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Gold mineralization associated with the Betts Cover Complex

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The Ordovician Betts Cove Ophiolite is located in northeast Newfoundland on the southeast side of the Baie Verte Peninsula, between the communities of Tilt Cove and Nippers Harbour. Ultramafic rocks occur at the base of the ophiolite in fault contact with the upper ophiolite stratigraphy (mainly pillow lava) to the south. North of the ophiolite, intermediate and felsic volcanic and sedimentary rocks of the Silurian Cape St. John Group, and the Cape Brule Quartz-Feldspar Porphyry are in fault contact with the ultramafic rocks. Locally the Cape St. John Group unconformably overlies the ophiolite.

All ultramafic rocks in the area have been altered to carbonate-bearing assemblages. Talc-magnesite is the most abundant ultramafic rock type present in the area. Lesser amounts of serpentine-magnesite and quartz-hematite-dolomite alteration assemblages also occur.

Two types of gold mineralization are described. The first type occurs in a talc-magnesite host and consists of a simple quartz, magnesite, Cu-sulphide mineralogy. The second type is hosted by the quartz-hematite-dolomite altered ultramafic rocks and shear zones within the Silurian Cape St. John Group. These Au-mineralized veins consist of quartz, ankerite, fuchsite, and specularite plus or minus magnetite and Cu-Fe sulphides.

Gold enrichment in the ultramafic rocks and gold mineralization are associated with regional scale carbonate alteration. This link is important for defining exploration targets.

Mineralization probably occurred as a result of metamorphic dehydration of underlying rocks during Acadian orogenesis. Faults related to those which presently define the margins of the ultramafic rocks probably acted as fluid conduits.

Bedrock aggregate potential of Newfoundland

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A reconnaissance study of bedrock quarries, road cuts and natural outcrops for aggregate potential was carried out on the Avalon and Burin peninsulas. This assessment was initiated as a result of declining unconsolidated (sand and gravel) aggregate deposits, due to their constant depletion by industry for road construction. Sporadic occurrences of high quality sand and gravel deposits were also a major factor in the initiation of this project. This assessment is ongoing and at present all areas east of Grand Falls are completed.

A total of 1200 sites were visited and 856 samples were taken, of these 486 samples show potential for high-quality bedrock aggregate, 210 samples are considered to be potentially marginal and 160 samples are considered to be of low or poor quality.

Good quality bedrock aggregate should be fresh, hard, dense and free from deleterious substances. The sandstones, granites and volcanic rocks in the field areas meet these requirements, when they are not highly weathered, altered or metamorphosed.

Geotechnical properties of the bedrock, such as geological features, deleterious substances, petrographic number and petrographic analyses were performed on all samples. Los Angeles Abrasion, Magnesium Sulfate Soundness, Alkali-reactivity and chemical analyses were performed on selected samples.

Metallogeny related to plutonism in the Northern Abitibi Belt

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The Northern Abitibi Belt consists of a narrow northern strip composed of two volcanic cycles and a terminal sedimentary phase, and a broad southern area consisting of a tholeiitic basalt plain with local felsic centres and a terminal sedimentary phase. Supracrustal rocks were folded isoclinally about E-W axes and traversed by E-W fault zones with both a vertical and a horizontal (dextral) movement component. The abundant felsic plutons formed at various structural levels and various periods, and had a profound influence on metallogenic patterns.

Subvolcanic plutons (2718 Ma) formed high-level cauldron subsidence complexes containing porphyry-type mineralization, and generated epithermal systems in the overlying volcanic rocks. Porphyry associations with typical alteration patterns occur both as disseminated and vein ore bodies within breccia pipes in the intrusion, and epithermal veins occur within the overlying volcanic rocks. Block foundering and dyke injection associated with synvolcanic plutons created zones of weakness which played an important role in ground preparation for later mineralization. Some of these zones were exploited during regional deformation, resulting in the development of gold-bearing lodes.

These large structurally isotropic intrusions occurring within

anisotropic supracrustal rocks, induced many deviations in structural trends during regional tectonism. Syn- to late-tectonic intrusions (2695 Ma) exploited the structural break between the early intrusions and the supracrustal rocks. Monzodiorite, tonalite/granodiorite and granodiorite suites occur. These intrusions display amphibolite facies metamorphic aureoles in contrast to the prevalent greenschist facies. The close association with regional deformation and metamorphism implies the plutons were emplaced at the depth of regional metamorphism. These plutons may have contributed to the fluids related to the emplacement of lode-gold deposits controlled by regional ductile faults. Minor disseminated sulphides in the ultramafic and mafic early phases of some monzodiorite and tonalite plutons has never been fully evaluated.

Late syntectonic and post-tectonic plutons are scattered throughout the belt, principally intruding the supracrustal rocks. The most abundant are porphyritic granodiorites occurring as clusters of small stocks. They appear to be cupolas derived from underlying granodiorite sheets, and most are late syntectonic in age. An episode of alkalic magmatism, represented by syenite stocks with associated carbonatite and lamprophyre dykes, occurs in linear array parallel to late northeast faults and appears to be youngest plutonic activity. Lode gold deposits occur in close spatial association with both the granodiorite and alkaline suite, although the source of the gold mineralization is still uncertain.

Geological structure from surface geochemistry

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The topographic expression of geological structure has long been a useful tool in geological mapping. Topographic linears are recognized from airphotos and topographic maps, and more recently, from digital airborne or spaceborne sensors measuring passive (visible or infra-red) or active (radar) electromagnetic radiation. The widespread availability of regional geophysical data, especially aeromagnetic data, affords another approach to the mapping of geological structures, either from contoured data or processed images.

Techniques similar to those used to enhance linear features in geophysical data can be applied to digital geochemical data. Although based on the geochemistry of surficial media, shaded-relief maps of lake sediment geochemistry display some clear linear and curvilinear features that can be related to bedrock structures. Both geochemical and geophysical surveys map compositional variations in bedrock, and linear features are caused in three main ways: (1) the juxtaposition of two geological units of contrasting composition (e.g., along an intrusive or faulted contact), (2) alteration along a linear zone (commonly fault-controlled), and (3) the offset of continuous geological units along a fault.

Geophysically and geochemically defined linears are complementary in that they reflect different aspects of variations in bedrock composition, and they both in turn complement topographic linears which reflect variations in the mechanical properties of bedrock. The use of video display systems, especially those incorporating data overlay and analysis capabilities are useful in identifying the more significant of what can be a plethora of linears.

Bay of Islands ophiolite harzburgites and refractory melts: the PGE story

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The Springers Hill area of Lewis Hills Massif, Bay of Islands Ophiolite Complex, western Newfoundland, preserves a section of highly depleted mantle harzburgite into which are intruded cm-m wide veins and dykes of dunite and pyroxenite. The harzburgite is composed of olivine, orthopyroxene and chromite. The orthopyroxene often preserves corroded margins where it breaks down to olivine. These features, coupled with the absence of clinopyroxene, plagioclase and primary base metal sulphides, clearly support the origin of the harzburgite as a residue from extreme partial melting. The veins and dykes occur as successive intrusions of dunite ± chromitite, orthopyroxenite and clinopyroxenite. The veins and dykes do not represent liquid compositions, but crystal fractionates from a melt. As such, their fractionation sequence mimics that of melts derived from refractory mantle sources, e.g., boninites.

Platinum group element (PGE) concentrations have been determined in all of the above mentioned rock types. Dunites and chromitites have Pd/Ir = 0.19-0.88. Enrichment in Os, Ir and Ru is due to the occurrence of Os-laurite in chromite. The orthopyroxenites contain primary Pt- and Pd-arsenide grains hosted within fresh orthopyroxene. Consequently, orthopyroxenites preserve Pd/Ir = 32-473. Complex Pt-Pd-Co-Ni arsenide phases, native Pt and Cu, Pd-Cu alloys and Cu bearing, Ni-rich pentlandites make their first appearance in the clinopyroxenites (Pd/Ir = 86-219). The complementary evolution of the PGEs with crystal fractionation indicates that the veins and dykes are comagmatic, and that the PGE concentrations are magmatic and not the result of alteration.

Harzburgites have Pd/Ir = 1.2-1.7 which disagree with their origin as mantle residues. The orthopyroxene content of harzbur-

gite is greater where it borders orthopyroxenite dykes. Petrographic examination of orthopyroxene-enriched harzburgites reveals delicate, interstitial orthopyroxene grains, which are considered melt impregnations. The elevated Pd/Ir ratios in harzburgite are thus the product of addition of an orthopyroxenite component (high Pd/Ir) to truly residual harzburgite (Pd/Ir <<1).

Synthetic aperture radar: a valuable remote sensing tool for the geoscientist in Newfoundland

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Two large areas in Newfoundland centered roughly on the Baie Verte Peninsula and Red Indian Lake were imaged using a C-band synthetic aperture radar (SAR) in September, 1988. These data were collected by the Canada Centre for Remote Sensing under the auspices of the Radar Data Development Program in support of a major effort to develop geoscience applications for SAR in anticipation of the launch of RADARSAT. Analysis of the data has included both analogue (visual) and digital methods. Results to date indicate that a multitude of specific structural, lithologic and glacial elements are represented uniquely by the SAR image data. SAR response is most effected by local terrain shape (specifically slope and aspect) and soil moisture, while changes caused by the relatively small scale roughness variations within the vegetation canopy are minimal. Since terrain shape is a major factor, SAR data must be collected at orthogonal viewing geometries during reconnaissance surveys to ensure that all geologic features of interest will be represented. Digital enhancement techniques, such as directional filtering, may be used to highlight linear elements of various scales and orientations. Integration of SAR with geophysical data, including aeromag and spectrometer, is proving to be a powerful exploration tool since linear elements which are due to some anomaly at depth are often represented at the ground surface on the SAR data.

Sphalerite/dolomite stratigraphy and the tectonic origin of an MVT deposit, Daniel's Harbour, western Newfoundland

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An MVT-zinc deposit at Newfoundland Zinc Mines occurs in dolostone complexes of Lower Ordovician platformal carbonates of the upper St. George Group. Like some other MVT deposits it is intimately associated with karst breccias beneath a regional unconformity. Detailed sphalerite/dolomite stratigraphy and structural relationships, however, indicate a deep burial/tectonic origin for the deposit. Several generations of breccias associated with two stages of sulphide deposition and three periods of dolomitization record a protracted history of fracturing and faulting under a regime of regional compression during early phases of the Middle Paleozoic Acadian orogeny.

Coarse, ore-stage dolostone/sphalerite bodies, including stratabound pseudobreccias and fracture-related breccias, overprint both limestones and early diagenetic dolostones. These coarse bodies envelope linear, stratabound vein systems which surround early dolomitized karst breccias and steep faults. They developed in four stages: (1) pervasive pre-ore dolomitization (I) of limestones along fractures, (2) fracturing and partial dissolution of these dolostones (I), (3) two episodes of sulphide precipitation separated by fracturing and brecciation, and (4) extensive replacement of pre-ore dolostones (I) and pore-filling by saddle dolomite (II and III) in association with late fracturing and brecciation. Hypersaline (25 eq. wt. % NaCl), hydrothermal (T_h = 90 to 185°C) inclusion fluids originated from a deep source area. Moreover, the presence of contemporaneous stylolites, evidence of elevated fluid pressures and reconstructed overburden estimates of more than 1000 m also imply burial conditions at the site of ore deposition. Rotated geopetal sediments in ore-stage cavities and displaced ore bodies along faults demonstrate that regional thrusting and uplift at the climax of the Acadian Orogeny post-dated ore deposition.

A deep structural cross-section of the Appalachian Orogen in Newfoundland: Lithoprobe east seismic reflection profiling, 1990

Lithoprobe East transect group

During the summer and early fall of 1990 Capilano Geophysical Company of Calgary recorded around 650 km of multichannel deep seismic reflection profile in three traverses across Newfoundland. Three transects were acquired. The main one - the Meelpaeg Transect - runs from the Bay of Islands through Deer Lake and Buchans to Meelpaeg Lake and Fortune Bay. The Burgeo Transect runs from Stephenville to Burgeo, and the Baie Verte Transect is a relatively short profile across the Baie Verte

Peninsula. In addition to these regional profiles, Capilano also recorded some high resolution profiles for Lithoprobe in the area of the Buchans mines: this work was supported by BP Minerals.

The data are now being processed by Western Geophysical in Calgary. Their final sections are likely to be available to us by mid-year. Processing is in iterative process and so we already have some 'brute' stacks which allow us to view how the processing is going, and also give an initial idea of what the data tells us about deep structure.

In this morning's session, members of the transect group will discuss various aspects of the data acquisition, processing and interpretation. The main emphasis will be on a poster display of the 'brute' stacks, with a guided tour of the sections and open discussion.

Speakers will include J. Hall, J. Wright, H. Williams, S. Colman-Sadd, S. O'Brien and G. Stockmal.

Late Precambrian basement - Silurian cover relationships and tectonostratigraphic affiliations in southern Newfoundland

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In the Hermitage Flexure segment of the Newfoundland Appalachians, a Silurian cover sequence, disposed in elongate fault-bounded basins, rests unconformably on a late Precambrian basement. The cover basins, which consist of 430-420 Ma fluvial clastic and subaerial felsic volcanic rocks (La Poile Group), exhibit strong, coincident, thermal and strain gradients increasing from depocenter to margins. An upright to recumbent structural transition in the La Poile Group reflects inhomogeneous, thrust sense, simple shear deformation. Regional high-T, low-P dynamothermal metamorphism produced hornfelsic schists near synkinematic granites that are preferentially intruded near basin margin faults. Where younger granites intrude the cover, static hornfelses are typical. The sub-La Poile Group basement includes a variety of late Precambrian, Cambrian and Ordovician rocks that record evidence of at least two pre-Taconian orogenic events. The oldest component of this basement is the Grey River-Cinq Cerf gneiss (post-686 +33/-15 Ma; pre-580 ± 10 Ma), a complex of amphibolitic gneiss, migmatite, hornblendite and metagabbro. During Silurian remobilization, these rocks were thrust imbricated with the La Poile cover, variably re-metamorphosed, and intruded by synkinematic granites. These events essentially completed fragmentation of a once-contiguous late Precambrian basement block.

Earliest metamorphism of the Grey River-Cinq Cerf gneissic basement post-dates Grenvillian metamorphism of Humber Zone basement inliers and is broadly synchronous with tectono-magmatic events in the Avalon Zone. The Dunnage Zone, which does not contain strata older than Cambrian, occurs in the western Hermitage Flexure, overthrust by late Precambrian basement. Field relationships indicate that Dunnage (and Gander) Zone rocks were never deposited on this crystalline basement, where Ordovician rocks do not intervene between basement and Silurian cover. However, the presence of detritus of possible late Precambrian basement affinity in the Ordovician rocks suggests their original proximity.

The Deer Cove mesothermal lode gold deposit, Baie Verte Peninsula, Newfoundland

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There are metallogenic, lithological, geochemical and tectonic similarities between the Mother Lode Gold District of California and the Baie Verte Belt associated with the Baie Verte-Brompton Line (BVBL) in the Newfoundland Appalachians. The boundary (suture) between the Humber and Dunnage zones of this orogen is defined by the BVBL which constitutes the most significant structure on the Baie Verte Peninsula. The Point Rousse Complex (PRC) is part of the Baie Verte Belt and consists of variably altered and deformed remnants of an ophiolitic suite; including ultramafics, gabbros and sheeted diabase dykes, and a cover sequence of mafic volcanic, volcaniclastic and sedimentary rocks. The Deer Cove Deposit is located within the PRC and consists of gold-bearing quartz veins in mafic volcanic and fragmental rocks and gabbro belonging to the cover sequence. These mafic rocks structurally overlie serpentinized and talc-carbonate altered ultramafic rocks. A listwaenite genetic model had been proposed for the mineralization which suggested that gold was derived from the ultramafic rocks during talc-carbonate alteration by external hydrothermal fluids and that the fluids migrated along fault planes to subsequently deposit the gold in the overlying mafic rocks. Newly derived geochemical data (K/Rb, K/Ba and Ba/Rb ratios) for altered wall rocks, however, are consistent with ore fluids having been derived from a crustal reservoir. ^{18}O and ^{13}C isotope ratios (-9.5 to -12.5 permil, and -8 to -4 permil, respectively) for carbonate separates are the same as those found in typical mesothermal lode gold systems; and the calculated ^{18}O ratios of the hydrothermal ore fluid are +4.5 to 8 permil.

Structural setting of Pb-Zn-Cu-Ag mineralization in the northern Purcell Anticlinorium, southeast British Columbia

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The Toby-Horsethief Creek area in the northeastern Purcell Mountains, SE British Columbia contains more than 80 base-metal deposits. These range from small high-grade silver-rich vein systems to deformed manto deposits, hosted by Helikian through Devonian strata of the Purcell Anticlinorium. This part of the Purcell Anticlinorium forms a northwest-plunging antiformal stack of metasediments, penetratively deformed by two fold events and bound by major east-verging thrust faults. Stratigraphic relationships indicate that this area evolved as a high-standing block (the Windermere High) on the terraced passive margin of ancestral North America.

Two distinct end-members from a spectrum of deposit types may be recognised: Type 1 - Stratabound MVT, Manto Type and disseminated stratiform Pb-Zn-(Ba-Cd) 'passive margin setting' deposits; and Type 2 - stratabound Ag-Cu-Pb vein 'collision setting' deposits. Mineralisation occurs below permeability barriers generated by the interaction of syndepositional faults and key regional unconformities which were formed around the margins of the Windermere High. Syndepositional extensional faults controlled the loci of early 'passive margin' mineralisation and these, upon inversion, also controlled the location of many later 'collisional' vein deposits.

The stratigraphy of the Alberta foreland basin: an interpretation in terms of Cordilleran tectonics

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An idealized foreland basin sequence resulting from a discrete terrane accretion event can be derived qualitatively from existing quantitative geodynamic models of the mechanical linkage between overthrusting and foreland basin subsidence. Such an idealized sequence is unconformity bounded and shallows upward, but deviations are anticipated also. Using this idealized sequence as a template, the generalized stratigraphy of the Alberta foreland basin can be divided into six discrete clastic wedges: (i) Fernie-Kootenay, (ii) Mannville, (iii) Dunvegan, (iv) Belly River, (v) Edmonton, and (vi) Paskapoo. These are seen to correlate strongly in time with the accretion of two superterranes and the four other principal terranes recognized in the Canadian Cordillera: (i) Intermontane superterrane, (ii) Bridge River, (iii) Cascadia, (iv) Insular superterrane, (v) Pacific Rim-Chugach, and (vi) Olympic, respectively. The implication is that each accretion event resulted in deposition of a recognizable clastic wedge in the foreland. However, all terranes but the first, the Intermontane superterrane, are too distant from the basin to have directly influenced foreland subsidence through lithospheric flexure. All subsequent accretions must have influenced the foreland indirectly by cratonward displacement and thickening of earlier accreted terranes and the telescoped pre-existing miogeocline.

Crustal structural relations on Port au Port Peninsula, western Newfoundland: insights from seismic reflection data, and implications for allochthoneity in the Humber Zone

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Structures associated with the Acadian deformation front in western Newfoundland are exposed on Port au Port Peninsula and are imaged on petroleum industry marine multichannel seismic reflection lines located 25 to 75 km NE of the peninsula. Field and seismic data support interpretation of the deformation front as a structural "triangle zone", characterized by an upper thrust detachment with a sense of vergence (SE) opposite to that of the orogen as a whole (NW). This upper detachment, in the Port au Port area, appears to preferentially lie at the base of the Late Ordovician (post-Taconian) Long Point Group, structurally separating the Long Point-Clam Bank succession from the underlying Humber Arm Allochthon. The Lourdes Limestone of the Long Point Group, seen on the seismic data to overlie the foreland succession in the offshore (conformably?), contain wide (up to 3

m) near bedding-parallel deformation zones dipping moderately NW with clear duplication locally. The critical basal contact with the Humber Arm Allochthon was dug out revealing a sharp uneven surface with strong down-dip slickenside striations. The Humber Arm rocks were highly sheared green plastic mudstones with a mm-scale anastomosing "scaly fabric". As strongly suggested by the seismic data, we interpret this contact as a thrust, not an unconformity as long believed. These relationships imply substantial Acadian transport of "autochthonous" platform carbonates and overlying rock in western Newfoundland.