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Giant Carlin-type gold deposits: characteristics, origins and exploration methodology

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Although presently known to be common only in western North America, Carlin-type deposits (CTDs) are a significant source (~11%) of world gold production. These deposits are characterized by extremely fine-grained disseminated gold, hosted primarily by arsenian pyrite. Gold may be present dissolved in the lattice, or as atomic clusters in sizes below the limit of microscopic observation. The host rocks are dominantly silty carbonates, but ore is also present in siliceous and silicified rocks as well as intrusive rocks. Alteration consists of decarbonatization, silicification (jasperoid formation), and argillization, which are arranged both spatially and temporally in that order. Argillic alteration is zoned from kaolinite-dominated cores to sericite-dominated margins. The deposits commonly exhibit significant structural (faults) and stratigraphic (composition/permeability) controls.

Because of their fine-grained nature and the lack of macroscopic features such as veins, it has proven quite difficult to extract geochemical data that are clearly related to their genesis. However, fluid inclusion data indicate pressures corresponding to depths of 2-4 kilometres under lithostatic conditions. Temperatures are constrained by fluid inclusions and phase equilibria to near 225°C. Stable isotope data from alteration minerals and fluid inclusions indicate that the ore fluids were dominated by meteoric waters, some of which had clearly exchanged oxygen with wall rocks during their passage through the crust. In addition, some recent data are supportive of the presence of a magmatic fluid. Sulphur isotope values reported from CTDs span a wide range, from -30 to +45‰ (sulphides & sulphates), with ore-related sulphides (pyrite, realgar) falling between 0 and +20‰. The most likely ultimate source of sulphur was sedimentary; bedded barite is abundant in the Paleozoic section. It is equivocal whether that sulphur was scavenged by a meteoric fluid, or incorporated into an ascending magma that eventually spawned CTDs. The alteration and mineral assemblage indicate the ore fluids were probably near-neutral and gold was likely carried as a bisulphide complex. Multiple depositional mechanisms are required to explain the deposition of gold along with the observed alteration features (quartz precipitation, calcite dissolution and sericite-kaolinite coexistence). The primary mechanism causing deposition of gold was probably sulphidation, but mixing, cooling and oxidation all may have played a role. Virtually no evidence of phase separation ("boiling") has been documented in these deposits.

Until recently, the age of these deposits in the Great Basin was subject to much speculation, but the most recent data indicate that the deposits are restricted to 42–35 Ma. This corresponds to the timing of a transition from compressional to extensional tectonism in western North America, which was accompanied by magmatism. There are insufficient data to assess the timing and tectonic environment for other CTDs around the world.

The origin of this large gold province remains enigmatic, but the predominant theory at present is that these are distal, magmatic-related deposits. In the Great Basin, they are clearly related in time and space to magmatism, and to deep crustal features as elucidated by geochemical (isotopic) and geophysical (gravity, magnetics) features. On a very large scale, the deposits cluster near the Precambrian craton boundary on the western margin of North America, and at the boundary between Archean crust (to the N) and accreted Proterozoic (to the S) terranes. In addition, the deposits are arranged in linears that correspond with hypothesized deep structures in the craton margin.

Exploration for these deposits in the Great Basin focused on the presence of outcropping jasperoids and fundamental geologic mapping. Given the apparent link to magmatism in the Great Basin, the presence of igneous rocks is considered positive; however, CTDs in other areas of the world (particularly China) do not all have such a strong documented link to magmatic activity. Although Au is the most important trace element indicator, other metals such as As, Sb, Hg, Tl and Ba are utilized as exploration tools. Abundant geochemical sampling is critical, as all of these elements can have an erratic distribution. On a regional scale, deep crustal structures as indicated by geophysics or geochemistry are important.

Macrofaunal evidence for disconformities in the early Ordovician (Canadian) of Ella Ø, north-east Greenland and western Newfoundland, Canada

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North-East Greenland is host to a very thick, dominantly carbonate, shelf sequence, which is time-equivalent to the Cambrian to Ordovician shelf sequence of western Newfoundland. On Ella Ø, several sections were logged through an apparently conformable succession of limestones of the Lower Ordovician Antiklinalbugt and Cape Weber formations. At least 125 macrofossil samples were collected, many from previously unreported silicified fossil horizons within the Cape Weber Formation. Comparison of the

Greenland macrofaunas with those of the St. George Group carbonates of western Newfoundland indicates the presence of a cryptic disconformity of significant duration separating the Antiklinalbugt and Cape Weber formations (as presently defined). This disconformity is correlated with the profound sub-Wandel Valley Formation unconformity of Kronprins Christian Land in eastern North Greenland.

Macrofaunas in the Antiklinalbugt Formation are dominated by trilobites and brachiopods (with some cephalopods and gastropods) indicative of an Early Canadian, Gasconadian age. The Cape Weber Formation hosts a mixed ostracode, trilobite, brachiopod, cephalopod, gastropod, rostroconch and sponge fauna of Late Canadian, late Jeffersonian and Cassinian age. The Antiklinalbugt Formation (as currently defined) broadly correlates with the Watts Bight Formation (St. George Group) of western Newfoundland; the Cape Weber Formation (as currently defined) correlates with the Barbace Cove Member of the Boat Harbour Formation and the Catoche Formation (St. George Group). No Middle Canadian, Demingian age macrofossils have been identified on Ella Ø. This indicates a faunal gap of considerable magnitude, encompassing (at least) the *Hystricurus oculilunatus*, *Leiostegium proprium* and *Randaynia saundersi* (trilobite) interval zones preserved in the lower part of the Boat Harbour Formation (St. George Group) in western Newfoundland.

This implies that the Greenland faunal gap is much greater than that recorded by the Boat Harbour "pebble bed" disconformity at the base of the Barbace Cove Member in western Newfoundland. This suggests that different depositional and possibly tectonic dynamics influenced the Greenland margin of Laurentia at this time compared to that in western Newfoundland. However, both disconformities and the sub-Wandel Valley Formation unconformity are coevally drowned by renewed marine flooding in the late Jeffersonian.

The history of gold exploration in the Botwood Basin of central Newfoundland

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The Botwood Basin of central Newfoundland gained prominence over the past year or so as one of the largest and most exciting gold exploration areas in Canada. The current gold exploration play was developed over a period of several years by geologists at Altius Minerals Corporation, based upon their local knowledge of the region. Even though the first geologist to visit the Botwood Basin more than one hundred years ago suggested that the region had potential for gold deposits, it was not until 1986 that the first gold occurrence was officially documented. More than 100 gold occurrences were discovered following the release of large areas from long-term mineral concessions in the mid 1980s but, with the decline of flow-through funding, few prospects were explored in detail, and the district-scale potential was not recognized. A significant antimony deposit discovery preceded Altius' work.

Altius began work in the area in the mid-1990s and was rewarded progressively with several important geological discoveries that will be discussed in this talk. To outline, Altius' work has considerably enhanced the understanding of the regional geology and structure, and also of permissible (and observed) mineralization styles. The geological architecture of the region has been shown to be quite analogous to Nevada's Carlin Trend. It consists of Ordovician marine sediments that have been thrust over Siluro-Devonian terrestrial to shallow marine (commonly calcareous) sediments. Two styles of gold mineralization have become the focus of Altius' exploration; i.e., low-sulphidation epithermal mineralization and sediment-hosted mineralization ("Carlin-type"). Both styles of mineralization have been clearly observed, and in each case observations support an age for the mineralization that is later than the thrusting event.

Recent, broad interest in the area seems to have been ignited when bonanza-grade drill intercepts were reported by Altius Minerals and its funding joint venture partner Sudbury Contact Mines/Agnico-Eagle Mines from the Moosehead property in the western Botwood Basin. This interest further expanded when it was announced that Barrick Gold Corporation had entered into an exploration and development funding agreement, targeting Carlin-type gold deposits in the eastern Botwood Basin on a land package comparable in size to the Carlin Trend in Nevada. A staking rush ensued in surrounding areas and more than 20 000 claims covering 5000 square kilometres were staked. Today there are more than 20 companies active in the Botwood Basin and many companies, including Altius, have successfully secured financing to explore their projects in 2003.

The second most recent diamond drill hole (MH-02-38) completed by Altius and Sudbury Contact Mines/Agnico-Eagle Mines at the Moosehead property in the western Botwood Basin returned 14.07 g/t gold over 16.84 metres, which included a quartz vein that assayed a spectacular 1154.35 g/t over 0.18 metres. Altius and Barrick are active in the eastern Botwood Basin and have discovered three broad target regions that exhibit alteration and mineralization features consistent with Carlin-type gold deposit models.

The Botwood Basin story illustrates that prospective and accessible parts of Canada remain underexplored. It also demonstrates that new ideas, combined with patient and persistent grassroots mineral exploration, can yield rewarding results. The past year has been an exciting one for the Botwood Basin, and exploration activity in 2003 is set to increase. With all the key ingredients in place, Altius believes that the best is yet to come.

Climate change and the northwest Atlantic: driving force, supporting player, or background noise?

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The general pattern of climate change throughout the terrain, communities, and cultures surrounding the northwestern North Atlantic Ocean, involving warming ca. 600-1300 AD, cooling ca. 1300-1850, and subsequent warming, is generally well-known. Similarly, the geological impacts that climate change has had on societies in northwest Europe are very well known to Quaternarists, and are familiar concepts to many residents. However, on the North American side of the North Atlantic Ocean, the role of climate change in recent human history since ca. 1000 AD is much less clearly defined. The Viking settlements in Greenland represent the only case where climate change is frequently and explicitly cited as a significant factor in their demise, although it is generally considered as a 'supporting player' in a multitude of other factors. Climate change and resultant geological processes clearly affected the establishment and development of Early European settlements, notably those of Champlain (Port-Royal; Québec) and Calvert (Ferryland; Baltimore). These phenomena, however, were not recognized as climate change, being overshadowed by the differences inherent in climate between northwest Europe and North Atlantic North America.

After 1850, most areas in North Atlantic North America were marked by gradually ameliorating climate. Climate change effects are progressively more limited in coastal areas, with Newfoundland showing little influence of climate warming and coastal Labrador showing evidence of regional cooling in the adjacent Labrador Sea. The impact of individual weather events and decadal variations are locally significant, but in reality are superimposed on other political, socio-economic, and technological factors which are of greater significance. This is particularly evident for the communities most dependent on biological resources, which in theory should be most subject to stress from climate change. Although climate change happens everywhere, the local effects felt in much of the region are indirect results. In contrast to the geological evidence for climate change visible to residents of Europe throughout the past 400 years, there was a lack of demonstrated direct climate change impacts on the societies of eastern North America until very recently. With a temporally-limited written history of occupation, and no glaciers to observe in retreat, the visual impact of climate change is muted. This may in turn have an impact on views of the relevance of ongoing climate change to everyday life. In a society that has no collective negative experience of the events or consequences, climate change may simply be perceived as background noise.

The Barth Island layered structure, Labrador: a reappraisal

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The Barth Island Layered Structure, a part of the 1.3 Ga Nain Plutonic Suite (NPS) is an oval series of concentric mafic, intermediate, and felsic rocks. The Layered Structure, located near Nain, Labrador, has previously been considered to be the result of differentiation of a single pulse of basic magma. Recent mapping and petrographic analysis show that this hypothesis is incorrect. The Barth Island Layered Structure is the result of successive pulses of different magmas that are not the product of differentiation of a common parent. U-Pb data for two units of the intrusion require the pulses to have occurred in a relatively short period of time. Also, comparison of U-Pb data from zircon and baddeleyite suggest assimilation, by the mafic member of Barth Island, of semicontemporaneous rocks. Geochemical data for the mafic member are presented. Possible emplacement mechanisms and chamber evolution models are suggested.

Microfauna of the mid-Cretaceous turbiditic systems of the Black Sea (off Romania): occurrence interpretations, fluctuations related to sedimentary regime and correlations at an oil-field scale

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Turbidite sediments are well-known in regions surrounding the western Black Sea, for example onshore Bulgaria (Srednogora region) and Turkey (Western Pontides). In the Romanian western Black Sea offshore, turbiditic sedimentation commenced at the beginning of the Aptian. During the Aptian-Cenomanian interval, turbidites accumulated as part of the Histria Trough tectono-structural unit. Three types of turbidite systems are recognized based on the sediment texture and type of feeder system. They correspond to the gravel-rich, sand-rich and mud/sand-rich turbidite systems distinguished by Reading and Richards in 1994.

The fossil assemblages show an admixture of four types. Planktonic foraminifera are mostly present as *in situ* constituents of the assemblages. Shallow-water benthic faunal constituents were delivered to the slope apron by short-duration transportation in turbidity currents. Deep-basin benthic fauna are most abundant in sediments that accumulated during peri-

ods of reduced terrigenous input, being present mainly in the dark marlstone interbeds at the top of gravel-rich turbiditic sequences. Reworked fossils from the adjacent continental areas are found mainly in the gravel-rich successions.

Two gravel-rich turbidite systems are recognized in the Lebada East oil-field and Portita discovery. Their age is Aptian-Albian and sediment thickness in the proximity of the footwall scarp is about 300 m. Organic material is mostly reworked from carbonate sediments of Late Jurassic age; such Jurassic carbonates are well-known in the North Dobrogea Fold Belt and Central Dobrogea sector of the Moesian platform. Most of the turbidite sequences contain sparse foraminiferal and ostracode assemblages. These foraminifera and ostracoda were transported downslope from the adjacent outer and distal shelves. The richest planktonic and deep-water benthic foraminiferal assemblages occur in the dark hemipelagites situated at the top of upward fining sequences. In these marlstone interbeds (whose thickness is no greater than a few centimetres), planktonics and deep-water benthics comprise up to 25% of the entire assemblage. Microfaunal abundance in the gravel-rich turbidite systems varies between 20 and 70 specimens/unit of sample (35 grams).

A sand-rich turbidite system of early Cenomanian age is widespread in the Histria Trough. Correlative outer-shelf siliciclastic sediments occur to the southwest in the 16 Iris and 18 Lotus boreholes. The extent of the turbidite system is strongly affected by the basin shape and dimensions. Basin scale is similar to basins of the California borderland. Microfaunal assemblages show lower abundance values when compared with those from the gravel-rich turbidites: 20-48 specimens/unit of sample. Up to 90% of the foraminiferal assemblage in the hemipelagic sediments consists of planktonic species. Deep-water *in situ* benthic foraminifera and ostracoda are scarce. This is regarded as an effect of sea-bottom instability due to sediment drifting from the north and southwest.

Middle-Upper Cenomanian turbidites are mud/sand-rich. A gradual increase in microfaunal abundance occurs throughout this interval (from 65-75 specimens/unit of sample at the base to 100-110 specimens/unit of sample at the top). Planktonic foraminifera dominate the microfossil assemblages, representing 75% of the total assemblage in the Upper Cenomanian. Reworked organic debris gradually decreases and eventually is absent in some samples. The microfauna present in these turbidite sediments show strong similarities with assemblages recorded in the coeval basinal sediments of the Tomis Formation. A hiatus spanning the latest Cenomanian to earliest Turonian is present in the Romanian western Black Sea offshore.

The fluctuations of the fossil assemblages have proved to be of paramount importance in developing correlations at the oil-field scale, particularly for poorly cored parts of the stratigraphic column.

Extra-terrestrial impacts: the record and effects

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Planetary exploration has shown that impact is a ubiquitous geologic process in the solar system and was a dominant process in early planetary evolution. The Earth, however, is the most endogenically active of the terrestrial planets and, thus, has retained the poorest sample of impacts that have occurred throughout geological time. The current known terrestrial sample consists of approximately 160 impact structures or crater fields. There are also some 20 impact events registered as depositional events in the stratigraphic record, some of which are related to known structures. The sample is biased towards young (<200 Ma), large (>20 km diameter) impact structures on the geologically better known cratonic areas. Approximately 30% of known impact structures are buried and were initially detected as geophysical anomalies and subsequently drilled to provide geologic samples.

The character of terrestrial impact structures provide important data for understanding impact processes, as they are the only source of ground-truth data on the lithological and structural nature of impact craters in the third dimension. In the geologically active terrestrial environment, anomalous quasi-circular topographic, geologic and/or geophysical features, however, do not automatically equate with an impact origin. Specific samples must be acquired and the occurrence of shock metamorphism, or, in the case of small craters, meteoritic fragments, must be demonstrated before an impact origin can be confirmed. Terrestrial impact structures result in unusual local geologic conditions, which can lead to the concentration of natural resources, such as minerals and hydrocarbons; in some cases, the economic deposits are world-class, such as Sudbury, Vredefort and the Campeche Bank oilfield. Impacts are highly transient, extremely high-energy events that can affect Earth systems. For example, a major impact on the proto-Earth is currently the best working hypothesis for the origin of the Earth's moon. In more recent geologic time, the Chicxulub impact structure in Mexico was most likely responsible for the global mass extinction of the biosphere, at the Cretaceous-Tertiary boundary, 65 Ma ago. Such events occur on time-scales of hundreds of millions of years. More frequent and smaller events occurring on the scale of less than a million years represent a long-term threat to human civilisation.

The serious side effects of suicidal sulphide segregation systems

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The metal contents of sulphide liquids largely depend upon the amount of silicate magma that they are able to "process" for metals. Some high-grade magmatic Ni-Cu (± PGE) deposits and many magmatic PGE (± Ni-Cu) deposits require very high magma: sulphide ratios that are hard to visualize. Recent models for some base-metal-dominated deposits suggest "multistage upgrading" processes, in which an early-formed sulphide liquid reacts with subsequent batches of silicate magma. Such models circumvent the requirement for small amounts of sulphide liquid to react with vast amounts of silicate magma in a single step. However, any later magmatic flux is likely to be sulphur-undersaturated, and will thus partially redissolve any pre-existing sulphide liquids as it enriches them. Empirical computer models and mathematical analyses of this combined process yield identical results, which suggest that it may be important in the genesis of high-grade magmatic sulphide deposits.

Multistage upgrading combined with sulphide liquid dissolution is a very efficient process, and could reduce the amount of silicate magma that must be processed by as much as two orders of magnitude. It also permits development of sulphide liquids that have metal contents above those attainable via single-stage, closed-system reaction between sulphide liquid and magma. Furthermore, the behaviour of base metals and PGE during advanced dissolution of sulphide liquids is fundamentally different. The base-metal contents of the sulphide liquids will generally stabilize, whereas their PGE contents will generally continue to increase. Mathematical analysis demonstrates that contrasting element behaviour is largely governed by the relative magnitudes of the sulphide/magma partition coefficient and the dissolution rate of the sulphide liquid. This "decoupling" effect provides a possible explanation for the unusually high grades and high PGE: base metal ratios exhibited by many PGE-dominated deposits.

However, every silver lining is surrounded by a cloud. If sulphide liquids can be partially dissolved during multistage upgrading, it is also possible that they could be *completely* dissolved, and all previously-extracted metals returned to later batches of magma. Should this occur, metal-depletion signatures characteristic of sulphide liquid segregation would still be preserved in the geological record, even though the sulphides themselves had been destroyed. Complementary metal-enrichment signatures in magmas would likely be very difficult to detect, particularly for the base metals. Caution is therefore dictated in the use of magmatic depletion signatures to infer overall mineral potential, or to estimate the possible size of undiscovered magmatic sulphide deposits.

Analogue experiments of crustal melting and contamination

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A series of analogue laboratory experiments were carried out to model the melting and mixing occurring in an underplating event, where hot, dense mantle-derived magmas are emplaced at the Moho. The crust was modelled by ice or a cold, low-melting point wax, arranged in an upside-down "U" with the two walls and roof dyed different colours. The mantle magma was modelled by a hot, dense aqueous solution which was injected into the cavity between the walls. The experiments revealed the potentially important role that side wall processes can have in partial melting and contamination in this environment. The walls melted back much faster than the roof and the melts from the opposite walls ponded next to each other under the roof. They mixed with each other only in the central region, suggesting a mechanism by which separate granite plutons in a batholith might retain distinctive source-derived chemical signatures even if they are generated by a single underplating event. The input solution crystallized vigorously in the side-wall boundary layers, leading to mixing between melt and model magma, suggesting that this may be a suitable environment for the generation of hybrid magmas, and for crustal contamination of the mantle-derived magma.

The oil and gas development partnership, Memorial University: recent activities and new initiatives

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The Oil and Gas Development Partnership (OGDP) was created in the fall of 2000, and mandated to develop a partnership between the Memorial University of Newfoundland (MUN), the oil and gas industry, associated service companies, and all levels of government. Ideally located in St. John's, Newfoundland and Labrador, a major centre for oil and gas operations on Canada's east coast, and the centre of Provincial Government, MUN is well positioned to form these critical and important alliances. The OGDP is moving quickly to create lasting relationships with the industry and government. Several new research initiatives are under consideration, and discussions with various industry partners are well underway to solidify these proposals.

In addition the OGDP is working to implement new oil and gas related programs. In particular, a Master's Program in Oil and Gas Studies, a unique executive development program, will be launched in September 2003, subject to the normal approvals of Memorial University.

As a public service, the OGDP will continue the

Distinguished Lecture Series on current topics in the oil and gas sector which are of importance to the general public. Topics such as the Newfoundland/Nova Scotia boundary dispute have been discussed in the past, and new topics related to challenges and changes, and the development of stranded gas, are in the planning stages.

An important new program is the Executive Development Program. For 2003, the OGDP is planning a seminar entitled *"Sustainable Development: Getting it Right the First Time"*, to be held in the St. John's and the Harlow campus. This particular topic will explore sustainable development as it will impact Newfoundland and Labrador, in particular because oil and gas developments are in their infancy in the province. Each year, the OGDP plans to sponsor at least one Executive Development seminar, always dealing with important oil and gas related topics of current interest to the global industry.

LAM-ICP-MS geochronological studies from the Botwood Basin and Buchans areas, Newfoundland

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Laser Ablation Microprobe Inductively Coupled Mass Spectrometry (LAM-ICP-MS) has proven increasingly successful for the determination of ages from both detrital and magmatic zircons. We have used the LAM-ICP-MS facility at Memorial University to date detrital zircon grains from Silurian-Ordovician sedimentary rocks in central Newfoundland, and detrital and magmatic zircons from the Buchans Group, west-central Newfoundland.

The Silurian-Ordovician sequences include: a) one sample each from the Badger (BAG) and Davidsville (DG) groups; these units represent roughly synchronous deep marine Ordovician sequences, b) two samples, one from the top and one from the bottom, of the Silurian Botwood Group (BOG), a sequence of continental red-bed sandstones, and c) one sample from the Silurian Indian Islands Group (IIG) which comprises shallow marine limestones and calcareous sandstones. The BOG and IIG samples represent material from opposed sides of the Dog Bay Line, a regional transpressive structure thought to represent the terminal suture of the Iapetus Ocean. The detrital zircon populations in all units define predominantly Paleozoic ages for all samples but with distinctly different older populations; the Paleozoic ages represent material from the island arc and other volcanism in the Iapetus Ocean. In detail, the BOG and BAG samples have a range of older ages which may represent material from the Grenville and Makkovik provinces (Laurentian margin), whereas the DG sample contained a range of older zircons which may represent Avalonian material from the Gondwanan margin. The IIG sample has older populations which may represent material from both the Laurentian and Gondwanan margins and which, therefore, suggest that this unit represents terminal sedimentation within the Iapetus Ocean.

Single samples with magmatic zircons were analysed from the Ski Hill Formation (SHF), Feeder Granodiorite and Prominent Quartz Rhyolite (PQR) of the Buchans Group. Two samples of detrital zircons were collected from the Sandy Lake Formation. The SHF rhyolite provided very small zircons which gave poorly defined ages of ~500 Ma and ~950 Ma (Grenvillian); a previously defined TIMS U-Pb zircon date for the Buchans River Formation, the overlying unit to the SHF, is 473 +3/-2 Ma. Zircons from the Feeder Granodiorite defined an age of 503 ± 8 Ma and the Prominent Quartz Rhyolite zircons clustered around 494 ± 4 Ma; one zircon contained a probable Grenvillian core. Zircons in one Sandy Lake Formation (SLF) sample defined a tight cluster of ages around 484 ± 4 Ma, and in the other sample clustered at 488 ± 6 Ma and also had a single grain with a probable Grenvillian core. The older ages for the SLF, which is the stratigraphically highest unit in the Buchans Group, would appear to be counterintuitive, however, the data actually support earlier work by others which suggested that the detritus in SLF was derived mainly from the PQR and that the PQR formed topographic highlands to the Buchans Group. Lack of other populations in the SLF samples also suggests deposition in a restricted, caldera-like basin.

A comparison of gold-bearing quartz boulders to their potential bedrock source, Golden Promise Prospect, Badger, Newfoundland

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The Golden Promise Prospect is located on the N.T.S. map sheet 12A/16, 12 km south of the town of Badger in central Newfoundland. Rubicon Minerals Corporation acquired the property in the spring of 2002 after a local prospector discovered a float train consisting of several-tonne quartz boulders that contained visible gold. The size and angularity of the boulders suggested minimal glacial transport distances and so trenching was undertaken in close proximity to the boulders. A thick till blanket hampered exploration and six of the nine trenches had to be abandoned after encountering four meters of till. The other three hit bedrock and one of these exposed a meter-wide vein of quartz containing visible gold. Drilling results suggested that the vein was continuous, with a strike length of 250 meters, and it assayed high gold values.

Four main glacial events affected the area, the most prominent originating southwest of the property. Till samples were collected perpendicular to the strike of the vein and boulder train, as well as within the three trenches. Ten till fabrics were derived at different heights throughout the trenches and plotted to determine the number of till directions. The clasts used for the till fabric delineations were kept to identify their lithologies and to determine indicator erratics and thus, travel distances of the float. Rock samples of both the boulders and bedrock were collected and analysed as hand samples, thin sections, polished sections and by X-Ray Fluorescence.

All of these processes were completed in order to determine the likelihood that the trenched bedrock is the source of the quartz boulders. Although some analyses have yet to be completed, the results so far justify this statement.

Permeability distribution in a deltaic system: a case study in the importance of basin processes in a fluvial-dominated succession

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The dominant controls on permeability in siliciclastic reservoir systems are grain size and sandstone composition. For any given porosity, coarser grained and more quartzose sandstones will typically comprise the most productive reservoir intervals. In marginal marine systems, like deltas, grain size is often predictably distributed with coarsest grained sandstones commonly described within channels settings, towards the tops of shorefaces and mouth-bars and as lag deposits of various types. Composition of sandstones is more an arduous descriptive exercise, especially when grain size distribution and porosity within a reservoir have a limited variability. However, sandstone composition can have an equal and sometimes greater influence on the distribution of reservoir quality than grain size and should have an equally predictable distribution. A case study will be presented that illustrates how compositional variability in a deltaic system influences permeability distribution.

Anorthositic, granitic and dioritic intrusions of the Nain-Okak Bay area, Labrador: two geographically coincident, but temporally separated plutonic suites

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A large area of anorthositic and granitic rocks sits astride the 1860 Ma collisional suture between the Archean Nain Province and the Paleoproterozoic Churchill Province in the vicinity of Okak Bay in northern coastal Labrador. All such rocks have historically been considered to be part of the Mesoproterozoic Nain Plutonic Suite (NPS). Field and geochronological investigations over the last five years indicate, however, that this region also encompasses compositionally similar plutonic rocks from a Paleoproterozoic episode of magmatism. These two superficially comparable "bimodal" groups of anorthositic and granitic rocks share one geographic area, yet are temporally divorced by nearly 800 million years.

The first evidence that Paleoproterozoic plutonic rocks had heretofore been erroneously included within the NPS was presented in the early 1990s – isotopic data from several granitic intrusions indicated crystallization ages greater than 2000 Ma. Prior to 1996, however, the full compositional spectrum and any wider distribution of the Paleoproterozoic rocks were unknown. In 1996 and 1997 the Geological Survey of Newfoundland and Labrador undertook a regional mapping program south of Okak Bay. One of the program's objectives was to subdivide the northern part of the NPS into its internal components as an aid to mineral exploration. The field work provided the first concrete indications that anorthositic, granitic, and dioritic rocks older than those of the NPS are well preserved in this part of Labrador. These older rocks were tentatively assigned a Paleoproterozoic age, and they could be separated from the lithologically similar NPS by applying a set of field criteria. The older rocks have (i) high-temperature hydration, (ii) swarms of synplutonic and post-crystallization metamorphosed basic dykes, (iii) deformed pink aplitic dykes, (iv) a penetrative foliation and associated upper greenschist-facies regional metamorphic overprint, and (v) a relatively high regional aeromagnetic signature. Subsequent geochronological investigations confirmed the field partitioning of Paleoproterozoic and Mesoproterozoic rocks, and provided absolute ages for several of the older and younger intrusions. The field characteristics and the isotopic ages clearly necessitate a stratigraphic separation of the two rock groups, and the Paleoproterozoic intrusions are now referred to as the Arnanunat Plutonic Suite (APS). The geological mapping and allied geochronology delineated numerous plutons in the Okak Bay area, and indicated that both the APS and the NPS were constructed through pulses of felsic and basic magmatism.

The age determinations from several components within the APS between Nain and Okak Bay have shown that the plutons and their basic dyke swarms represent magmatism between ca. 2140 Ma and ca. 2020 Ma. This Paleoproterozoic magmatism is confined to the Nain Province side of the ca. 1860 Ma collisional suture. Most intrusions are aligned parallel to the southeast-trending regional grain of the enclosing Archean gneisses, indicative of a pre-existing structural control on magma emplacement. The deformation and greenschist-facies metamorphism imposed on the APS was generated during the Nain-Churchill collision. NPS intrusions post-date the 1860 Ma collision, straddle the Nain - Churchill suture, have ages of 1330 Ma and 1320 Ma in the Okak Bay area, show no preferred regional trend, and are generally unaltered because no subsequent regional tectonism has been imposed on them. Anorthositic rocks of both the APS and the NPS south of Okak Bay host Ni-Cu sulphide prospects.

The APS is distributed along a 150 km, NW-trending belt

in which the intrusions become younger from north to south. This pattern may attest to the migration path of the Archean crust relative to an underlying (plume-related?) heat source or to a southward-propagating rift that was formed during the Paleoproterozoic fragmentation of the North Atlantic Archean craton. The NPS, advocated to have developed within a Mesoproterozoic intracontinental doming and rifting setting, is regionally oriented along the Nain - Churchill collisional suture, and also shows an overall age decrease from north to south but likewise from west to east. The juxtaposition of two nearly identical suites of anorthositic and granitic intrusive rocks within the same geographic region, but separated in time by some 800 million years, raises intriguing questions about the crust and mantle links that give rise to such repetitive "bimodal" magmatism.

Landscape change and prehistoric settlement, Porcupine Strand, Labrador

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Porcupine Strand, southeastern Labrador, is a 40-km-long sandy beach backed by eroding coastal cliffs. It is one of the longest unoccupied coastlines in eastern North America, but this has not always been the case. Recent identification of artifacts from archaeological sites within coastal sand dunes suggests that the Strand has been occupied by at least seven different cultural groups over the last 7000 years (Maritime Archaic Indian, Intermediate Indian, Recent Indian, Pre Dorset, Groswater Paleo Eskimo, Dorset Paleo Eskimo and Historic Inuit). Over time the landscape on which these prehistoric people lived has been modified in response to sea level change and shifting sand dunes. The ability of prehistoric cultures to adapt to these landscape changes is seen in the shifting location of their sites. An understanding of the relationship between settlement patterns and landscape adjustments is useful in developing strategies for site surveys and to assess how environmental change affected economic and social adaptations and interactions of prehistoric cultures along Porcupine Strand.

Basin segmentation, architecture and inversion on a passive margin, offshore Newfoundland (poster presentation)

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The Mesozoic rift basins of offshore Newfoundland have undergone multiple rift episodes. Three documented phases of rifting coupled with subsidence have provided the framework for structural and stratigraphic controls for the Jeanne d'Arc and other basins of the Newfoundland Grand Banks. The three sequential rift phases are NW- SE extension in the Late Triassic/ Early Jurassic, E-W extension in the Late Jurassic/ Early Cretaceous and Mid-Cretaceous NE-SW extension.

Geophysical evidence indicates development of several NW-SE transfer faults in the Jeanne d'Arc basin. The initial rift basin architecture appears to extend northward beyond the Jeanne d'Arc into the Orphan basin across a transfer fault that lies along the Cumberland Belt. This transfer fault shows at least two periods of reactivation causing strike slip movement in the Late Jurassic/ Early Cretaceous and Mid Cretaceous times. The timing of development of the Orphan basin suggests a similar structural and stratigraphic history to other basins of the Grand Banks.

New interpretations suggest that the transfer faults segmented the Jeanne d'Arc and controlled initial basin development offshore Newfoundland. Subsequent multiple reactivation of the transfer faults caused multiple episodes of basin inversion. This new insight suggests a more complex structural and stratigraphic basin evolution for offshore Newfoundland.

The search for diamonds in Canada

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Canada's Archean terrane has excellent potential for diamonds. Together with the somewhat less prospective adjacent younger Precambrian terrane, these rocks extend across much of the Canadian Shield and under the Phanerozoic cover of the Plains, Hudson Bay, and Arctic. Early world exploration relying on recognition of diamond in alluvial sediments led to production from India, Brazil, and Africa. Over the past century, advanced science and technology, and large investments, have led first to Russia, and now Canada, joining Africa as leading producers of high-quality gems. Progress in Canada accelerated after 1960, first in Ontario and the Arctic, then Saskatchewan in 1988, and most importantly the Chuck Fipke/ Stew Blusson discovery at Lac de Gras that was announced in 1991. Canadian exploration relies on analysis of tectonics, indicator minerals, geophysical surveys, and multiple stages of drilling and bulk sampling, similar to other regions. Very different from other regions, however, is Canada's surficial environment, in which recent glaciation has caused fresh labile indicator minerals to be transported hundreds of km from source, having been transported by glacial processes that cross watershed boundaries.

Geology of Proterozoic anorthosite intrusions in the Nain Plutonic Suite, Nain Bay area, Labrador

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The Nain Plutonic Suite (NPS) comprises a 19 000 km^2, undeformed, Proterozoic massif type anorthosite terrane, dominated by anorthositic and granitic rocks, with subordinate amounts of troctolite, ferrodiorite, and monzonite. Emplacement occurred between 1.36-1.30 Ga, with no subsequent regional deformation, making the NPS one of the best exposed, undeformed Proterozoic anorthosite suites in the world. The discovery of the NPS-related Voice's Bay ore deposit, in the mid 90s, has highlighted the economic importance of understanding anorthosite magmatism, which remains one of the last great remaining puzzles in igneous petrology.

Three summers of fieldwork on the NPS, covering over 400 km^2 immediately west of the town of Nain, have been compiled at a scale of 1:20 000. The study area straddles a previously defined, major petrographic division in the NPS, between orthopyroxene-bearing anorthosite in the west, and olivine bearing anorthosite in the east. The area includes parts of four major anorthosite intrusions, as well as scattered bodies of ferrodiorite, quartz monzonite, granite, and country rock. Though there are significant structural and compositional differences between igneous bodies, most appear to be composite, fracture-controlled bodies, with broadly similar components.

Extremely coarse-grained anorthosite interiors are surrounded by marginal leuconorite, gabbronorite, ferrodiorite, and monzonite sheets. Petrography and new mineral chemistry data will be discussed under the context of the presented mapped plutonic units. New major, trace and isotope geochemistry data will also be presented, and will be used to better define plutonic units identified in the field. New geochronological data will be presented, and will be used to argue for active shearing during emplacement of NPS bodies.

Technology and the environment: a retrospective examination of 19th century mining and smelting operations at Tilt Cove, Newfoundland

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In their first phase of production, the mines at Tilt Cove, on the northeastern tip of the Baie Verte Peninsula, were worked from 1864 to 1917. From 1889-1892 a smelter facility also operated here to produce copper from the East Mine ores; documentary records from this operation do not exist. This facility, along with another at nearby Betts Cove, constituted the largest integrated, non-fishery-related industrial complex outside St. John's, and possibly the largest in the country at the time. At Tilt Cove, there has been minimal industrial re-development and remnants of the 19th century mining and smelting facilities are relatively intact. Aside from mining and smelting, it appears (based on scrap material on site) that the operation may also have involved the quarrying and transport of marble from Cobb's Arm, New World Island.

The ore was handpicked (cobbed) at the mine surface and broken into pieces about 2-5 cm in diameter; the grade of ore at Tilt Cove for the smelter was at best 4% Cu. Copper smelting in the late 19th century was a complicated process, involving three key steps: (1) calcining, whereby the ore was dry roasted to expel arsenic (As) and sulphur (S) and to convert iron (Fe) to Fe-oxide, (2) melting to remove Fe-oxide, and (3) roasting and melting to completely remove S and produce metallic Cu. During the early melting stages, calcium (Ca) in the form of marble-limestone ($CaCO_3$) was added as a flux. Following calcining, in a typical operation, the ore was melted and roasted up to five more times to synthesize the final metallic Cu product. Apparently all of these steps were not carried out at the Tilt Cove facility.

From the first stage of melting, copper matte was collected in bowl-like pots; our geochemical data from the pot slag indicate a range of Cu concentrations from 1637 to 2702 ppm. In the final stages of processing, the copper matte should have been upgraded to the point that it represented nearly pure copper and the slag should also have become progressively more oxide-rich. At Tilt Cove, none of the final copper product remains, but slag from the heaps contains 0.5-0.7 % Cu and up to 1.7% Zn, thus indicating that the Tilt Cove process was not particularly efficient. Furthermore, the slag contains up to 5% S and is obviously not an Fe-oxide. The Tilt Cove operation was probably a feeder plant producing low-grade blister copper for further refining at Swansea. Geochemical data, however, also suggest an elemental consistency to the copper production at the smelter.

Although it was only operative for three years, the smelter had tremendous deleterious effects on the local environment as described by contemporary sources; these included consistently igniting forest fires. These effects are still discernable today, over 110 years after the facility closed. Geochemical data, for instance, indicate that As had been removed from the matte during the final smelting and was presumably volatized out the chimney stack into the surrounding countryside. Other heavy metals are likewise enriched in soils around the chimneys.

New frontiers for petroleum exploration in the deep water of Atlantic Canada

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EnCana is one of the largest acreage holders in offshore Nova Scotia with interests in 15 exploration licences totalling more than 2.4 million net acres. In addition, EnCana has a 100% interest in the Deep Panuke discovery, on which regulatory approval is expected during 2003. EnCana is the largest landholder in offshore Newfoundland with nearly 2.8 million net acres in 10 exploration licences in 4 different sedimentary basins. The combination of this acreage makes EnCana the largest offshore acreage holder in Atlantic Canada with a total of 5.2 million net acres under licence. Although EnCana has significant interests in the shallow waters of both provinces, the majority of this acreage lies in water deeper than 500 m. The exploration licences cover two primary basins, the Scotian Slope in Nova Scotia and the Flemish Pass basin in Newfoundland.

The Scotian Slope and Flemish Pass represent two very different "deep water" basins. The Scotian Slope is the deep water portion of the Scotian Basin, a large passive margin basin under Atlantic Canada's continental shelf and slope that encompasses a corridor 100 to 150 km wide by 900 km long on the southern margin of the province of Nova Scotia. The Scotian Slope is expected to be a gas province, as is the Sable Sub-basin. It exhibits play types and depositional systems typically associated with exploration in areas like the deep-water Gulf of Mexico and West Africa. On the Scotian Slope, reservoir sediments were transported into the deep water in front of the major Jurassic to early Cretaceous aged Sable delta during periods of shelf instability and lowstand events. These reservoirs were eventually deposited in areas of accommodation on the slope or on the basin floor in submarine channels, lobes and fans. Halokinetic movement of the Jurassic-aged Argo salt not only created much of this accommodation but also created various structures associated with halokinetic swells, walls, ridges and domes as well as minibasin and subsalt exploration prospects. Hydrocarbons will be derived from Jurassic to Cretaceous-aged pro-delta and slope gas prone source rocks. On the other hand, the Flemish Pass basin is an intra-cratonic rift basin, similar to the neighbouring Jeanne d' Arc basin. It is 45 km wide and 170 km. long, making it much smaller than the Scotian Basin. The target reservoirs are the same Jurassic to Cretaceous-aged clastics as those on the Scotian Slope but in the Flemish Pass they are interpreted to predominantly be shallow-marine to marginal-marine sandstones. The mapped play types in the Flemish Pass are structural closures in the form of rift-related horsts and tilted fault blocks and stratigraphic plays in the form of sub-crop pinchouts. The Flemish Pass basin contains the same oil-prone Kimmeridgian source rock as the Jeanne d'Arc basin, which is interpreted to be mature over much of the basin.

Significant exploration work commitments have been bid by the oil industry in both provinces in the deep water. Numerous exploration wells are planned over the next few years, including the Mizzen and Tuckamore wells in the Flemish Pass, operated by Petro-Canada and in which EnCana is a 33.33% interest holder. Examples of prospectivity will be presented from a variety of locations in both basins using seismic and schematic representations.

Geology and structure of the Kikkertavak Anorthosite, Labrador

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The Kikkertavak Anorthosite is a young member of the Mesoproterozoic Nain Plutonic Suite. Recent mapping of this body has revealed that it preserves features of its emplacement and crystallization history that have not been readily observed in older, more deformed anorthosite. Many phases are observed within the Kikkertavak Anorthosite, and the mineralogical and textural relationships within and between these phases preserve a physical record of the history of this pluton. The cumulate texture, mineralogy, and differences in texture between components of the Kikkertavak Anorthosite suggest that it is the product of more than one melt and has had a protracted history of crystallization and fractionation.

The Kikkertavak Anorthosite is cut by several smaller intrusions of monzonite and ferrodiorite, the distribution and characteristics of which may be significant in the history of the Nain Plutonic Suite. The relative similarities and differences between these rocks and the host anorthosite provide clues about their origin. The presence of shear zones, sinistral faulting, and mafic dyking are all features of a transpressional/extensional regime, and are indicative of the mechanisms required for the emplacement of the voluminous magmas of the Nain Plutonic Suite.

Climatic signals from Canadian glaciers and ice caps: what do they tell us ?

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The National Glaciology Program (NGP) was established in 1998 through a collaborative agreement between Natural Resources Canada (Geological Survey of Canada - Glaciology section) and Environment Canada (National Water Research Institute). Its mandate is to investigate the climatic and hydrological significance of Canadian glaciers in past, present and future contexts. NGP has ongoing research programs over a broad geographic range that includes many sites in the Arctic archipelago as well as in the western Cordillera, from the coast mountains of British Columbia to the St-Elias range of the Yukon. Some of its principal research activities involve monitoring the mass balance of glaciers and ice caps to detect and measure climatic change, estimating the impact of climatic variations on glacier-fed hydrological networks, and also investigating the climatic and environmental records locked in glacier ice. Many of these activities are pursued through collaboration with provincial agencies, universities and foreign research institutions. This presentation will give a general overview of NGP's research agenda, using examples from past and ongoing projects. The emphasis will be placed on the relationship between glaciers and climate, and on the nature of climate-related information that can be obtained through the study of glaciers and glaciation. The narrative will be illustrated with images and anecdotes taken from recent NGP expeditions in the Canadian Arctic and the Yukon.