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PRELIMINARY GEOCHRONOLOGICAL, GEOCHEMICAL AND ISOTOPIC STUDIES OF AURIFEROUS SYSTEMS IN THE BOTWOOD BASIN AND ENVIRONS, CENTRAL NEWFOUNDLAND

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ABSTRACT

Gold exploration within the Botwood basin began in the late 1980s, and subsequently several styles of mineralization were recognized in the region, including low-sulphidation epithermal and orogenic (or mesothermal) lode types. More recently, the presence of possible Carlin and intrusion-related styles has been postulated. With the recognition of the basin as a host to a variety of gold occurrence types, it has become essential to understand the area's geological history and the inter-relationships of the occurrence types. The objective of this project is to study and compare 20 gold occurrences from within the basin and the immediate surrounding rocks, and also to determine if regional intrusive suites (granitic to gabbroic) were related to the ore-forming systems, i.e., acting as heat sources that drove ore fluids, or simply as rheologically contrasting host rock-types. This paper presents preliminary S-isotope, geochemical and geochronological results for a subset of occurrences and rocks found within, and adjacent to, the basin.

Preliminary conclusions from this study indicate that: 1) there are wide ranges in sulphur isotope ratios for sulphide mineral separates from different occurrences and the dominant control appears to be the lithological source of the sulphur, e.g., occurrences within deep-marine sedimentary rocks are negative in terms of $\delta^{34}S$, occurrences in proximity to intrusive suites are around 0‰, and occurrences in which S was derived from igneous rocks have ratios that are slightly to moderately positive in terms of $\delta^{34}S$; 2) trace-element compositions suggest that pyrite from the Mustang and Bowater prospects resemble Carlin-type pyrite, pyrite from the Bruce Pond epithermal prospect resembles that of low-sulphidation epithermal types, and pyrite from the Stog'er Tight orogenic lode-gold occurrence is not notably enriched in trace-metal contents; and 3) geochronological data indicate a common ca. 430 to 424 Ma age for granite to gabbro plutonism in the Botwood basin. Zircon inheritance in the granitoid rocks suggests that they were generated through crustal anatexis of lower crustal material by mantle-derived gabbroic melts. This magmatism may have provided the energy to drive at least some of the auriferous mineralization systems in the Botwood basin and vicinity.

INTRODUCTION

The Botwood basin (or belt) comprises middle Paleozoic cover sequences deposited on dominantly Ordovician rocks of the eastern Dunnage Zone, central Newfoundland (Figure 1). It is being actively explored for its potential gold resources by several mineral exploration companies. This study focusses on the examination of auriferous systems within the basin and environs from the perspective of developing metallogenic models based on documentation and definition of mineralization styles. The major questions to be answered are, whether there are different types of auriferous systems present in the basin and environs, such as orogenic (cf. Bierlein and Crowe, 2000; Groves *et al*., 1998, 2003), low-sulphidation epithermal (cf. Cooke and Simmons, 2000; Hedenquist *et al*., 2000), intrusion-related (cf. Lang *et al.*, 2000; Thompson and Newberry, 2000) and/or Carlin-type (cf. Arehart, 1996, 2000, 2003; Hofstra and Cline, 2000), and, if present, how are these different types related to each other and the geological evolution of the region?

Numerous pyrite ± arsenopyrite-bearing gold occurrences have been discovered in the region since the late 1980s (Figure 1; *see* Evans, 1996). Some of these occurrences, in Ordovician rocks, such as the Duder Lake prospects (Churchill, 1994) are of mesothermal–orogenic style having strong carbonate alteration and fluid inclusions (Flinc) containing CO_2, T_{HOMO}'s of 250 to 400°C and low salinities, whereas, others on the western and southern margins of the basin, such as the Moosehead (Dalton, 1998) and Rolling Pond (Turmel, 2000) are of low-sulphidation epithermal style with high-level brecciation and Flinc with T_{HOMO}'s of 200 to 325°C and even lower salinities. A

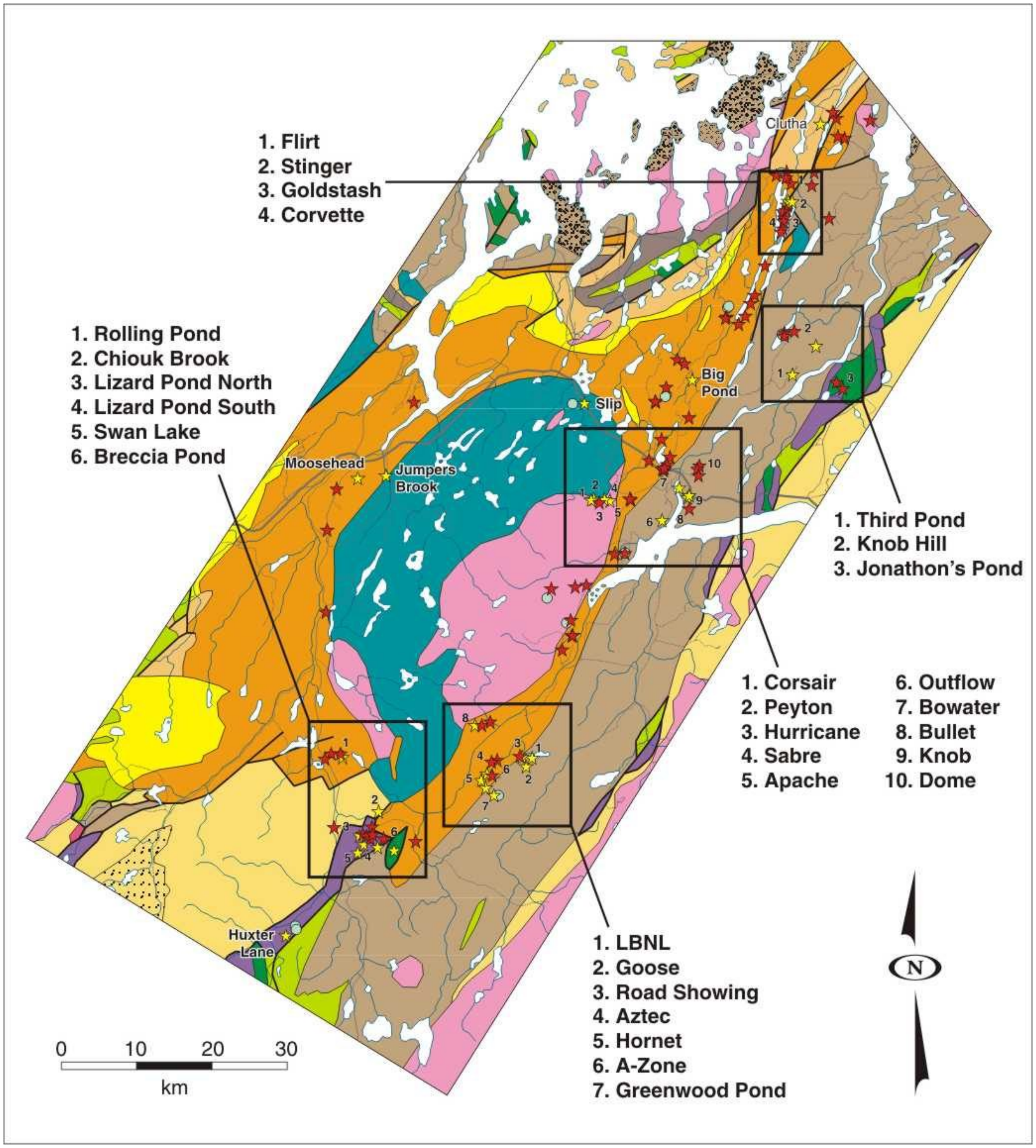

Figure 1. *Generalized geology of the Botwood basin and environs, and specific locations of auriferous showings sampled for this study (yellow stars), showings from which sulphur/isotope ratios have been determined for sulphide minerals (red stars), and location of geochronological samples (green circles). Geology from Colman-Sadd and Crisby-Whittle (2002).*

hypothesis recently advanced by Altius Minerals Corporation (Butler, 2003) suggests that some of the occurrences on the eastern side of the basin are Carlin-style, in that they are hosted by carbonaceous shales and limestones of the Indian Islands Group (IIG). In this scenario, the IIG was overthrust by the Ordovician Davidsville Group.

LEGEND (Figure 1)

POST-ORDOVICIAN OVERLAP SEQUENCES

Silurian

Bimodal to mainly felsic subaerial volcanic rocks; includes unseparated sedimentary rocks of mainly fluviatile and lacustrine facies

Shallow marine and non-marine siliciclastic sedimentary rocks, including sandstone, shale and conglomerate

DUNNAGE ZONE

Stratified rocks

Middle and Late Ordovician

Llandeilo to Ashgill black shale, slate and argillite, including subordinate chert and greywacke

Cambrian to Middle Ordovician

Melange, containing sedimentary and volcanic blocks of Cambrian to Ordovician age

Marine siliciclastic sedimentary rocks, including slate, shale, argillite, siltstone, sandstone, conglomerate, and minor unseparated carbonate, volcanic and intrusive rocks, and schist, gneiss and migmatite

Submarine mafic, intermediate and felsic volcanic rocks, including mafic volcanic rocks of ophiolite complexes; includes unseparated intrusive, sedimentary and metamorphic rocks

Intrusive rocks

Cambrian and Ordovician

Mafic intrusions, including unseparated granitoid rocks, and gabbro, diabase and trondhjemite of ophiolite complexes

Ultramafic rocks of ophiolite complexes

POST-ORDOVICIAN INTRUSIVE ROCKS

Silurian and Devonian

Gabbro and diorite intrusions, including minor ultramafic phases

Posttectonic gabbro-syenite-granite-peralkaline granite suites and minor unseparated volcanic rocks (northwest of Red Indian Line); granitoid suites, varying from pretectonic to syntectonic, relative to mid-Paleozoic orogenies (southeast of Red Indian Line)

GANDER ZONE

Stratified rocks

Cambrian (?) and Ordovician

Quartzite, psammite, semipelite and pelite, including minor black slate, conglomerate, limestone, mafic and felsic volcanic rocks, and unseparated migmatitic rocks

Migmatitic schist, gneiss, and minor amphibolite, derived in whole, or in part from Cambrian(?) and Ordovician protoliths

Intrusive rocks

Ordovician

Granite intrusions

This study is based on detailed mapping and sampling; the results reported herein are preliminary and further analytical work is ongoing. In excess of 200 whole-rock samples have been collected including: 1) mineral occurrences and host rocks (minimum of three samples per showing), 2) regional rock types, 3) samples for geochronology, and 4) fossiliferous samples for paleotonological dating. Laboratory data derived to-date are reported here and include: 1) sulphur/isotope ratios for sulphide mineral phases, 2) trace-element contents of pyrite (and other sulphide mineral) grains, especially the so-called "toxic-element suite" that include As, Se, Pb, Sb, Te, and 3) geochronology of the host rocks. These data indicate that the auriferous systems are not simple and that different geochemical–geochronological signals are apparent. This project will continue as an M.Sc. study by the senior author at the Department of Earth Sciences, Memorial University. The analytical work has, and will be, conducted at the laboratories of the Department of Earth Sciences, Memorial University. Some of these results will be published as an Open File report submitted to the Geological Survey, Newfoundland and Labrador Department of Natural Resources.

The Botwood Basin

During exploration of this region by geologists working with Noranda Exploration Ltd. in the late 1980s (e.g., Tallman, 1989), this part of central Newfoundland was considered to consist of contrasting Ordovician deep-marine sedimentary units of the Davidsville Group, and Silurian, in part terrestrial redbed, sedimentary rocks of the Botwood Group. Blackwood (1982) suggested that the Botwood Group conformably overlies the Davidsville Group, but that the contact near Glenwood was in part nonconformable. In defining the depositional environments of the two sequences, Blackwood (*op. cit.*, p. 48) stated that "the Davidsville and Botwood groups seem to represent a submarine fan with distal deposits in the east (i.e., Davidsville) and proximal deposits in the west (i.e., Botwood)".

Subsequent work by Williams *et al.* (1993) in the Gander Bay region resulted in a considerable revision to the regional stratigraphy. These authors defined a major Silurian tectonic boundary that they termed the Dog Bay Line. To the east of the line, minor red sandstones overlie shallow-marine shales and limestones and the complete sequence constitutes the IIG; the limestones contain Silurian brachiopods and crinoids. According to Williams *et al.* (*op. cit.*), the contact between the IIG and underlying Ordovician shale–greywacke ranges from apparently conformable to either faulted or structurally conformable. To the west, they grouped the rocks into the Botwood belt, within which the Silurian redbeds and volcanic rocks were assigned to the Botwood Group and the regionally conformable, but locally fault-bounded, underlying Late Ordovician–Early Silurian turbiditic sequences were termed the Badger Group. The Dog Bay Line, thus, is defined as the boundary between the Botwood and Indian Islands tectonostratigraphic belts (Williams *et al.*, 1993). The IIG shallow-marine shales and limestones separate the deep-marine Davidsville Group from the continentally derived Botwood Group redbeds. The Botwood basin comprises the Botwood and Indian Islands tectonostratigraphic belts.

RESULTS

S-ISOTOPE DATA

Interpretation of sulphur/isotope ratios for sulphides associated with auriferous mineralization is difficult unless the isotopic compositions of regional rock types and local Redox relationships are understood. For instance, different gold deposit types define wide ranges and/or non-diagnostic ratios. Bierlein and Crowe (2000, p. 121) suggest that while sulphides in most Phanerozoic orogenic lode-gold deposits occurrences "cluster around 0‰", sediment-hosted deposits such as the Meguma in Nova Scotia can have ratios of up to +10 to +30‰ (after Kontak and Smith, 1993).

In Carlin-type gold deposits, S-isotope variations can be even more extreme. A compilation of sulphur–isotope data by Hofstra and Cline (2000) indicates that ratios range from 0 to +17‰ in main ore stages of Carlin deposits, but can be as low as -32‰ in distal edges of ore-forming systems. Arehart (2003) defined pre-ore pyrite as having sulphur/isotope ratios between -5 and +10‰, main ore pyrite as up to +20‰, and post-ore pyrite as -15 to -30‰. Ion microprobe analysis of individual pyrite grains from the Carlin deposits (Arehart *et al*., 1993) indicated that primary pyrite in host igneous rocks had isotope ratios of ~9‰, whereas primary sedimentary pyrite had ratios of -4 to -6‰. Auriferous arsenian overgrowths on ore-zone pyrites had ratios up to +20‰ and in later non-auriferous arsenian overgrowths the sulphur/isotope ratios were -12 to -29‰.

Previously derived sulphur–isotope data (Churchill, 1994; Dalton, 1998; Evans and Wilson, 1994; Greenslade, 2002; D. Evans, personal communication, 2005; D. Wilton (unpublished data)) compiled for occurrences in the region indicate a very wide range in ratios for pyrite, arsenopyrite and/or stibnite mineral separates (Figure 2). At the simplest level, the compiled data can be subdivided into three different groups based on their isotopic ratios as: 1) a group with negative (or isotopically light) $\delta^{34}S$ ratios, 2) a group with ratios around 0‰, and 3) a group with positive (isotopically heavy) ratios.

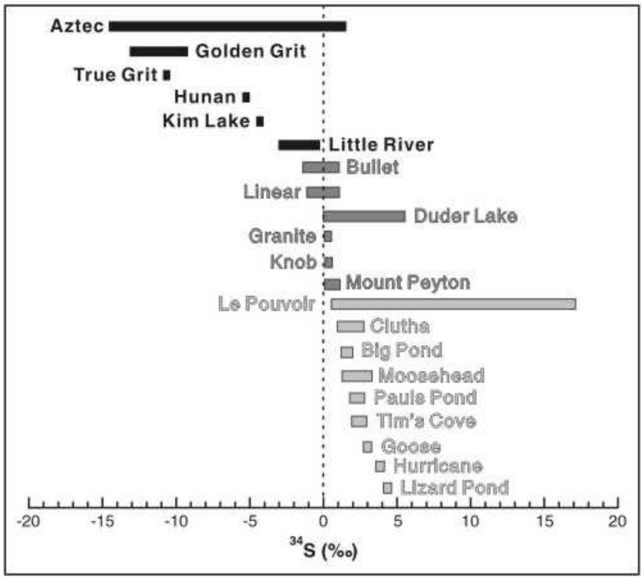

Figure 2. *Compilation of sulphur–isotope data for sulphide-mineral separates from auriferous occurrences of the Botwood basin; data complied from Churchill (1994), Dalton (1998), Evans and Wilson (1994), D. Evans (unpublished data, 2005), Greenslade (2002) and unpublished data from D. Wilton.*

The sulphides that constitute the isotopically light group are from showings hosted within the dominantly sedimentary Baie d'Espoir Group (i.e., Golden Grit, True Grit, Kim Lake and Little River). These negative ratios probably reflect a sedimentary source for the sulphur. Exceptions are the separates from the Aztec Showing and Hunan (Beaver Brook) mine. The Aztec material has a wide range of ratios, up to and including slightly positive ratios. This particular showing is quite complex because it is hosted by mixed sedimentary rocks having a wide range of sulphide paragenetic relationships (Wilton, 2003). The Hunan (Beaver Brook) stibnite was obtained from large quartz-filled veins in the Indian Islands Formation (?) (cf. Colman-Sadd and Crisby-Whittle, 2002).

The intermediate (ca. 0‰) group includes sulphides from showings near the contact with the Mount Peyton Intrusive Suite, and thus may indicate a magmatic input to the sulphur. Sulphur in the mineral separates from the group with slightly to moderately positive (isotopically heavy) isotope ratios are, at least in part, derived from ultramafic (e.g., Lizard Pond), mafic (e.g., Clutha, Lizard Pond) and granitic–granodioritic (e.g., Tim's Cove, Hurricane) host rocks. The Le Pouvoir separates, however, are hosted by the Baie d'Espoir Group sedimentary rocks and also plot with this group.

The new, albeit preliminary, sulphur/isotope results for samples collected in this study are listed in Table 1 and indicate a wide range in values similar to those in the compiled data on Figure 2. The greatest variations are in the samples from Jonathon's Pond and Breccia Pond; most of the other samples are similar to the intermediate (~0‰) group. The Breccia Pond sample was derived from an ultramafic-hosted occurrence and its sulphur/isotope ratios match those of the nearby Lizard Pond occurrence, both associated with the ultramafic rocks of the Great Bend Complex (Colman-Sadd and Swinden, 1984; Dickson, 1992). The Jonathon's Pond occurrence is located well within the Davidsville Group Zone and its noticeably isotopically light ratio (-8.2‰) indicates the sulphur was derived from a reduced sedimentary source (i.e., the deep-marine Davidsville Group turbidites).

Table 1. Preliminary S-isotope data

Sample	Prospect	Mineral	$\delta^{34}S$ (‰)
JOD97B	Corvette	Pyrite	-0.02
JOD82A	A-Zone	Pyrite	1.28
JOD117	Jonathon's Pond	Pyrite	-8.20
JO23	Hurricane	Pyrite	3.80
JOD110	Dome	Pyrite A	0.57
JOD110	Dome	Pyrite B	0.41
JOD80A	Breccia Pond	Pyrite	7.11
JOD26B	Slip	Arsenopyrite	2.93

TRACE-ELEMENT ANALYSES OF PYRITE

Trace-element analyses were conducted on pyrite from four separate auriferous occurrences to ascertain whether there was a definable distinction between deposit types. The analyses were completed using the Laser Ablation Microprobe-Inductively Coupled Plasma-Mass Spectrometer (LAM-ICP-MS) in the Department of Earth Sciences, Memorial University. Pyrite grains in single polished thin sections were analysed. The technique has been described by Hinchey *et al.* (2003), except that in this case the internal standard was MASS1, a United States Geological Survey pressed-powder pellet, rather than a FeS standard.

From within the Botwood basin, pyrite grains were analysed from the Mustang and Bowater properties (samples W90-49b and W90-48, respectively); these samples were collected by D. Wilton during field work with D.T.W. Evans in 1990. These same samples were chosen to represent postulated "Carlin-style" occurrences. Sample W89-82 from the Stog'er Tight prospect, Baie Verte Peninsula (Ramezani *et al*., 2000) was selected as a representative of orogenic (or mesothermal) lode-gold occurrences. Sample KP-32-H1 is from the Gallery Resources Ltd. Bruce Pond epithermal system, located about 15 km south of the Huxter Lane showing (Figure 1), and the bladed pyrite crystals in the sample are interpreted to have been produced in a low-sulphidation epithermal system. None of the samples contained visible gold.

The derived geochemical data are listed on Table 2 and indicate (Figure 3) significant differences between the deposit types. Although Au was detected in most samples, it was not present as micro-nuggets or inclusions and thus was "refractory" (i.e., held within the sulphide crystal lattice; *see* Hinchey *et al.* (2003) and references therein). For instance, the Mustang pyrites contain much higher Au, As, Sb and Pb contents than all other samples. The Bowater pyrites contain lower concentrations of these elements, but they are still more enriched than in the epithermal or orogenic samples. The Bruce Pond pyrites contain the highest concentrations of Se; the pyrite crystals in this sample also had very elevated local Ba concentrations that essentially tripped the LAM-ICP-MS detector. The orogenic pyrite contained the highest concentrations of Te, whereas most other elements in the grains were below detection limits.

These data suggest that there are fundamental differences between pyrite compositions depending on the type of auriferous occurrence sampled. Arsenic, Sb, Tl, Hg, W, and Te, the so-called "toxic-element suite" (Arehart, 2000, 2003), are typically associated with Carlin-style gold deposits and many of these elements are concentrated in the pyrite grains (Hofstra and Cline, 2000). As defined by this preliminary study, pyrites from the Mustang prospect, and to a lesser extent those from the Bowater prospect, have Carlin-like trace-element signatures and are distinct from the orogenic and epithermal types sampled.

Hedenquist *et al.* (2000) suggest that both Se and Ba are associated with low-sulphidation epithermal gold deposits. In particular, Se is associated with shallow-depth examples. The pyrite grains from the Bruce Pond epithermal occurrence contain appreciable amounts of Se and Ba that distinguish them from the other pyrite samples and which also suggests a correlation between this occurrence and low-sulphidation epithermal examples.

U–Pb GEOCHRONOLOGY

Nine samples, including gabbro, granite, diorite, granodiorite and sedimentary rocks, from throughout the region were prepared for U–Pb zircon geochronological study (*see* Figure 1 for locations); these data were to be generated in an attempt to correlate the different intrusive rocks within the basin, derive detrital ages for sedimentary facies, and, in places, determine maximum ages for local epigenetic auriferous occurrences. The prepared samples were: JOD8, JOD25, JOD39, JOD57A, JOD66A, JOD81A, JOD90A, JOD100 and W03-27. The analyses were completed using the LAM-ICP-MS facility at the Department of Earth Sciences laboratories, following the procedures described by Košler *et al.* (2002).

Sample JOD8 is a clastic fragment from a conglomerate near Bellman's Pond. Two samples, JOD25 and JOD90A, unaltered diorite from the Corsair prospect and granite from Red Rock Brook, respectively, are phases of the bimodal Mount Peyton Intrusive Suite; the Corsair diorite is associated with auriferous mineralization. Sample JOD39 was collected along the contact between the Silurian IIG and shales; it consists of dark, dense material.

Three samples were collected from gabbroic rocks cutting a variety of rock types including Indian Islands, Davidsville and Duder groups north of the Trans-Canada Highway. These include: 1) JOD57A from a gabbroic dyke to the west of Ten Mile Lake defined by Evans *et al.* (1992); 2) JOD66 a metamorphosed gabbro, similar to that which hosts the Duder Lake Prospects, from just north of the Duder Lake prospects; and 3) JOD100 from a gabbroic dyke north of Twin Ponds as mapped by Evans *et al.* (1992).

Sample JOD81A is from a least altered gabbro that hosts auriferous mineralization at the Greenwood Pond #2 showing. W03-27 is a sample of granodiorite from the Charles Cove pluton, which hosts the Tim's Cove prospect, Gander Bay (Evans, 1996).

Of the nine samples prepared, only six contained zircon grains. Three samples, JOD66A, JOD81A, and JOD57A, did not contain zircon, nor any other dateable minerals such as baddeleyite or titanite. More material from these samples will be processed in an attempt to date the rocks.

Geochronology of the Mount Peyton Intrusive Suite

Past attempts to define the age of the Mount Peyton Intrusive Suite (MPIS) have proved very difficult. Bell *et al.* (1977) defined an Rb–Sr age of 390 ± 15 for the MPIS granite. Reynolds *et al.* (1981), on the other hand, defined a 420 ± 8 Ma Ar–Ar age for biotite and hornblende from the gabbro phases. Dunning (1992) dated a pegmatitic gabbro, supposedly from the MPIS gabbro, near Rolling Pond and defined a U–Pb zircon age of 424 ± 2 Ma. Dunning (1994; U–Pb zircon) dated a gabbro phase of the northern MPIS from near Norris Arm at a similar 424 ± 2 Ma age. Mitchinson (2001), however, showed that these gabbro dates were problematical as the Rolling Pond pegmatite is actually part of the geochemically distinct Caribou Hills intrusion that was intruded by the MPIS gabbro.

In 1992, L. Dickson (Geological Survey, Newfoundland and Labrador Department of Natural Resources) collected a sample from a fine-grained, micrographic granite phase of the MPIS granite near Red Rock Brook, close to the faulted contact with sandstone and siltstone. These sedi-

Table 2. Trace-element concentrations in pyrite from the Botwood basin and Baie Verte, Newfoundland (derived by LAM-ICP-MS)

Sample	As (ppm)	Se(ppm)	Sb(ppm)	Te(ppm)	W(ppm)	Au(ppm)	Hg(ppm)	Pb(ppm)
W90-48 Bowater								
je06a03	1085.0	19	74	0.00	0.63	0.04	3.7	25
je06a04	760	29	39	0.00	0.17	0.01	2.8	2.4
je06a05	1257	56	116	0.00	0.12	0.08	2.6	21
je06a06	1359	45	103	0.00	0.11	0.10	1.5	58
je06a07	1189	48	226	0.00	0.15	0.18	2.4	25
je06a08	956	37	92	0.00	0.18	0.03	3.3	32
je06a09	1941	39	175	0.00	0.57	0.87	2.6	142
je06a10	1680	38	294	0.65	0.14	0.72	2.7	126
je06a11	1698	38	300	0.61	0.14	0.73	2.7	128
je06a12	1278	85	156	0.00	0.12	0.23	1.8	83
je06a13	1333	43	117	0.00	0.06	0.22	2.2	29
je06a14	662	67	102	0.00	0.00	0.53	0.85	100
je06a15	3817	57	182	0.00	0.51	1.4	1.7	164
je06a16	1420	59	109	0.00	0.25	0.13	3.0	47
je06a17	1405	91	85	0.00	0.07	0.09	1.3	40
je06a18	2984	110	246	0.00	0.48	1.3	1.9	308
W89-82 Stog'er Tight								
je06b03	1479	5.8	0.05	4.3	0.14	0.02	0.00	2.1
je06b04	2686	8.4	0.07	22	0.00	0.10	0.00	0.47
je06b05	16	111	0.00	1.6	0.00	0.00	0.33	1.2
je06b06	21	60	0.39	3.0	0.20	0.19	0.21	9.2
je06b07	97	119	0.55	5.2	0.12	0.07	0.23	2.8
je06b08	45	32	0.32	6.6	0.00	1.2	0.92	17
je06b09	15	62	0.48	2.8	0.00	0.70	0.31	5.5
je06b10	2384	23	0.04	3.2	0.00	0.04	0.34	0.88
je06b11	33	94	0.10	2.7	0.00	0.04	1.0	4.6
je06b12	24	47	0.08	1.8	0.09	0.00	0.59	0.59
je06b13	20	55	0.00	0.00	0.00	0.02	1.1	0.46
je06b14	26	150	0.00	2.3	0.00	0.06	0.70	2.3
je06b15	18	39	0.00	3.3	0.00	0.02	1.3	0.33
je06b16	32	53	1.19	3.0	48	0.11	0.44	10
je06b17	5.6	16	0.00	0.00	0.00	0.02	1.9	0.12
je06b18	0.00	13	0.54	0.00	0.96	0.42	0.85	1.4
W90-49b Mustang								
je06c03	16779	0.00	173	0.00	0.00	0.66	0.00	108.5
je06c04	16801	0.00	174	0.00	0.00	0.66	0.00	109.5
je06c05	17564	0.00	981	0.00	0.00	0.60	2.6	247
je06c06	12942	65	2699	0.00	0.00	15.2	0.85	6412
je06c07	12473	78	774	5.5	0.44	4.4	0.69	255
je06c08	7301	86	220	0.00	0.43	0.57	1.8	63
je06c09	187	0.00	16	14	0.00	0.09	2.6	80
je06c10	1730	45	24	0.00	0.00	0.28	13.3	85
je06c11	281	68	42	0.00	3.4	0.00	7.5	66
je06c12	194	43	5.5	11	0.00	0.00	12.6	65
je06c13	13960	0.00	517	11	2.5	1.8	0.66	121
je06c14	11547	26	502	0.00	0.41	1.7	1.7	156
je06c15	540	70	1.0	6.3	1.4	0.00	0.00	13
je06c16	7.8	0.00	2.6	7.5	0.00	0.00	0.00	4.9
je06c17	15575	0.00	907	0.00	0.00	0.18	0.88	745
je06c18	31028	38	1084	0.00	0.00	4.9	1.2	1086
KP-32-H1 Bruce Pond								
je06d03	882	90	25	0.00	0.00	0.00	1.8	93
je06d04	306	192	12	5.4	0.00	0.00	0.75	51
je06d05	1663	147	13	0.00	0.00	0.46	0.45	41
je06d06	171	135	8.9	2.9	0.00	0.00	1.2	53
je06d07	402	173	11	3.6	0.00	0.17	1.3	7.9
je06d08	289	250	6.7	1.9	0.51	0.09	1.3	37
je06d09	313	104	12	0.00	0.33	0.20	1.1	45
je06d10	3.2	161	4.5	0.00	0.00	0.00	0.40	20
je06d11	557	32	1345	0.00	1.0	0.00	1.6	0.86
je06d12	509	30	270	0.00	5.5	0.06	1.2	3.3
je06d13	84	0.00	32	0.00	6.9	0.06	0.79	0.18
je06d14	1945	16	506	3.2	0.89	0.14	2.2	0.00
je06d15	535	0.00	1407	0.00	1.3	0.00	2.2	0.12
je06d16	658	0.00	790	0.00	0.85	0.00	1.2	0.09
je06d17	320	327	27	0.00	0.00	0.32	1.3	187
je06d18	545	224	5.0	2.5	0.27	0.15	0.26	23

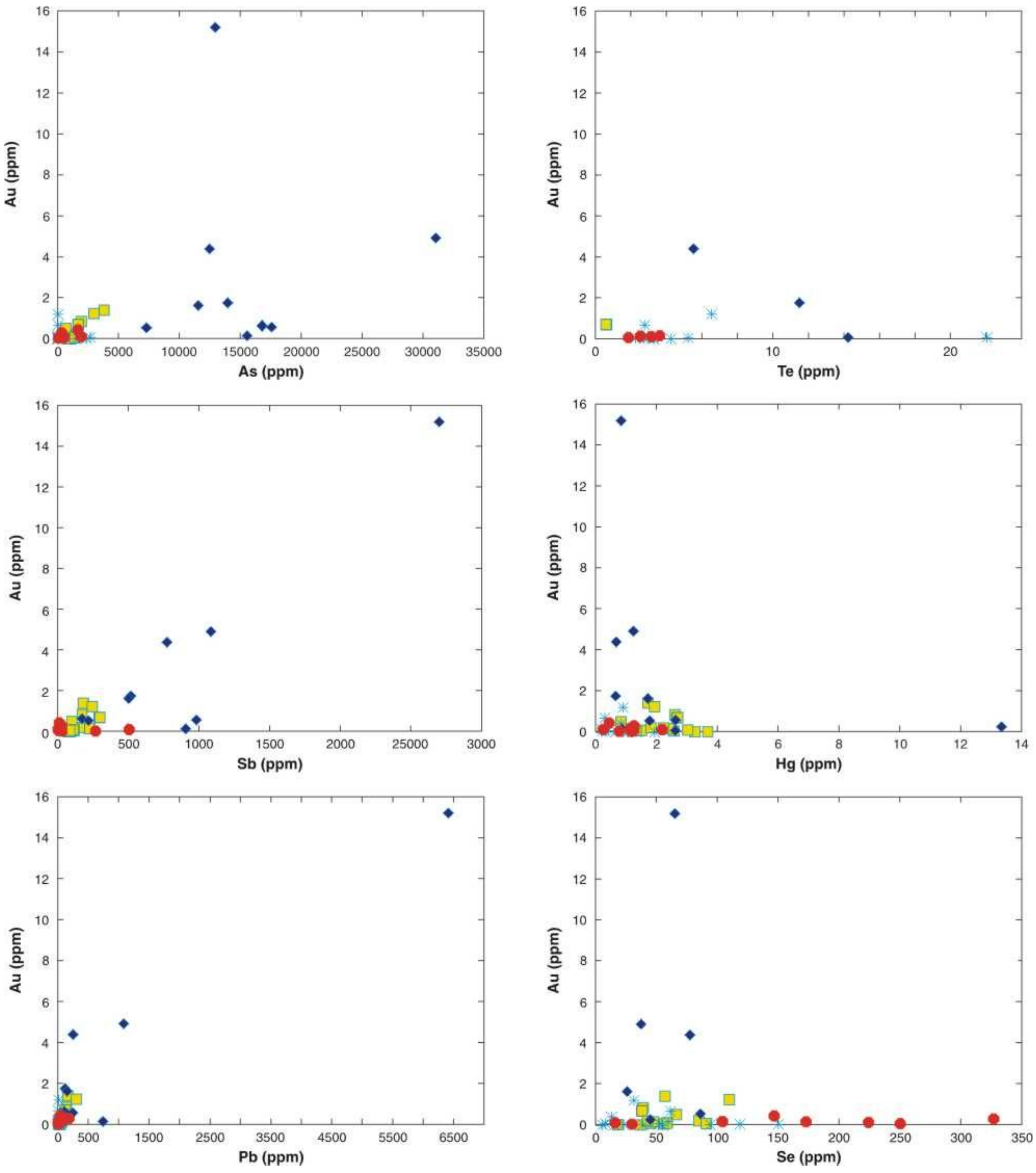

Figure 3. *Trace-element data for pyrites from the Mustang (diamonds), Bowater (squares), Bruce Pond epithermal (circles) and Stog'er Tight (asterisks) prospects. Analysis by LAM-ICP-MS of pyrite grains in polished thin sections; all data reported in ppm.*

mentary rocks have been assigned to the Indian Islands Group (Dickson, 1993; Squires, 2004). Dunning and Manser (1993) analysed five zircon fractions from this sample; they noted that the granite contained significant amounts of small zircon crystals ("prisms"). The resulting U–Pb isotope data suggested two possible age interpretations (Dunning and Manser, *op. cit.*) as: 1) fractions 1, 2 and 3 defined a mixing line (37% probability of fit) that extended from 419 ± 2 Ma to 2680 Ma, which Dunning and Manser (*op. cit.*) dismissed because it required old inherited zircons be present in all three fractions to be correct, and 2) fractions 1, 3, 4 and 5, which yielded a discordia line (56% probability of fit) that intersected concordia at 31 ± 85 Ma and 439.5 +9/-6 Ma. Dunning and Manser (*op. cit.*) preferred this latter age (i.e., 439.5 +9/-6 Ma) for the granite and noted that ^{207}Pb–^{206}Pb ages for the four fractions agreed within error.

L. Dickson (written communication, 2005), however, prefers the 419 ± 2 Ma age on geological grounds. Most especially, the fact that MPIS gabbro is nowhere seen to have intruded MPIS granite and Dunning (1992, 1994) had dated the gabbro at around 424 Ma, thus he feels that the younger, ca. 419 Ma date, is the more geologically consistent.

Corsair Diorite (Mount Peyton Intrusive Suite)

Sample JOD25 is of unaltered diorite from the Corsair prospect at UTM 644408/5425289. Approximately 50 zircon grains were picked from the sample. The crystals are generally elongate, clear, and some have a yellow tint. They range in size from 30 by 30 µm to 50 by 120 µm. A few grains are small and rounded, and some were broken. The zircons were imaged in backscatter electron (BSE) mode on the electron microprobe (EMP) at the Memorial University laboratories. The images obtained indicate that the grains are similar, in that they are generally euhedral and somewhat elongate (Plate 1). No evidence of compositional zoning was indicated by the images. A concordia age of 427 ± 4.2 Ma was calculated for this phase of the intrusion (Figure 4).

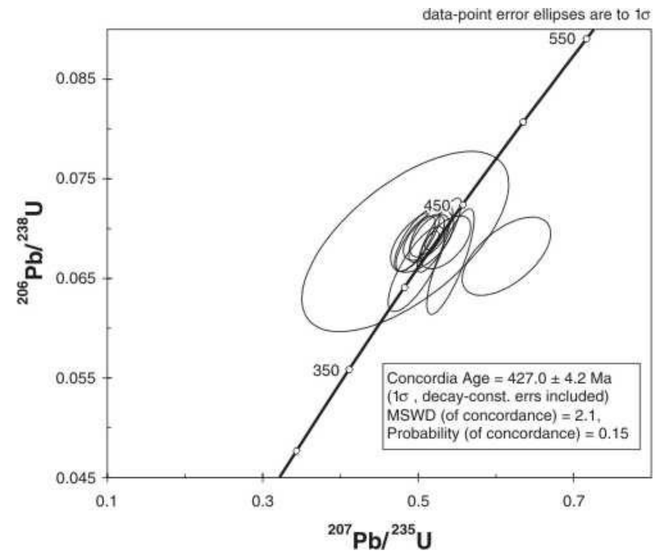

Figure 4. *Concordia diagram for sample JOD25, Corsair prospect; the size of the ellipse represents the error measurement (1 δ) for that particular analysis.*

Twin Ponds Gabbro

Sample JOD100 was collected from an elongate gabbroic dyke mapped by Evans *et al.* (1992) north of Twin Ponds at UTM 652973/5438288. There are actually several gabbro outcrops in this area (previously mapped as a single large intrusion) that appear to be of the same intrusive suite. Approximately 40 zircon grains were picked from the sample and the grains were generally euhedral (some broken). Some zircons contain small inclusions and exhibit slight compositional zoning. The grains range in size from 40 by 40 µm to 80 by 120 µm and in colour from pale yellow to clear, with a lesser amount of very pale pink zircons. BSE-EMP images indicate that some grains have what appears to be oscillatory compositional zoning, but generally the grains are homogeneous and no inherited cores were detected (Plate 2). A concordia age of 429.3 ± 4.4Ma was obtained on the LAM-ICP-MS (Figure 5), corresponding to the age obtained from the unaltered MPIS diorite at the Corsair prospect. This age suggests that this gabbroic intrusion could be related to the MPIS.

Charles Cove Pluton (Tim's Cove Prospect)

The Tim's Cove prospect consists of a long (>1 km), undeformed quartz vein ranging from 0.6 to 4.5 m wide that lies within the Charles Cove pluton (Evans, 1996). This granodiorite intruded both the Silurian IIG and the Ordovician Davidsville Group near their mutual contact. There has been some debate as to what constitutes the actual host unit to the granodiorite as Currie (1995) mapped the pluton as being surrounded by Davidsville Group rocks. Re-mapping of the area in 2003 indicated that the unit that Currie (*op. cit.*) mapped as IIG on the shoreline is the same unit found along the eastern margin of the granodiorite. Wilton and Taylor (1999) indicated that granodiorite slightly hornfelsed the IIG siltstones and hence is younger.

Geochronological analysis of this pluton was conducted because of

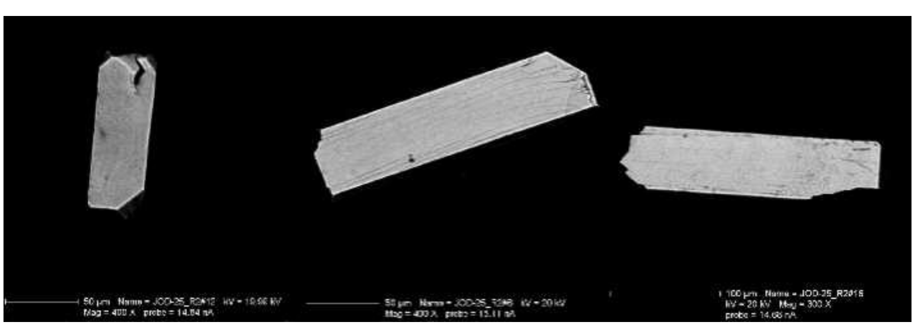

Plate 1. *BSE–EMP images of zircon separates from JOD25.*

its auriferous nature and because it is the single largest felsic intrusion in this region of the Botwood basin. Sample W03-27 was collected at UTM 681434/5475798.

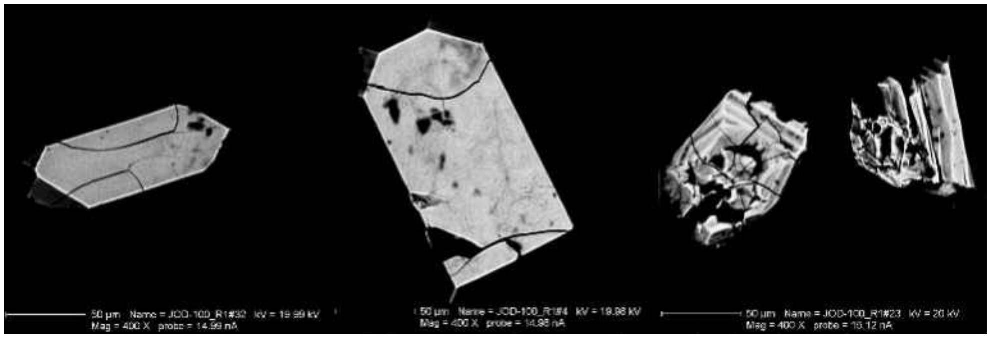

Plate 2. *BSE–EMP images of zircon separates from JOD100.*

The LAM-ICP-MS analyses of zircon separates from the granodiorite define a Late Silurian discordia age of 429 ± 19 Ma (Figure 6a) with an upper intercept on the order of 1850 Ma. The discordia line suggests a mixed population of zircons from the ca. 429 Ma group to very old Proterozoic ones. The low precision of the date results from the younger zircons not plotting on concordia (Figure 6b) and thus indicates, at least partial, inheritance from older zircons. The data imply that the granodiorite magma either inherited Proterozoic zircons enroute to intrusion or was derived as a partial melt of Proterozoic crust with relict zircon grains.

More detailed work is required to refine the upper intercept and hence possible basement rocks to this part of the Dunnage Zone. In a study of detrital zircons from the Gander Bay region, D. Wilton (unpublished data, 2005) and J. Pollock (unpublished data, 2005) report a zircon with an age of 1843 Ma from the IIG that they suggest may have been derived from the Makkovik Province, Laurentia. Murphy *et al*. (*in press*) describe the presence of ca. 2050 to 1900 Ma Eburnian crust in the West African Craton.

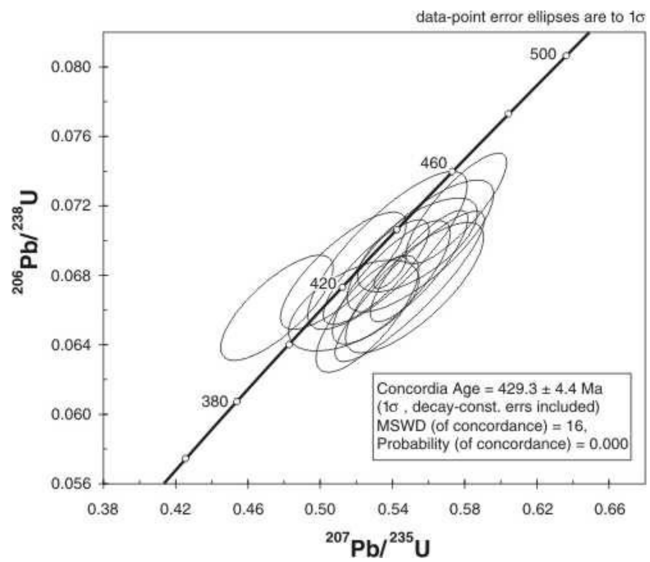

Figure 5. *Concordia diagram for sample JOD100, Twin Ponds gabbro; the size of the ellipse represents the error measurement (1 δ) for that particular analysis.*

Red Rock Granite (Mount Peyton Intrusive Suite)

Sample JOD90A was collected from the MPIS granite at Red Rock Brook. Approximately 40 clear to pale pink, subhedral, elongate and broken zircon grains were picked from the sample. The grains range in size from 40 by 30 µm to 60 by 120 µm. BSE analyses did not reveal any evidence of inherited cores but there is some degree of compositional zoning and inclusions are present in several grains (Plate 3). The data define a discordia age of 424 ± 24 Ma (Figure 7). The range in the data would appear to result from the zircon having mixed Pb contents with magmatic zircon from the actual granite magmatism and inherited older zircon. As shown by Dunning and Manser (1993), geochronological systematics in the granite phases of the MPIS are very complex and more work is required to better define the ages of the granite magmatism and inherited material.

Contact between Davidsville and Indian Islands Groups

Sample JOD39 was collected at the contact between the Silurian IIG and shales that, in outcrop, resemble either the Ordovician Davidsville Group or the Caradocian Shale. The contact appears to be gradational between the two units, as brown silty layers, similar to those in the IIG are interbedded with the shale unit. The sample was collected from a dark, dense rock within a shale unit originally thought to be a mafic dyke. Petrographic analysis indicates that the rock is actually a sedimentary rock composed of unaltered clast-supported, sand-sized grains of plagioclase feldspar and quartz; the source appears to have been gabbroic. Approximately 30 zircon grains were picked from the sample and, in general, the grains are mainly small and euhedral, along with some elongate crystals. The grains range in size from 20 by 20 µm to 60 by 100 µm. Minor compositional zoning was noted on some of the wider grains and a few of the grains contain small inclusions. Two different ages were obtained from the analysis (Figure 8). One group of grains yield average concordia ages of 472 ± 8.5 Ma and one grain was dated at ca. 900 Ma. D. Wilton (unpublished data, 2005) and J. Pollock (unpublished data, 2005) report detrital zir-

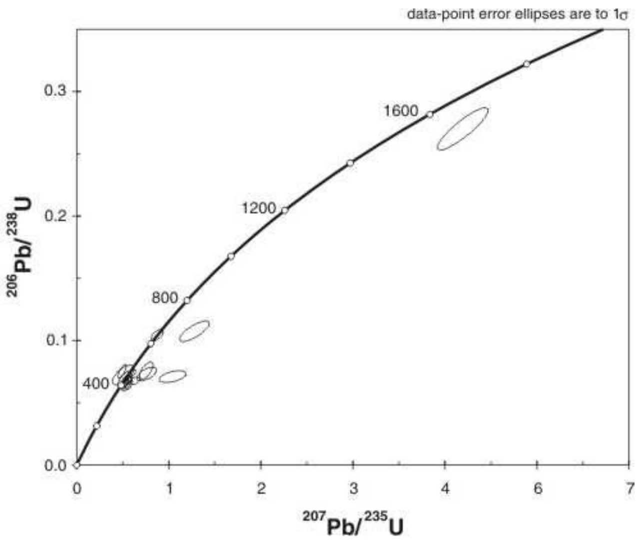

Figure 6a. *Full data set and concordia diagram for sample W03-27, Charles Cove pluton; the size of the ellipse represents the error measurement (1 δ) for that particular analysis.*

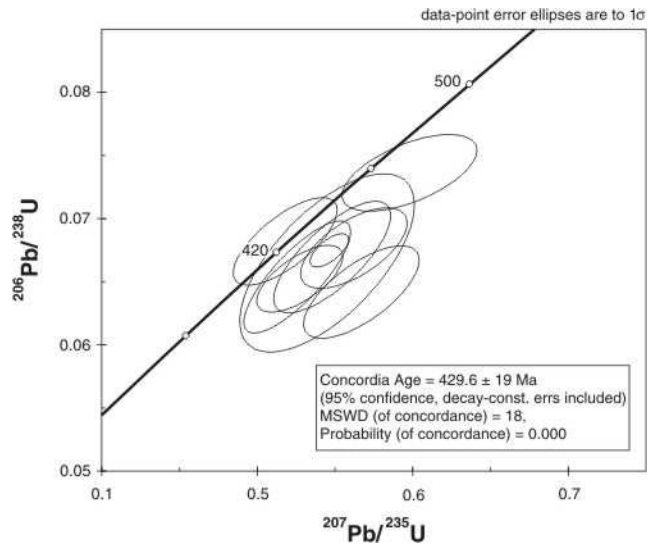

Figure 6b. *Concordia diagram for sample W03-27, Charles Cove pluton; the size of the ellipse represents the error measurement (1 δ) for that particular analysis.*

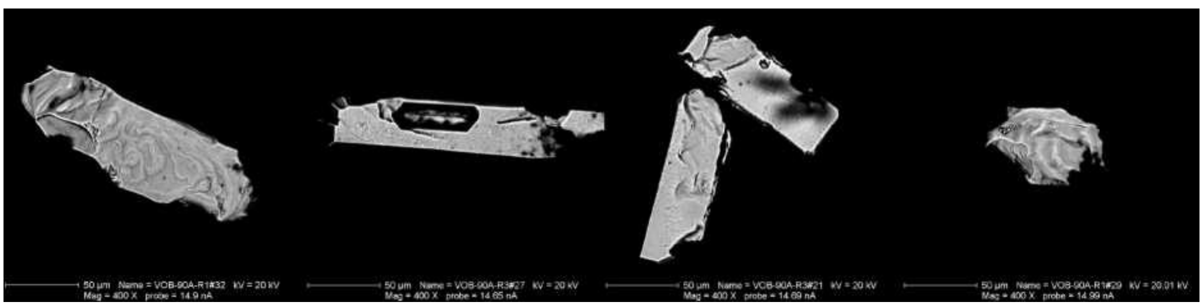

Plate 3. *BSE–EMP images of zircon separates from JOD90A.*

cons from the Davidsville Group with ages from 507 to 449 Ma and 964 to 886 Ma; thus this detrital sample probably belongs to the Davidsville Group. The detrital grains are obviously older than the MPIS intrusives and reflect derivation from pre-Silurian gabbroic intrusives. Boyce *et al.* (1993) had previously mapped the shales as Davidsville Group.

Bellman’s Pond Conglomerate Clast

A small sliver of conglomerate crops out along the eastern shoreline of Bellman’s Pond within Davidsville Group shale–siltstone. The conglomerate has been variously mapped as a thrust slice of Davidsville Group (Evans *et al*., 1992) or a later Devonian unit (Currie, 1995). Thus, determination of the age of the conglomerate might aid in unraveling the structural history of the Davidsville–Indian Islands contact. The unit varies from locally matrix-supported to predominately clast-supported. The clasts are rounded to subrounded, consisting mainly of red and green siltstone, red sandstone, limestone and volcanics(?). The matrix consists of reddish sandstone. Although the contact was not exposed, the conglomerate is assumed to be in contact with interbedded Davidsville Group sandstone and siltstone mapped to the northeast of the outcrop.

Sample JOD08 is a clast from the conglomerate at UTM 670009/5447133 that has an intense green carbonate alteration and abundant sulphides. The sample was rather poor in zircon containing only four very small, pink and rounded grains. When collected in the field, the clast was thought to be a volcanic fragment, but petrographic examination indicates that the rock is an altered sediment; thus the zircon grains collected are detrital in origin. These grains as analyzed by the LAM-ICP-MS yielded several very old ages from the mid Proterozoic ca. 1775 to 1550 Ma (Figure 9). These detrital ages far exceed the Paleozoic age of the host conglomerate but forcefully illustrate the ancient crustal material available for sampling in the region, probably from the Gondwanan margin (cf. D. Wilton, unpublished data, 2005, and J. Pollock, unpublished data, 2005).

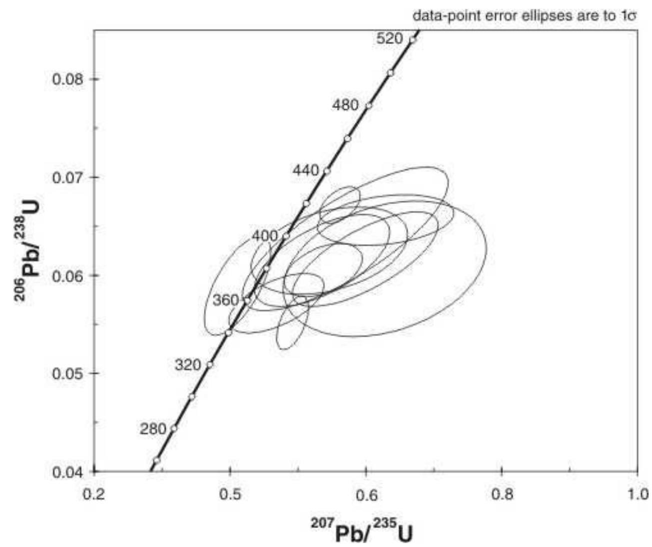

Figure 7. *Concordia diagram for sample JOD90A, Red Rock granite (MPIS); the size of the ellipse represents the error measurement (1 δ) for that particular analysis.*

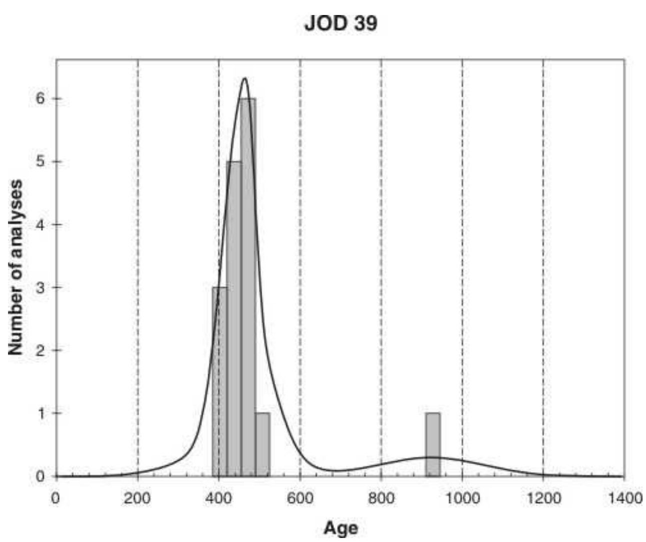

Figure 8. *Histogram of detrital zircon dates for sample JOD39.*

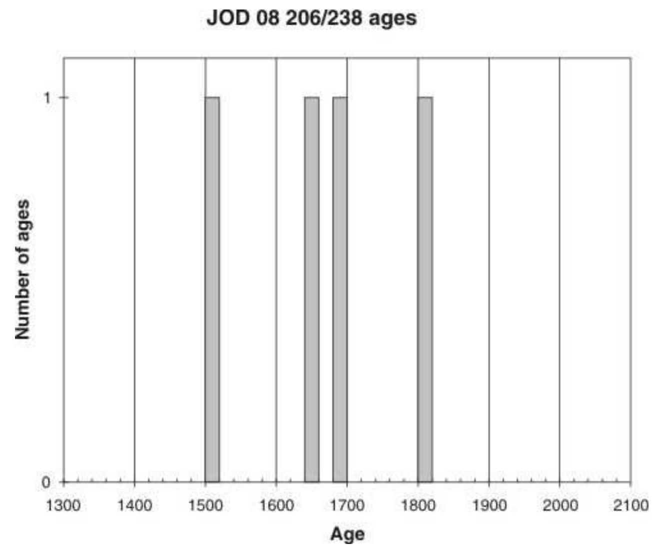

Figure 9. *Histogram of detrital zircon dates for sample JOD08.*

SIGNIFICANCE OF THE LAM-ICP-MS AGE DATES TO REGIONAL METALLOGENY

The intrusive rocks analysed in this study seem to define a general ca. 430 to 424 Ma (mid-Silurian) age for magmatism in the northern Botwood basin region that includes the MPIS. This magmatism was generally bimodal as the rocks analysed range from gabbro through minor granodiorite and diorite to granite.

Based on the LAM-ICP-MS data derived in this study, it is obvious that zircon inheritance is an intrinsic feature of the Silurian granitoids. The data for the Charles Cove pluton suggest that the Silurian granitoid rocks were generated as partial melts of old crust that contributed zircons to the melts. This supports the model of Strong (1979) and Strong and Dupuy (1982) who postulated that the MPIS gabbroic rocks represent mantle melts and that the granites represent partial melts of lower crust produced by these mantle melts. Traditional thermal ionization mass spectrometry (TIMS) zircon work, without the knowledge of zircon imaging, would simply define average ages for the zircon separates. This study has shown that individual zircons should be dated to fully understand the genetic parameters of these intrusives.

The common mid-Silurian age for diorite and granite of the MPIS, the Charles Cove granodiorite and the Twin Ponds gabbros suggests that there was regionally extensive high heat flow. Linkage of the Twin Ponds gabbro and Charles Cove pluton with the MPIS indicates that the areal extent of the deep-seated magmatism and high heat flow is much greater than previously realized and may underlie the complete Botwood basin. In all models suggested for Carlin-style gold deposits (e.g., Arehart, 1996, 2000, 2003; Hofstra and Cline, 2000), and indeed epithermal and orogenic types of gold deposits, a large-scale heat-flow system is a fundamental requirement to drive hydrothermal fluid movement. Thus, as a preliminary conclusion, the MPIS system may have been the energy source for the auriferous mineralization hosted by at least the Silurian rocks.

Squires (2004), however, dismisses the MPIS as the possible heat engine that drove the auriferous Botwood basin hydrothermal fluids, because he interprets most of the gold occurrences to be Devonian or younger (i.e., postdates the MPIS). At this time, the ages of the auriferous mineralization cannot be unequivocally defined, but the data presented here do suggest that there was significant heat flow during the Silurian.

CONCLUSIONS

Rocks in the basin and environs were mapped at local scales and then sampled for geochemical and geochronological purposes. A number of preliminary conclusions have been reached, including:

1) Sulphur/isotope ratio data for sulphide mineral separates indicate a wide range in isotopic compositions. The predominant distinction between samples from different occurrences indicates different sulphur sources related to the regional geology. More detailed work will be required to examine paragenetic variations within individual occurrences.

2) Pyrite crystals from different types of auriferous occurrences appear to exhibit distinctly different trace-element compositions. Though the trace-element database in the geological literature on pyrite compositions from gold deposits is limited (most information comes from Carlin-deposit studies, e.g., Hofstra and Cline, 2000), it appears that pyrites from the Mustang and Bowater prospects have compositions similar to those of pyrite from Carlin occurrences, most especially in terms of the "toxic-element suite" so distinctive of the Carlin deposits. Trace-element compositions of pyrite from the Bruce Pond epithermal prospect resemble those of pyrite from low-sulphidation epithermal systems (i.e., elevated Ba and Se concentrations). Pyrite from the Stog'er Tight prospect, a typical orogenic type occurrence, contains low concentrations of most trace metals.

3) Geochronological data indicate a common ca. 430 Ma age for plutonism in the Botwood basin. Zircon inheritance in the granitoids suggests that they were generated through crustal anatexis of lower crustal material by mantle-derived gabbroic melts. This ca. 430 Ma magmatism may have provided the energy to drive the auriferous mineralization systems in the Botwood basin.

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REFERENCES

Arehart, G.B.
1996: Characteristics and origin of sediment-hosted disseminated gold deposits: a review. Ore Geology Reviews, Volume 11, pages 383-403.

2000: Carlin-type gold deposits of the North American Cordillera; What are they and where are they? Mineral Deposit Research Unit, University of British Columbia, Short Course 27.

2003: Giant Carlin-type gold deposits - Characteristics, origins and exploration methodology. Keynote talk at Geological Association of Canada, Newfoundland Branch, Winter meeting, 2003. Atlantic Geology, Volume 39.

Arehart, G.B., Eldridge, C.S., Chryssoulis, S.L. and Kesler, S.E.
1993: Ion microprobe determination of sulphur isotope variations in iron sulphides from the Post/Betze sediment-hosted disseminated gold deposit, Nevada, USA. Geochemica Cosmochemica Acta, Volume 30, pages 479-496.

Bell, K, Blenkinsop, J. and Strong, D.F.
1977: The geochronology of some granitic bodies from eastern Newfoundland and its bearing on Appalachian evolution. Canadian Journal of Earth Sciences, Volume 14, pages 454-476.

Bierlein, F.P. and Crowe, D.E.
2000: Phanerozoic orogenic lode gold deposits. Reviews in Economic Geology, Volume 13, Gold in 2000, pages 103-139.

Blackwood, R.F.
1982: Geology of the Gander Lake (2D/15) and Gander River (2E/2) areas. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-4, 56 pages.

Boyce, W.D., Ash, J.S., and Dickson, W.L.
1993: The significance of a new bivalve fauna from the Gander map area (NTS 2D/15) and a review of Silurian

bivalve-bearing faunas in central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 93-1, pages 187-194.

Butler, R.
2003: The history of gold exploration in the Botwood Basin of central Newfoundland. Geological Association of Canada, Newfoundland Branch, Winter meeting, 2003. Atlantic Geology, Volume 39.

Churchill, R.A.
1994: An integrated study of epigenetic gold mineralization, Duder Lake area, northeastern Newfoundland. Unpublished M.Sc. thesis. Memorial University of Newfoundland, St. John's, Newfoundland, Canada, 305 pages.

Colman-Sadd, S.P. and Crishy-Whittle, L.V.J.
2002: Partial bedrock geology dataset of the Island of Newfoundland (NTS areas 02E, 12H, 12G and parts of 01M, 02D, 02L, 12A, 12B and 12I). Newfoundland and Labrador Department of Mines and Energy, Open File NFLD/2616.

Colman-Sadd, S.P. and Swinden, H.S.
1984: A tectonic window in central Newfoundland? Geological evidence that the Appalachian Dunnage Zone may be allochthonous. Canadian Journal of Earth Sciences, Volume 21, pages 1349-1367.

Cooke, D.R. and Simmons, S.F.
2000: Characteristics and genesis of epithermal gold deposits. Economic Geology Reviews, Volume 13, Gold in 2000, pages 221-244.

Currie, K.L.
1995: Geology, Gander River, Newfoundland. Geological Survey of Canada (Map) Open File 3162.

Dalton, B.
1998: A descriptive and genetic study of mineralization and alteration at the Moosehead Prospect, central Newfoundland. Unpublished B.Sc. (Hons.) thesis, Memorial University of Newfoundland, St. John's, Newfoundland, Canada, 82 pages.

Dickson, W.L.
1991: Eastern Pond (west half) map area (2D/11W), Newfoundland. Newfoundland Department of Mines and Energy, Geological Survey, Map 91-166.

1992: Ophiolites, sedimentary rocks, posttectonic intrusions and mineralization in the Eastern Pond (NTS 2D/11W) map area. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 92-1, pages 97-118.

1993: Geology of the Mount Peyton map area [NTS 2D/14], central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report. 93-1, pages 209-220.

1996: Whole-rock geochemical and field data from the Mount Peyton Intrusive Suite, the Great Bend Complex and miscellaneous rocks, central Newfoundland (NTS map areas 2D/11E, 2D/14, 2E/3 and parts of 2D/13 and 2D/15). Newfoundland Department of Mines and Energy, Geological Survey, Open File NFLD2614.

Dunning, G.R.
1992: U-Pb Geochronological research agreement final report for the Newfoundland Department of Mines and Energy. Unpublished report to Newfoundland Department of Mines and Energy.

1994. U-Pb Geochronological research agreement final report for the Newfoundland Department of Mines and Energy. Unpublished report to Newfoundland Department of Mines and Energy.

Dunning, G.R. and Manser, K.
1993: U/Pb Geochronological Research Agreement Final Report for the Newfoundland Department of Mines and Energy, Newfoundland Mapping Section. Unpublished report to Newfoundland Department of Mines and Energy.

Evans, D.T.W.
1996: Epigenetic gold occurrences, eastern and central Dunnage Zone, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Resources Report 9, 135 pages.

Evans, D.T.W., Hayes, J.P. and Blackwood, R.F.
1992: Gander River, Newfoundland, N.T.S. 2E/02. Newfoundland and Labrador Geological Survey Open File map 92-02.

Evans, D.T.W. and Wilson, M.
1994: Epigenetic gold occurrences in the eastern Dunnage Zone, Newfoundland: Preliminary stable-isotope results. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 94-1, pages 211-223.

Greenslade, S.
2002: Geochemical and petrographical analysis of the

Tim's Cove vein system, Gander Bay, Newfoundland. Unpublished B.Sc. (Hons.) thesis, Memorial University of Newfoundland, St. John's, Newfoundland, Canada,102 pages.

Groves, D.I., Goldfarb, R.J., Gebra-Mariam, M., Hagemann, S.G. and Robert F.
1998: Orogenic gold deposits: a proposed classification in the context of their crustal distribution and relationships to other gold deposits types. Ore Geology Reviews, Volume 13, pages 7-23.

Groves, D.I., Goldfarb, R.J., Robert F. and Hart, C.J.R.
2003: Gold deposits in metamorphic belts: Overview of current understanding, outstanding problems, future research, and exploration significance. Economic Geology, Volume 98, pages 1-31.

Hedenquist, J.W., Arribas, A. and Gonzalez-Urien, E.
2000: Exploration for epithermal gold deposits. Economic Geology Reviews, Volume 13, (Gold in 2000), pages 245-277.

Hinchey, J.G.,Wilton, D.H.C. and Tubrett, M.
2003: A LAM-ICP-MS study of the distribution of gold in arsenopyrite from the Lodestar Prospect, Newfoundland, Canada. Canadian Mineralogist, Volume 41, pages 353-364.

Hofstra, A.H. and Cline, J.S.
2000: Characteristics and models for Carlin-type gold deposits. Economic Geology Reviews, Volume 13, (Gold in 2000), pages 163-220.

Kontak, D.J. and Smith, P.K.
1993: A metaturbidite-hosted lode gold deposit; the Beaver Dam Deposit, Nova Scotia; I, Vein paragenesis and mineral chemistry. Canadian Mineralogist, Volume 31, pages 471-522.

Košler, J., Fonneland, H., Sylvester, P., Tubrett, M. and Pedersen, R.-B.
2002: U-Pb dating of detrital zircons for sediment provenance studies: a comparison of laser ablation ICPMS and SIMS techniques. Chemical Geology, Volume 182, pages 605-618.

Lang, J.R., Baker, T., Hart, C.R. and Mortenson, J.K.
2000: An exploration model for intrusion-related gold systems. Society of Economic Geologists Newsletter, No. 40, pages 1, 6-15.

Mitchinson, D.E.
2001. Petrography and geochemistry of the Caribou Hill Intrusion, central Newfoundland, and its discordant pegmatites. Unpublished. B.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, Canada, 95 pages.

Murphy, J.B., Fernandez-Suarez, J., Keppie, J.D. and Jeffries, T.E.
In press: Contiguous rather than discrete Paleozoic histories for the Avalon and Meguma terranes based on detrital-zircon data. Geology.

Ramezani, J., Dunning, G.R. and Wilson, M.R.
2000: Geologic setting, geochemistry and U-Pb age of hydrothermal zircons from the Silurian Stog'er Tight gold prospect, Newfoundland Appalachians, Canada. Exploration and Mining Geology, Volume 9, pages 171-188.

Reynolds, P.H., Taylor, K.A. and Morgan, W.R.
1981: $^{40}Ar/^{39}Ar$ ages for the Botwood - Mount Peyton region, Newfoundland: possible paleomagnetic implications. Canadian Journal of Earth Sciences, Volume 18, pages 185-1855.

Squires G.C.
2004: Selected epigenetic gold and antimony mineralization in the Exploits Subzone and Gander Zone: a progress report. *In* Report of Activities. Newfoundland and Labrador Department of Natural Resources, Geological Survey, pages 59-64.

Strong, D.F.
1979: The Mount Peyton Batholith, central Newfoundland, a bimodal calc-alkaline suite. Journal of Petrology, Volume 20, pages 119-138.

Strong, D.F. and Dupuy, C.
1982: Rare earth elements in the bimodal Mount Peyton batholith: evidence of the crustal anatexis by mantle-derived magma. Canadian Journal of Earth Sciences, Volume 19, pages 308-315.

Tallman, P.
1989: First year assessment report on Licences 3361, 3468, 3536, 3480, 3418, 3547, 3539, 3549, 3537, 3538, 3550, NTS 2D/11. Unpublished report, Noranda Exploration Ltd., 20 pages.

Thompson, J.F.H. and Newberry, R.J.
2000: Gold deposits related to reduced granitic intrusions. Economic Geology Reviews, Volume 13, (Gold in 2000), pages 377-400.

Turmel, R.A.
2000: Petrography and geochemistry of alteration associated with the Rolling Pond Epithermal Gold Prospect, Newfoundland. Unpublished B.Sc. (Hons.) thesis, Memorial University of Newfoundland, St. John's, Newfoundland, Canada, 110 pages.

Williams, H., Currie, K.L. and Piasecki, M.A.J.
1993: The Dog Bay Line: a major Silurian tectonic boundary in northeast Newfoundland. Canadian Journal of Earth Sciences, Volume 30, pages 2481-2494.

Williams, S.H.
1993: More Ordovician and Silurian graptolites from the Exploits Subzone. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 94-1, pages 311-315.

Wilton, D.H.C.
1998: First year mineral assessment report on geological geophysical and prospecting surveys covering Mineral Claim Licence No.''s 5241M, 5299M, 5297M, 5298M, 5357M and 5358M (NTS map sheets 2E/7,8) The Tim's Cove Property, Newfoundland. Unpublished report, Copper Hill Resources Inc., 20 pages.

2003: A review of drill hole intersections of auriferous mineralization at the Aztec Prospect, central Newfoundland (NTS 2D/11). Unpublished report for Grayd Resources Inc., 27 pages.

Wilton, D.H.C. and Taylor, R.C.
1999: Second year mineral assessment report on geological geophysical and prospecting surveys covering Mineral Claim Licence No.'s 5241M, 5299M, 5297M, 5298M, 5357M and 5358M (NTS map sheets 2E/7,8) The Tim's Cove Property, Newfoundland. Unpublished report, Copper Hill Resources Inc., 28 pages.