tarnish (evidenced by interference colours) in pH 4.5 solution and a thicker tarnish in pH 2 solution. Pyrite did not tarnish within 24 days in the distilled water solutions. A thick tarnish appeared on pyrrhotite in the bacterial solution within 1 day, and tabular transparent crystals appeared after 7 days, but the pyrite was not tarnished. The tarnish is

probably an oxidation product, such as amorphous ferrihydrite, $\text{Fe}(\text{OH})_3$, and the transparent crystals are possibly jarosite, $\text{KFe}_3(\text{SO}_3)_2(\text{OH})_6$.

The results are consistent with the simple observation that polished sections of pyrrhotite become tarnished even in air, while pyrite remains unchanged. Eh-pH relationships show that pyrrhotite will be thermodynamically less stable than pyrite under oxidising conditions; the greater chemical affinity of pyrrhotite for oxidation would indicate faster rates of oxidation according to transition state theory. We suggest that the Fe^{3+} in the defect structure of pyrrhotite also increases the oxidation rate, considering that other workers have shown that Fe^{3+} in solution accelerates pyrite oxidation. Accelerated oxidation of pyrrhotite by *Thiobacillus* bacteria is consistent with results for pyrite reported in the literature. However, our experiments show that the oxidation rate of pyrrhotite remains faster than pyrite, even in the presence of *Thiobacillus* bacteria. These results support the proposal that the bacteria accelerate oxidation while in direct contact with sulphide surfaces, in this case populating the pyrrhotite surface in preference to pyrite.

It appears the abundance of pyrrhotite is a factor in the severity of the acid drainage problem at the Halifax International Airport. The sulphide mineralogy should be an important consideration in the risk assessment of acid drainage. Also, we suggest that the magnetic susceptibility of pyrrhotiferous rock affords an avenue for field assessment of acid potential.

Stratigraphic and structural significance of a new Late Ordovician graptolite locality in the Elmtree Formation of northern New Brunswick

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In the latter part of 1992, a graptolite locality (GSC Locality Number 0-105763) was found near Mitchell Settlement, approximately 35 km northwest of Bathurst, in black shales previously considered to be part of the Early Devonian Dalhousie Group. These rocks are now assigned to the Elmtree Formation (formerly Elmtree Group) of the Ordovician Tetagouche Group.

The Elmtree Formation constitutes the western and structurally lowest part of the Elmtree Inlier, the eastern and structurally highest part being underlain by the ophiolitic Fournier Group. The Belledune River Mélange, a tectonic mélange mappable at 1:20,000 scale, separates autochthonous Elmtree Formation from allochthonous Fournier Group rocks and contains clasts of both units as well as exotic peridotite blocks. Hence this mélange is younger than both units.

Previously reported fossil localities in the Elmtree Inlier are either in the Pointe Verte Formation (GSC Locality

Numbers 99365, 99366, 99367, 0-101732 and 0-102620) of the Fournier Group or in the Belledune River Mélange (GSC Locality Number 91889). Arenigian and Llandeilian conodonts, as well as early Caradocian graptolites (*N. gracilis* Zone) constrain the age of the Pointe Verte Formation. However, the age of the Elmtree Formation, until now, was poorly constrained based on a single *Orthograptus* sp., which ranges in age from Caradocian to Llandoveryan, found in a clast in the Belledune River Mélange.

The new locality in autochthonous Elmtree rocks contains elements typical of the upper *gracilis* Zone and possibly the lowest *multidens* Zone, i.e., earliest Caradocian. This confirms the previous interpretation that the Elmtree Formation is time equivalent to Caradocian black slates near Bathurst, which belong to the Boucher Brook Formation of the Tetagouche Group.

Lead arsenate occurrence in urbanized former orchard lands, Wolfville, Nova Scotia

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Lead arsenate (PbHAsO_4 or AsHO_4Pb) has been a preferred chemosterilant insecticide for apple maggot (*Rhagoletis pomonella*) control in deciduous fruit trees in many regions of North America in the last century. It was known to have been used in Nova Scotian orchards since 1914 and in New Brunswick since the 1920s. Use of such arsenicals on food crops in this region has now generally been eliminated.

Frequent applications of lead arsenate over several decades resulted in significant lead and arsenic accumulation in the topsoils of these orchards. The phytotoxic arsenic component of this insecticide has been shown to have a much greater downward mobility and redistribution compared to its less mobile lead counterpart in these soils. These soil

residual elements represent a substantial biogeochemical hazard because they are carcinogenic when ingested by humans.

Some former orchard lands within Wolfville, Nova Scotia, have been developed for urban subdivisions over the past two decades. Their lead arsenate-bearing soils remain largely unaltered as the surficial units except where foundation spoil and/or offsite fill have covered them for landscaping purposes. These former orchard land soils, where exposed as flower beds and garden plots, now pose a potential health risk to unsuspecting gardeners and children playing in them. Regions where lead and arsenic concentrations were expected to be significant were delineated for this study.

Early Caradoc (Late Ordovician) graptolites from the Elmtree Formation, Tetagouche Group, northern New Brunswick

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A sample of black shale from a roadcut near Patapat, east of Mitchell Settlement, New Brunswick, has yielded an age-diagnostic graptolite fauna of earliest Caradoc age. These shales had been previously mapped as part of the Early Devonian Dalhousie Group, but are now assigned to the Elmtree Formation of the Tetagouche Group. The fauna consists of

Nemagraptus gracilis (Hall), *Corynoides calicularis* Nicholson, *Climacograptus bicornis* (Hall), *Pseudoclimacograptus modestus* (Ruedemann), *Normalograptus brevis* Elles and Wood and *Lasiograptus* cf. *L. costatus* Lapworth. These taxa overlap in age only in the upper part of the *gracilis* Zone (or possibly the lowest *multidens* Zone).

This information provides a significant refinement in the age of the Elmtree Formation, which had previously only been dated as Middle Ordovician to Early Silurian based on more poorly preserved graptolites. Furthermore, it corroborates the regional stratigraphic evidence for an early Caradoc age for this part of the Tetagouche Group. Although most of these taxa are widespread in geographic distribution,

Lasiograptus costatus has only previously been reported from southern Scotland, Wales and central Newfoundland, strongly indicating an Iapetus affinity for this fauna. The collection, however, does not permit us to suggest which side of the Iapetus this unit may represent, although further collecting in this and related units may yield more paleogeographically useful information.

A method to refine the palinspastic restoration of Late Proterozoic Avalonian-Cadomian belt

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The Avalonian-Cadomian orogenic belt developed at the periphery of a Late Proterozoic supercontinent oblique to interior collisional orogenic sutures associated with supercontinent assembly. As a result, segments of the peripheral orogenic belt are likely to have evolved upon different cratonic basements. Contrasting basement signatures are indicated by available Nd and U-Pb (detrital zircon) isotopic data which suggest that West Avalonia lay adjacent to the Amazonian Craton during the Late Proterozoic whereas East Avalonia, Cadomia and the Meguma Terrane occupied positions adjacent to the West African Craton.

Initial ϵ_{Nd} data for crustally derived felsic igneous rocks from Avalonian and Cadomian terranes define ϵ_{Nd} growth lines typical of upper crustal rocks. However, ϵ_{Nd} values for West Avalonia are strongly positive and yield depleted mantle model ages of 0.8 to 1.1 Ga, whereas ϵ_{Nd} data for Cadomia are predominantly negative and give crustal residence ages of 1.0 to 1.9 Ga. The envelope of Nd isotopic compositions for West Avalonia, defined by ϵ_{Nd} growth lines, shows little overlap with that for Cadomia, suggesting basements of contrasting isotopic characteristics. A similar envelope

to that of West Avalonian is defined by ϵ_{Nd} data for the Tocantins Province of Central Brazil, supporting the peri-Amazonia position for West Avalonia suggested by detrital zircon data which match all age provinces of the Amazonian Craton.

Nd isotopic data for Cadomian basement (2.0 Ga Icart Gneiss) closely resemble those for 2.0 to 2.1 Ga (Eburnian) granitoids in the West African Craton. Basement of very similar isotopic characteristics to that of Cadomia, is also suggested by the envelope of Nd isotopic compositions for the Meguma Terrane, where a West African connection is supported by detrital zircon data which match age provinces of the West African Craton. East Avalonia shows ϵ_{Nd} affinities with West Avalonia and Cadomia, and may have lain adjacent to a suture between their basements.

Such variations in basement isotopic contrasts provide important constraints for the Late Proterozoic reconstruction of the now-dismembered Avalonian-Cadomian orogenic belt and may be of more general application to the palinspastic restoration of dispersed Precambrian terranes.

The geology of the eastern St. Mary's Basin, central mainland Nova Scotia

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The eastern St. Mary's Basin, central mainland Nova Scotia, is a Late Paleozoic intra-continental fluviatile to lacustrine basin-fill sequence that occupies the boundary between the Meguma and Avalon Composite terranes of the Canadian Appalachians. Paleogeographic reconstructions imply basin formation and deformation occurred during collisional orogeny associated with the formation of Pangea. On a regional scale, the sequence faces from northwest to southeast, coarsens upward and thickens towards the southeastern margin of the basin. The clasts were predominantly derived from the Meguma Terrane to the south, and a sedimentological linkage with the Avalon Composite Terrane to the north cannot be demonstrated. The rocks of the eastern St. Mary's Basin unconformably overlie Meguma Ter-

rane rocks and it is probable that the eastern St. Mary's Basin is underlain by Meguma basement.

A strong tectonic influence on sedimentation is apparent along the entire southern flank of the basin in which coarse conglomerates were deposited in a basin subsiding along northerly dipping listric normal faults. Dextral motion along the northern margin (Chedabucto Fault) has resulted in the development of broad open northeast-trending folds. The character of the sediments does not vary with proximity to the fault suggesting that it does not constitute the original basin margin and that an unknown portion of the basin and its Meguma basement have been tectonically removed and may be found north of the fault.

Surficial geology and glacial dispersal around the Captain North Extension massive sulphide deposit, northern New Brunswick

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The Captain North Extension (CNE) deposit (208,000 tonnes grading 7.38% Zn, 2.76% Pb) was discovered in 1978 by stream sediment geochemistry and drilling of IP survey targets. A B-horizon soil survey detected no base-metal anomaly over the deposit. Overburden drill samples from the bedrock-till interface detected anomalous Zn values directly over the deposit. Glacial transport in a westerly direction was suggested by a Zn value of 20,000 ppm, 150 m west of the deposit. Three mining campaigns from 1990 to 1992 extracted 39,278 tonnes of ore from the CNE pit.

The CNE deposit straddles the boundary between the Miramichi Highlands and the New Brunswick Lowlands. The north-northeast trending Curventon-Bathurst valley (CBV), a low lying, poorly drained area with many swamps and fluted bedrock terrain, crosses the study area, which is underlain by Ordovician Tetagouche Group felsic volcanic and sedimentary rocks. Sampling (48 samples on a 250 m grid) was done to trace glacial dispersal of anomalies in an east through to north direction away from the CNE deposit, with some sampling west and southwest (up-ice) to obtain background geochemical values.

Surficial materials include weathered bedrock; basal till; sandy-bouldery ablation till; and glaciofluvial (large esker system in the CBV), alluvial and organic deposits. Initially ice flowed in an eastward direction off the Miramichi Highlands; subsequently ice flowed north-northeast through the CBV. Late stage ice may have flowed in a northwest direction under the influence of the Escuminac Ice Center located north of Prince Edward Island in the Gulf of St. Lawrence. This may explain the high Zn values found west of the CNE deposit but high mobility of Zn makes hydromorphic dispersion more likely. Till is thicker and more clay-rich over the CNE deposit than in other parts of the area. The deposit sits in a slight topographic depression where thick till deposited by the eastward ice movement would have been protected from erosion by north-northeast moving ice. Thick overburden, lack of outcrop and poor geophysical and geochemical response of the CNE deposit make it an example of a near surface deposit that may still be found in the Bathurst Mining Camp. Data obtained from this study will be added to the existing till geochemical database (approximately 6900 samples).

1953 to 1993: a look at the history of the Bathurst Mining Camp, northern New Brunswick

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January 15, 1993, marked the fortieth anniversary of the announcement of the discovery of the Brunswick No. 6 massive sulphide deposit, which operated from 1966 to 1983. Although exploration and minor mining had occurred previously in northern New Brunswick, e.g., Tetagouche Manganese (1842-1864) and the Austin Brook Iron Mine (1907-1915 and 1943), this discovery and a Geological Survey of Canada aeromagnetic survey prompted the resulting staking rush that led to the April 1953 discovery of the Brunswick No. 12 deposit, one of the largest massive sulphide deposits in the world (148 million tonnes, including past production, grading about 12.5% combined Pb-Zn). During 1953, a total of 41,606 claims were recorded in northern New Brunswick and "The Bathurst Mining Camp" was born.

Subsequent exploration outlined approximately 100 massive sulphide deposits and/or occurrences within the Bathurst Mining Camp and surrounding area. Of these, eight have

been producing mines over the years; the (a) Keymet Mine (1954-1956), (b) Wedge (1962-1968), (c) Heath Steele (1962-1993), (d) Caribou (1970-1974; 1983 and 1989-1990), (e) Nigadoo (1967-1971 and 1973-1977), (f) Murray Brook (1989-1992), (g) Stratmat (1989-1993), and (h) Captain North Extension (CNE) (1990-1992) deposits. Exploration has gone on throughout the life of the Bathurst Mining Camp and several areas are presently receiving high priority, namely the Half Mile Lake, Key Anacon, Murray Brook and Restigouche deposits and the Brunswick Belt extending from the Brunswick No. 12 area to the Heath Steele Mine. With reserves at Brunswick No. 12 estimated to last another 10 years, present exploration and government geoscience surveys are concentrated on finding another large deposit, in an effort to keep mining alive and well in the Bathurst Mining Camp for another 40 years.

Geochemistry and petrogenesis of Late Cretaceous bentonites from the Kanguk Formation, Axel Heiberg and Ellesmere islands, Canadian High Arctic

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Late Cretaceous explosive volcanism in the Canadian High Arctic deposited blankets of volcanic ash over much of the eastern Sverdrup Basin region. These ash layers have been altered to bentonitic clays, that are interbedded with organic-rich mudstones of the Kanguk Formation on Axel Heiberg and Ellesmere islands. Initial fieldwork in 1990 revealed ten individual bentonites on the Kanguk Peninsula, western Axel Heiberg Island. A more comprehensive sampling was undertaken during the 1992 field season and documented 27 individual bentonites with a cumulative thickness of over 9 m on the Fosheim Peninsula, western Ellesmere Island. Remnant volcanic minerals, including sanidine, quartz, ilmenite, and zircon, have been separated for radiometric dating and geochemical work. Preliminary $^{40}\text{Ar}/^{39}\text{Ar}$ dating of sanidine crystals, combined with micropaleontology of the intercalated sediments (undertaken at the University of Calgary), yield a late Turonian to early Campanian age

for this formation. Detailed major and trace element geochemistry on both volcanic minerals and bulk bentonites, in conjunction with discriminant diagrams, reveals a within-plate tectonic setting for the parent volcanism, and a dominance of peralkaline rhyolite compositions. Microprobe analyses of unaltered glass inclusions in quartz phenocrysts provide confirmation of such parent melt compositions. Analysis of element mobility during bentonite formation will help to determine the possibility of geochemical correlation between individual units or groups of units. The Kanguk bentonites may represent late-stage magmatic activity along the Sverdrup Rim, or they may be the products of extra-basinal volcanism. Late Cretaceous to Tertiary peralkaline volcanism has been documented along the north coast of Ellesmere Island and northwestern Greenland; however, no exact match to the age and composition of the bentonites has been found to date.

Pluton emplacement by wall-rock thrusting and roof lifting in the western Cobequid Highlands, Nova Scotia

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Latest Devonian A-type granite-gabbro plutons in the western Cobequid Highlands are spatially associated with the Cobequid fault zone. Field studies have defined a sequence of ductile deformational structures in four plutons and adjacent country rock. Areas close to the Cobequid fault zone, which was the main conduit for magma, show the youngest plutonic products. Two phases of deformation are recognized accompanying magma emplacement. Early magmas pushed aside mechanically softened wall-rock in order to create space by left-lateral oblique thrust movements. A second stage of right-lateral thrusts or normal oblique slip faults is associated with the increasing elevation of the inboard side of the zone of plutons. During this stage, coarse granite was emplaced

in the most elevated region of the zone, through a process of roof lifting. Adjacent basins contain conglomerates with undeformed granite clasts, with deformed clasts at higher levels. These sediments are cut by granitic dykes. They indicate rapid uplift of the plutons, probably as a pop-up structure bounded by elements of a positive flower structure. Pluton emplacement was not the result of extension in releasing bends in the major shear zone. Rather, flower-structure high-angle faults acted as magma conduits and space was created by wall-rock deformation and hanging wall expansion on thrust faults at depth, and by roof lifting as the plutons were uplifted to higher structural levels.

Petrographic and geochemical evaluation of the mantle-plume hypothesis for the opening of the Devonian-Carboniferous Magdalen Basin

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Hypotheses for the origin of the Devonian-Carboniferous Magdalen Basin include a wrench-type basin, a failed-rift basin, or an orogenic collapse basin. The geochemical character of the associated igneous rocks is used to assess the failed-rift hypothesis. Detailed geochemical and Pb isotope analyses have been made of mafic rocks representing the full geo-

graphic and chronologic range of igneous activity in the basin. Chemically, the Middle Devonian rocks from the Antigonish Basin appear mildly alkaline; most Late Devonian to Early Carboniferous volcanic rocks are tholeiitic, while later Carboniferous rocks again have alkalic character. Mean Pb content is about 10 ppm and correlates posi-

tively with TiO_2 . Mafic rocks from the Cobequid Highlands have higher Ga/Al than those in other regions, probably reflecting their association with A-type granites.

Lead isotopic analysis shows that many samples have experienced crustal contamination. The least contaminated samples include the Folly Lake diorite, Middle Devonian

Ballantynes Cove basalt, and early Carboniferous basalts from Cape Chignecto and Northumberland Strait. These samples are relatively unradiogenic: in this respect, they differ from most mantle plumes. There is thus no evidence for mantle plume activity from either trace elements or Pb isotopes.

Land-use planning, resource management, and surficial geology in New Brunswick

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The relevancy and value of surficial geology and till geochemistry maps is recognized by the mineral exploration and aggregate resource industries. More recently, forest managers began to use surficial geology as important information in their long-term management plans. A few recent projects that the geochemistry section of this department has been conducting, although directed at aiding mineral exploration, can also be used for land-use management. The first and largest project involves the surficial mapping of the Fundy Model Forest region. This Green Plan initiative is looking at a 4000 km² area in southeast New Brunswick,

which includes Fundy National Park, Sussex, Petitcodiac, and Hampton, in relation to its natural resources, tourism, transport, economy, biodiversity, etc. DNRE surficial geology mapping will form the base on which forest and ecosystem management research will be built. The geochemistry section is also providing baseline data for the Catamaran Brook Habitat Research Project, managed by Fisheries and Oceans. The third project involved the soil geochemistry of the Mount Pleasant mine property. The results of the work were used to evaluate the effect of tree cutting operations on the mineral resource that underlies the property.

Apatite fission track thermochronometry from central Alberta: implications for the thermal history of the western Canada sedimentary basin

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Apatite separated from 47 Cretaceous and Tertiary drill core and surface samples from the foreland basin strata of the Western Canada Sedimentary Basin (WCSB) have been analyzed for their apatite fission track (AFT) age and confined track length distribution. Thermal histories of the fission track data were then estimated using a constrained random search inversion technique based on the Durango apatite annealing model. Most importantly, this technique provides an estimate of the peak post-depositional temperature experienced by each sample with error bounds determined by the precision of the fission track data. Most apatite samples retain at least some tracks that formed prior to the time of maximum Cenozoic burial, assumed to be coincident with maximum temperature.

Seven apatite samples from near the deformation front

were fully annealed (at $T \geq 120^\circ\text{C}$) during or following the Laramide Orogeny, and provide a minimum age of 42 Ma for heating. In contrast, stratigraphically equivalent Lower Cretaceous samples at the northeastern end of the transect near the Cold Lake heavy oil and tar sand deposits did not exceed 80°C . Paleogeothermal gradients calculated using bounded estimates of the peak temperatures experienced by the samples, together with maximum burial estimates from coal moisture studies, range from ca. $20^\circ\text{C}/\text{km}$ near the deformation front to as high as $60^\circ\text{C}/\text{km}$ near the cratonic edge of the basin. This variation has greater contrast but the same trend across the basin as present geothermal gradients. The results are consistent with the concept of heat transport by basinal scale fluid flow.

Preliminary results of a search for an onshore record of the 1929 Grand Banks tsunami

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Layers of sand and pebbly sand discovered in peat about 12 to 20 cm below the turf line at Taylor's Bay and Lamaline on the Burin Peninsula of Newfoundland may record the tsunami generated by the 1929 'Grand Banks' earthquake. If so, this would be the first case of onshore tsunami depos-

its documented in eastern North America. The 'Grand Banks' earthquake of surface wave magnitude $M_s = 7.2$ stands as Canada's most destructive and costly earthquake. The slumping of the continental slope at the mouth of the Laurentian Channel caused a turbidity current that severed 12 trans-Atlantic tele-

graph cables and set up a tsunami that did damage in southern Newfoundland, Nova Scotia and Bermuda. The brunt of the tsunami damage occurred in about 40 coastal communities along the south coast of the Burin Peninsula. Twenty-eight deaths occurred in Newfoundland and an additional death is now known in Nova Scotia.

The possible tsunami deposits were discovered in August 1993 during reconnaissance along the portion of the southern Burin Peninsula hardest hit by the 1929 tsunami. The sandy layers range up to 17 cm in thickness and are characterized by sharp contacts; no grading was observed within the layers. The layers are fairly continuous over areas of 10,000 m² at Taylor's Bay and ca. 1,000 m² at Lamaline. The areal extent of the possible tsunami deposits and the post-tsunami positions of houses that had been moved inland indicate a runup of about 7 m above sea level at Taylor's Bay and 3 m at Lamaline. Not to be confused with the possible tsunami deposits, a diffuse zone of rounded pebbles

observed in the uppermost peat both within and above the 1929 runup zone is thought to be anthropogenic in origin and probably resulted from fertilization of hay fields with pebble-bearing seaweed.

Currently, various options are being considered for dating the possible tsunami deposits. Site investigations planned for next summer will examine in more detail the areal distribution, topographic settings, and sedimentary characteristics of these deposits with a view to utilizing tsunami deposits in palaeoseismicity studies.

These preliminary results suggest that a record of prehistoric offshore earthquakes may be preserved as tsunami deposits along the eastern seaboard of North America. In order to utilize tsunami deposits in palaeoseismicity studies in this region, efforts are currently underway to develop criteria for distinguishing between tsunami and other types of coastal deposits.

The lithogeochemistry and metallogeny of the southern Tobique Zone, New Brunswick

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Massive-, disseminated- and stringer-type base metal sulphide deposits in the Tobique Zone are hosted by Lower Devonian felsic domes and associated hyaloclastic flows. The deposits of economic interest occur close to the contact between the felsic volcanic rocks and units composed of intercalated mafic volcanic rocks, greywackes and slates. Major, minor and REE lithogeochemistry was carried out to characterize the volcanic sequences that host the various sulphide deposits.

Plots of FeO(tot)/MgO vs SiO₂ indicate that the volcanic sequences hosting the deposits are characterized by bimodal tholeiitic to mildly calc-alkalic compositions. Zr/TiO₂ vs Nb/Y plots indicate that the mafic volcanic rocks range in composition from sub-alkalic basalts to andesites, whereas the felsic volcanic rocks range from rhyolites to rhyodacites. TiO₂ vs Zr and Zr/Y vs Zr plots for the mafic volcanic rocks are consistent with within-plate basalts, but most of the samples plot close to the island-arc tholeiite field due to relatively low TiO₂ values. Zr vs Ce (highly incompatible elements) plots for all the investigated volcanic rocks show that most of the felsic volcanic rocks have distinctly different Ce/Zr ratios than the associated basalts. This indicates that crustal contamination was involved in their formation.

Rock/chondrite variation diagrams for the REE show the following patterns: (1) light rare earth elements (LREE) are enriched relative to heavy ones (HREE), but the degree of enrichment is greater in the felsic than in the mafic volcanic rocks; (2) the relative enrichment of LREE vs HREE is greater in the Gravel Hill (La/Yb - 6.0), Taffy Lake (La/Yb - 6.4) and Bear Lake (La/Yb - 5.3) prospects than in the Riley Brook area (La/Yb - 4.7), but the overall REE content in the latter is greater; and (3) all the felsic volcanic rocks show pronounced negative Eu anomalies that reflect plagioclase fractionation. The flatter REE pattern and more pronounced negative Eu anomalies in the felsic volcanic rocks of the Riley Brook area, as compared to the Gravel Hill, Taffy Lake and Bear Lake areas, are consistent with a higher degree of partial melting and more intense plagioclase fractionation in higher level magma chambers. This probably favoured the formation of base metal sulphide deposits in the Riley Brook area. This implies that REE along with major and minor element lithogeochemistry and detailed stratigraphic mapping can be used to distinguish volcanic units with potential for prolific base metal sulphide deposits.

Sedimentology and paleoclimate of the Pennsylvanian Hub Cyclothem, Cape Breton

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The Late Carboniferous Sydney Mines Formation near Sydney, Nova Scotia, comprises a succession of cyclothem, 40 m thick on average, which show a basinwide alternation of red mudstones and grey coal-bearing strata. The Hub Cyclothem (Westphalian D - Stephanian), which lies be-

tween the Hub coal seam and the Bonar (or Lloyd Cove) seam, is exposed along 30 km of depositional strike.

The Hub Cyclothem consists of three major units: a lower grey coal-bearing unit, a middle muddy unit with redbeds and a calcrete, and an upper anastomosed river sequence.

The lowest part of the cyclothem, deposited under humid conditions, is typically 20 to 30 m thick and contains brackish-water foraminifera, abundant macerated plant debris, tree trunks, rooted zones, siderite nodules and hydromorphic paleosols, as well as large meandering channel fill bodies and associated splays.

The central part of the cyclothem represents a change from a humid climate to a dry, seasonal climate, as indicated by the transition from coal-bearing strata to calcrete horizons and redbeds.

The upper part of the cyclothem was deposited in an

anastomosed river setting and represents a return to deposition of grey strata in a humid climate, with a relative rise in sea level. The sandstones occupy narrow (less than 50 m wide), U-shaped channel fills. Raindrop imprints, desiccation cracks and reptilian trackways are all common features in the overbank fines. Carbonate cements are common in this unit, but absent in the lower two units. Above the anastomosed river complex, the rocks are similar to the coal bearing strata at the base of the Hub Cyclothem, indicating a return to marine-influenced, humid climate conditions.

A new archive: Late Quaternary climatic reconstruction using the deepwater coral *Desmophyllum cristagalli*

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A collection of solitary corals from Orphan Knoll in the North Atlantic, 550 km northeast of Newfoundland, contains individuals with ages that range from recent to > 70,000 B.P. One particularly large pseudocolony lived from 12,400 to 11,200 B.P., within the transition from the last glacial to the present interglacial period. The stable-isotope stratigraphy preserved in the skeleton of this coral documents not only this deglaciation, but also the climatic anomalies known to have occurred during this time. Most conspicuously, the onset of the Younger Dryas cooling event, an especially sudden and severe climatic deterioration, was preserved as a > 2 per mil shift in the $\delta^{18}\text{O}$ signal, suggesting profound changes in mid-water circulation. This abrupt return to glacial conditions may have been caused by a shutdown of the Gulf Stream heat conveyor: models of ocean circulation predict a rise in the $\delta^{18}\text{O}$ of the ocean interior during the onset of the Younger Dryas.

The isotope data, combined with estimates of coral growth rates, also show that the onset of the Younger Dryas may have occurred within 50 years. This rate is comparable to those estimated from ice and sediment cores for the atmosphere and surface waters, implying a close linkage among these three parts of the climate system. The nature of future climate change, sea level rise and global warming can only be understood through an understanding of the nature of this coupling between the atmosphere and the ocean. To date, most paleoclimatic reconstructions have been based on foraminifera from deep-sea cores. Corals are immune to the confounding effects of fluctuating sedimentation rates, bioturbation and transport, and may be superior to forams as archives of benthic oceanographic data.

Recharge region of the surficial aquifer in the College Brook Catchment, Wolfville, Nova Scotia: preliminary assessment

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One of the main municipal water supply wells for the Town of Wolfville, Nova Scotia, exploits an aquifer composed of interbedded sand, gravel and diamicton of glacial origin. This well is located in the lower portion of the College Brook Catchment. This watershed occupies an area of approximately 247 ha. It has two main physiographic elements: the steeply inclined northern slope of the Wolfville Ridge and the low gradient dykelands of the Cornwallis River. Its maximum relief is 122 m from the ridge crest to the river some 3.1 km distant. The aquifer recharge areas in this catchment have not previously been delineated.

The catchment has become increasingly urbanized in its central and lower regions as the town and Acadia University have grown. Land use activities associated with this urban growth have potential to have a negative impact on

groundwater quality in this aquifer. No municipal zoning restrictions to limit such activities or regulate access to important recharge regions are currently in place.

Soil survey maps and reports were used to identify regions where the textural and structural aspects of soils would maximize infiltration in this catchment. Ranges of saturated hydraulic conductivity values were inferred from the data presented in these reports. Soil classification study pits were excavated to provide samples to test these assumptions. Hydraulic properties of these soils were also directly measured with the Guelph Permeameter in the field. A preliminary map based on this work was produced to identify regions where aquifer recharge is most likely to occur in the College Brook Catchment.

Calcareous paleosols as indicators of climato-eustatic change in the Late Carboniferous Sydney Coalfield, Nova Scotia

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Three calcareous paleosol associations are present a few metres to tens of metres below the Phalen, Backpit, Bouthillier, Bonar and Point Aconi Coals of the Sydney Coalfield:

- (a) Calcretes: zones about 1 m thick of carbonate-cemented sandstone with stratification strongly disrupted by roots or vadose diagenesis, overlain by a nodular, calcareous crust about 50 cm thick with a pronounced vertical fabric.
- (b) Red calcic vertisols: red mudstones up to 7 m thick, with dispersed carbonate nodules, weakly developed carbonate accumulation zones, concave up joints and slickensides.
- (c) Grey calcic vertisols: grey mudstones with features similar to those of (b). They contain nodular, bivalve bearing carbonate beds that formed by pedogenetic modification of lake deposits (palustrine carbonates).

The calcareous paleosols can be traced for > 25 km and form part of cyclothems with a systematic stratal succession and mean duration of 200 ka. Grey detrital bay fills with hydromorphic paleosols and a restricted-marine biota are capped by one or more calcretes. The overlying alluvial strata contain red calcic vertisols. In the Glace Bay Syncline where groundwater levels were persistently high, grey calcic vertisols and palustrine carbonates are present at these horizons. The cyclothems terminate with further grey bayfills and thick, economic coals.

The calcareous paleosols reflect a profound change in climate (semi-arid, strongly seasonal) at mid-cyclothem level from that indicated by coals and hydromorphic paleosols at the cyclothem base and top (humid, weakly seasonal). At least one calcareous paleosol formed on an interfluvium between paleovalleys and reflects semi-arid pedogenesis during a glacioeustatic lowering of sea level.

Silurian-Devonian subsidence history of the Arisaig Group, Nova Scotia: a record of terrane interaction?

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The Arisaig Group contains one of the best documented successions of fossiliferous Silurian strata in Atlantic Canada. It overlies bimodal volcanics of the Bear Brook Group that records local Early Silurian crustal extension, which may be synchronous with strike-slip motion associated with the accretion of the Avalon Composite Terrane. The Arisaig Group was deposited in generally shallow water; the thicknesses of the various units are therefore related to subsidence of the underlying basement.

To obtain a quantitative record of subsidence, formations are successively removed from the top of the succession (backstripping) and units are allowed to expand according to an empirical depth-porosity relationship derived from modern basins (decompaction). The tectonic component of subsidence can then be identified assuming an Airy or other model for isostatic compensation. Small corrections to the subsidence curve result from variations in water depth (estimated from sedimentary facies and paleontological evidence) and eustatic sea-level fluctuations (estimated from published

curves). Thicknesses have also been corrected to account for tectonic strain, which probably thickened the whole package approximately homogeneously.

The resulting subsidence curve for the lower Arisaig Group fits predictions for thermal subsidence of crust rapidly stretched by about 20% ($\beta = 1.2$). However, a conspicuous acceleration of subsidence occurred approximately at the time of the Late Silurian Moydart Formation. This acceleration coincides with a change from southeastward to northwestward paleocurrent flow noted by previous workers.

We propose that accelerated subsidence reflects early stages in Meguma-Avalon terrane interaction. However, the sedimentary record in the Meguma Terrane continues into the Early Devonian, suggesting that no major uplift of the Meguma block occurred at this time; the data therefore probably reflect transcurrent motion along the Avalon-Meguma boundary rather than major overthrusting.

Big Bald Mountain project geology of Mountain Brook-Stony Brook area, NTS 21 O/1h

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The Mountain Brook-Stony Brook area is underlain by volcanic and sedimentary rocks of the Miramichi and Tetagouche

groups. From oldest to youngest, the formations present are the Chain of Rocks and Knights Brook formations (Miramichi

Group), and the Patrick Brook, Stony Brook (new name), Nepisiguit Falls, Flat Landing Brook, and Boucher Brook formations (Tetagouche Group).

The Chain of Rocks Formation predominantly consists of medium- to thick-bedded, light green quartzite, and rare interbeds of dark grey phyllite. The Knights Brook Formation comprises thin- to medium-bedded, light to medium grey or green quartzite and quartz wacke, and dark grey to dark green phyllite and slate. Intercalated with the Knights Brook Formation are local felsic meta-igneous rocks that appear to occur as sills, although some thin units of tuffaceous-looking felsic rocks are also present.

The Patrick Brook Formation mainly consists of very dark grey, thin-bedded quartz wacke, slate, phyllite, and chert with local interbeds of light grey or green quartzite similar to those in the underlying Miramichi Group. Felsic tuffaceous rocks interbedded with these sedimentary rocks in the headwaters of Stony Brook record the onset of volcanic activity in the Tetagouche Group.

The Nepisiguit Falls Formation is present only to the north of the Mountain Brook Fault. Porphyritic felsic volcanic rocks in this area are predominantly quartz-feldspar crystal tuffs, although quartz-crystal and feldspar-crystal tuffs, and aphyric rhyolites are present as well. In the northwest corner of the survey area, Nepisiguit Falls Formation sedimentary rocks comprise green quartzose and feldspathic wacke, siltstone, metapelite, and minor slate and quartzite.

The Stony Brook Formation (new name) consists of feldspar-porphyritic felsic volcanic rocks that are exposed in the Northwest Miramichi River-Stony Brook area between the Fraser-Burchill Road and Mountain Brook Fault. These rocks constitute a relatively narrow belt that overlies the Patrick Brook Formation and underlies or is intercalated with aphyric rhyolites of the Flat Landing Brook Forma-

tion; it therefore appears to be coeval, at least in part, with the Nepisiguit Falls and Flat Landing Brook formations.

The Flat Landing Brook Formation consists of light green to grey, moderately to strongly foliated, typically aphyric rhyolite. It is spatially related to the Stony Brook Formation porphyritic felsic rocks in the northwest Miramichi-Stony Brook area, and also occurs near the northern boundary of the survey area, where it is intruded by abundant light to dark green gabbroic and diabasic sills(?).

The Boucher Brook Formation consists mainly of massive to pillowed basalt, with minor interbeds of aphyric and quartz-feldspar-phyric felsic volcanic rocks, and local thin beds of brick-red shaly or cherty iron formation.

The dominant foliation in the area is an east-southeast/west-southwest-trending composite S_2 transposition foliation. South of the Mountain Brook Fault, S_2 dips are shallow to moderate (flat belt) as a result of large-scale F_3 recumbent folding, whereas north of the fault S_2 is normally steep (steep belt). Earlier foliations are thrown into open to tight minor F_4 folds in the southwest part of the survey area, or in the northern half of the area into tight F_5 crenulations with penetrative axial planar S_5 cleavage. West-northwest/east-southeast-trending sinistral faults transect the survey area in the Mountain Brook region; east-northeast/west-southwest-trending dextral faults include the Tomogonops-Tozer Fault, a major shear zone with over 2 km of right-lateral displacement, and the Little River and Mowat faults.

Mineralization has been intersected in several drill holes in the Mountain Brook-Little River area, hosted by mafic volcanic rocks and associated iron formation and felsic volcanic rocks within the (lower?) Boucher Brook Formation. The best reported intersections are 4.5% Pb+Zn over 1.85 m and 3.75% Pb+Zn over 1.9 m.

Organic matter involvement in the genesis of epigenetic, predominantly volcanic-hosted, strata-bound copper deposits in Chile

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After porphyry coppers, the most important copper producers in Chile are epigenetic, strata-bound, disseminated, high-grade (ca. 2% Cu), chalcocite-bornite-chalcopyrite deposits, hosted in predominantly sub-aerial volcanic and volcanoclastic successions of Mesozoic age. These show a strong control by pre-mineral permeability and porosity, such as that provided by vesicular tops of lava flows, primary pores in clastics, and fractures. Their genesis is controversial and has been ascribed to syn-volcanic concentration, to exhalative processes connected to intrusions coeval with the lavas, to burial metamorphic fluids, and to much younger granites. Dating of the mineralization is a problem because the temperature of the fluids responsible for the ores was generally less than

ca. 250°C, and there are few phases suitable for dating; alteration is generally albitization and carbonatization.

We have recognized solid bitumen (R^o 2-4.5%) associated with the ores in several of the producing mines, which poses severe constraints on genetic hypotheses and has important implications for exploration. In addition, this bitumen creates rock-stability problems. Textures indicate that the material represents overmature petroleum that occupied porosity before and during the copper mineralizing process. Isotopic data for C and O in total organic carbon and carbonate confirm the organic affiliation of the carbon, and suggest that gangue carbonates are the result of oxidation of the same petroleum, whose source may be black shale

lenses that underlie some of the deposits. Stable isotopes indicate varied (organic and igneous) sources for sulphur, the involvement of meteoric water, and radiogenic isotopes (Pb and Rb/Sr) pose additional constraints. Rb/Sr, and Fission Track analysis of apatite are showing to be useful tools in confirming the late epigenetic age of the deposits.

We propose that copper mineralization in some deposits exploited pre-existing hydrocarbon (petroleum, gas) reservoirs. The hydrocarbons physically prevented burial metamorphic minerals (zeolites, chlorites, carbonates) from sealing

the porosity, and acted chemically as a reductant at the site of sulphide precipitation. Oxidized basinal fluids of meteoric origin appear to have been responsible for copper transport, and the mineralizing event was a response to tectonic, thermal, and igneous, pulses often distal to the deposits.

We thank FONDECYT (Chile) for financial assistance through grants to F. Munizaga. This is a contribution to IGCP Project 342 "Age and Isotopes of South American Ores" and IGCP Project 357 "Organics and Mineral Deposits".