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GEOLOGY, LITHOGEOCHEMISTRY AND U–Pb GEOCHRONOLOGY OF THE BAIE D'ESPOIR GROUP AND INTRUSIVE ROCKS, ST. ALBAN'S MAP AREA, NEWFOUNDLAND

A. Westhues and M.A. Hamilton[1]
Regional Geology Section
[1]Jack Satterly Geochronology Laboratory, Department of Earth Sciences,
University of Toronto, Toronto, ON, M5S 3B1

ABSTRACT

A 1:50 000-scale bedrock mapping project continued in the western St. Alban's map area (NTS 01M/13). A preliminary map that incorporates bedrock mapping and information from detailed magnetic and radiometric airborne geophysical surveys is presented for the area. The Day Cove Thrust, a major feature of this map area, defines the boundary between the Gander Zone and the Exploits Subzone of the Dunnage Zone. The Little Passage Gneiss of the Gander Zone is intruded by the Gaultois Granite and Northwest Brook Complex in the southeast corner. The Baie d'Espoir Group of the Dunnage Zone is intruded by the North Bay Granite Suite in the west.

The northwestern part of the map area is mainly underlain by the Salmon River Dam Formation of the Baie d'Espoir Group, which is dominantly purplish to green-grey sandstone of low-metamorphic grade, and pelitic, psammitic and graphitic schist of amphibolite-metamorphic grade that are folded on a regional scale. A small outcrop of ultramafic rocks occurs within the schists of the Salmon River Dam Formation. The Baie d'Espoir Group is intruded by the North Bay Granite Suite in the western part of the St. Alban's area, which is here subdivided into five major units.

Lithogeochemistry of metavolcanic rocks ranging from rhyolite, dacite, and andesite to basalt of the Isle Galet and Riches Island formations, and of the Twillick Brook Member of the St. Joseph's Cove Formation, show distinct features of subduction-related processes, and argue for the emplacement of these rocks in an intra-oceanic island-arc volcanic environment.

A metavolcanic rhyolite of the Isle Galet Formation was dated by ID-TIMS U–Pb zircon geochronology to have a Darriwilian age of 465.73 ± 0.46 Ma, which is slightly younger than, but overlaps within error of, a Dapingian age (468 ± 2 Ma) previously determined for a felsic metavolcanic of the Twillick Brook Member of the St. Joseph's Cove Formation. Further, a non-foliated posttectonic quartz monzonite is dated at 419.65 ± 0.46 Ma, and provides a limit on the end of deformation during the Salinic orogeny.

INTRODUCTION

The western portion of the St. Alban's map area (NTS 01M/13) was the focus of the second field season of a multi-year 1:50 000-scale bedrock mapping project. Here, the metavolcano-sedimentary sequences of the Ordovician Baie d'Espoir Group, namely the Riches Island, Salmon River Dam and St. Joseph's Cove formations, are in contact with intrusions of the North Bay Granite Suite, a composite batholith.

Several assays from known and previously unknown mineralized zones in the St. Alban's map area yielded elevated As, Sb, Au and base-metal contents (Westhues, 2017a). Several more mineralized zones were visited during this year's field work, and sampled for their composition. Common mineralization minerals (besides pyrite and pyrrhotite) include arsenopyrite, galena, chalcopyrite, molybdenite and stibnite.

An important part of this project is the generation of robust lithogeochemical datasets for the St. Alban's map area. The only available data from Elias (1981) and Elias and Strong (1982) focused on the granitoids rocks of the area, and data for a few metavolcanic rocks (Saunders, 1995) are available on the Geoscience Atlas of the Government of Newfoundland Labrador, Department of Natural Resources (http://geoatlas.gov.nl.ca, Honarvar *et* *al.*, 2015). These older datasets do not include critical trace-element results, which are routinely measured today and are useful for geological interpretations. Preliminary whole-rock geochemistry results including a range of trace-element data for selected samples from the St. Alban's area are presented and discussed here.

Further, no U–Pb geochronological constraints were available from the St. Alban's area until now. Age constraints are based on one fossil occurrence in the area (Boyce *et al.*, 1993) and regional correlations from south-central Newfoundland (Dunning *et al.*, 1990; Colman-Sadd *et al.*, 1992). Two new isotope dilution (ID-TIMS) U–Pb single-grain zircon-age determinations are presented that help to constrain the stratigraphy of the Baie d'Espoir Group and the deformation history of the area.

PREVIOUS BEDROCK MAPPING AND EXPLORATION WORK

Previous bedrock mapping studies of the St. Alban's area include preliminary surveys of the Bay d'Espoir area (Jewell, 1939; Moore, 1953), a 1:253 440 (1 inch to 4 miles) map of the Belloram area (Anderson, 1965) and a 1:50 000 mapping project of NTS 01M/13 map area in the 1970s (*e.g.*, Colman-Sadd, 1974, 1976a, b). Part of the map area 01M/13 was included in a detailed structural study along the coast of the Bay d'Espoir region (Piasecki, 1988), and in the Meelpaeg transect of the Lithoprobe project (deep seismic reflection profiles, Quinlan *et al.*, 1992, and geological studies along transects, *e.g.*, Williams *et al.*, 1989).

The St. Alban's map area, especially the Baie d'Espoir Group, has been a target for commercial exploration activity for several decades focussing on the base-metal potential of the Barasway de Cerf area (*e.g.*, Dunlop, 1953; Saunders and Prince, 1977) and for the antimony, arsenic and gold potential of the Little River area (*e.g.*, McHale and McKillen, 1989; Wells *et al.*, 2003). The Little River area (Woods, 2011) and the True Grit occurrence (Breen, 2005) were drilled more recently. Elevated As, Sb, Au and base-metal contents in assay samples from the 2016 field season (Westhues, 2017a) enhance and highlight the mineral potential of this area.

REGIONAL GEOLOGY OF THE ST. ALBAN'S MAP AREA

The St. Alban's map area 01M/13 on the south coast of Newfoundland includes part of the boundary between the Gander and Dunnage zones, two of Newfoundland's major tectonostratigraphic structures. The Dunnage Zone, namely the Exploits Subzone, constitutes most of the map area and consists of the volcano-sedimentary sequences of the Ordovician Baie d'Espoir Group. The boundary to the Gander Zone is proposed at the Day Cove Thrust where the low-grade metamorphosed Baie d'Espoir Group have been thrust over the amphibolite-facies Little Passage paragneiss of the Gander Zone (Figure 1; Colman-Sadd and Swinden, 1984; Piasecki, 1988; Williams *et al.*, 1988). The Little Passage Gneiss is intruded by the syntectonic megacrystic Gaultois Granite, and both the Little Passage Gneiss and Gaultois Granite are intruded by a muscovite–biotite granite assigned to the Northwest Brook Complex. The Baie d'Espoir Group is intruded by the North Bay Granite Suite, a composite batholith.

The biostratigraphic age of the Baie d'Espoir Group is based on a deformed trilobite pygidium found in the Riches Island Formation, which suggest a Late Arenig deposition age (Boyce *et al.*, 1993), equivalent to Dapingian in the current International Chronostratigraphic Chart (*ca.* 470 to 467 Ma). This overlaps with another Dapingian biostratigraphic age for graptolite and trilobite from the Coy Pond ophiolite complex in central Newfoundland. With a U–Pb TIMS (zircon, multigrain) date of 468 ± 2 Ma, the felsic metavolcanic Twillick Brook Member of the St. Joseph's Cove Formation has also been determined to be Dapingian, occurring to the north of the map area (Colman-Sadd *et al.*, 1992). Another felsic volcanic unit within the Baie d'Espoir Group (North Steady Pond Formation) locally hosting the Katie volcanogenic massive sulphide occurrence yielded an age of 471.1 ± 1.4 Ma (U–Pb TIMS single-grain zircon; J. Hinchey, personal communication, 2016). Other age constraints for the Baie d'Espoir Group farther north in central Newfoundland include the mineralized Mosquito Hill porphyry, interleaved with rocks assigned to the Baie d'Espoir Group (Colman-Sadd, 1985), dated at 494 ± 14 Ma and 477 ± 8 Ma, whilst an age of 464 ± 7 Ma was determined for a crosscutting dacite dyke (U–Pb zircon LA-ICPMS, Sandeman *et al.*, 2013). In the same area, brachiopods of Darriwilian age (*ca.* 467 to 458 Ma) occur within a limestone conglomerate of uncertain stratigraphic relations (Colman-Sadd and Swinden, 1984; Colman-Sadd *et al.*, 1992). In conclusion, the existing age constraints for the Baie d'Espoir Group broadly overlap as Late Cambrian to Middle Ordovician; however, discrepancies exist and the stratigraphic relations between the four formations within the St. Alban's map area remain unclear.

The metamorphic peak recorded in the Little Passage Gneiss (423 +5/-3 Ma) and the intrusive age of the Gaultois Granite (421 ± 2 Ma) have been determined in the Gaultois map area to the south of St. Alban's (U–Pb TIMS, multigrain zircon, Dunning *et al.*, 1990). These ages have been interpreted to be part of the peak deformation of the Silurian Salinic orogeny. The North Bay Granite Suite that intrudes the Baie d'Espoir Group has been dated at 396 +6/-3 Ma as

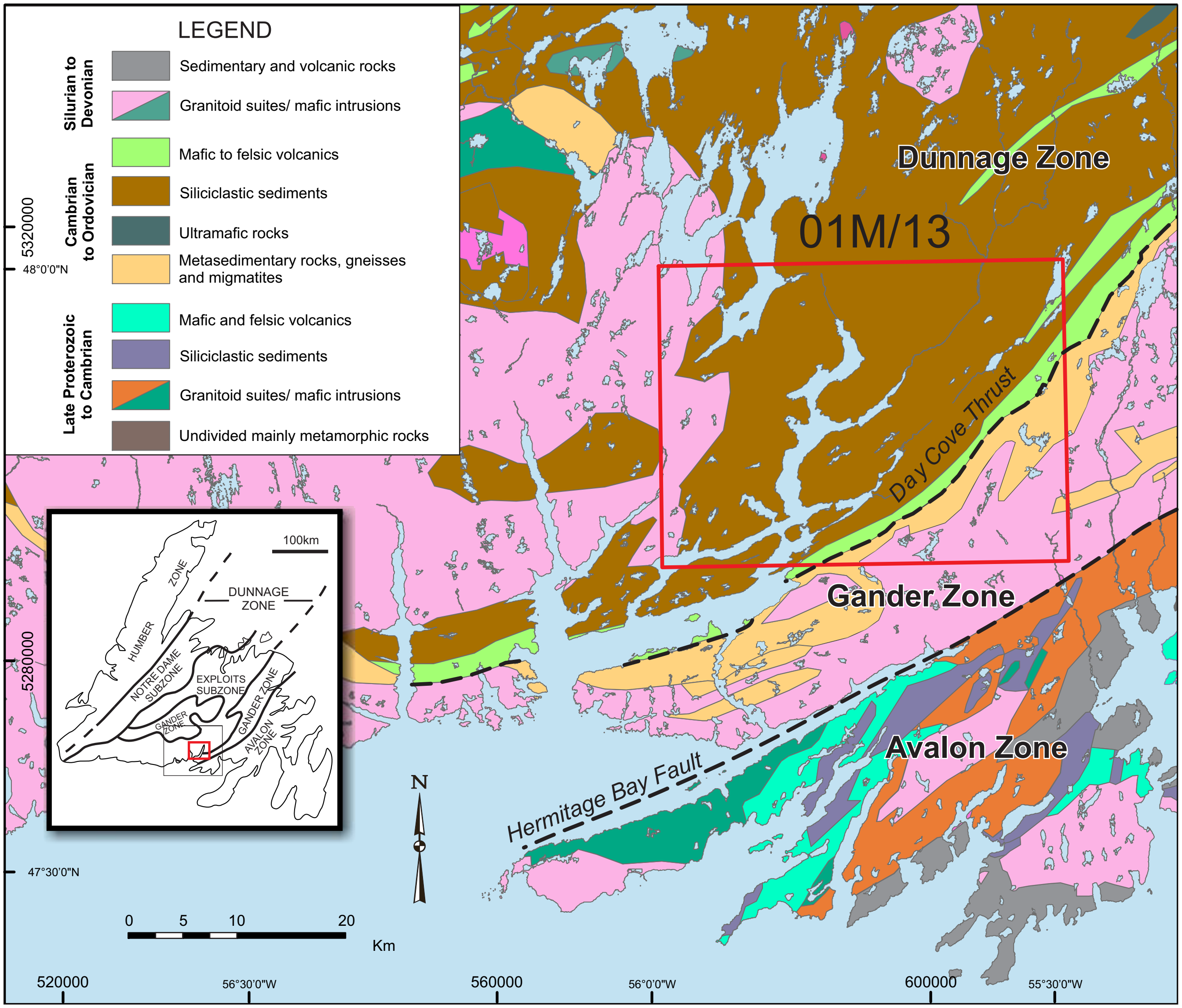

Figure 1. *Simplified regional geology of the south coast of Newfoundland modified after Colman-Sadd* et al. *(1990) and information from GSNL Geoscience Atlas, showing the location of NTS map area 01M/13 and approximate locations of boundaries between the tectonostratigraphic zones of Newfoundland. Inset shows the Island of Newfoundland with major tectonostratigraphic provinces and the location of map area (red box).*

part of the same study (Dunning *et al.*, 1990), providing a younger limit for the regional deformation during the Acadian orogeny in the Devonian.

GEOLOGY OF THE ST. ALBAN'S MAP AREA

Many of the lithological units of the St. Alban's map area (NTS 01M/13, Figure 2) have been described, in detail, in Westhues (2017b). Detailed descriptions are provided for all units of the Salmon River Dam Formation and the North Bay Granite Suite located in the western part of the map area. Most rock types have been described previously (*e.g.*, Colman-Sadd, 1976b). All units are labelled using the identifier system on the Geoscience Atlas of the Government of Newfoundland Labrador, Department of Natural Resources (http://geoatlas.gov.nl.ca, Honarvar *et al.*, 2015), based on the bedrock geology dataset for Newfoundland (Crisby-Whittle, 2012), where possible.

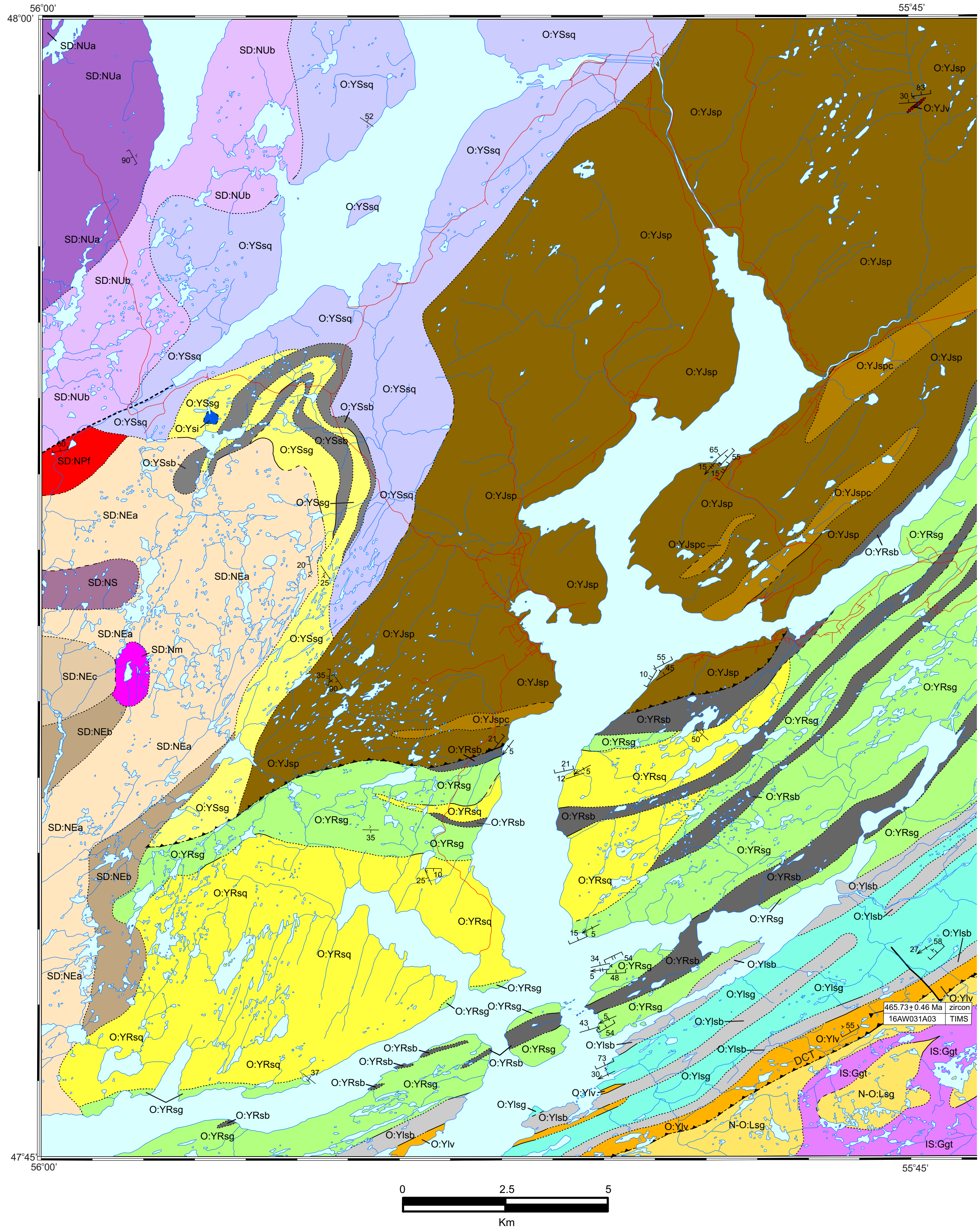

Figure 2. *Preliminary geological map of the St. Alban's map area and selected structural observations. DCT–Day Cove Thrust.*

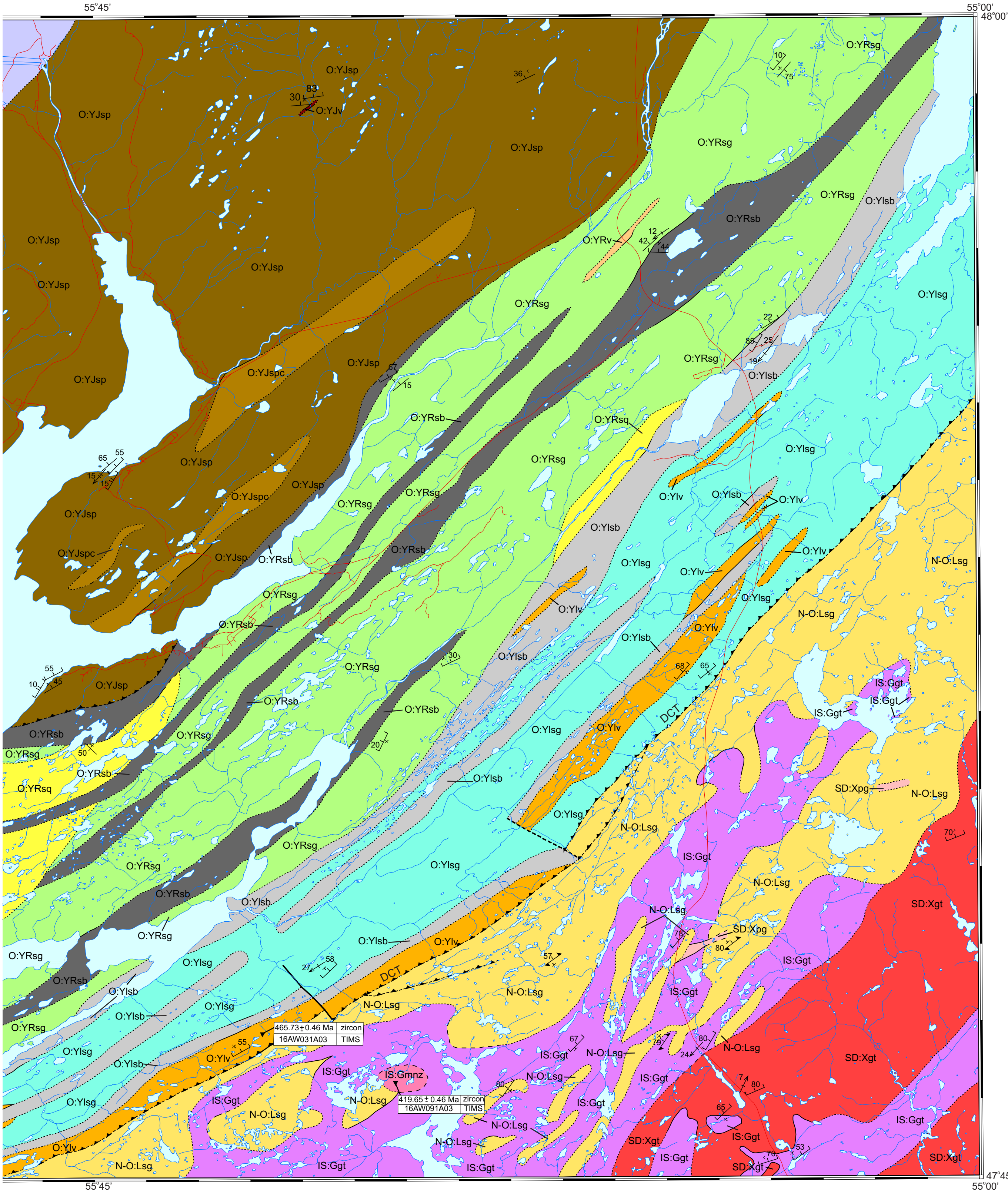

Figure 2. *Continued.*

Post-Ordovician intrusive rocks

Devonian
North Bay Granite Suite

SD:Nm	Buff to grey, fine-grained, massive, magnetite-bearing biotite–muscovite granodiorite, equigranular, weakly foliated
SD:NS	D'Espoir Brook: white to pink biotite–muscovite–garnet granite, magnetite bearing, moderately foliated, medium grained, equigranular
SD:NE a, SD:NE b, SD:NE c	East Bay Granite: leucocratic, slightly pink or buff, biotite ± muscovite granite, weakly to strongly foliated; a) medium grained equigranular; b) medium- to coarse-grained muscovite ± biotite, garnet bearing, c) medium grained, strongly foliated to migmatitic
SD:NU a, SD:NU b	Upper Salmon Road Granite: grey to buff, weakly to moderately foliated biotite granite to granodiorite; a) coarse grained porphyritic, b) fine to medium grained, equigranular
SD:Npf	Strongly foliated pink muscovite ± biotite granite in Salmon River, equigranular

Late Silurian or younger

SD:Xpg	Leucocratic pegmatite and aplite dykes containing muscovite, tourmaline, garnet

Late Silurian

SD:Xgt	Northwest Brook Complex: pink to buff, variably foliated, medium-grained biotite–muscovite ± garnet granite
IS:Gmnz	Mesocratic non-foliated, coarse-grained magnetite–titanite–biotite quartz monzonite
IS:Ggt	Gaultois Granite Suite: Leuco- to mesocratic, coarse-grained, well foliated biotite ± tourmaline ± titanite granite and granodiorite, often containing K-feldspar and plagioclase megacrysts; includes tonalite, quartz diorite and diorite

Dunnage Zone
Ordovician
Baie d'Espoir Group

Salmon River Dam Formation

O:YSsq	Thick-bedded, brown to purplish arenous sandstone, metasandstone and minor interbedded siltstone and locally shales
O:YSsb	Thin-bedded to laminated graphitic schists, often rusty weathered, commonly pyritic
O:YSsg	Thin- to medium-bedded semipelitic, pelitic and psammitic brownish-grey mica schist, commonly contain garnet and staurolite
O:YSi	Massive dark-green ultramafic intrusive (?) rocks, commonly serpentinized, orange weathering

St. Joseph's Cove Formation

O:YJsp	Thin- to medium-bedded dark-grey-weathering shale and thin-bedded brown-red-weathering siltstone, often cut by sulphide-bearing quartz veins; locally includes beds of sandstone

Figure 2 Legend.

O:YJspc	Medium- to thick-bedded light-brown to grey sandstone and minor conglomerate
O:YJv	Intermediate volcanic rocks, rich in sulphides
	Riches Island Formation
O:YRsg	Thin-bedded to laminated greenish-grey shale with interbeds of siltstone, commonly metamorphosed to phyllite and schist, locally contains beds rich in garnet porphyroblasts and staurolite close to contact with East Bay Granite
O:YRsq	Thin- to medium-bedded yellow-brown sandstone and metasandstone
O:YRsb	Thin-bedded to laminated black shale and siltstone to graphitic schist, often pyritic and rusty weathered
O:YRv	Felsic to intermediate metavolcanic rocks
	Isle Galet formation
O:YIsg	Thin-bedded greenish-grey phyllite and schist, often sheared, folded and mylonitized; locally interbedded with medium-bedded metasandstone and metaconglomerate
O:YIsb	Thin-bedded to laminated graphitic schist, black shale and siltstone, often pyritic and rusty weathering, locally mylonitized, folded and sheared; includes minor metavolcanic rocks
O:YIv	Felsic to intermediate metavolcanic rocks, often sheared, folded, and mylonitized, locally includes thin layers of mafic metavolcanic rocks
	Gander Zone **Neoproterozoic to Ordovician**
N-O:Lsg	Little Passage Gneiss: K-feldspar–muscovite–biotite–quartz ± garnet, chlorite paragneiss with well-developed compositional banding, reddish-brown to rusty weathering, commonly complexly folded; locally includes amphibolite

SYMBOLS

Bedding (tops known)

Foliation or cleavage (1st, 2nd generation)

Gneissic foliation

Linear fabric (1st, 2nd generation)

Geological contact (defined, approximate, assumed)

Fault (defined, assumed)

Thrust fault (defined, assumed)

age	material
sample #	method

U–Pb geochronology

Figure 2 Legend. *Continued.*

GANDER ZONE

Little Passage Gneiss (Unit N-O:Lsg)

The Little Passage Gneiss consists mainly of banded, K-feldspar–muscovite–biotite–quartz ± garnet semipelitic to psammitic paragneiss commonly preserving well-developed compositional banding (light-coloured bands mainly quartz, dark bands rich in biotite) and locally migmatitic textures. Accessory phases include garnet porphyroblasts (typically 0.2 to 1 cm in diameter), staurolite, sillimanite and amphibole. The banding in the gneiss has complex folds and a mylonitic foliation developed in proximity to the Day Cove Thrust. The unit is typically reddish brown to rusty-weathered. On the residual magnetic field and the various derivatives of the magnetic field, the Little Passage Gneiss generally shows high signatures, which are used to refine the boundaries between this unit and the Gaultois Granite.

DUNNAGE ZONE

Baie d'Espoir Group (O:Y)

The Baie d'Espoir Group consists of Ordovician metasedimentary and metavolcanic rocks that are considered to have formed along the eastern margin of the Iapetus Ocean and are part of the Exploits Subzone of the Dunnage Zone (*e.g.*, Colman-Sadd, 1980; van Staal *et al.*, 1998). In the St. Alban's map area, the Baie d'Espoir Group is subdivided from east to west into the Isle Galet Formation, Riches Island Formation, St. Joseph's Cove Formation and Salmon River Dam Formation (Colman-Sadd, 1976a, b).

Isle Galet Formation (Units O:YIsg, O:YIsb, O:YIv)

The Isle Galet Formation is a metasedimentary and metavolcanic succession that is separated from the Little Passage Gneiss by the Day Cove Thrust in the southeast. Exploration in the region has focused on the antimony, arsenic and gold potential of this formation in recent decades. The rocks are schists, locally mylonitized, close to the thrust and strongly cleaved elsewhere, and are metamorphosed to greenschist and epidote amphibolite facies. For this report, the formation is separated into three units. These are:

i) Unit O:YIsg consists of thin-bedded greenish-grey phyllite and schist that are interbedded with medium-bedded metasandstone and metaconglomerate, which are locally dominant.

ii) Thin-bedded to laminated graphitic schist and black shales, commonly pyritic, are combined into Unit O:YIsb. This unit forms an excellent marker horizon in the field and in the magnetic survey, where it shows a high response, likely related to elevated contents of pyrrhotite.

iii) Unit O:YIv includes the metavolcanic rocks of the Isle Galet Formation (Plate 1A). Felsic compositions are dominant, typically rhyolitic vitric or crystal tuff with few K-feldspar and/or crystals; locally lithic tuff or lapilli tuff occurs. Mafic to intermediate metavolcanic rocks occur as thin layers within felsic metavolcanic rocks or can be found within metasedimentary units. Close to the eastern border of the map area, a medium-grained equigranular amphibole granite of small areal extent occurs within the Isle Galet Formation. Further petrographic and geochemical analyses are planned to determine the relationship of this intrusive unit to other intrusions in the area.

Plate 1. *Selected rock types of Isle Galet and Riches Island formations. A) Metavolcanic rhyolite of the Isle Galet formation that was sampled for geochronological U–Pb zircon analyses (16AW031A03), having foliation and small isoclinal folds; B) Staurolite–mica schist of Riches Island Formation, close to contact with North Bay Granite Suite, Lampidoes Passage.*

Riches Island Formation (Units O:YRsg, O:YRsq, O:YRsb, O:YRv)

The Riches Island Formation occurs to the northwest of the Isle Galet Formation, the conformable contact is defined by a graphitic schist layer. Metasedimentary rocks are dominant in this formation; metavolcanic layers are less common compared to the Isle Galet Formation. The Riches Island Formation is separated here into four units. These are:

i) Thin-bedded to laminated greenish-grey shale with interbedded siltstone are commonly metamorphosed to phyllite and schist (Unit O:YRsg). Phyllite and schist may contain semi-pelitic layers rich in garnet. Closer to the contact with the North Bay Granite in the southwest of the map area, this unit is a staurolite–mica schist (Plate 1B).

ii) Thin- to medium-bedded arenaceous sandstone, metasandstone and quartzite occur locally in the northeast, but are a common unit in the southwest around Roti Bay (Unit O:YRsq).

iii) Thin-bedded to laminated black shale and locally graphitic schist of the Riches Island Formation can be traced by the high magnetic resonance of this unit (Unit O:YRsb).

iv) Metavolcanic rocks are intermediate andesite to dacite, fine grained to aphanitic with locally crystals of feldspar, quartz and amphibole (Unit O:YRv).

St. Joseph's Cove Formation (Units O:YJsp, O:YJspc, O:YJv)

The St. Joseph's Cove Formation consists of variable interbedded shale and siltstone beds and lesser sandy to conglomeratic beds, and primary sedimentary structures, such as parallel bedding, lamination, ripple structures, load clasts or rip-up clasts, are preserved. Thin- to medium-bedded shale interbedded with thin-bedded siltstone is the dominant unit of this formation (Unit O:YJsp). Medium- to thick-bedded sandstone and minor conglomerate form channels within the St. Joseph's Cove Formation (Unit O:YJspc). The only mappable volcanic unit of the St. Joseph's Cove Formation occurs as a 10-m-thick light-grey aphanitic to fine-grained andesite tuff in Southwest Brook, north of Head of Bay d'Espoir (Unit O:YJv). It contains rare phenocrysts of feldspar and quartz, and is rich in sulphides, dominantly pyrite. Assay results for this unit from this study are not available yet, but Colman-Sadd (1976b) reports elevated contents of silver.

Salmon River Dam Formation (Units O:YSsq, O:YSsb, O:YSsq, O:YSiu)

The Salmon River Dam Formation is a metasedimentary succession that occurs in the northwestern part of the map area. Intrusions of the North Bay Granite bound this unit to the west. The contact to the St. Joseph's Cove Formation in the east is covered by vegetation, but is expected to be concordant and gradational (Colman-Sadd, 1976b), except in the south, where the contact is faulted. In the west, the Salmon River Dam Formation is intruded by the North Bay Granite Suite (Plate 2). The main rock type of the Salmon River Dam Formation is thick-bedded sandstone and metasandstone metamorphosed up to greenschist facies. Also included in this formation are graphitic schist and staurolite–mica schist, both strongly folded and of higher metamorphic grade up to amphibolite facies. Additionally, small outcrops of ultramafic rocks occur within the schists and thin layers of amphibolite schists of potentially igneous origin can be found within the higher metamorphic terrain. The magnetic signature visible in the geophysical survey suggests a wide north-plunging synform of the higher metamorphic terrain, in accordance with the outcrop pattern, where observable.

The dominant unit of the Salmon River Dam Formation consists of thick-bedded, brown to purplish arenaceous sandstone, metasandstone and minor interbedded siltstone, and locally shales (Unit O:YSsq). The composition is dominantly lithic arenite and lesser quartz arenite, and arkosic arenite. At the contact to the North Bay Granite intrusions, a hornblende hornfels is developed locally, *e.g.*, in a tributary to Salmon River west of the dam. Shales become more abundant to the east toward the gradational contact with the St.

Plate 2. *Equigranular medium-grained, grey, locally pink Upper Salmon Granite of the North Bay Granite Suite intrudes sandstone of the Salmon River Dam Formation, shore of Jeddore Lake (locally known as Long Pond) reservoir.*

Joseph's Cove Formation. Primary sedimentary structures, such as parallel lamination and crossbedding, are commonly observed (Plate 3A). This unit has a very low response on the aeromagnetic survey, which is used to better define the contact with the St. Joseph's Cove Formation.

Graphitic schist (Unit O:YSsb) occurs along the southern part of the contact between Salmon River Dam Formation and the East Bay Granite, part of the North Bay Granite Suite. The fine-grained graphitic schists are thinly bedded to laminated, black on fresh surfaces and commonly rusty-weathered. Pyrite and pyrrhotite are common. Similar to black shale and graphitic schist in other parts of the Baie d'Espoir Group, this unit has an elevated response in the aeromagnetic survey and can be traced in boggy areas toward Jeddore Lake, which helps to define the large synform.

Semipelitic, pelitic and psammitic brownish-grey mica schist (Unit O:YSsg) occurs in several outcrops of small areal extent between graphitic schist and granitic intrusions. Sedimentary structures are obscured by stronger deformation and outcrop-scale folding in this unit. The penetrative schistocity is defined by biotite and muscovite; garnet and staurolite porphyroblasts are common. In several cases, Units O:YSsb and O:YSsg occur interleaved (Plate 3B).

Ultramafic rocks occur in several small outcrops, up to 10 m wide, about 1 km southeast of Salmon River Dam at the north shore of Gonzo Pond (informal name) (Unit O:YSiu) within semipelitic and psammitic schist. The dark-green, medium-grained rocks are commonly serpentinized, hence primary mineralogy is obscured in hand sample, are very magnetic, and show orange-weathering crusts (Plate 3C, D). A small high in the aeromagnetic survey (coincides with the ultramafic rocks) is clearly distinguishable from the surrounding semipelitic and psammitic schist, but not from the graphitic schists in the vicinity. Hornblende schist potentially of igneous origin occurs as a band within graphitic and mica schists and is possibly related to the ultramafic rocks. Further petrographic and geochemical study will show the significance of these rocks in a regional context in comparison with other ultramafic occurrences in central Newfoundland, such as the Gander River Ultrabasic Belt (GRUB line, *e.g.*, Blackwood, 1982).

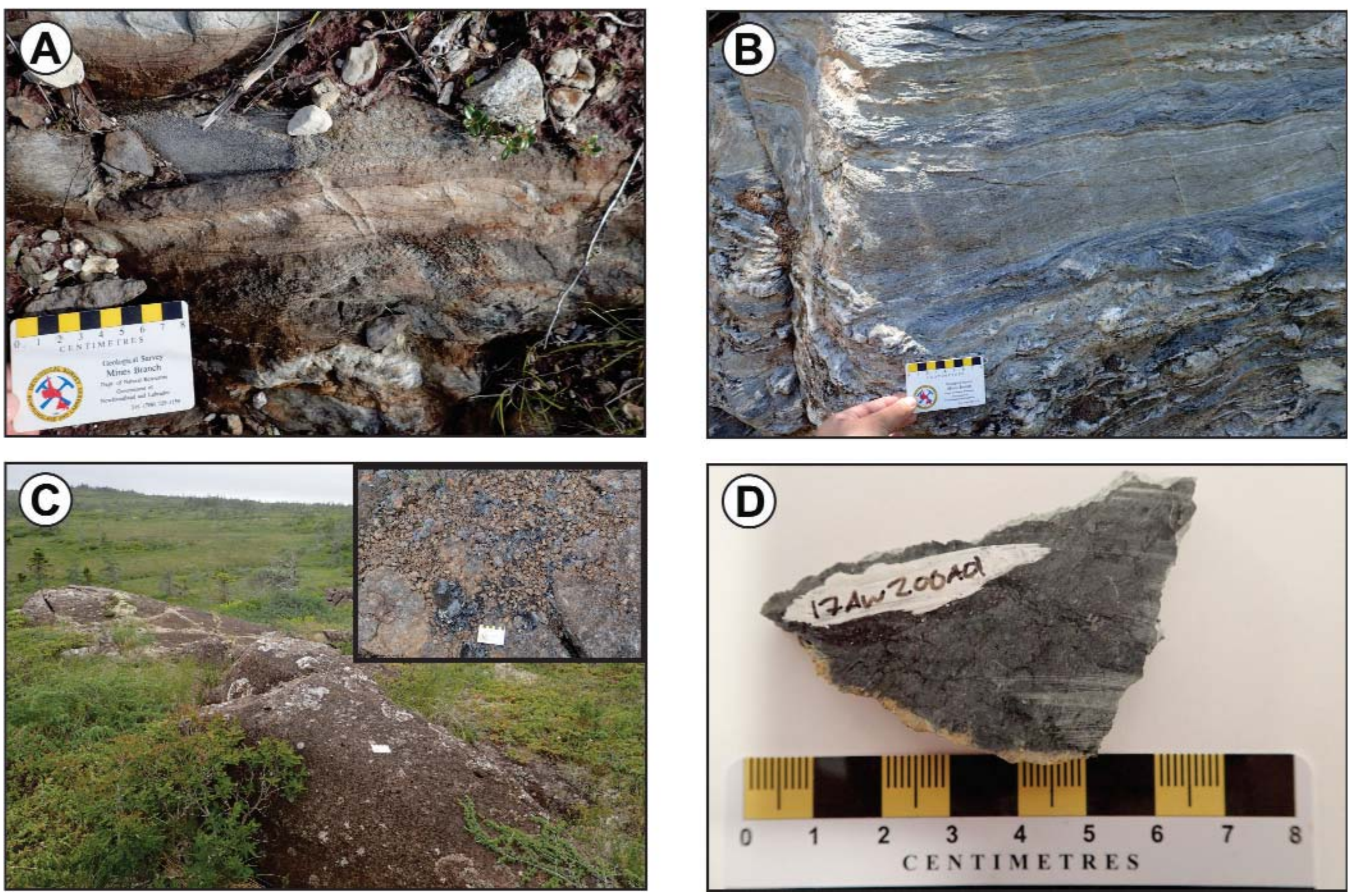

Plate 3. *Salmon River Dam Formation. A) Sandstone with crossbedding; B) Layered graphitic and psammitic schist; C) Outcrop of ultramafic rocks, inset shows typical orange-weathering; and D) fresh surface of ultramafic rock.*

SYN- TO POSTTECTONIC INTRUSIONS

Plutonic rocks are present in two main areas in the St. Alban’s map area: in the southeast corner, the Gaultois Granite and Northwest Brook Complex intrude the Little Passage Gneiss, and the North Bay Granite Suite intrudes the metavolcano-sedimentary sequences of the Baie d'Espoir Group in the west. It is noteworthy that the former intrusions are restricted to the Gander Zone, whereas the North Bay Granite Suite only occurs in the Dunnage Zone.

Gaultois Granite (Unit IS:Ggt)

The laterally extensive Gaultois Granite encompasses leuco- to mesocratic, medium- to coarse-grained feldspar-megacrystic, lineated and foliated biotite ± tourmaline ± titanite granite and granodiorite. Magnetite is generally absent, resulting in relatively low intensity of this unit in the geophysical survey. The general southwest foliation is defined by the alignment of biotite, elongated quartz grains and recrystallization of quartz in bands. Included in this unit are diorite and gabbro that occur locally and as small inclusions throughout the Gaultois Granite, dominantly consisting of amphibole and plagioclase. The ubiquitous foliation within this unit supports a syntectonic emplacement of these intrusions into the Little Passage Gneiss, which can be found as rafts within the Gaultois Granite.

Unnamed Non-foliated Coarse Monzonite (Unit IS:Gmnz)

This biotite–titanite monzonite was newly defined in the 2016 mapping season (Westhues, 2017b) based on a strong high in the residual magnetic signal and features uncharacteristic of the typical Gaultois Granite. These include the equigranular coarse grain size, lack of foliation and deformation in the intrusion, visible magnetite, and a related high response in the residual magnetic signal. The lack of foliation, especially, may argue for this intrusion to be posttectonic and it was therefore selected for geochronological analyses (*see* details below).

Northwest Brook Complex (Units SD:Xgt, SD:Xpg)

The Northwest Brook Complex is dominantly a pink to buff medium-grained, equigranular biotite–muscovite granite to granodiorite and minor syenite (Unit SD:Xgt). It is weakly foliated and the fabric is defined by the preferred orientation of mica and elongated quartz grains; garnet and tourmaline occur locally. This unit intrudes the Gaultois Granite and Little Passage Gneiss as dykes and dykelettes and is the dominant rock type in the southeastern most corner of the map area where it occurs as massive intrusive bodies. Pegmatite and aplite occur in many outcrops of Gaultois Granite, Northwest Brook Complex and Little Passage Gneiss as dykes and veins of muscovite–garnet–tourmaline granite (Unit SD:Xpg). Two dykes, of a mappable scale, are preserved up to 150 m wide. This unit is likely a late phase of the Northwest Brook Complex.

North Bay Granite Suite (SD:N)

In previous mapping of the St. Alban’s map area, the dominantly granitic intrusions in the western area have been lumped together as North Bay Granite (Jewell, 1939; Colman-Sadd, 1976a). Mapping of the D’Espoir Brook map area (NTS 11P/16), located to the west of the St. Alban’s map area, has delineated several subdivisions of this composite granitic batholith and the name North Bay Granite Suite was introduced (Dickson, 1990). In the bedrock geology dataset for Newfoundland (Crisby-Whittle, 2012), as found on the Geoscience Atlas of the Government of Newfoundland Labrador, Department of Natural Resources (http://geoatlas.gov.nl.ca, Honarvar *et al.*, 2015), some of Dickson’s subdivisions have been assigned (Upper Salmon Road Granite for the northern, East Bay Granite for the southern exposure) for the St. Alban’s map area. Using the new field data and the geophysical survey, the North Bay Granite is subdivided into five major units in the St. Alban’s map area (four shown in Plate 4), three of which are likely equivalent to subdivisions of Dickson (1990). However, continuity of the units across the map area boundary is not clear. Contacts between different units are rarely observed, so the units are introduced in order of relative abundance and no intrusive order is implied by the sequence. The massive porphyritic biotite Dollard Brook Granite in the D’Espoir Brook map area, one of the youngest plutons of North Bay Granite Suite, has been dated to 396 +6/-3 Ma (Dunning *et al.*, 1990). With some exception, the rocks of the North Bay Granite Suite show only weak to moderate foliation, and are late syntectonic to posttectonic intrusions with regard to the Acadian orogeny in the Devonian.

East Bay Granite (Subunits SD:NEa, SD:NEb, SD:NEc)

The East Bay Granite is typically an equigranular biotite ± muscovite granite to granodiorite that can be weakly to strongly foliated and occurs in the southwestern part of the St. Alban’s map area. Three subunits with gradational contacts have been delineated during the 2017 mapping season. The dominant subunit SD:NEa is medium grained, leucocratic to slightly pink and buff, and weakly foliated (Plate 4A). Porphyritic K-feldspar is observed locally. Biotite is more common than muscovite, and amphibole occurs locally. Foliation, if present, is defined by alignment of mica and has a dominantly northeast–southwest trend. Subunit SD:NEb is white, medium to coarse grained and weakly

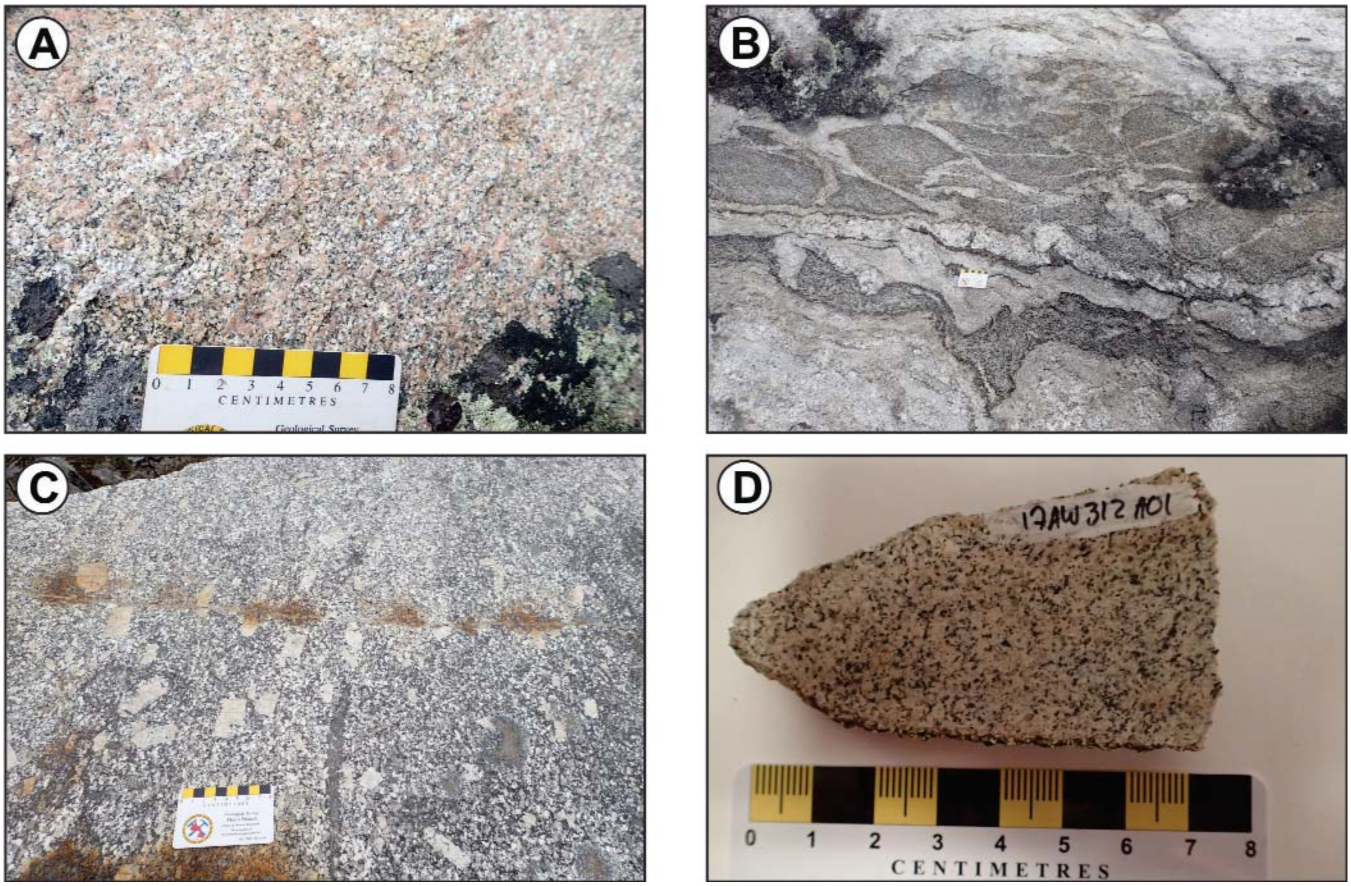

Plate 4. *Selected units of the North Bay Granite Suite. A) Equigranular medium-grained, leucocratic to slightly pink East Bay Granite (subunit SD:NEa); B) Strongly foliated, partly gneissic, East Bay Granite (subunit SD:NEc) intruded by garnetiferous leucocratic East Bay Granite (subunit SD:NEb); C) Megacrystic Upper Salmon Road Granite to granodiorite (subunit SD:NUa), Witch Hazel Hill, and D) Magnetic fine-grained granodiorite (Unit SD:Nm).*

foliated. This subunit has a more felsic composition, muscovite is common, whilst biotite is rare, and commonly contains garnet. It forms the dominant outcrop in a few areas, but also occurs as small patches and garnetiferous aplite to pegmatite veins within SD:NEa. Subunit SD:NEc is medium grained and strongly foliated, in some cases migmatitic, granite to granitic gneiss (Plate 4B). Colman-Sadd and Swinden (1982) also describe, locally, tonalitic gneiss within this subunit. The foliation is defined by biotite and elongated quartz; gneissic banding is present in several instances. This subunit is older than the other subunits of the East Bay Granite, because it can be found as screens within the other units of the East Bay Granite and is intruded by them where it forms the dominant outcrop.

Upper Salmon Road Granite (Subunits SD:NUa, SD:NUb)

The typical Upper Salmon Road Granite occurs in the northwestern part of the St. Alban's map area and is a grey to buff, weakly to moderately foliated biotite granite to granodiorite; muscovite is very rare. The Upper Salmon Road Granite has here been divided into two distinct subdivisions. A contact between the two subunits is not exposed, but the geophysical signature suggests a gradual change. Subunit SD:NUa is a coarse-grained porphyritic granodiorite and minor granite that contains megacrystic K-feldspar up to 15 cm across (Plate 4C) and may contain amphibole, magnetite and titanite, visible in hand sample. It is found predominantly in the northwest corner of the map area and forms the Witch Hazel Hill and surrounding ridge. The subunit also coincides with positive anomaly in the aeromagnetic survey, related to the higher content of magnetite. Subunit SD:NUb is a fine- to medium-grained equigranular granite, lesser granodiorite having lower contents of magnetite compared to subunit SD:NUa (*i.e.*, intermediate response in aeromagnetic survey). This subunit can be observed in direct contact to sandstone of the Salmon River Dam Formation at the shore of Jeddore Lake (Plate 2).

D'Espoir Brook Granite (Unit SD:NS)

The leucocratic garnetiferous biotite–muscovite D'Espoir Brook Granite in the D'Espoir Brook map area is moderate to strongly foliated (Dickson, 1990). Similar rocks are observed along an area having an elevated aeromagnetic signature to the southeast of the D'Espoir Brook Granite and are likely a continuation of smaller areal extent of this unit into the St. Alban's map area. Like the D'Espoir Brook Granite, these rocks are leucocratic garnetiferous biotite–muscovite granites that are medium grained, equigranular and show moderate foliation. The main difference to the garnetiferous subunit SD:Neb of the East Bay Granite is the significantly higher content of biotite and magnetite, the latter responsible for the observed higher response in the aeromagnetic survey.

Unnamed Magnetic Fine-grained Granodiorite (Unit SD:Nm)

A prominent high in the aeromagnetic survey coinciding with a low in the radiometric response (most prominent in potassium) is underlain by rocks different from the surrounding East Bay Granite. This fine-grained, equigranular grey biotite–muscovite granodiorite is weakly foliated, defined by alignment of mica (Plate 4D). The higher response in the magnetic survey is related to higher contents of magnetite. Titanite is visible in hand sample.

Unnamed Pink Foliated Granite (Unit SD:Npf)

Deep pink equigranular muscovite ± biotite granite occurs in Salmon River, southwest of the Salmon River Dam. The rocks show a strong tectonic fabric and were suggested by Colman-Sadd (1976b) to be older than the North Bay Granite, potentially of Precambrian age, based on southeasterly foliation trends that are discordant to the predominant northeasterly trends in the St. Alban's map area. Subsequent mapping in the D'Espoir Brook map area revealed similar foliation in other parts of the North Bay Granite, and Dickson (1990) suggests that this unit could be related to the Bottom Brook Granite of the North Bay Granite Suite. However, observations of this unit in the St. Alban's map area are incompatible with the description of the porphyritic grey Bottom Brook Granite. The stronger foliation of this pink granite could be related to the Salmon River Fault in the area.

MINERALIZATION

Several assays from the 2016 field season confirmed the mineral potential of the Bay d'Espoir area (Westhues, 2017a), which has seen exploration activity for several decades in the Baie d'Espoir Group. The focus of exploration are the stratabound base-metal-rich sulphide mineralization within volcanic layers of the Isle Galet Formation, Barasway de Cerf region (*e.g.*, Dunlop, 1953; Saunders and Prince, 1977) and structurally controlled quartz veins throughout the Baie d'Espoir Group for the gold, antimony, and arsenic potential (*e.g.*, review by Evans, 1996). The Little River area and its northeast extension in the Isle Galet Formation have seen several trenching and drilling projects (*e.g.*, McHale and McKillen, 1989; Woods, 2011). Within the St. Joseph's Cove Formation, the True Grit and Golden Grit areas are known for elevated gold contents and have been drilled for exploration (Breen, 2005). This present bedrock mapping project highlighted further targets of high Au contents within the St. Joseph's Cove Formation (Westhues, 2017a), for instance a quartz vein sample with *ca.* 7 ppm Au in the Southeast Brook area close to Head of Bay d'Espoir. These elevated Au values coincide with a relative low in residual magnetic signature (Kilfoil, 2016), *i.e.*, the sandstone and conglomerate channels within the St. Joseph's Cove Formation (Unit O:YJspc), which could be used as a guide for further exploration in the area.

Several additional mineralized locations were visited during the 2017 field season. A number of galena-rich silicified and/or barite-rich veins within metasandstone of the Riches Island Formation have been documented with similar mineralization styles as can be found at Hardy Cove. Assay samples from that location yield 22 ppm Ag, almost 30 000 ppm Pb and *ca.* 7300 ppm Zn (Westhues, 2017a). One silicified galena vein, previously undocumented, has been discovered in the Lampidoes Passage (Plate 5A). Further, the Riches Island Formation is intruded by aplite dykes (related to the North Bay Granite Suite) that can be very rich in molybdenite, especially in Northwest Cove (Plate 5B), but molybdenite also has been observed in other places throughout the Lampidoes Passage. Assays for these locations and others in the western part of the St. Alban's area will be available in 2018.

PRELIMINARY GEOCHEMISTRY OF METAVOLCANIC ROCKS

METHODS

Geochemical characteristics of selected representative felsic, intermediate and mafic metavolcanic rocks of Unit O:YIv of the Isle Galet Formation and of an intermediate metavolcanic rock of Unit O:YRv of the Riches Island Formation from the 2016 field season are presented here (Table 1). The samples taken may show moderate foliation, but any weathered crusts have been carefully avoided. Analyses for major- and trace-element geochemistry have

Table 1. Representative lithogeochemical data for metavolcanic rocks of the Isle Galet and Riches Island formations, Baie d'Espoir Group. UTM coordinates are in NAD 27, zone 21. Major elements are given in weight percent, trace elements in ppm and sorted by atomic number

Sample No.		16AW031A02	16AW070B02	16AW033A02	16AW059A02	16AW017A02	16AW137A02	16AW448A02	16AW496B02
Lab No.		11040014	11040045	11040034	11040026	11040031	11040053	11040068	11040099
Formation		Isle Galet	Isle Galet	Isle Galet	Isle Galet	Isle Galet	Isle Galet	Riches Island	Isle Galet
Rock type		rhyolite	rhyolite	rhyolite	rhyolite	dacite	andesite	andesite	andesite
UTM easting		595180	596835	598255	605218	602596	599955	603606	586987
UTM northing		5292508	5293020	5294179.45	5301352	5303478	5294930	5311685	5289486
SiO2	a	75.68	75.45	74.53	73.84	59.25	63.98	62.56	59.39
TiO2	a	0.15	0.15	0.19	0.20	0.41	0.85	0.61	0.29
Al2O3	a	12.49	12.32	12.87	12.34	12.42	17.08	17.96	10.92
Fe2O3T	a	1.19	2.32	2.46	2.85	3.91	6.06	4.90	10.43
Fe2O3	a	0.16	0.33	0.69	0.20	0.29	0.93	0.61	n.a.
FeO	a	0.92	1.79	1.59	2.38	3.26	4.62	3.87	n.a.
MgO	a	0.35	0.55	0.61	0.42	3.79	2.70	2.76	10.66
CaO	a	0.25	0.46	2.65	0.39	7.47	0.59	1.07	0.50
Na2O	a	2.68	0.94	2.96	3.96	3.15	1.72	4.63	0.15
K2O	a	4.93	5.87	1.63	3.78	0.90	3.55	2.38	0.11
MnO	a	0.01	0.06	0.31	0.06	0.10	0.07	0.03	0.41
P2O5	a	0.14	0.03	0.26	0.02	0.03	0.10	0.14	0.25
LOI	Grav	0.82	1.37	0.76	0.49	8.37	2.78	2.1	6.16
Total		98.68	99.53	99.22	98.36	99.82	99.48	99.14	99.24
Li	b	8.7	9.6	8.8	43.2	117.8	13.8	42.6	132
Be	b	1.5	1.7	2.1	3.1	1.4	1.1	1.7	0.3
Sc	b	5.3	4.7	6.3	3.1	9.2	7.4	10.2	11.9
V	b	4	4	7	12	47	40	97	77
Cr	c	3	4	3	8	23	86	12	117
Co	b	1	2	1	2	6	9	16	12
Ni	b	4	4	5	8	13	23	28	59
Cu	b	4	7	3	5	18	12	44	31
Zn	b	19	51	55	75	162	40	60	264
Ga	c	13	11	17	23	18	17	18	15
Ge	c	2	1	3	3	4	2	2	4
As	b	11	6	<2	<2	2	194	2	3
Rb	b	184	144	85	121	41	63	62	13
Sr	c	17	58	156	37	251	60	358	8
Y	c	27	25	45	44	59	15	10	17
Zr	a	79	76	138	314	302	196	127	66
Nb	c	10.7	10.9	10.8	25.1	10.4	11	6	7.9
Mo	c	<2	<2	<2	2	<2	<2	<2	<2
Cd	b	<0.1	<0.1	0.6	<0.1	0.5	<0.1	<0.1	0.1
Sn	c	4	5	3	6	2	2	1	3
Cs	c	1	1.3	4	3	3.8	5.1	5.3	1.9
Ba	a	378	787	709	630	359	402	429	9
La	c	4.9	2.4	14.5	23.5	23.6	5.1	13.8	6.9
Ce	c	12.5	8.7	34.4	72.3	49.8	13.4	28.8	15.5
Pr	c	1.7	0.8	4.5	6.6	6.3	1.7	3.3	1.9
Nd	c	7	3.1	18.2	26.7	27.3	7	12.6	7.5
Sm	c	2.5	1	5.2	5.5	6.8	1.7	2.4	2.1
Eu	c	0.31	0.26	0.9	0.91	3.72	0.46	0.82	0.45
Tb	c	0.7	0.4	1.1	0.9	1.6	0.3	0.3	0.4
Gd	c	3.3	1.9	5.7	5.3	8.8	1.7	2.3	2.4
Dy	c	4.8	3.5	7.8	7	9.8	2.3	2.1	2.8
Ho	c	1	0.8	1.7	1.7	2.1	0.6	0.4	0.6
Er	c	3.2	3	5.4	6.1	6.2	2	1.1	1.8
Tm	c	0.48	0.48	0.83	1.03	0.89	0.33	0.16	0.28
Yb	c	3.3	3.1	5.6	7.5	6.1	2.6	1.1	1.8
Lu	c	0.47	0.53	0.93	1.26	1.02	0.41	0.17	0.3
Hf	c	2.9	2.8	4.7	10	7.3	5.1	3.4	1.9
Ta	c	2	1.4	0.6	3.4	0.6	0.9	<0.5	<0.5
W	c	4	1	<1	2	<1	1	1	4
Tl	c	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.1
Pb	b	13	8	20	11	38	34	10	23
Th	c	5.4	5	8.9	10.6	5.6	8.9	4.3	2.6
U	c	3	2.1	4.5	2.3	3.8	2.7	1.9	1.1

Note: LOI - loss on ignition, "<" - concentration at or below detection limit, n.a. - not analyzed. Methods: a) ICP-OES-FUS, b) ICP-ES 4 ACID, c) ICP-MS-FUS, Grav: gravimetric.

Table 1. Continued

16AW366A02	16AW405A02	16AW500B02	16AW038B02
11040098	11040059	11040074	11040036
Isle Galet	Isle Galet	Isle Galet	Isle Galet
andesite	andesite	basalt	basalt
605744	606833	584784	610477
5302316	5305288	5289675	5306181
56.63	55.98	51.13	49.93
1.19	1.20	1.01	1.77
14.93	14.54	17.76	14.93
8.08	8.38	9.86	11.54
1.04	0.78	1.00	1.32
6.33	6.84	7.97	9.20
3.92	6.02	5.40	6.89
6.80	3.15	8.32	11.23
5.32	5.97	2.23	2.78
0.24	1.08	0.91	0.18
0.18	0.17	0.30	0.26
0.19	0.10	0.10	0.09
0.61	1.42	1.5	0.53
98.1	98.01	98.52	100.13
7	83.2	74.9	10.4
0.5	3.3	1.1	0.7
29.4	29.1	33.3	46.3
165	198	207	314
23	67	295	265
19	64	36	43
17	186	108	73
17	21	28	4
95	103	88	132
16	12	15	17
4	3	3	5
6	<2	24	29
12	72	76	7
59	241	263	500
40	25	23	29
156	113	100	122
9.9	4.7	5.7	2.5
<2	<2	<2	<2
0.4	0.4	0.4	0.4
3	3	1	3
2.3	10.3	17.8	<0.5
23	336	329	113
15.3	7.8	13.7	6
33.2	19	29.9	16.7
4.1	2.3	3.6	2.6
17	9.8	14.9	13.4
4.2	2.8	3.5	4.3
1.78	0.97	0.78	1.48
1	0.7	0.7	0.9
5.8	3.6	3.9	5.5
6.4	4.6	4.3	5.9
1.4	1	0.9	1.2
4.2	3	2.7	3.5
0.62	0.4	0.38	0.49
3.9	2.7	2.6	3.2
0.68	0.39	0.38	0.52
4.8	2.9	2.8	3.1
0.5	<0.5	<0.5	<0.5
5	<1	<1	<1
0.1	<0.5	<0.5	<0.5
0	0	7	0
5.3	3.4	3.1	0.5
1.2	0.8	0.6	0.2

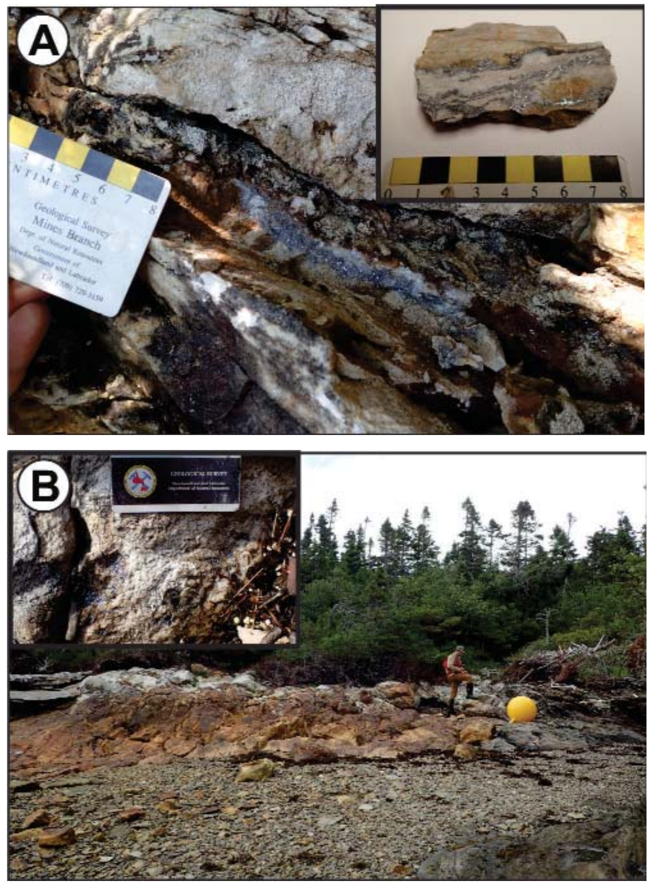

Plate 5. *Selected mineralization in the western part of the St. Alban's map area. A) Galena-rich silicified vein within metasandstone of the Riches Island Formation, Lampidoes Passage. Inset shows crosscut through vein; B) Aplite dyke intruding metasandstone of Riches Island Formation containing molybdenite (*see *insert, scale card is 8 cm wide), Northwest Cove.*

been done at the GSNL laboratory, St. John's. Major elements (plus Cr, Zr and Ba) were determined by inductively coupled plasma-optical emission spectrometry following a lithium tetraborate fusion (ICP-OES-FUS). Where the oxidation state was determined by titration, iron is presented as FeO and Fe_2O_3, otherwise as Fe_2O_3 (total). Select trace elements were determined by inductively coupled plasma emission spectrometry following a four acid (HF-HCl-HNO_3-$HClO_4$) total digestion (ICP-ES 4 ACID). Other trace elements were determined by inductively coupled plasma mass spectrometry following a lithium tetraborate fusion (ICP-MS-FUS). Analytical method of determination is indicated for each element in Table 1. Quality control was done by routinely measuring standard materials and duplicate analyses to assess accuracy and precision. This information can be accessed in Westhues (2017a).

SAMPLE DESCRIPTIONS AND CLASSIFICATION

Most metavolcanic rocks in the Isle Galet Formation are found within one main volcanic belt that trends southwest–northeast and can be over a kilometre wide across strike. This main volcanic belt is separated into southern, central, and northern section by two faults (Figure 2). Representative samples were taken from the three sections of the main volcanic belt and of the smaller metavolcanic layers off the main belt that occur throughout the Isle Galet Formation, totalling eleven samples plus one sample from a metavolcanic lens within the Riches Island Formation. The data are further compared with five samples from the felsic metavolcanic Twillick Brook Member of the St. Joseph's Cove Formation (H. Sandeman, personal communication, 2017).

The metavolcanic rocks range from rhyolite to basalt in composition with several samples of intermediate composition, as the total alkali *versus* silica diagram (TAS, Figure 3A) after LeBas *et al.* (1986) and the trace-element discrimination diagram (Winchester and Floyd, 1977; modified by Pearce, 1996) for the different rock types shown (Figure 3B). The latter rock classification diagram uses immobile trace elements (Figure 3B), which are generally better suited for rocks that underwent alteration and/or higher grade metamorphism. A few intermediate samples are classified in different categories compared to the TAS diagram; in these cases, the rock type classification based on the immobile trace elements is preferred.

The four samples having the highest SiO_2 (from 73.8 to 75.7 wt. % SiO_2) are from different areas of the main volcanic belt in the Isle Galet Formation and form the main rock types at the sampling locations. These samples are cream to light-grey rhyolite vitric and crystal tuffs from the three sections of the main volcanic belt. Phenocrysts are quartz and feldspar, and are partly deformed and elongated parallel to the main foliation defined by the alignment of muscovite in the groundmass.

The intermediate compositions (56.0 to 64.0 wt. % SiO_2) occur within the Isle Galet and the Riches Island formations as mappable lenses that can be followed for several hundred metres along strike, or as thin layers less than a metre thick within metasedimentary rocks or felsic metavolcanic rocks. One sample is a dacite lapilli tuff that has few feldspar phenocrysts from a discrete lens in the Isle Galet Formation. Four samples are classified as andesite on the trace-element discrimination diagram (Figure 3B). A fifth sample plots between andesite and basalt on this diagram, but is classified as andesite based on the intermediate SiO_2 content. They range from medium-grey biotite–amphibole andesite to greenish meta-andesite schist and usually have a well-developed foliation, and may be folded.

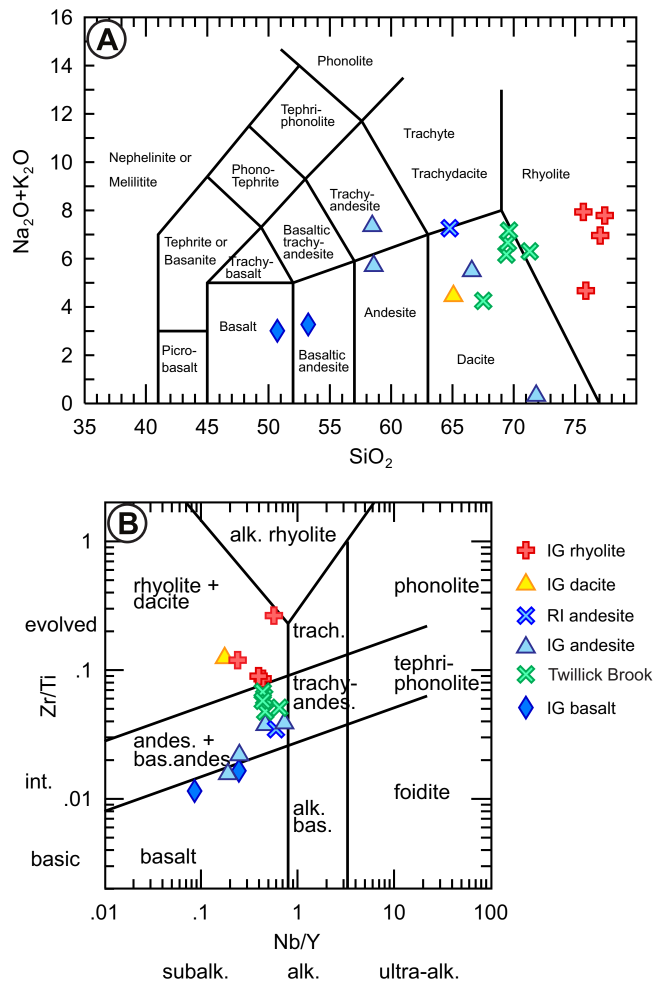

Figure 3. *Whole-rock geochemistry of metavolcanic rocks from the St. Alban's area on A) Total alkali* vs. *silica (TAS) diagram after LeBas* et al. *(1986), and B) Trace-element discrimination diagram by Pearce (1996) and Winchester and Floyd (1977). Five samples from the Twillick Brook Member (H. Sandeman, personal communication, 2017) are included for comparison. IG: Isle Galet, RI: Riches Island for Figures 3-6.*

Five samples from the Twillick Brook Member (H. Sandeman, personal communication, 2017) are quartz and plagioclase porphyritic light-coloured metavolcanic rocks that are weakly foliated (dacite/rhyolite on TAS, andesite on trace-element diagram). One sample is strongly foliated and has a higher chloritized groundmass and a slightly different chemical composition compared to the other four samples (*e.g.*, lower SiO_2 and K_2O).

The lowest SiO_2 contents (49.9 and 51.1 wt. % SiO_2) are found in mafic layers interbedded within Unit O:YIsg, ranging from medium-grey plagioclase-amphibole basalt to chlorite schist.

GEOCHEMISTRY AND TECTONIC SETTING

All metavolcanic rocks of this sample set are subalkaline, and most follow a calc-alkaline trend based on the AFM diagram (after Irvine and Baragar, 1971; Figure 4A), except the two basaltic samples. Using the Zr/Y–Th/Yb discrimination diagram (Ross and Bédard, 2009; Figure 4B) for this distinction, only one basaltic sample falls into the tholeiitic category. Most samples cluster together as transitional, whereas one rhyolite, two andesite, and all five Twillick Brook samples plot within the calc-alkaline field.

The chondrite-normalized REE pattern of the rhyolite samples (Figure 5A) show a range of REE enrichment (La/Yb_{CN} = 0.56–2.25), a negative slope for the LREE, a negative Eu anomaly (Eu/Eu* = 0.33–0.58), and a flat to slight positive slope for the heavy REE (HREE, Gd/Yb_{CN} = 0.51–0.84). Two rhyolite samples have a positive Ce anomaly. The dacite sample has an overall similar pattern (La/Yb_{CN} = 2.78; Gd/Yb_{CN} = 1.19), but a distinct positive Eu anomaly (Eu/Eu* = 1.47). On a multi-element variation diagram normalized to N-MORB (modified after Sun and McDonough, 1989; Figure 5B), all rhyolite and dacite samples show an overall LILE enrichment, and have prominent negative Ti anomalies, whereas negative Nb and P anomalies are more or less distinct.

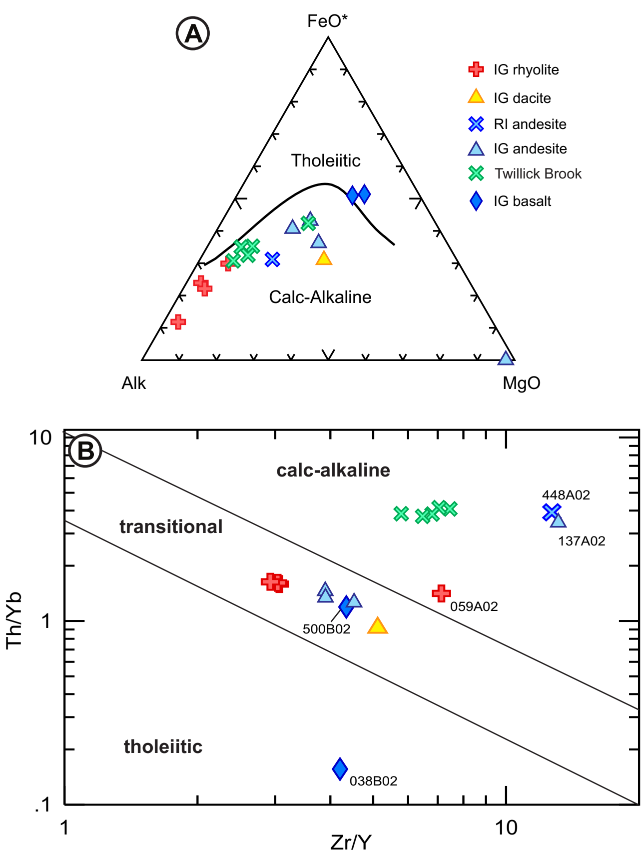

Figure 4. *Samples from this study on A) Alkali (K_2O + Na_2O) – total iron (FeO + Fe_2O_3) – magnesium (MgO) triangular plot (AFM diagram, Irvine and Barager, 1971), and B) Th/Yb* vs. *Zr/Y diagram (Ross and Bédard, 2009), to assign the magmatic affinities tholeiitic* vs. *calc-alkaline.*

The andesite from the Isle Galet Formation (Figure 5C) show REE patterns either similar to the rhyolite samples (negative LREE slope and flat HREE), or show an overall flat overall pattern (La/Yb_{CN} = 1.41–2.81; Gd/Yb_{CN} = 0.54–1.23). Two samples have a slight negative Eu anomaly, whereas the other two have no or slightly positive anomalies (Eu/Eu* = 0.61–1.10) The andesite of the Riches Island Formation shows a negative slope for the HREE, which clearly distinguishes it from intermediate and mafic volcanic rocks of the Isle Galet Formation (La/Yb_{CN} = 9.00; Gd/Yb_{CN} = 1.73). Andesite samples from the Twillick Brook Member form a tight group and have a steeper slope in their REE pattern, higher enrichment of LREE and intermediate levels of HREE (La/Yb_{CN} = 0.56–2.25; Gd/Yb_{CN} = 0.51–0.84). Negative Nb and P anomalies are present, but less distinct compared to the felsic samples, whereas the negative Ti anomaly only exists in one andesite sample (Figure 5D). The Twillick Brook andesite samples have prominent negative Nb, P and Ti anomalies. The LIL elements are enriched in all samples, whereas most other elements displayed are at or slightly above N-MORB level (*i.e.*, around 1).

One basalt sample has a REE pattern comparable to felsic and some andesite samples that have a negative LREE slope, flat HREE and a negative Eu anomaly (La/Yb_{CN} = 3.78; Gd/Yb_{CN} = 1.24, Eu/Eu* = 0.65) and have a general enrichment in LILE (Figure 5C, D). The second basalt sample has a rather flat REE pattern (La/Yb_{CN} = 1.34; Gd/Yb_{CN} = 1.42, Eu/Eu* = 0.93) and is less enriched in LILE compared to the rest of the sample set. Both basalt samples have negative Nb and P anomalies.

The observed trace-element patterns are typical of subduction-related arc magmas. Fluids involved in the formation of magmas at subduction zones concentrate the very mobile LIL elements in contrast to the immobile HFS elements such as Hf or Zr (*e.g.*, Pearce, 1996). Similar levels of the latter compared to N-MORB indicate a similar depleted mantle source in arc magmas. The negative Nb (+Ta) anomaly is probably related to the presence of Nb-bearing residual mineral, (*e.g.*, amphibole, rutile, ilmenite, or titanite) in the mantle wedge and/or subducted plate, whereas the neighbouring highly immobile elements Th and La are added to arc magma (*e.g.*, Pearce, 1996).

Samples from the St. Alban's area have been plotted on a selection of discrimination diagrams (Wood, 1980; Pearce, 2008; Figure 6) that have demonstrated to distinguish vol-

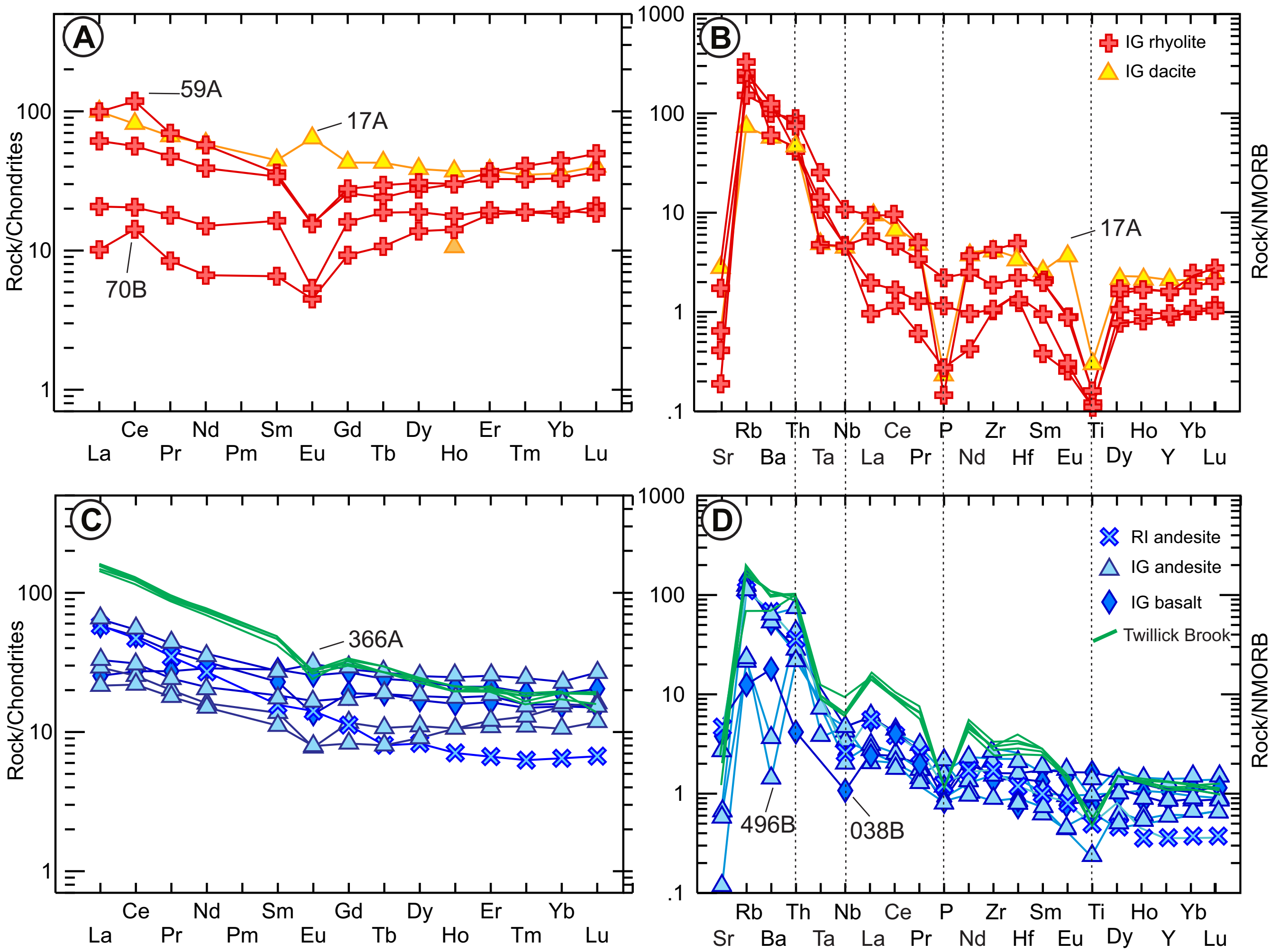

Figure 5. *Trace-element variation diagram for metavolcanic rocks of the Baie d'Espoir Group. A) Rare-earth element (REE) concentration of felsic metavolcanic rocks from this study (values after Sun and McDonough, 1989); B) Multi-element variation diagram normalized to N-MORB (after Sun and McDonough, 1989) for felsic metavolcanic rocks of the Isle Galet Formation; C) REE concentration normalized to chondrite for intermediate metavolcanic rocks, including five samples from the Twillick Brook Member and basaltic metavolcanic rocks; D) Multi-element variation diagram normalized to N-MORB (after Sun and McDonough, 1989) for intermediate and mafic metavolcanic rocks.*

canic-arc basalts (VAB) from mid-ocean ridge (MOR) and ocean-island basalts (OIB). Both diagrams confirm that metavolcanic rocks of the Baie d'Espoir Group can be classified as volcanic-arc magmas, including the samples from the Twillick Brook Member north of the St. Alban's map area. The basalt sample, 16AW038B02, is clearly distinct in both diagrams, mainly due to the lower contents of Th. This sample also contains high contents of Ca (11.23 wt. %), so that is possible that this sample has been altered by carbonate fluids.

In conclusion, the metavolcanic rocks of the Baie d'Espoir Group (Isle Galet, Riches Island formations and Twillick Brook Member) show distinct geochemical features of subduction-related processes, as do the intrusions of the Gaultois Granite and the Northwest Brook Complex (A. Westhues, unpublished data, 2017). These include negative Nb, P, and Ti anomalies on multi-element variation diagrams normalized to N-MORB, and elevated abundances of LILE and relatively low HFSE abundances. Discrimination diagrams suggest that these rocks formed in a calc-alkaline to transitional volcanic-arc setting. The close association of the metavolcanic rocks with submarine sedimentary rocks implies their formation in an intra-oceanic volcanic island-arc environment.

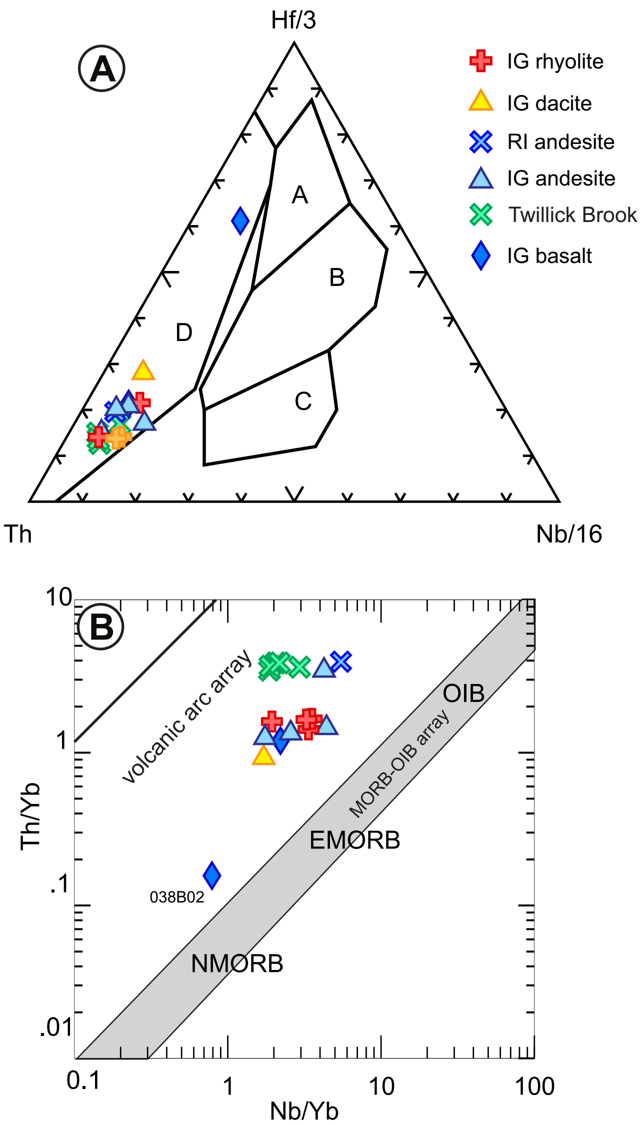

Figure 6. *Whole-rock geochemistry of samples plotted on different discrimination diagrams for tectonic setting. A) Th–Hf–Nb triangular plot modified after Wood (1980), using Nb instead of Ta, which is below detection limit for several samples; B) Nb/Yb* vs. *Th/Yb plot by Pearce (2008). A – N-MORB (normal mid-ocean ridge basalt), B – E-MORB (enriched MORB), C – OIB (ocean-island basalt), D – Arc basalt.*

U–Pb GEOCHRONOLOGY

Two samples were processed for isotope dilution–thermal ionization mass spectrometry (ID–TIMS) U–Pb geochronology at the Jack Satterly Geochronology Laboratory (JSGL), University of Toronto. Methods used in sample preparation, analysis and treatment of isotopic data followed those described by Kerr and Hamilton (2014). Both samples contained abundant quantities of recovered zircon. All zircon grains, including the selected representative grains shown in Figures 7 and 9, were annealed and etched using a chemical abrasion pre-treatment before dissolution and final analysis, following a modified version of protocols described by Mattinson (2005). Uranium–lead isotopic results for the two samples are listed in Table 2. Analytical errors presented in the table, in the concordia diagrams, and for ages presented in the text are all provided at the 2σ level of uncertainty.

16AW031A03 – Metarhyolite Crystal Tuff, Main Volcanic Belt of Isle Galet Formation, South of Little River Basin and Collins Brook (UTM E 595181 N 5292509)

The main volcanic belt of the Isle Galet Formation was targeted for geochronological investigation to better define the stratigraphy of the Baie d'Espoir Group. The metarhyolite sampled occurs within the southern part of the main volcanic belt of the Isle Galet Formation (Unit O:YIv). These rocks are easy to distinguish in the field and on airphotos due to their light-coloured weathering and because they typically form ridges. Sample 16AW031A03 was collected from the centre of *ca.* 550-m-wide ridge of dominantly felsic metavolcanic rocks, *ca.* 4 km south from the mouth of Collins Brook into the Little River basin. The unit is in concordant contact with black schist beds of the Isle Galet Formation (Unit O:YIsb) to the northwest. The Day Cove Thrust separates the main volcanic belt from the Little Passage Gneiss about 350 m to the southeast across strike from the sample location.

The rock is a light-grey, foliated, fine-grained metarhyolite crystal tuff having small isoclinal folds (Plate 1A). In thin section, a fine-grained quartz and muscovite matrix contains quartz and K-feldspar phenocrysts. Foliation and folds are determined by the alignment of muscovite and recrystallized quartz bands.

Zircon recovered from the rhyolite sample are dominated by a population of clear and colourless, elongate 3:1 to 4:1, well-terminated but commonly broken prisms with square cross-sections (Figure 7D). Flat prismatic grains also occur but are rare. Small fluid and mineral inclusions are common. Subpopulations of larger, subangular and subrounded pale-brown cracked grains, and smaller spindle morphologies are present in minor quantities. Optical cores are visible in approximately 5% of the total population. Four single grains (Figure 7C) of the dominant population (Z1, Z4, Z5, and Z6) have moderate U contents (200–330 ppm), Th/U ratios ranging from 0.31–0.66, and yield overlapping concordant results where $^{206}Pb/^{238}U$ ages narrowly range between 465.1 ± 0.9 and 466.5 ± 1.2 Ma (Table 2, Figure 7A, B). Three of the analyzes (Z4, Z5, Z6) have slightly ele-

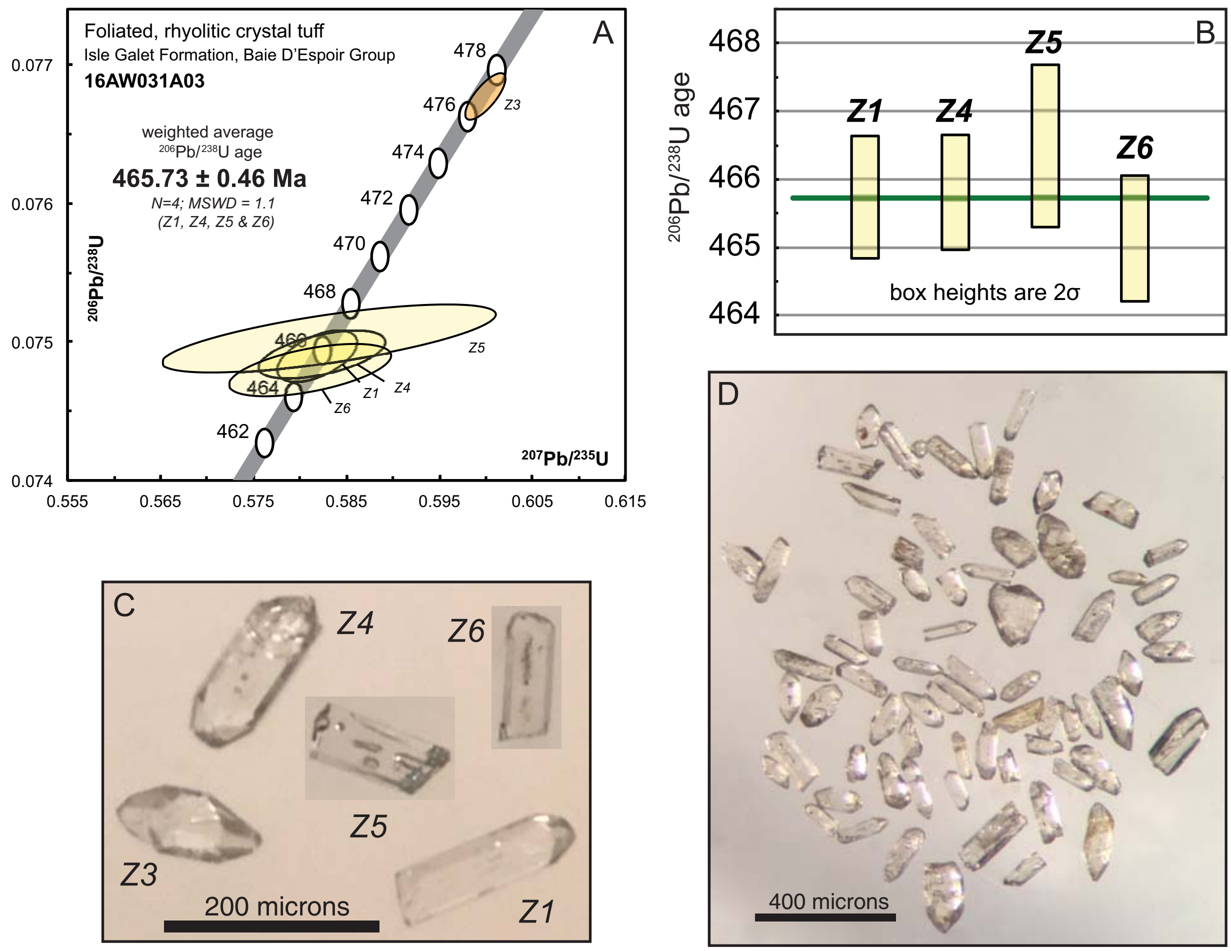

Figure 7. *U–Pb geochronological results for zircon from the metavolcanic rhyolite, Isle Galet Formation, sample 16AW031A03. A) Concordia diagram showing U–Pb data for five concordant zircon analyses with weighted average $^{206}Pb/^{238}U$ age of the four younger analyses. Concordia 'band' reflects uncertainties in U decay constants; B) Plot of $^{206}Pb/^{238}U$ ages for youngest population (bar is weighted average age shown in A); C) Transmitted light images of the zircon fractions analysed; D) Image of the broader, best quality zircon grains present in sample 16AW031A03.*

vated total common Pb and likely reflect the presence of mineral inclusions, such as apatite. A combined weighted mean $^{206}Pb/^{238}U$ age for the four youngest analyses is 465.73 ± 0.46 Ma (MSWD = 1.1). An additional fraction (Z3; short spindle-shape) has similar U and Th/U characteristics, and is 0.5% discordant, but is distinctly older having a $^{206}Pb/^{238}U$ age of 476.9 ± 0.8 Ma and a $^{207}Pb/^{206}Pb$ age of 479.0 ± 4.4 Ma. This zircon is interpreted as being xenocrystic in origin, with *ca.* 477 Ma representing a minimum age for the inherited component.

16AW091A – Highly Magnetic Quartz Monzonite Potentially Late Gaultois Granite or Posttectonic Intrusion, Close to Salmonier Pond (UTM E 598387 N 5291388)

The unit sampled for dating underlies a strong high in the residual-magnetic geophysical survey within a zone of alternating Little Passage Gneiss (medium high) and Gaultois Granite (low residual-magnetic signal) around Salmonier Pond in the south-central part of the map area (Figure 8A, B). The sample location is relatively low lying compared to surrounding peaks of the Gaultois Granite. The high content of modal magnetite in this quartz monzonite accords with the anomalous aeromagnetic signature. The non-foliated and non-deformed nature of this unit is uncharacteristic of the surrounding Gaultois Granite (Figure 8C, D), and it was therefore expected to represent a late tectonic intrusive rock (Westhues, 2017b). Additionally, this coarse-grained equigranular granitoid does not show the porphyritic to megacrystic feldspars otherwise typical of the Gaultois Granite. However, direct intrusive contact relationships are covered by vegetation and bogs, so that this magnetite-rich unit was targeted for geochronology to better understand its temporal relation to the Gaultois Granite and to the deformation history in the area.

Table 2. U–Pb TIMS zircon data for samples 16AW031A03 and 16AW091A03

Fraction	Description	Weight (µg)	U (ppm)	Pb^T (pg)	Pb_C (pg)	Th/U	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{238}U$	± 2σ	$^{207}Pb/^{235}U$	± 2σ	$^{207}Pb/^{206}Pb$	± 2σ	Ages (Ma) $^{206}Pb/^{238}U$	± 2σ	Ages (Ma) $^{207}Pb/^{235}U$	± 2σ	Ages (Ma) $^{207}Pb/^{206}Pb$	± 2σ	Disc. (%)
16AW031-A03 Metarhyolite crystal tuff, Isle Galet Fm. (UTM E 595181 N 5292509)																				
Z1	1 clr, cls, brkn euh >4:1 flat pr	1.1	199	15.03	0.44	0.371	2189	0.074923	0.000149	0.58184	0.00350	0.056323	0.000294	465.7	0.9	465.6	2.2	465.1	11.6	-0.1
Z3	1 clr, cls, dbly term 2:1 pr	2.1	332	66.82	0.70	0.365	6095	0.076777	0.000136	0.59998	0.00178	0.056677	0.000112	476.9	0.8	477.2	1.1	479.0	4.4	0.5
Z4	1 clr, cls, dbly term 3:1 pr, incl	2.9	212	47.15	2.45	0.310	1265	0.074934	0.000140	0.58229	0.00556	0.056358	0.000490	465.8	0.8	465.9	3.6	466.5	19.3	0.2
Z5	1 clr, cls, brkn euh >2:1 pr, incl	1.3	226	18.41	2.48	0.655	456	0.075047	0.000198	0.58308	0.01476	0.056350	0.001326	466.5	1.2	466.4	9.5	466.2	52.5	-0.1
Z6	1 clr, cls, brkn euh >2:1 pr, incl	1.3	327	26.49	1.16	0.644	1371	0.074821	0.000153	0.58103	0.00713	0.056321	0.000635	465.1	0.9	465.1	4.6	465.1	25.0	0.0
16AW091-A03 Massive quartz monzonite (magnetic high), near Salmonier Pond (UTM E 598387 N 5291388)																				
Z1	1 clr, cls, brkn el euh 3.5:1 pr, incl	4.4	277	93.03	19.22	0.817	264	0.067316	0.000187	0.51216	0.01665	0.055181	0.001729	420.0	1.1	419.9	11.2	419.6	70.5	-0.1
Z2	1 clr, cls, eq pr	1.8	234	34.38	0.75	0.680	2709	0.067232	0.000120	0.51197	0.00248	0.055229	0.000225	419.5	0.7	419.8	1.7	421.5	9.1	0.5
Z3	1 clr, cls, 2:1 dbly term, flat pr	1.0	518	40.19	1.07	0.610	2257	0.072437	0.000131	0.56162	0.00331	0.056232	0.000289	450.8	0.8	452.6	2.2	461.5	11.4	2.4
Z4	1 clr, cls, brkn 2:1 pr, incl	2.3	251	45.03	1.12	0.598	2431	0.067273	0.000122	0.51205	0.00268	0.055204	0.000247	419.7	0.7	419.8	1.8	420.5	10.0	0.2

Notes:

All analyzed fractions represent best quality, crack- and optically core-free zircon, pretreated *via* chemical abrasion methods (1000°C annealing and acid leaching). Abbreviations: clr - clear; cls - colourless; dbly term - doubly-terminated; euh - euhedral; eq - equant; pr - prism, brkn - broken; incl - mineral ± fluid inclusions;

Pb^T is total amount (in picograms) of Pb.

Pb_C is total measured common Pb (in picograms) assuming the isotopic composition of laboratory blank: 206/204 - 18.221; 207/204 - 15.612; 208/204 - 39.360 (errors of 2%). Pb/U atomic ratios are corrected for spike, fractionation, blank, and, where necessary, initial common Pb; $^{206}Pb/^{204}Pb$ is corrected for spike and fractionation.

Th/U is model value calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio and $^{207}Pb/^{206}Pb$ age, assuming concordance.

Disc. (%) - percent discordance for the given $^{207}Pb/^{206}Pb$ age. Uranium decay constants are from Jaffey *et al.* (1971).

The mineralogy of the sample is dominated by K-feldspar, plagioclase, biotite, and quartz. Feldspar is sericitized in some cases and biotite is locally chloritized. Titanite and magnetite (>3 modal percent) are very common, and commonly occur in clusters with biotite. Apatite and zircon (up to 0.4 mm long) are relatively common accessory minerals. The modal mineralogy and chemistry classify this rock as a quartz monzonite, whereas the typical Gaultois Granite in the map area is compositionally closer to granodiorite or diorite.

The sample yielded a modest amount of zircon, most of which comprised water-clear, colourless to very pale-brown prisms, subequant to elongate forms (up to 4:1 length:breadth; Figure 9). Although most grains are sharply faceted, rare grains show signs of rounding and may represent partly resorbed xenocrysts. Many zircon grains contain fluid and/or mineral inclusions, including apatite. Four high-quality zircon grains were selected for analysis (Figure 9C), and of these, three show younger, concordant results that are completely overlapping (Figure 9D). These have consistent, moderate U contents (230–280 ppm), and Th/U ratios ranging from 0.6-0.8 (Table 2). A weighted average $^{206}Pb/^{238}U$ age for the three fractions (Z1, Z2, Z4) is 419.65 ± 0.46 Ma with an MSWD of 0.31 and a high probability of fit (73%). This is interpreted to represent a robust estimate of the age of emplacement and crystallization of the quartz monzonite. A fourth fraction (Z3; Figure 9A), consisted of a clear, sharply faceted 2:1 euhedral prism, but has higher U, is over 2% discordant and has a minimum age of 450 Ma (Table 2).

DISCUSSION OF GEOCHRONOLOGICAL RESULTS

The weighted mean $^{206}Pb/^{238}U$ age of 465.73 ± 0.46 Ma for youngest zircon fractions from sample 16AW031A03 is interpreted as the eruption age of the Isle Galet Formation metavolcanic rhyolite. The Darriwilian (upper Middle Ordovician) age of this sample is slightly younger, but overlaps within error with the Dapingian age (468 ± 2 Ma) of the Twillick Brook Member of the St. Joseph's Cove Formation (Colman-Sadd *et al.*, 1992). The 477 Ma age for the partly xenocrystic zircon grain is interpreted to be an inherited component whose source is currently unknown.

The Darriwilian age of the rhyolite could indicate that the Isle Galet Formation is not a true time equivalent of the St. Joseph's Cove Formation, as was suggested earlier (Colman-Sadd, 1980). There is an overlap with a Darriwilian age of a tuff from the Bay du Nord Group of 466 ± 3 Ma (Dunning *et al.*, 1990) in the western part of the Hermitage Flexure. Perhaps this suggests a connection between the Bay

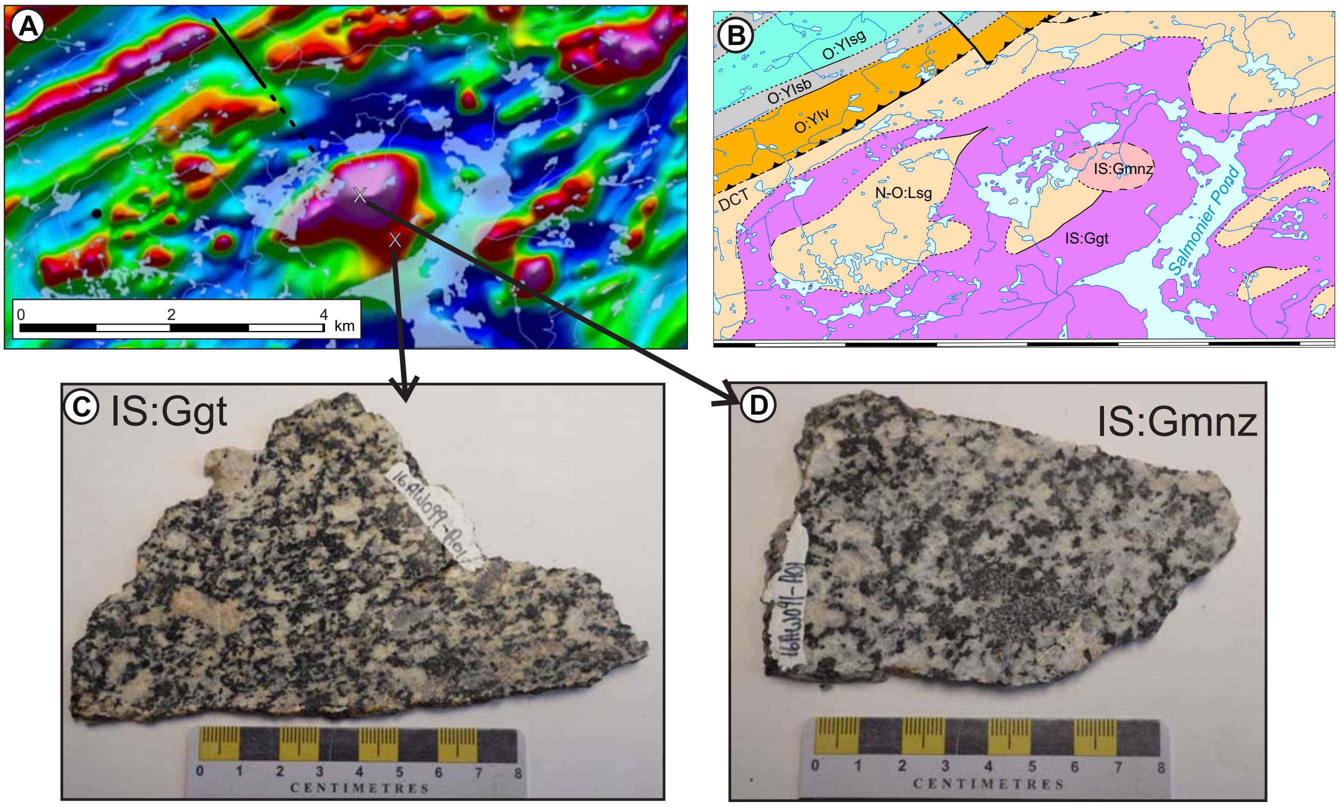

Figure 8. *Location of sample 16AW091A03 and comparison to Gaultois Granite. A) Residual-magnetic geophysical map, "X" marks stations 16AW091 and 16AW099; B) Detail of geological map of same area; C) Image of Gaultois Granite sample 16AW099; D) Image of quartz monzonite 16AW091. (Legend for B: N-O:Lsg - Little Passage Gneiss, O:YIsg – pelitic schist of Isle Galet Formation, O:YIsb – graphitic schist of Isle Galet Formation, O:YIv – metavolcanic rocks of Isle Galet Formation, IS:Ggt – Gaultois Granite, IS:Gmnz – non-foliated quartz monzonite, DCT – Day Cove Thrust.)*

du Nord and Baie d'Espoir groups, concealed by the intrusion of the North Bay Granite. Further geochronological studies of volcanic members of the Riches Island and St. Joseph's Cove formations are planned to clearly define the stratigraphy of the Baie d'Espoir Group and possible correlations.

The U–Pb zircon age of 419.65 ± 0.46 Ma for the unfoliated quartz monzonite sample 16AW091A03 is slightly younger than, but overlaps within 2σ error of, the 421 ± 2 Ma age for the surrounding syntectonic Gaultois Granite (Dunning *et al.*, 1990) whose age was determined to the south of the St. Alban's map area. As the quartz monzonite show no signs of deformation and no tectonic overprinting, it may thus represent a late stage phase of the Gaultois Granite (Unit IS:Ggt), given the close overlap in age of these two intrusions, or a later unrelated intrusion. In either case, the lack of a tectonic fabric in the quartz monzonite places a tight limit on the end of deformation during the Salinic orogeny in this area.

CONCLUSIONS

The St. Alban's map area includes a major tectonic boundary between the Gander and the Dunnage zones. Bedrock mapping in the 2017 field season focused on the contact of the North Bay Granite Suite with the Baie d'Espoir Group in the Dunnage Zone. The Riches Island and Salmon River Dam formations show higher grades of metamorphism in the contact region, manifested in the formation of staurolite–mica schists or hornfels. The Salmon River Dam Formation includes small outcrops of ultramafic rocks within the higher metamorphic terrain, which could be of regional significance.

Lithogeochemistry of metavolcanic rocks of the Isle Galet and Riches Island formations suggests that they represent calc-alkaline to transitional island-arc volcanic magmas that formed in an oceanic setting. A precise ID-TIMS U–Pb zircon age was obtained for a metavolcanic rhyolite of the Isle Galet Formation, at 465.73 ± 0.46 Ma (Darriwilian), and

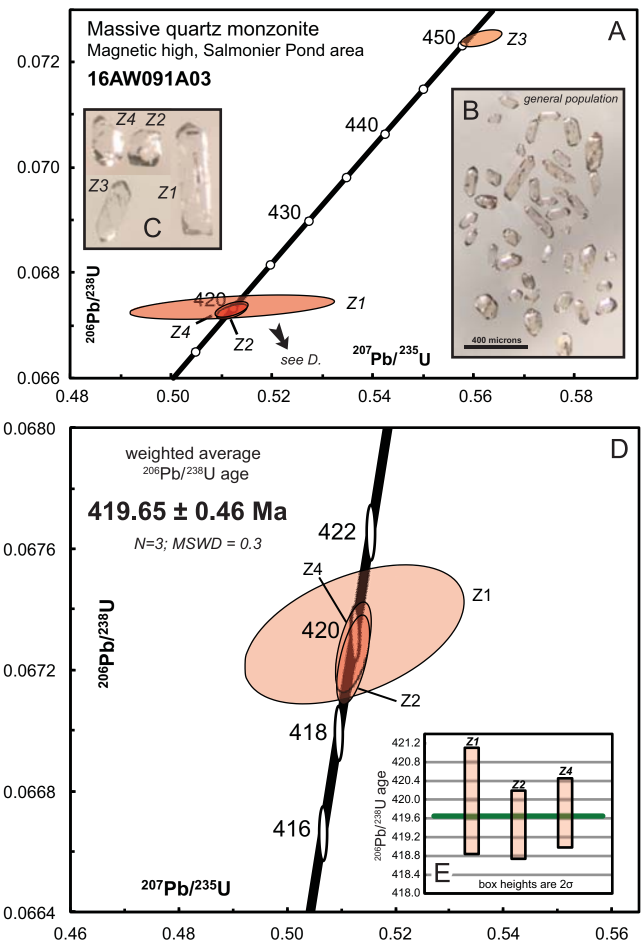

Figure 9. *U–Pb geochronological results for zircon from the quartz monzonite sample 16AW091A03. A) Concordia diagram showing full U–Pb data for four concordant and near-concordant zircon analyses; B) Transmitted light image of the general zircon population from this sample; C) Image of four single grain zircon fractions analyzed; D) Concordia diagram showing details of the three concordant and overlapping younger zircon analyses and their weighted average* $^{206}Pb/^{238}U$ *age; E) Plot of* $^{206}Pb/^{238}U$ *ages for youngest population (bar is weighted average age shown in D).*

has implications for the stratigraphy of the Baie d'Espoir Group (slightly younger than, but within error of, a previously reported Dapingian age for the Twillick Brook Member of the St. Joseph's Cove Formation). A non-foliated quartz monzonite outcropping within the Gaultois Granite has a crystallization age of 419.65 ± 0.46 Ma, which presents a limit on the end of deformation in that area.

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