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# LITHOGEOCHEMISTRY OF GAULTOIS GRANITE, NORTHWEST BROOK COMPLEX AND NORTH BAY GRANITE SUITE INTRUSIVE ROCKS, ST. ALBAN'S MAP AREA

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## ABSTRACT

*Intrusive rocks occur in two different tectonic zones in the St. Alban's map area (NTS 01M/13) and, a) intrude the Little Passage Gneiss of the Gander Zone in the east, and b) the volcanosedimentary rocks of the Baie d'Espoir Group, Exploits Subzone of the Dunnage Zone in the west. The oldest intrusive rock suite in the area is the Late Silurian leuco- to mesocratic, medium- to coarse-grained, megacrystic, lineated and foliated biotite ± tourmaline ± titanite Gaultois Granite (~421 Ma) in the Gander Zone. The rocks are dominantly granodiorite and it is therefore suggested, herein, to use the informal name Gaultois Granite suite. Subunits of the Gaultois Granite suite include hornblende tonalite, quartz diorite, and a slightly younger non-foliated posttectonic coarse equigranular biotite–titanite monzonite (419.6 ± 0.46 Ma). Also, the undated Northwest Brook Complex two-mica granite and numerous felsic aplite and pegmatite dykes intrude the Gaultois Granite suite.*

*Intrusive rocks in the Dunnage Zone are part of the laterally extensive Devonian North Bay Granite Suite with several major units (one of the youngest dated at* ca. *396 Ma). The East Bay Granite in the southwest is typically an equigranular biotite ± muscovite granite to granodiorite that can be weakly to moderately foliated. The second major unit of the North Bay Granite Suite is a weakly- to moderately-foliated, megacrystic biotite granodiorite to granite named the Upper Salmon Road Granite. The Salmon River Dam Fault separates this unit from the southern part of the North Bay Granite.*

*Lithogeochemistry of intrusive rocks in the area shows distinct differences in major- and trace-element contents (*e.g.*, $SiO_2$, alkali, Sr, rare-earth-element contents). Extended trace-element diagrams show characteristic geochemical signatures of subduction-related processes for all suites, including negative Ti and Nb anomalies. Metaluminous to peraluminous Gaultois Granite suite and North Bay Granite Suite are calc-alkaline intrusions related to subduction-related magmatism during the Salinic and Acadian orogeny, respectively. The stronger peraluminous Northwest Brook Complex is likely related to late tectonic magmatism during continent collision.*

*The main intrusive bodies in the St. Alban's area are generally barren of mineralization, except pyrite, within the more mafic members of the Gaultois Granite suite. Several dykes and related quartz veins in contact with rocks of the Dunnage Zone, especially the Riches Island Formation, contain molybdenite or galena.*

## INTRODUCTION

The St. Alban's map area 01M/13 on the south coast of Newfoundland is part of a bedrock-mapping project at a 1:50 000 scale (Westhues, 2017; Westhues and Hamilton, 2018). This project is utilizing a new detailed airborne geophysical survey (Kilfoil, 2016) and expands on previous bedrock mapping (Colman-Sadd, 1976a, b). The map area includes rocks assigned to two major tectonostratigraphic subdivisions, the Gander and Dunnage zones, separated by the Day Cove Thrust, a major tectonic feature in the area (Williams *et al.*, 1988; Figure 1), with different suites of intrusive rocks on each side of the thrust.

Part of this project includes extensive lithogeochemical sampling. Existing geochemical data for plutons were analyzed in the late 1970s and early 1980s (available in the Geoscience Atlas of the Newfoundland and Labrador Geological Survey and in a data compilation of Dickson and Kerr, 2007). In addition, Elias (1981) and Elias and Strong (1982) published geochemical data for plutons in the Bay d'Espoir area. These older datasets include some of the large ion lithophile elements (LILE: Sr, Rb, Ba, *etc.*), but not all trace-element results such as rare-earth elements (REE: La–Lu) and high-field strength elements (HFSE: Y, Nb, Ta, Zr, Hf, Sc, *etc.*). Preliminary whole-rock geochemistry results including a range of trace-element data for selected

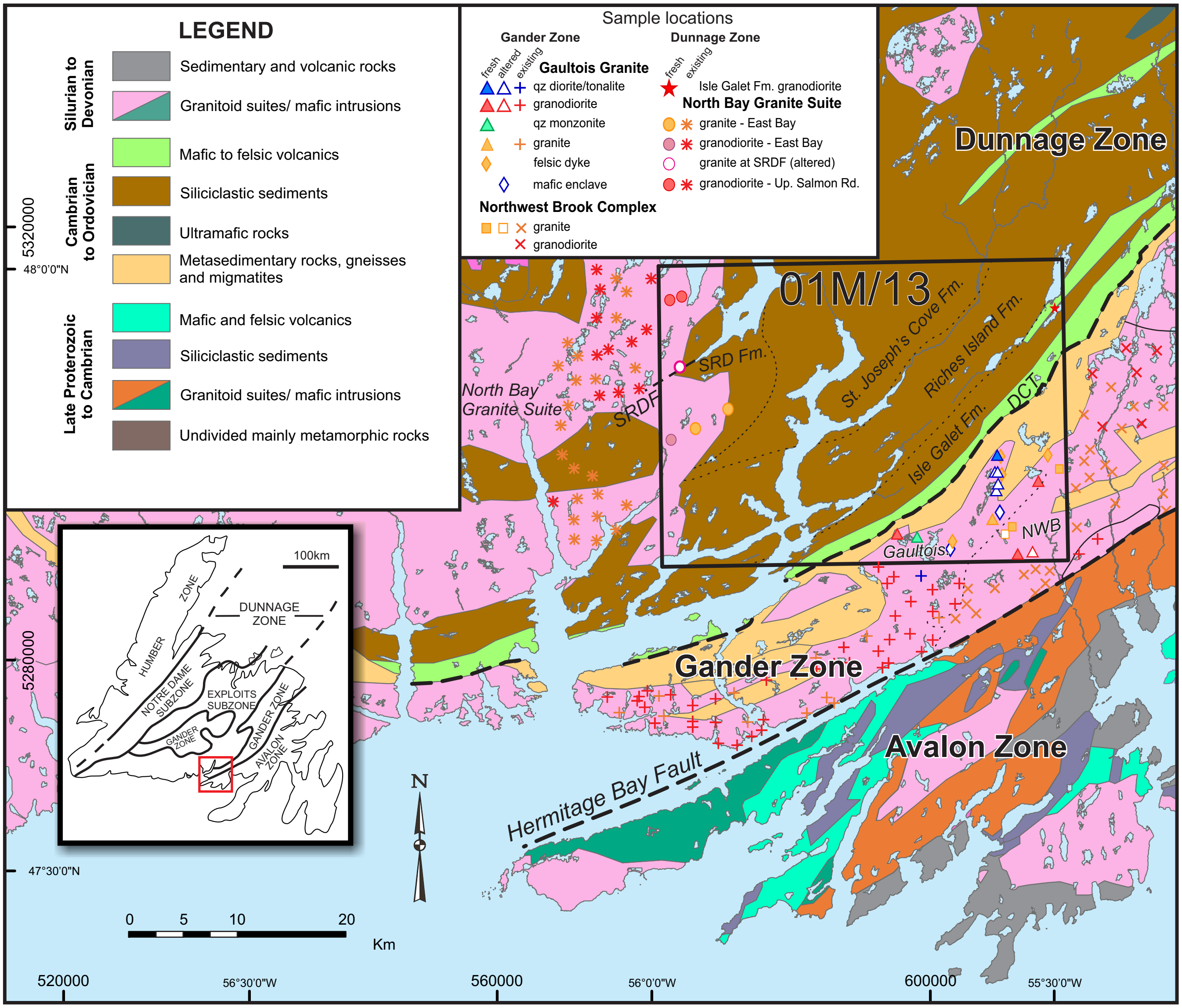


**Figure 1.** *Simplified regional geology of the south coast of Newfoundland modified after Colman-Sadd* et al. *(1990) and information from GSNL geoscience atlas, showing the location of NTS map area 01M/13 and approximate locations of boundaries between the tectonostratigraphic zones of Newfoundland. Boundaries between formations and intrusive suites are shown for the St. Alban's map area as dashed lines. The Salmon River Dam Fault (SRDF) divides the North Bay Granite Suite into the Upper Salmon Road Granite in the north and the East Bay Granite in the south. Sample locations from this study and from selected existing GSNL geochemical data around the St. Alban's map area, including rock type ("granite" > 68 wt. % $SiO_2$) are shown. Inset shows the Island of Newfoundland with major tectonostratigraphic zones and the location of map area (red box). SRD–Salmon River Dam, SRDF–Salmon River Dam Fault, DCT–Day Cove Thrust, NWB–Northwest Brook Complex, Up. Salmon Rd.–Upper Salmon Road.*

samples from the St. Alban's area are discussed here. All geochemical data from this current project are available in Westhues (2018).

## PREVIOUS BEDROCK AND EXPLORATION WORK

The St. Alban's map area was included in a preliminary survey of the Bay d'Espoir area (Jewell, 1939) and a 1:253 440 (1 inch to 4 miles) map of the Belloram area (Anderson, 1965). The area was mapped at a 1:50 000 scale in the 1970s (*e.g.*, Colman-Sadd, 1974, 1976a, b) and included in a detailed structural study along the coast of the Bay d'Espoir region (Piasecki, 1988). In addition, the area was included in the Meelpaeg transect of the Lithoprobe project with both deep seismic reflection profiles (Quinlan *et al.*, 1992), and geological studies along transects (*e.g.*, Williams *et al.*, 1989). The granitoids of the area were studied in detail in a M.Sc. thesis by Elias (1981) and further discussed in Elias and Strong (1982). Their work included major-element and select trace-element geochemistry and Sr isotope data. Dickson (1990) presented a detailed overview of the North Bay Granite Suite that included geochemical data.

The St. Alban's map area, especially the Baie d'Espoir Group, has been a target for 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 (Westhues, 2018) highlight the mineral potential of this area once again.

## REGIONAL GEOLOGY AND ROCK TYPES OF THE ST. ALBAN'S MAP AREA

The Dunnage and Gander zones are part of the Appalachian orogen in Newfoundland, and their tectonic boundary in the St. Alban's map area (NTS 01M/13; *see* Figure 1 for location) is considered to be the northeast–southwest-trending Day Cove Thrust (Colman-Sadd and Swinden, 1984; Williams *et al.*, 1988; Figure 1). It represents a major sinistral ductile shear zone that ranges up to 4 km wide in coastal outcrops (Piasecki, 1988). In the map area, the shear zone separates Ordovician greenschist-metamorphosed volcanosedimentary sequences of the Baie d'Espoir Group of the Dunnage Zone, from the amphibolite-facies Little Passage Gneiss of the Gander Zone. Intrusive rocks of different suites are present throughout the area. The Late Silurian Gaultois Granite suite and the undated Northwest Brook Complex, both intrude Gander Zone rocks to the southeast, and the Devonian North Bay Granite Suite, intrude rocks of the Dunnage Zone to the northwest of the thrust.

Deformation fabrics of the Little Passage Gneiss, Gaultois Granite suite, Baie d'Espoir Group and locally developed in the Northwest Brook Complex, define an overall northeast–southwest orientation, subparallel to the Day Cove Thrust (Piasecki, 1988; Westhues, 2017). Foliation in the North Bay Granite Suite is less well developed with some massive subunits (*e.g.*, *see* Dickson, 1990), but if foliation is present, it is generally subparallel to the regional northeast–southwest trends. The emplacement of the North Bay Granite resulted in contact metamorphism aureoles, especially in the Riches Island and Salmon River Dam formations of the Baie d'Espoir Group, with the development of garnet, staurolite and sillimanite (Colman-Sadd, 1980; Westhues and Hamilton, 2018).

The lithological units of the St. Alban's map area have been described in detail in Westhues (2017) and Westhues and Hamilton (2018). Characteristics and estimated ages of the Little Passage Gneiss, the Baie d'Espoir Group and the intrusive rocks are briefly summarized here. More detailed descriptions of the intrusive rocks discussed here can be found in the rock classification section of this report.

### LITTLE PASSAGE GNEISS

The Little Passage Gneiss (Unit N-O:LSG[1]) in the Gander Zone consists mainly of semipelitic to psammitic paragneiss and minor orthogneiss commonly preserving well-developed compositional banding and locally migmatitic textures. The gneiss has been metamorphosed to amphibolite-facies conditions, with porphyroblasts of garnet (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. A tonalitic gneiss sampled in Little Passage, Gaultois map area, is interpreted to record the metamorphic peak of the gneiss at 423 +5/-3 Ma (U–Pb TIMS, multigrain zircon; Dunning *et al.*, 1990).

### BAIE D'ESPOIR GROUP

The Baie d'Espoir Group (O:Y) consists of Ordovician metasedimentary and minor 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 Isle Galet Formation (O:YI), Riches Island Formation (O:YR), St. Joseph's Cove Formation (O:YJ) and Salmon River Dam Formation (O:YS; Colman-Sadd, 1976a, b). The Ordovician age is based on, a) a biostratigraphic age of the Riches Island Formation from Late Arenig trilobite pygidium (Boyce *et al.*, 1993; *Dapingian* in current International Chronostratigraphic Chart, 470 to 467 Ma); b) a zircon multi grain U–Pb TIMS date of 468 ± 2 Ma for the felsic metavolcanic Twillick Brook Member of the St. Josephs' Cove Formation (Colman-Sadd *et al.*, 1992); and c) a zircon ID-TIMS date of 465.73 ± 0.46 Ma for a metavolcanic rhyolite of the Isle Galet Formation (Westhues and Hamilton, 2018).

The rocks of the Baie d'Espoir Group have been subject to two deformations events ($D_1$ and $D_2$). The first foliation

[1]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.

($S_1$) is subparallel to bedding, especially well developed, and preserved as cleavage in the shales of the St. Joseph's Cove Formation away from the Day Cove Thrust, and probably related to regional-scale isoclinal folding ($F_1$). The second foliation ($S_2$) is most intense in the Isle Galet Formation closest to the Day Cove Thrust, where it is a penetrative schistocity. $S_2$ is also developed as schistocity in most of the Riches Island Formation and as a cleavage elsewhere. Most sandstone and siltstones of the Salmon River Dam Formation are less deformed. An exception are staurolite–mica and graphitic schist and psammite that are amphibolite-facies metamorphosed and folded close to the contact with the North Bay Granite Suite. This area is tentatively assigned to the Salmon River Dam Formation, but contacts with the metasandstone of this formation are not exposed. Several small outcrops of ultramafic rocks (O:YSiu) occur within this higher metamorphosed area about 1 km southeast of Salmon River Dam at the north shore of Gonzo Pond.

### INTRUSIVE ROCKS

The Gaultois Granite suite and Northwest Brook Complex extend from the current map area to the town of Gaultois (about 40 km to the southwest) and into the Hungry Grove Pond map area to the east. Dunning *et al.* (1990) interpreted the foliated syntectonic Gaultois biotite granite to granodiorite (421 ± 2 Ma) to be part of the Silurian Salinic orogeny. A massive quartz monzonite, dated at 419.65 ± 0.46 Ma, likely represents a late phase of the Gaultois Granite. The Northwest Brook Complex is undated, but it intrudes the Gaultois Granite suite.

The North Bay Granite Suite (SD:N) is a composite batholith with a large areal extent throughout the Exploits Subzone of the Dunnage Zone (*e.g.*, Dickson, 1990). With some exceptions, the rocks of the North Bay Granite Suite show only weak to moderate foliation. Monazite from a gneissic subunit of the East Bay Granite yielded $^{207}Pb/^{235}U$ dates of 416 and 410 Ma, interpreted to record the intrusion of the East Bay Granite into the gneissic part of the North Bay Granite Suite (T.E. Krogh *in* Dickson, 1990). The massive Dolland Brook Granite, one of the youngest subunits of the North Bay Granite Suite was dated at 396 +6/-3 Ma (Dunning *et al.*, 1990). Combined, these dates provide a time frame for the intrusive age of North Bay Granite Suite, which are considered syntectonic to posttectonic intrusions in relation to the Acadian orogeny in the Early Devonian. The 396 Ma age further provides a limit on the regional deformation. The units of the North Bay Granite Suite within the St. Alban's map area are described below. Contacts are obscured by cover and as such, the units are introduced in order of areal extend and no intrusive order is implied by the sequence.

## ROCK CLASSIFICATIONS

Plutonic rock samples discussed here, include a) intruding rocks of the Gander Zone: ten samples from the Gaultois Granite suite, three samples from the Northwest Brook Complex, six samples from felsic to intermediate dykes and mafic enclaves within the Gaultois Granite suite, and one sample of a late garnet–tourmaline–muscovite granitic aplite within the Little Passage Gneiss, and b) intruding rocks of the Dunnage Zone: six samples of the North Bay Granite Suite and one intermediate intrusion in the Isle Galet Formation. Rock types have been determined modally in hand sample and thin section (Figure 2A; Streckeisen, 1976). Table 1 lists the samples with UTM locations (NAD 27, Zone 21) and sample characteristics.

### GANDER ZONE INTRUSIONS

The Gaultois Granite suite (IS:G) encompasses biotite granodiorite to granite and minor hornblende tonalite and quartz diorite. In the St. Alban's area, the dominant rock type in the Gaultois Granite suite is a leuco- to mesocratic, medium- to coarse-grained porphyritic to feldspar-megacrystic, lineated and foliated biotite ± titanite granodiorite (IS:Ggt; Plate 1). The rocks are rich in biotite; accessory minerals include titanite, apatite, zircon, and some epidote. The general southwest foliation is defined by the alignment of biotite, elongated quartz grains and quartz ribbons.

Currently included in the Gaultois Granite suite are tonalite, quartz diorite and gabbro (IS:Gm; Colman-Sadd, 1976b) close to the northwest contact of the suite with the Little Passage Gneiss. Contacts of these rocks and Gaultois granodiorite are obscured by cover, so that an intrusive rela-

**Figure 2.** *(Figure on page 5.) Whole-rock geochemistry and modal composition of intrusive rocks from the St. Alban's area. A) On the Q-A-P diagram, based on observations in thin section (Streckeisen, 1976); B) A Spitz-Darling type alteration diagram to assess major-element mobility (using $Na_2O$* vs. *$Al_2O_3/Na_2O$ after Spitz and Darling, 1978); C) Total alkali* vs. *silica (TAS) diagram for plutonic rocks after Wilson (1989); D) Trace-element discrimination diagram by Pearce (1996) after Winchester and Floyd (1977); E) On the alkali-MgO-FeO* diagram to assign tholeiitic* vs. *calc-alkaline affinity (Irvine and Baragar, 1971); F) On the Al/(Ca + Na + K)* vs. *Al/(Na + K) plot (after Maniar and Piccoli, 1989) to determine peraluminous, metaluminous or peralkaline character using Shand's index (after Shand, 1943). Fields for existing GSNL geochemical data are included in C for comparison. SRDF–Salmon River Dam Fault.*

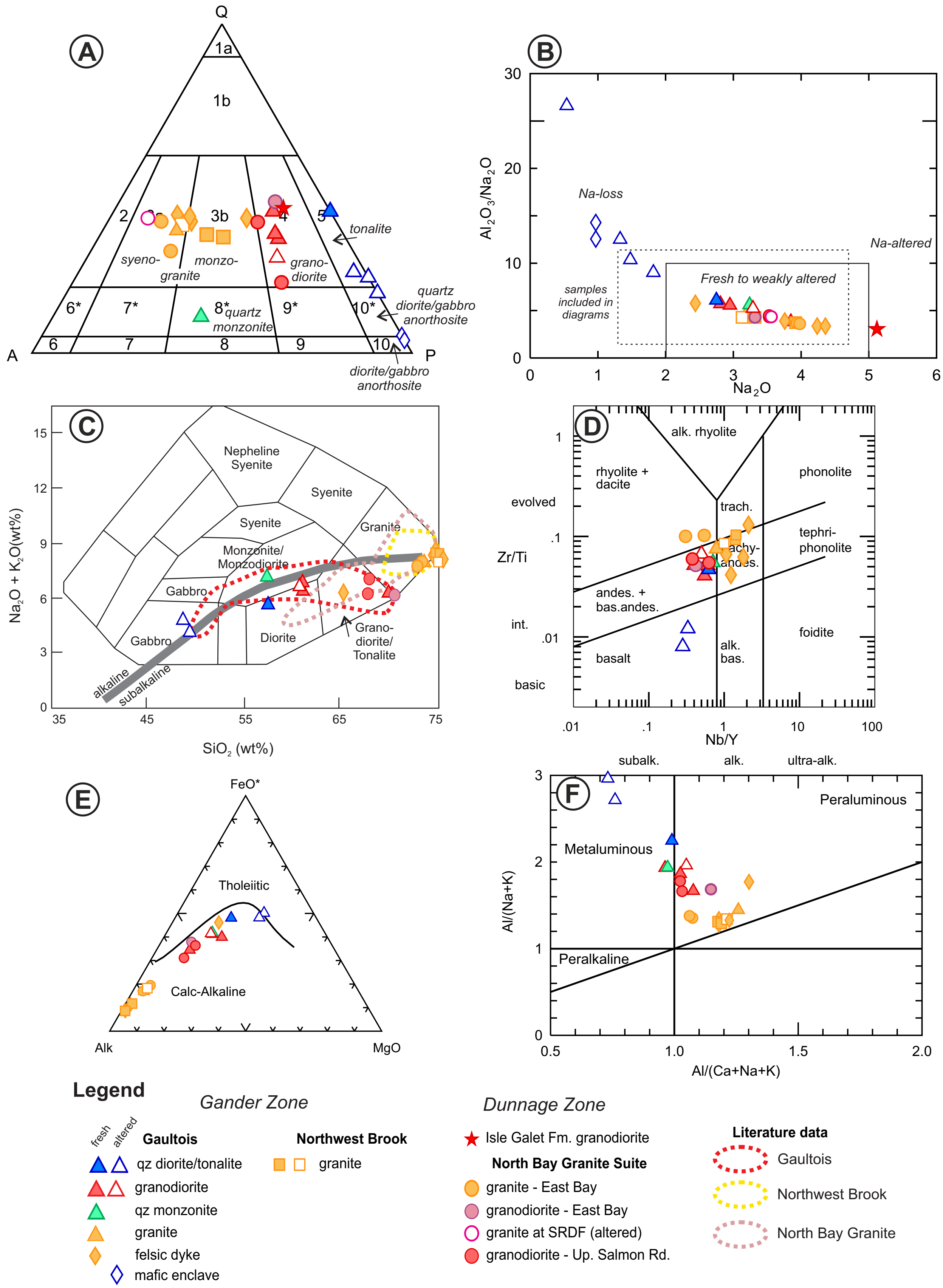


**Figure 2.** *Caption on page 4.*

**Table 1.** Representative plutonic rocks within the St. Alban's map area. UTM coordinates are in NAD 27, Zone 21. Mineralogy is listed in order of decreasing content for major and minor minerals

| Sample No. | Lab No. | UTM Easting | UTM Northing | Formation | Rock Type | Mineralogy | Characteristics |
|---|---|---|---|---|---|---|---|
| 16AW001A02 | 11040009 | 605661 | 5298810 | IS:Gm | tonalite | plag-bt-qz-hbl-chl-epi-tt | m.gr., fol., eq., alt. |
| 16AW001B02 | 11040011 | 605661 | 5298810 | aplite dyke in IS:Gm | granite | qz-kfs-msc-plag | f.gr., fol., eq. |
| 16AW002A02 | 11040027 | 605780 | 5297273 | IS:Gm | tonalite | plag-chl-amph-epi-qz-tt | f.gr., m., eq., alt., py, X |
| 16AW002A03 | 11040028 | 605780 | 5297273 | IS:Gm | tonalite | plag-chl-amph-epi-qz-tt | f.gr., m., eq., alt., py, X |
| 16AW002B02 | 11040029 | 605780 | 5297273 | aplite dyke in IS:Gm | granite | qz-kfs-msc-plag | f.gr., m., eq. |
| 16AW025A02 | 11040032 | 605778 | 5296207 | lS:Ggt | tonalite | amph-bt-plag-qz-tt-epi | m.gr., fol., eq. |
| 16AW026A02 | 11040012 | 606383 | 5291622 | SD:X | granite | kfsp-qz-plag-msc-ser-bt | m.-c. gr., fol., eq., alt. |
| 16AW047A02 | 11040023 | 610285 | 5298758 | aplite in N-O:LSG | granite | qz-kfs-plag-msc-tur | f.gr., m., eq. |
| 16AW048A02 | 11040024 | 611729 | 5297648 | SD:X | granite | kfs-qz-plag-msc-bt | m.gr., fol., eq. |
| 16AW049A02 | 11040038 | 609448 | 5296427 | lS:Ggt | granodiorite | plag-bt-qz-kfs-ser-epi-chl | m.gr., fol., por. |
| 16AW050A02 | 11040039 | 607085 | 5292371 | SD:X | granite | kfsp-qz-plag-msc-bt | f.-m.gr., m., eq. |
| 16AW052A02 | 11040025 | 608730 | 5289605 | lS:Ggt | granodiorite | plag-bt-qz-kfs-ser-epi-chl | m.gr., fol., por., alt. |
| 16AW083A02 | 11040046 | 596539 | 5291641 | IS:Ggt | granodiorite | plag-bt-qz-kfs-chl | m.gr., fol., por. |
| 16AW091A02 | 11040047 | 598387 | 5291388 | IS:Gmnz | qz monzonite | kfs-plag-bt-qz-tt-mt | m.-c.gr., m., eq. |
| 16AW100B02 | 11040049 | 601351 | 5290231 | mafic enclave in IS:Ggt | hbl diorite | amph-bt-chl-epi-plag | f.gr., fol.,eq., alt., X |
| 16AW127B02 | 11040052 | 601630 | 5291004 | bt-rich dyke in IS:Ggt | (monzo)granite | bt-qz-plag-kfs-msc | f.gr., fol., eq. |
| 16AW138A02 | 11040054 | 607548 | 5289753 | IS:Ggt | granodiorite | qz-plag-bt-kfs-chl | f.gr., fol., eq., alt. |
| 16AW188A02 | 11040055 | 605694 | 5295746 | IS:Gm | qz diorite | amph-bt-plag-qz-tt-ser | m.gr., fol., eq., alt., py |
| 16AW238A02 | 11040062 | 605259 | 5293104 | IS:Ggt | granite | qz-kfs-msc-plag | m.gr., fol., eq., alt. |
| 16AW254B02 | 11040063 | 605906 | 5293864 | mafic enclave in IS:Ggt | hbl diorite | amph-bt-chl-plag | m.gr., m.,eq., X |
| 17AW056A02 | 11040113 | 588253 | 5292587 | SD:NPf | granite | kfs-qz-plag-bt | m.gr., fol., eq., alt., X |
| 17AW061A02 | 11040114 | 587790 | 5292056 | SD:NUa | granodiorite | qz-plag-bt-kfs-ser | c.gr., fol., por., alt. |
| 17AW297A02 | 11040129 | 578876 | 5291504 | SD:NEa | granite | kfs-qz-plag-msc-bt-chl-ser | m.gr., fol., por., alt. |
| 17AW309A02 | 11040131 | 594914 | 5296123 | SD:NEc | granodiorite | qz-plag-bt-kfs | f.-m.gr., m., eq. |
| 17AW317A02 | 11040132 | 595082 | 5296305 | SD:NEa | granite | kfs-qz-plag-bt-ser | m.gr., m., por., alt. |
| 17AW395A02 | 11040135 | 576923 | 5313262 | SD:NUa | granodiorite | qz-plag-bt-kfs-epi-ser | c.gr., fol., por., alt. |
| 17AW670A02 | 11040165 | 588345 | 5302341 | intrusion in O:YI | granodiorite | plag-qz-chl-kfs-msc-epi-tt-bt | m.gr., fol., eq., alt., X |

**Note:** plag–plagioclase; kfs–k-feldspar; qz–quartz; bt–biotite; hbl–hornblende; chl–chlorite; epi–epidote; tt–titanite; tur–tourmaline; ser–sericite; mt–magnetite; srp–serpentine; tlc–talc; ol–olivine; f.gr./m.gr./c.gr.–fine/medium/coarse grained; m–massive; fol.–foliated; eq.–equigranular; por–porphyritic to megacrystic; alt.–altered; py–pyrite mineralization; X–not used in diagrams

tionship and order between the granodiorite and tonalite/quartz diorite is undetermined. Samples taken during this project are fine to medium grained, equigranular, weakly to moderately foliated and range from quartz diorite to tonalite (Plate 2A, B, quartz range from 4 to 22 modal %). Mafic minerals are green hornblende (up to almost 50 modal %) and biotite. Titanite is a common minor mineral; contents of chlorite and sericite vary from minor to trace contents depending on the degree of alteration. Accessory minerals are opaque minerals (commonly ilmenite), epidote, apatite, and zircon, some samples contain pyrite mineralization.

Further, mafic enclaves occur in several places in the Gaultois Granite suite. These biotite–hornblende diorite enclaves within the Gaultois granodiorite are fine to medium grained, massive or weakly foliated and are moderately altered (*e.g.*, chlorite, epidote, sericite).

The Gaultois granodiorite is further intruded by a slightly younger massive equigranular quartz monzonite of small areal extent close to Salmonier Pond. This rock has similar biotite contents as the granodiorite, but is higher in titanite, magnetite (>3 modal %) and contains traces of amphibole (Plate 2C, D). The higher magnetite content creates an anomaly in the residual magnetic signature.

Foliated megacrystic Gaultois Granite with a granitic composition *sensu stricto*, as it has been described (Colman-Sadd *et al.*, 1979) and dated (Dunning *et al.*, 1990) farther south (*e.g.*, in Little Passage) is not common within the extent of the Gaultois Granite suite in the St. Alban's map area.

The Northwest Brook Complex (SD:X) is dominantly a pink to buff, medium-grained, equigranular biotite–muscovite granite to minor granodiorite and minor syenite that intrudes the Gaultois Granite suite (Plate 3A, B). It is massive to moderately foliated with trends subparallel to those in the Gaultois Granite suite and the fabric, where present, is defined by the preferred orientation of mica and elongated quartz grains. Accessory minerals are apatite and zircon, and occasionally include garnet and tourmaline.

Pegmatite and aplite muscovite granite dykes intrude the Gaultois Granite suite, Northwest Brook Complex and the Little Passage Gneiss (Plate 3C, D). Tourmaline and gar-

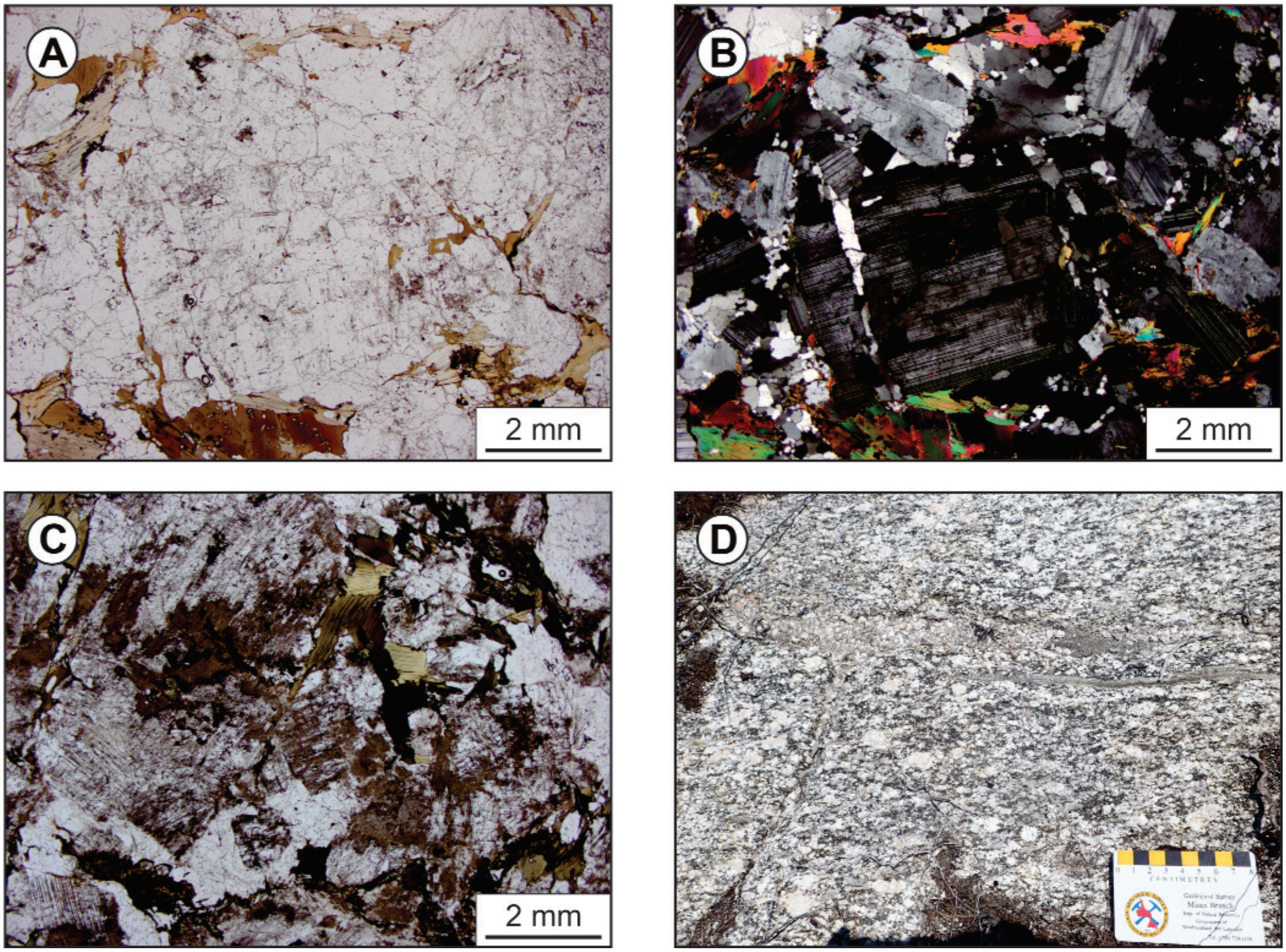


**Plate 1.** *Typical Gaultois granodiorite. A, B) Photomicrograph of relatively fresh granodiorite with large plagioclase and reddish-brown biotite (plain and cross polarized, respectively); C) Photomicrograph of granodiorite with stronger sericitization of feldspar and chloritization of biotite, which is also more dark-brown greenish compared to biotite in (A), plain polarized; D) Typical porphyritic Gaultois granodiorite with mafic schlieren and small enclaves, scale card is 8 cm.*

net are accessory minerals. A massive fine-grained garnet–tourmaline–muscovite aplite also intrudes the Little Passage Gneiss, in the vicinity to the contact with the Northwest Brook Complex.

## DUNNAGE ZONE INTRUSIONS

The North Bay Granite Suite in the St. Alban's map area can be generally subdivided by the Salmon River Dam Fault into northern and southern subunits, the East Bay and Upper Salmon Road granites, respectively.

The East Bay Granite (SD:NE) is typically a leucocratic to buff, medium-grained equigranular biotite ± muscovite granite to granodiorite that is locally weakly to moderately foliated (Plate 4A, B). It occurs in the southwestern part of the St. Alban's map area, south of the Salmon River Dam Fault. Porphyritic K-feldspar and amphibole occasionally occur. Foliation, if present, is defined by alignment of mica and has a dominantly northeast–southwest trend. Accessory minerals may include apatite, titanite, opaque phases, epidote and zircon. A variety of white, medium- to coarse-garnet–muscovite ± biotite granite occurs close to the contacts of the intrusion with the Baie d'Espoir Group and also, as aplite and pegmatite dykes and veins in the metasediments of the group. The East Bay Granite also includes an older phase of medium-grained and strongly foliated garnet–biotite granodiorite and granite (Plate 4C, D). The foliation is defined by biotite and elongated quartz, gneissic banding is present in several instances. Accessory minerals are muscovite, apatite and zircon.

North of the Salmon River Dam Fault, the Upper Salmon Road Granite occurs as a grey to buff, weakly to

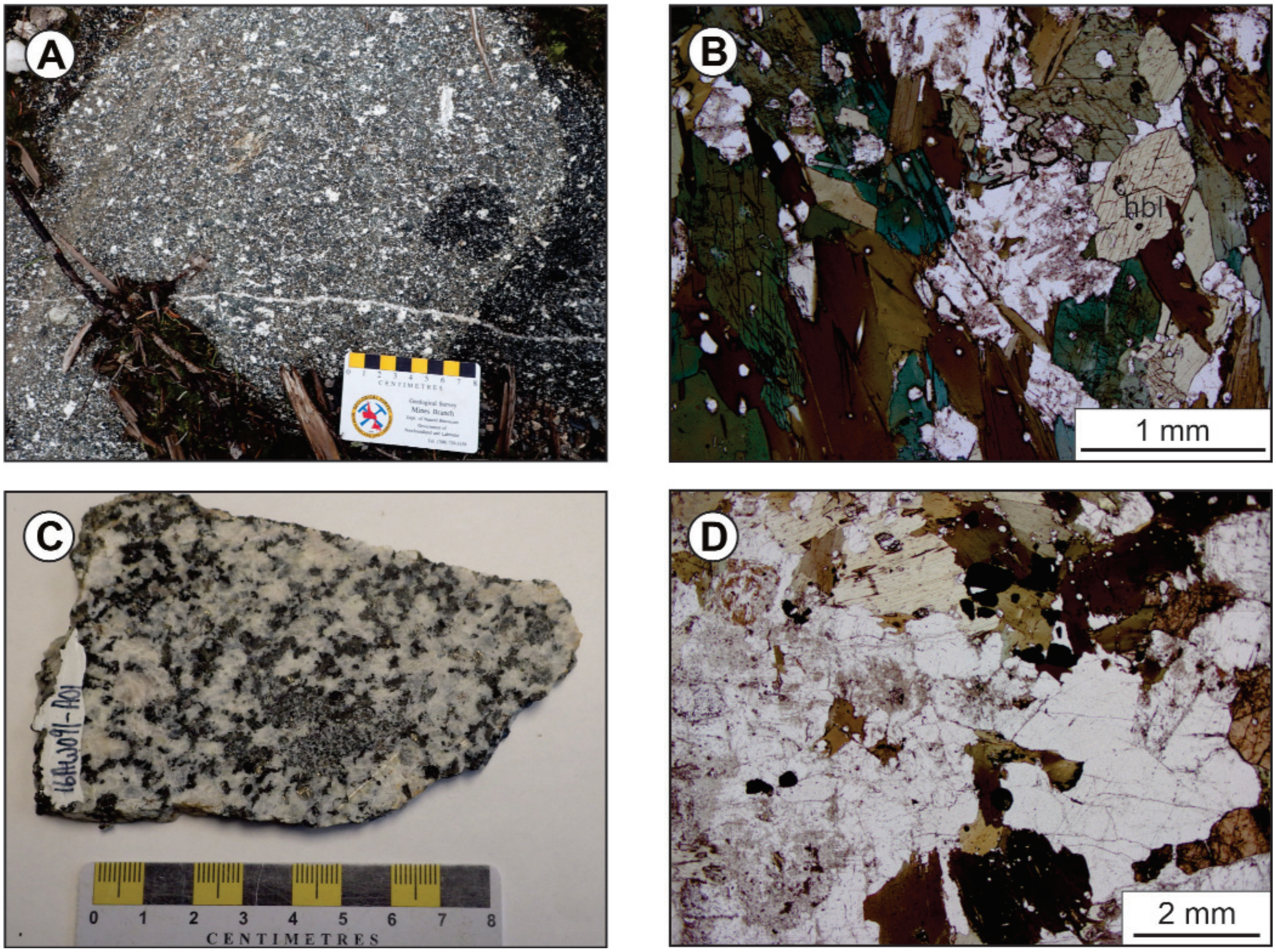


**Plate 2.** *Gaultois tonalite, quartz diorite and quartz monzonite. A) Tonalite with porphyritic plagioclase, hornblende and biotite, scale card is 8 cm; B) Photomicrograph of quartz diorite with hornblende (hbl), biotite, and sericitized plagioclase; C) Image of massive equigranular quartz monzonite; D) Photomicrograph of quartz monzonite with sericitized plagioclase, quartz, biotite, titanite and magnetite.*

moderately foliated, biotite granodiorite to granite. A coarse-grained, porphyritic to megacrystic variety is dominantly a biotite granodiorite (Plate 5A, B). Accessory minerals include titanite, amphibole, magnetite, apatite, epidote, muscovite and zircon. This unit forms prominent hills and coincides with a strong positive anomaly in the aeromagnetic survey. The Upper Salmon Road Granite also includes a fine- to medium-grained equigranular granite that be observed in direct contact to sandstone of the Salmon River Dam Formation at the shore of Jeddore Lake.

Directly south of the Salmon River Dam Fault, a pinkish, medium-grained equigranular biotite granite (SD:Npf) with a strong foliation and alteration occurs in Salmon River. Feldspar is strongly sericitized and biotite moderately chloritized. Recrystallized quartz bands and alignment of biotite (Plate 5C, D) define the foliation. The strong tectonic fabric of this pink granite is likely related to the Salmon River Fault, and it may represent a stronger foliated and altered version of the other units of the North Bay Granite Suite.

Further, an intrusive rock of small areal extent occurs within the volcanic belt of the Isle Galet Formation (Dunnage Zone) close to the Day Cove Thrust in the eastern map area. This intrusion is a foliated, medium-grained, equigranular granodiorite. This rock is distinct from rocks of the Gaultois Granite suite, Northwest Brook Complex as well as North Bay Granite and greenschist metamorphosed similar to the surrounding rocks of the Isle Galet Formation. It contains remnants of titanite and biotite replaced by chlorite and epidote grains in plagioclase (Plate 6).

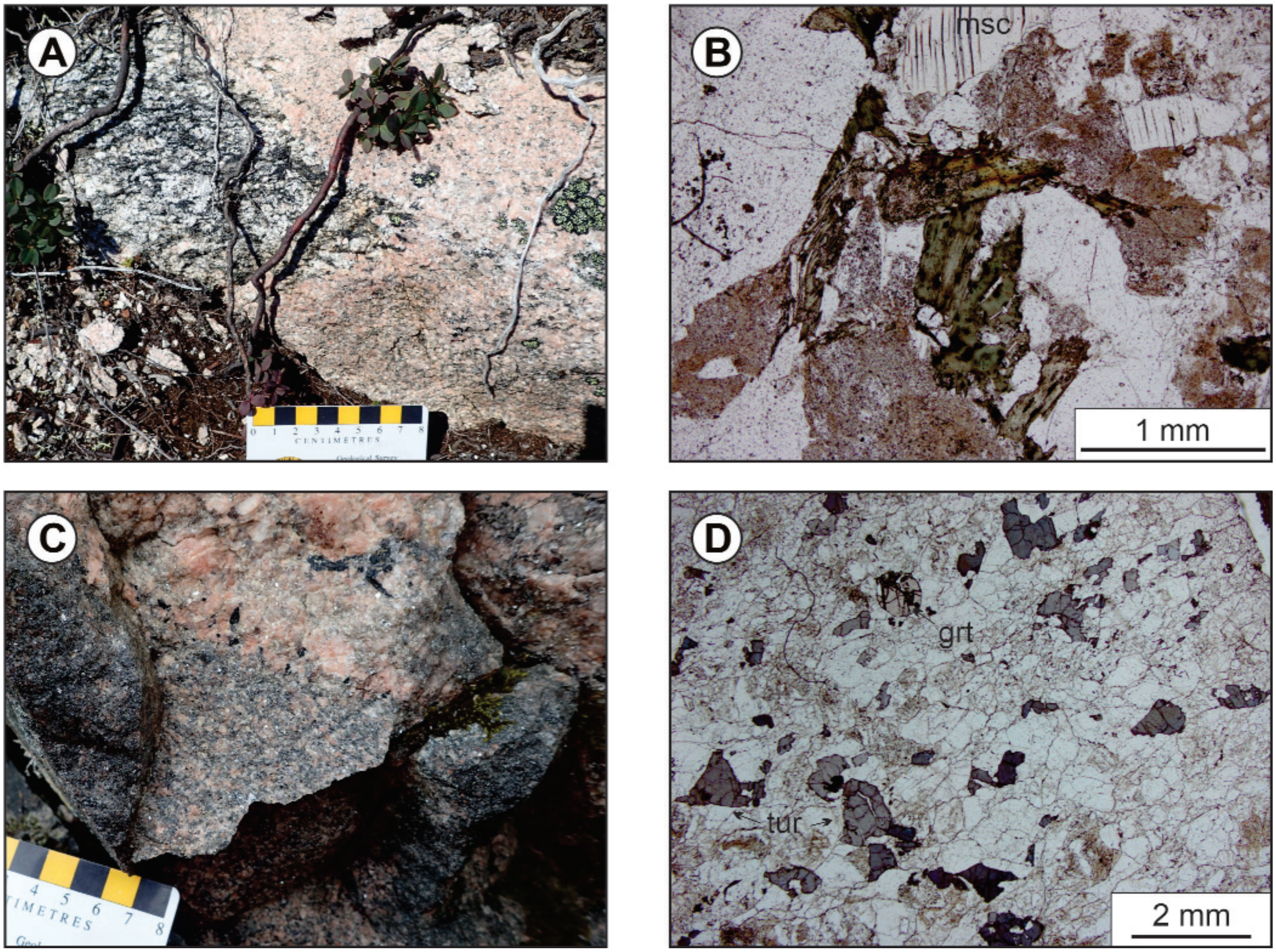


**Plate 3.** *Northwest Brook Complex and felsic dykes. A) Typical Northwest Brook Complex intruding Gaultois granodiorite; B) Photomicrograph of altered Northwest Brook Complex granite with sericitization of feldspar and chloritization of biotite, and muscovite (msc); C) Pegmatite dyke intruding Gaultois granodiorite with coarse tourmaline and garnet; D) Photomicrograph of garnet(grt)–tourmaline(tur)–muscovite granitic aplite.*

## PRELIMINARY GEOCHEMISTRY OF INTRUSIVE ROCKS

### METHODS

Geochemical characteristics of selected representative plutonic rocks from the 2016 and 2017 field seasons are discussed here; UTM locations (NAD 27, Zone 21), rock types and characteristics are listed in Table 1, sample locations are shown in Figure 1. All geochemical data are published in Westhues (2018). Samples for geochemical analyses of these intrusive rocks have been collected throughout the St. Alban's map area and, in most cases, represent the dominant rock type at an outcrop. Prominent dykes and enclaves that differ from the main rock type have also been collected. The samples collected may show moderate foliation, but all weathered surfaces were avoided. Analyses for major- and trace-element geochemistry have been done at the GSNL laboratories, St. John's, following the methods in Finch *et al.* (2018). Analytical method of determination for each element and quality control (routinely measuring standard materials and duplicate analyses to assess accuracy and precision) are published in Westhues (2018). The geochemical data of this study are compared with existing GSNL data for the intrusive rocks from the area (Dickson and Kerr, 2007; *see* Figure 1 for locations).

### ALTERATION

Samples chosen for geochemical analyses represent the least altered rock at each outcrop location. However, the geological units show different degrees of alteration throughout the study area. The degree of alteration was evaluated in the field, in thin section and using a Spitz-Darling

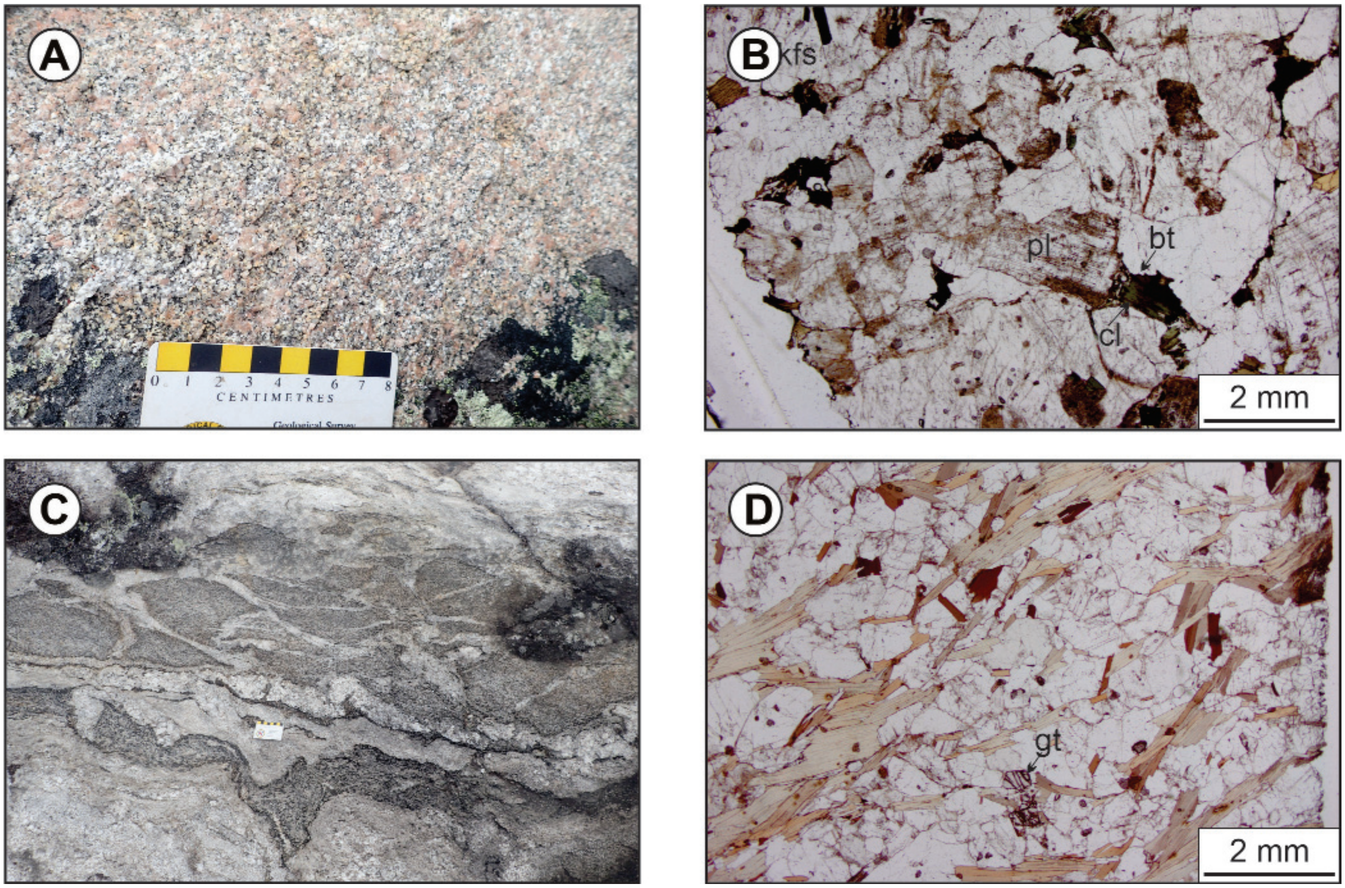


**Plate 4.** *East Bay Granite of the North Bay Granite Suite. A) Equigranular medium-grained, leucocratic to slightly pink East Bay Granite; B) Photomicrograph of moderately altered weakly foliated East Bay Granite with plagioclase (pl), K-feldspar (microcline, kfs), both sericitized, biotite (bt) replaced by chlorite (cl); C) More strongly foliated East Bay Granite intruded by garnetiferous leucocratic East Bay Granite, scale card is 8 cm; D) Photomicrograph of more strongly foliated East Bay Granite with alignment of biotite and some garnet.*

type alteration diagram to assess major-element mobility (after Spitz and Darling, 1978; using $NaO_2$ *vs.* $Al_2O_3/NaO_2$ (mobile $NaO_2$ and immobile $Al_2O_3$), Figure 2B). The most altered samples of each unit, as described in the following, are shown as open symbols to distinguish them from the less altered samples (filled symbols) in Figures 2–7. Samples with a high degree of Na loss (mafic enclaves and two Gaultois tonalite samples) and Na alteration (granodiorite within Isle Galet Formation) are omitted from the further diagrams and discussion, only samples within the dashed box in Figure 2B are considered.

The most altered Gaultois granodiorite shows a strong sericitization of feldspar and chloritization of biotite (Plate 2C) with otherwise similar petrography compared to the less altered relatively silica-poor granodiorite. The altered sample has dark-brown and greenish biotite compared to light reddish-brown biotite in the fresher samples. A more silica-rich Gaultois granodiorite is moderately altered in thin section with intermediate sericitization and chloritization. The Gaultois quartz monzonite is relatively fresh and shows only low degrees of sericitization and chloritization. All Gaultois granodiorite have geochemical characteristics within the range of fresh to weakly altered samples (Figure 2B).

All plagioclase-rich Gaultois tonalite and quartz diorite samples show some degree of alteration in thin section (chlorite, epidote, sericite, Plate 2B) and have experienced Na loss according to the Spitz-Darling alteration diagram (Figure 2B). Two quartz-poor samples with the least Na loss are included in the following diagrams and discussion as representatives of this subunit of the Gaultois Granite suite. Also included is a relatively quartz-rich tonalite with epidote and moderate sericitization and chloritization that has not experienced significant Na loss.

The most altered granite of the Northwest Brook Complex is pinkish in hand sample, feldspar is strongly

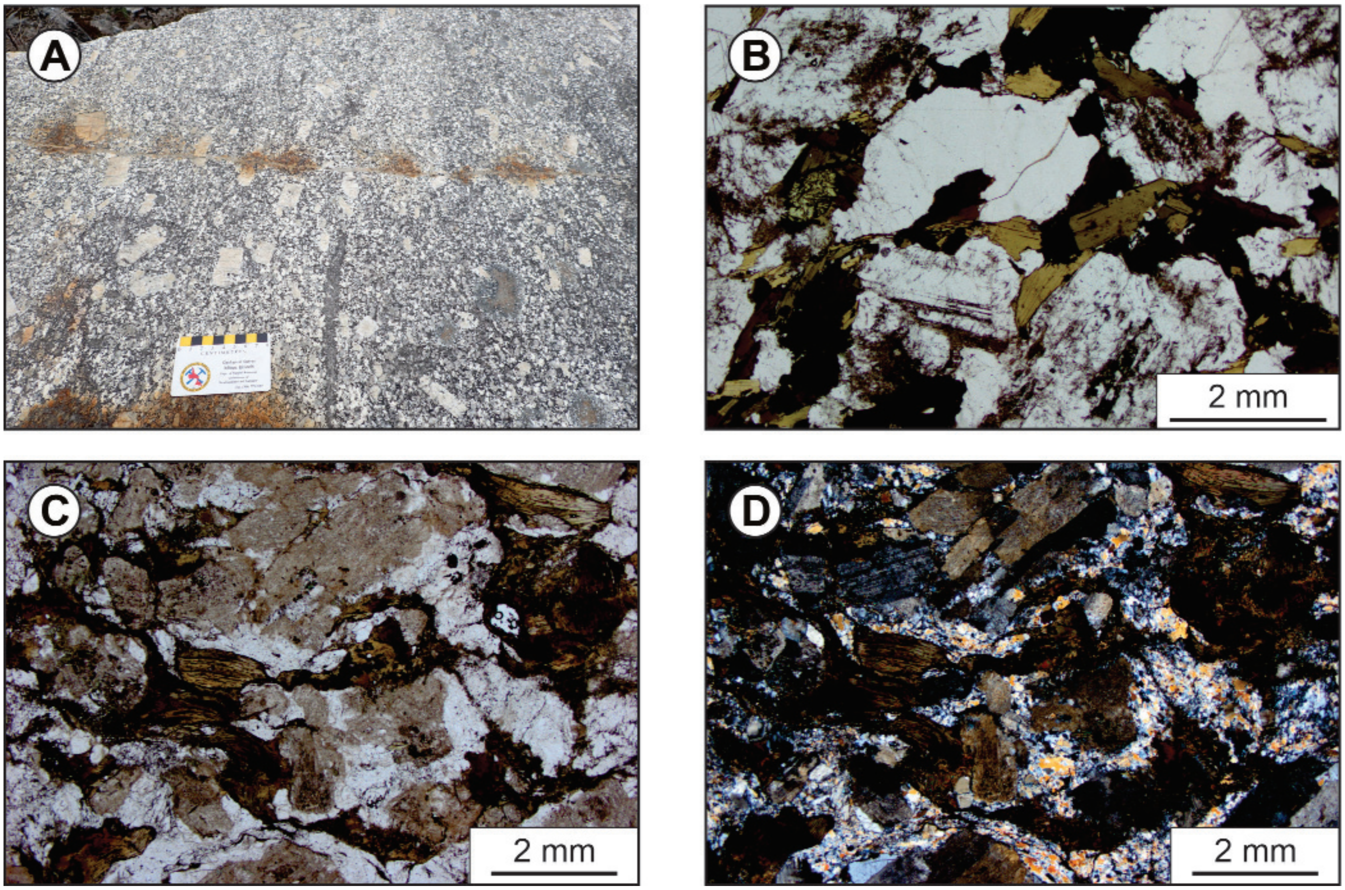


**Plate 5.** *Upper Salmon Road Granite and granite at Salmon River Dam Fault. A) Typical megacrystic Upper Salmon granodiorite, Witch Hazel Hill, with megacrystic microcline, mafic schlieren and enclaves; B) Photomicrograph of moderately altered (sericitization of feldspar, mostly plagioclase in this image) and foliated granodiorite (defined by biotite), plain polarized; C, D) Photomicrograph (plain and cross polarized) of strongly altered and foliated granite, Salmon River Dam Fault: note strong seritization of K-feldspar and plagioclase and recrystallized quartz bands.*

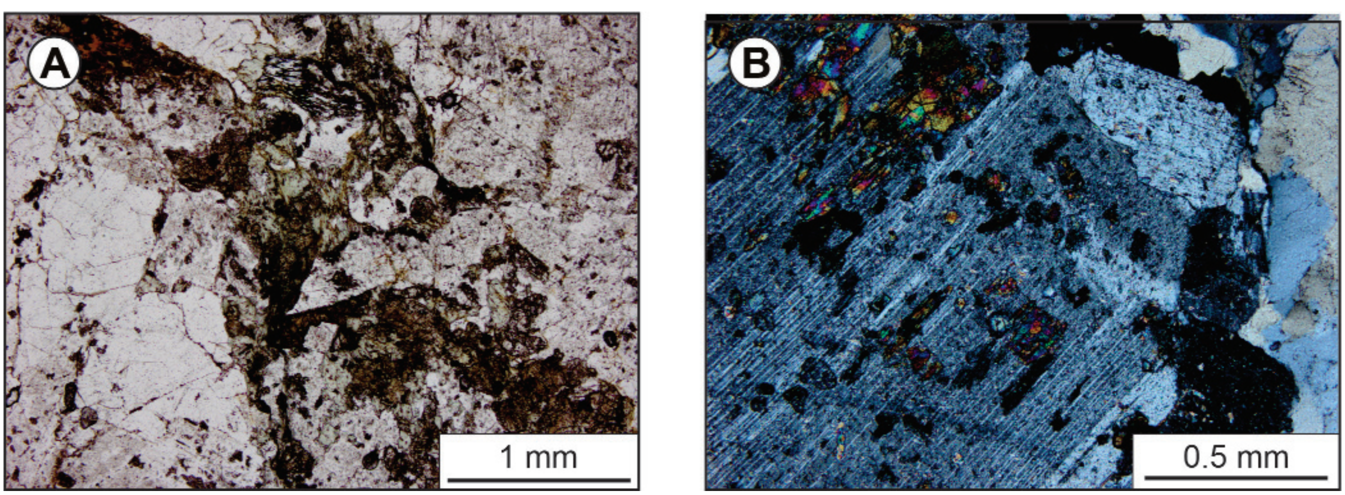


**Plate 6.** *Granodiorite in Isle Galet Formation. A) Photomicrograph of typical assemblage with sericitized plagioclase, biotite and titanite with chlorite rims and replacement; B) Photomicrograph (cross polarized) of epidote within plagioclase.*

sericitized and biotite may show some chloritization. Geochemically, the sample falls within the fresh to least altered range (Figure 2B), but plots distinct from the less altered Northwest Brook Complex samples.

Alteration in the North Bay Granite Suite within the St. Alban's map area is most intense in the granite at the Salmon River Dam Fault, which is pink in hand sample, and has strongly sericitized feldspar and is not considered in the following diagrams. The East Bay Granite shows moderate sericitization of feldspar and may have chloritized biotite. Granodiorite from the East Bay and Upper Salmon Road subunits are generally fresh to weakly altered in hand sample and thin section. All samples of the North Bay Granite Suite, including the granite at the Salmon River Dam Fault, fall within the fresh to weakly altered range of the Spitz-Darling alteration diagram (Figure 2B).

## GEOCHEMISTRY RESULTS

The rock type has been determined based on modal composition (Figure 2A; Streckeisen, 1976). The fresh to least-altered samples selected for this study are shown on various classification diagrams (Figure 2C–F): on total alkali *vs.* silica diagram (TAS; Figure 2C; adjusted for intrusive rocks after Wilson, 1989) and on an immobile trace-element diagram (Figure 2D; after Winchester and Floyd, 1977; modified by Pearce, 1996). Further, the magmatic affinities tholeiitic *vs.* calc-alkaline are assigned on alkali-MgO-FeO* diagram (Figure 2E; Irvine and Baragar, 1971). The aluminous saturation index is determined following Shand (1943) using the Al/(Ca + Na + K) *vs.* Al/(Na + K) diagram (or A/CNK *vs.* A/NK, Figure 2F; after Maniar and Piccoli, 1989). Selected major, compatible and incompatible elements are plotted against MgO wt. % (Figure 3), together with existing data (Dickson and Kerr, 2007). Volatile contents (expressed as loss of ignition, LOI) are below 2 wt. % for the selected least altered samples.

Samples from the Gaultois Granite suite have the largest range in composition (Figure 2B, C) with $SiO_2$ concentrations from 47 wt. % (quartz diorite) over 59 wt. % (granodiorite) to around 70 wt. % (granite). The $Al_2O_3$ concentration range from 15 to 18 wt. %, $K_2O$ from 2.3 to 4.5 wt. %, $Na_2O$ from to 1.5 to 3.9 wt. % and CaO from 0.8 to 8.7 wt. %. The Gaultois quartz monzonite has lower $SiO_2$ and higher $Na_2O + K_2O$ contents compared to Gaultois granodiorite. All rocks of the Gaultois Granite suite have a range of Zr/Ti and relatively low Nb/Y ratios in the subalkaline field of the immobile trace-element diagram (Figure 2D). The samples are dominantly calc-alkaline (Figure 2E) and peraluminous to metaluminous (Figure 2F). Major and most trace elements form linear arrays with MgO (Figure 3), with $SiO_2$ decreasing and $TiO_2$, $Fe_2O_{3tot}$, V, Sr, and Y increasing with increasing MgO. Niobium shows no clear trend with MgO and ranges from 8 to 17 ppm. Most samples are potassic, with the exception of the most silica-rich granodiorite and the most altered granodiorite, which are sodic. The more altered granodiorite has major and trace elements in similar abundance as in the less altered samples, except slightly elevated Sr contents.

Granite of the Northwest Brook Complex has more restricted $SiO_2$ and $Al_2O_3$ concentrations around 73 wt. % and 14 wt. %, respectively. The samples are potassic, calc-alkaline and peraluminous with $K_2O$ from 4.5 to 5.0 wt. %, $Na_2O$ from 3.1 to 3.9 wt. % and CaO around 0.6 wt. %. Major elements form clusters with MgO rather than arrays given the restricted range of compositions with low contents of MgO, $TiO_2$, $Fe_2O_{3tot}$, volatiles, V and Sr and intermediate contents of Nb and Y. The more altered Northwest Brook Complex sample has major elements in similar abundances as in the fresh samples, but has slightly elevated volatile, Sr, Nb and Y contents.

Felsic aplite dykes within the Gaultois Granite suite and Little Passage Gneiss are granites (Figure 2A) with $SiO_2$ concentrations ranging from 63 to 74 wt. % and $Al_2O_3$ concentrations from 14 to 15 wt. %. The samples are calc-alkaline and peraluminous (Figure 2E, F) with $K_2O$ ranging from 3.6 to 4.4 wt. %, $Na_2O$ from 2.4 to 4.4 wt. % and CaO from 0.5 to 1.6 wt. %. Major elements from linear arrays with MgO similar as described for the Gaultois Granite suite, but most trace elements show a wider range and no clear pattern (Figure 3). Samples can be both sodic or potassic.

Samples of the Northwest Brook Complex and felsic and intermediate dykes in the Gaultois Granite suite have elevated Nb/Y ratios in the immobile trace-element classification diagram (Figure 2D). A garnet–tourmaline aplite intruding the Little Passage Gneiss has the highest Nb/Y and Zr/Ti ratios.

Samples from the North Bay Granite Suite are granite and granodiorite (Figure 2A) and have $SiO_2$ and $Al_2O_3$ concentrations ranging from 62 to 72 wt. % and 14 to 16 wt. %, respectively. The samples are mostly sodic (Figure 3) with $K_2O$ from 2.8 to 3.0 wt. %, $Na_2O$ from 3.3 to 3.9 wt. % and CaO from 1.5 to 3.5 wt. %. The samples have a range of Zr/Ti and relatively low Nb/Y ratios in the subalkaline field of the immobile trace-element diagram (Figure 2D) and are calc-alkaline and peraluminous (Figure 2E, F).

The chondrite-normalized REE pattern of the more plagioclase-rich samples of the Gaultois Granite suite, from granodiorite to quartz diorite (Figure 4A, C) are closely grouped with a negative slope for the light REE (LREE) ([La/Yb]CN = 6.78–10.25, CN: chondrite normalized).

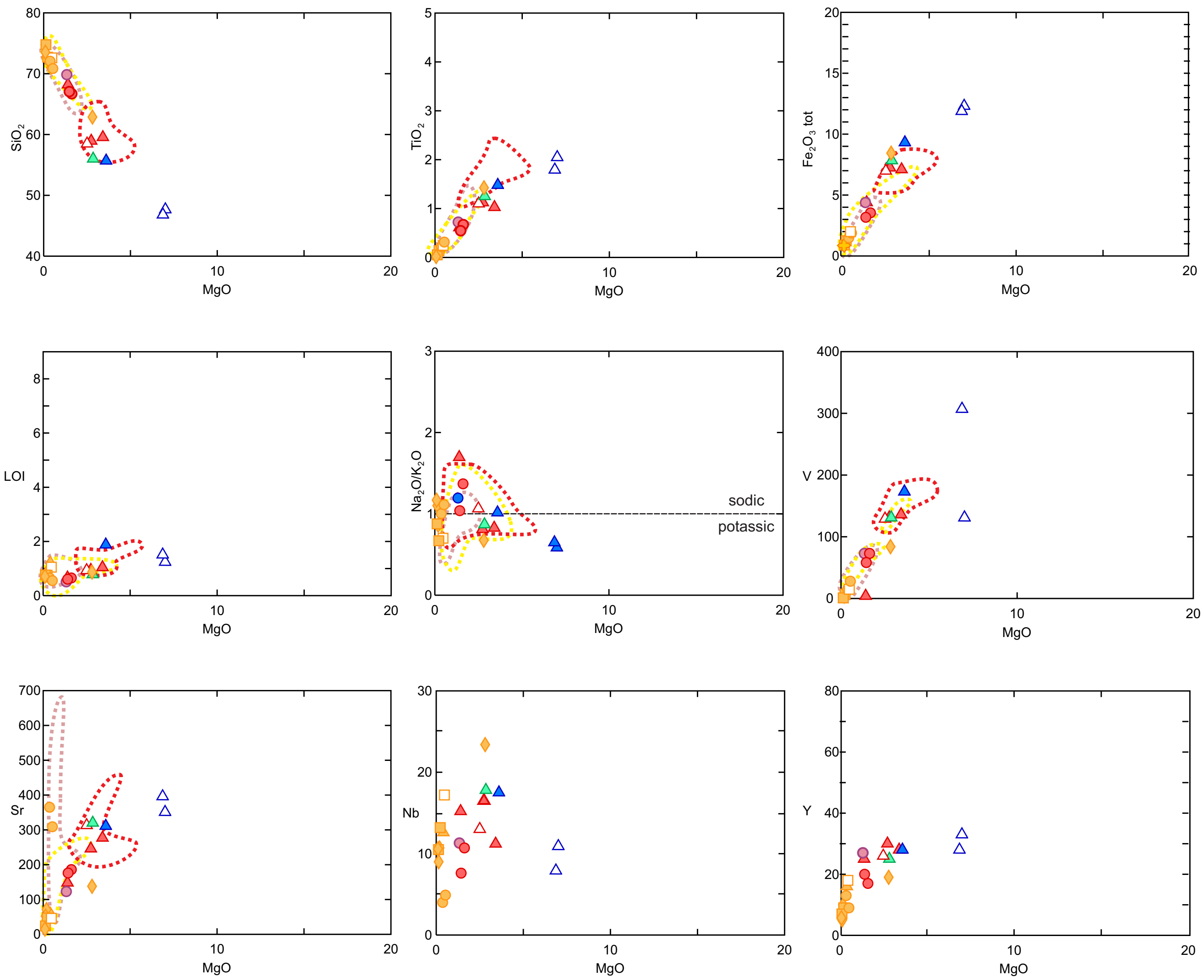


**Figure 3.** *Selected major and trace elements* vs. *MgO wt. % for intrusive rocks of the St. Alban's map area. Symbols as in Figure 2. Fields for existing GSNL geochemical data are included for comparison, where available.*

They have a small to very small negative Eu anomaly (Eu/Eu* = 0.56–0.91; Eu/Eu* = EuCN /√SmCN* GdCN) and a flat to slight negative slope for the heavy REE (HREE, [Gd/Yb]CN = 1.78–2.62). The more alkali feldspar-rich Gaultois Granite suite samples have slightly lower REE contents and a more pronounced Eu anomaly (Eu/Eu* = 0.45) with an otherwise similar pattern ([La/Yb]CN = 8.17; [Gd/Yb]CN =2.35).

The Northwest Brook Complex and the felsic dykes (Figure 4E, G) show a large range in REE enrichment ([La/Yb]CN = 2.27–32.94) with an overall negative slope (for HREE [Gd/Yb]CN = 0.83–5.03) and a negative Eu anomaly (Eu/Eu* = 0.28–0.96). The more altered Northwest Brook Complex granite has higher REE contents compared to the less altered samples with a similar pattern. The garnet–tourmaline granitic aplite has the lowest REE enrichment (Figure 4G), elevated Sm contents and a positive HREE slope likely related to its higher contents of garnet ([La/Yb]CN = 8.17; [Gd/Yb]CN = 2.35, Eu/Eu* = 0.45). Samples of the North Bay Granite Suite form a tight cluster, and have higher REE enrichment and steeper negative slope for LREE (Figure 5A, [La/Yb]CN = 8.23–83.80) than intrusions in the Gander Zone, a more distinct negative Eu anomaly (Eu/Eu* = 0.56–0.75) and a flat to slightly negative HREE pattern ([Gd/Yb]CN = 1.75–6.89).

On extended trace-element diagrams normalized to primitive mantle (modified after Sun and McDonough, 1989; Figures 4B, D, F, H and 5B), all samples show an overall LILE enrichment (Rb, Ba as representatives). Barium has lower normalized concentrations compared to

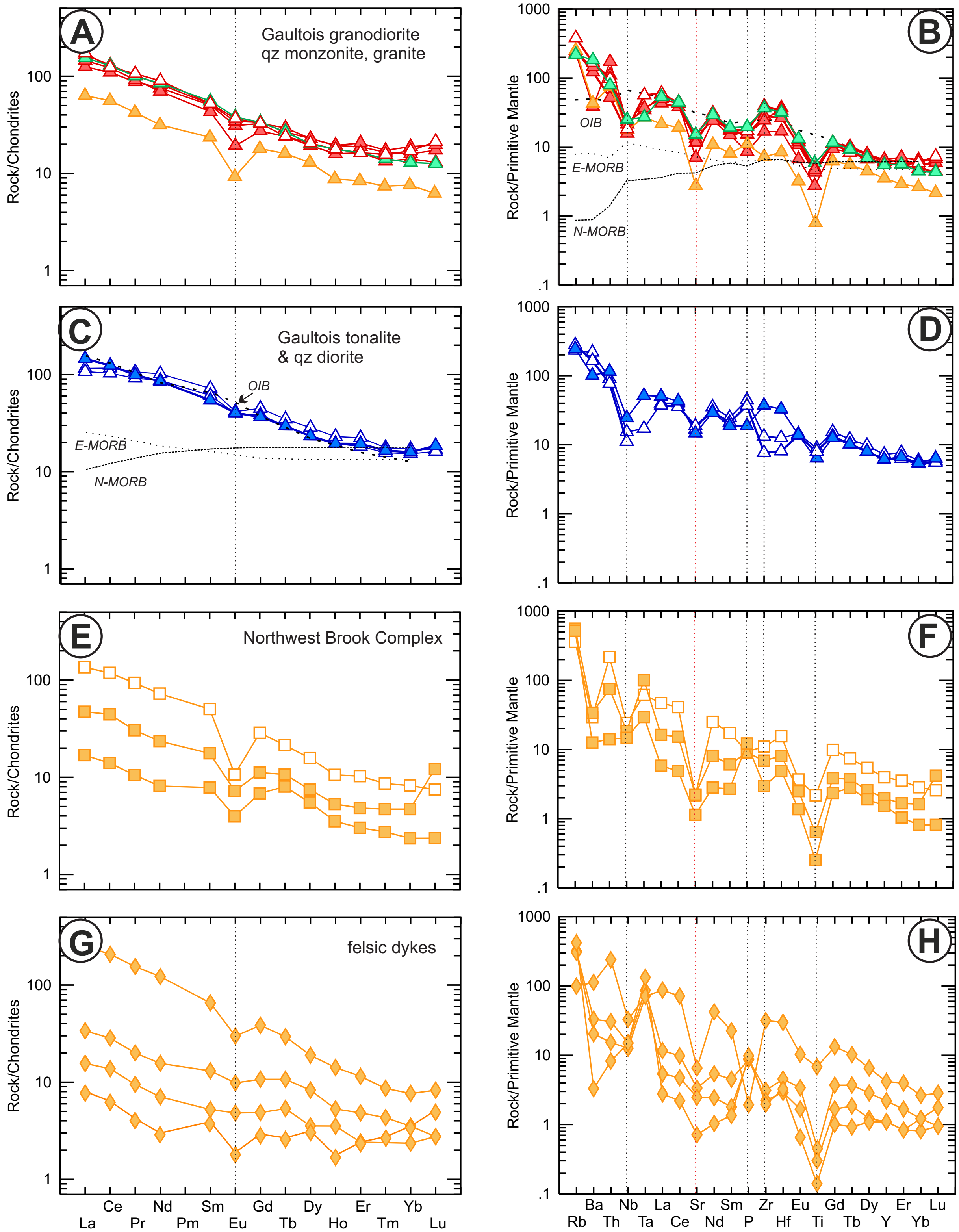


**Figure 4.** *Trace-element variation diagrams: Chondrite-normalized rare-earth element and primitive mantle-normalized multi-element plots (Sun and McDonough, 1989) for intrusive rocks of the Gander Zone, St. Alban's map area,* this study. *A, B) Gaultois granodiorite and quartz monzonite; C, D) Gaultois tonalite and quartz diorite; E, F) Northwest Brook Complex granite; G, H) felsic and mafic dykes and lenses within Gaultois Granite suite. Symbols as in Figure 2.*

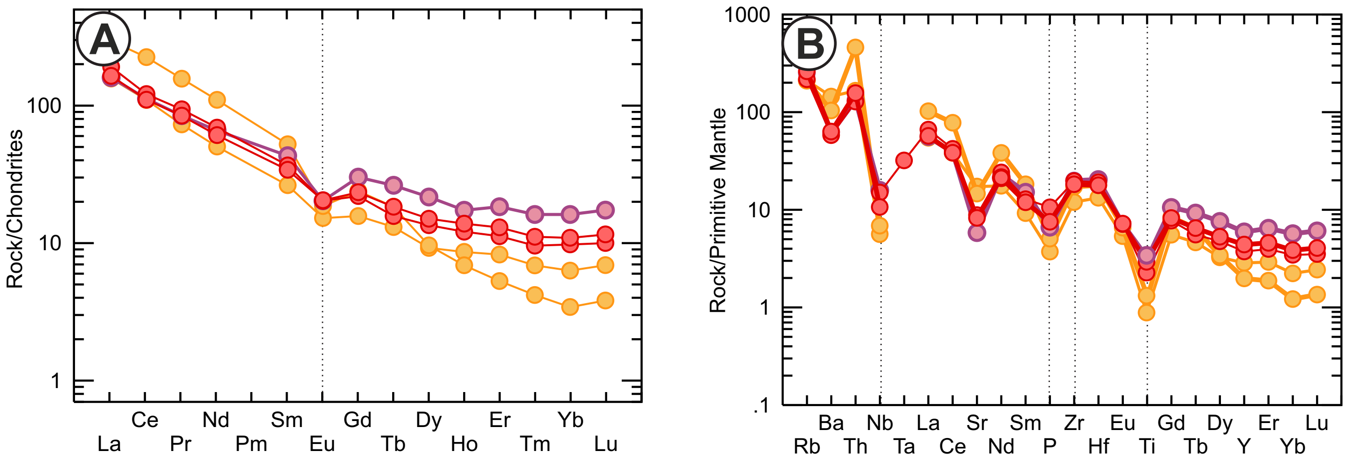


**Figure 5.** *Trace-element variation diagrams: Chondrite-normalized rare-earth element and primitive mantle-normalized multi-element plots (Sun and McDonough, 1989) for intrusive rocks of the Dunnage Zone, St. Alban's map area, this study. A, B) North Bay Granite Suite granite and granodiorite. Symbols as in Figure 2.*

Rb and Th in some of the more silica-rich Gaultois Granite suite and Northwest Brook Complex samples. Negative Ti, Sr, and Nb anomalies are present in most samples, except in one Northwest Brook Complex granite and in a garnet-bearing tourmaline granitic aplite intruding the Little Passage Gneiss. Tantalum, where detected, is decoupled from Nb in several samples of the Gaultois Granite suite (*e.g.*, compare typical Nb–Ta behaviour for quartz monzonite (green) with most granodiorites (red), Figure 4B), and in the Northwest Brook Complex and the felsic dykes (Figure 4F, H). In the North Bay Granite Suite, Ta is generally below detection limit, but appears decoupled from Nb in one Upper Salmon granodiorite, where it was detected (Figure 5B). This unusual geochemical behaviour of these two elements will be discussed below. Phosphorous has a variable signature with a distinct negative anomaly in the North Bay Granite Suite samples, but no or a slight positive anomaly in other samples. Distinct Zr–Hf troughs occur in the quartz-poor variety of the Gaultois tonalite and quartz diorite. More altered Gaultois granodiorite and Northwest Brook Complex granite (Figure 4B, H) follow similar patterns compared to fresher samples of their groups. The altered Northwest Brook Complex granite has higher trace-element contents in comparison to the less altered samples of this suite.

On tectonic discrimination diagrams, all samples from this study fall in the volcanic arc granite (VAG) and syn-collision granite (syn-COLG) field, when plotted on a Y *vs.* Nb diagram (Figure 6A; after Pearce *et al.*, 1984). On the Y + Nb *vs.* Rb diagram (Figure 6B; after Pearce *et al.*, 1984), Gaultois Granite suite and North Bay Granite Suite fall within the VAG field. Samples from the Northwest Brook Complex and most of the felsic dykes fall within the syn-COLG field.

## MINERALIZATION WITHIN INTRUSIVE ROCKS

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 and confirmed the mineral potential, especially within the Baie d'Espoir Group (Westhues, 2018). The main intrusive bodies of Gaultois Granite suite, Northwest Brook Complex and North Bay Granite Suite in the St. Alban's area are generally barren of mineralization except pyrite within the plagioclase-rich members of the Gaultois Granite suite. Elements commonly associated with certain granitoids have low concentrations within the St. Alban's map area (Sn max. 12 ppm, W max. 6 ppm, Mo max. 6 ppm). Fluorite concentrations are highest in the plagioclase-rich varieties of the Gaultois Granite suite (up to 1270 ppm), and range from 297 ppm (East Bay Granite) to 650 ppm (Northwest Brook Complex) in the granite and granodiorite samples.

More significant mineralization related to intrusive rocks is documented in dykes and associated quartz veins, commonly within the Riches Island Formation of the Baie d'Espoir Group (*see* Westhues, 2018). Examples of mineralization (UTM locations in NAD 27, Zone 21) include molybdenite in aplite dykes and related quartz veins in Northwest Cove (E578491, N5291543: 2170 ppm Mo, 158.7 ppm Be), and galena in Ba-rich quartz veins and networks found in Hardy Cove (E586131, N5294003: 29.280 ppm Pb, 7324 ppm Zn, 22 ppm Ag), at the known mineral occurrence "In Between" on hills north of Lampidoes Passage (E581106, N5291461: 4128 ppm Pb, 206 ppm Zn, 42 ppm Ag), in addition to a new find at the shore of Lampidoes Passage (E582536, N5291429; 24 200 ppm Pb, 68 900 ppm Zn, 799 ppm Cd, 23 ppm Ag).

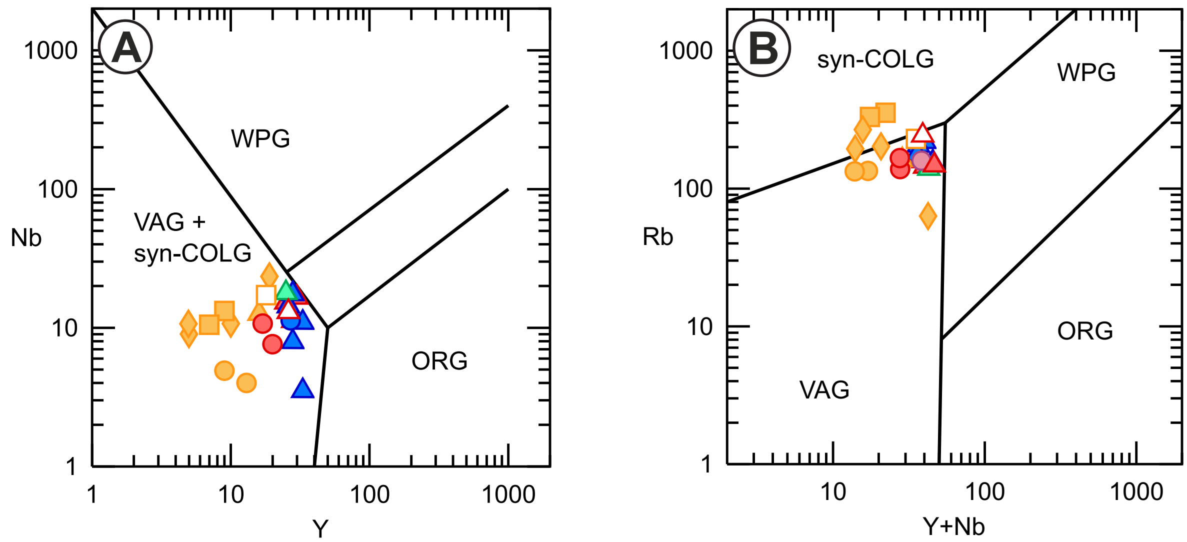


**Figure 6.** *Whole-rock geochemical data of samples from this study plotted on different discrimination diagrams for tectonic setting. A) Y* vs. *Nb diagram, and B) Y + Nb* vs. *Rb (after Pearce* et al.*, 1984). WPG–within plate granite, ORG–ocean ridge granite, VAG–volcanic arc granite, syn-COLG–syn-collisional granite.*

## DISCUSSION

Major-element data for the intrusive rocks in the St. Alban's map area overlap well with existing analytical results for Gaultois Granite suite, Northwest Brook Complex and North Bay Granite Suite (Dickson and Kerr, 2007; Figures 2C and 3). The rocks of the Gaultois Granite suite in the St. Alban's map area are typically granodiorite in modal and chemical composition. The geochemical data of this study overlap very well with the geochemical results from the literature for the Gaultois Granite. Actual granitic compositions are less common over the areal extent of this intrusive suite (Figure 1) and several quartz-poor and plagioclase-rich compositions are part of the Gaultois Granite (Figure 3): it is therefore suggested to use the informal term Gaultois Granite suite instead, to better reflect the range of compositions. The Northwest Brook Complex has a more restricted composition and is typically a two-mica granite. The North Bay Granite Suite is a composite batholith with several subunits and a range of compositions from granodiorite to granite. The ones in the St. Alban's area include both biotite–granodiorite and granite of both East Bay and Upper Salmon Road subunits, and muscovite–biotite granite that occurs only within the East Bay Granite.

Distinct differences exist between similar rock types of the different intrusive suites of the area. Gaultois granodiorite typically has lower $SiO_2$, and higher $TiO_2$, $Fe_2O_{3tot}$ and V contents than the North Bay granodiorite, but the existing data show some overlap between the two intrusive suites (Figures 2C and 3). Granodiorite of both Gaultois Granite suite and Upper Salmon Road granodiorite have an aluminous saturation index A/CNK around 1 and are weakly peraluminous to weakly metaluminous (Figure 2F). East Bay granodiorite is stronger peraluminous (A/CNK >1.1). Granite of the Northwest Brook Complex has higher $K_2O$ and $SiO_2$ contents, lower Sr contents, higher Nb/Y ratios and a strong peraluminous character (A/CNK >1.1, Figure 2F) compared to granite of the North Bay Granite Suite. Felsic aplite dykes within the Gander Zone have very similar major- and trace-element contents as the Northwest Brook Complex that has a strong peraluminous character.

Light REE are fractionated from the HREE in all intrusive rocks of the St. Alban's area ([La/Yb]CN <8 for most), in contrast to average mid-ocean ridge basalts (MORB) with a flat and smooth pattern (values for normal N-MORB and enriched E-MORB in Figure 4C from Sun and McDonough, 1989). The negative Eu anomaly, due to fractionation of plagioclase, distinguishes most samples from average ocean-island basalt (OIB, Sun and McDonough, 1989) that has a similar REE fractionation, but smooth pattern. An exception are Gaultois tonalite and quartz diorite that have only a very small negative Eu anomaly and a REE pattern that resembles that of an average OIB.

The extended trace-element diagrams normalized to primitive mantle show distinct differences for the intrusive rocks from average mid-ocean ridge and ocean-island rocks (Figure 4B). The LILE (represented by Rb and Ba in Figures 4 and 5) are enriched in the samples from this study over HFSE (Zr, Hf, *etc.*), compared to a depletion or equal levels of LILE over HFSE in N-MORB and E-MORB, respectively (included in Figure 4B; Sun and McDonough, 1989).

Most intrusive rocks of the St. Alban's area have negative Ti, Nb, Sr and P anomalies on multi-element variation diagrams normalized to primitive mantle (Figures 4 and 5), which further distinguishes them from OIB that has similar elemental abundances, but a smooth pattern (Sun and McDonough, 1989). Strontium can become depleted during plagioclase fractionation in the magma source, resulting in the observed negative Sr anomalies, which is consistent with the negative Eu anomalies observed in the REE patterns (Figures 4 and 5). Normalized Ba contents are low in a few samples compared to Rb and Th, which can be explained by the presence of K-feldspar or mica that retain Ba preferentially over those elements during partial melting of the mantle wedge (*e.g.*, Elburg *et al.*, 2002).

As noted earlier, the extended trace-element diagrams (Figures 4 and 5) show an unusual behaviour of Ta and Nb for many samples. Tantalum generally behaves similar to Nb due to similar geochemical properties (ionic potential, lithophile and refractory character) and would not be fractionated under most geological processes (Goldschmidt, 1937), *i.e.*, show a similar behaviour in extended trace-element diagrams ($Ta_{PM}/Nb_{PM}$ ~1). In some samples of this study, Nb and Ta show a decoupled behaviour (Figure 7A, $Ta_{PM}/Nb_{PM}$ >>1), which could be related to analytical issues. The normalizing value of the primitive mantle is given at 0.041 ppm (Sun and McDonough, 1989), whereas the current detection limit for Ta at the GSNL laboratories is 0.5 ppm. In many samples, where Ta concentrations are at, or just above, the detection limit, the normalized Ta values may be unrealistically high. However, Nb/Ta ratios have been found to be variable, especially in granitic rocks where the ratios range from <2–25 (Green, 1995), in contrast to Nb/Ta ratios of the bulk silicate earth of 14.0 ± 0.3 (Münker *et al.*, 2003). Low Nb/Ta ratios in peraluminous granites have been attributed to fractional crystallization/partial melting (*e.g.*, Stepanov *et al.*, 2014) or the interaction of evolved peraluminous granite with late-stage magmatic fluids (*e.g.*, Ballouard *et al.*, 2016). During low-temperature partial melting, biotite, which preferentially incorporates Nb over Ta, is a residual phase, resulting in melts with low Nb/Ta. In contrast, biotite is consumed completely during high-temperature partial melting, and residual Ti-oxides with a preference for Ta over Nb cause the resulting melt to have high Nb/Ta ratios (Stepanov *et al.*, 2014). Ballouard *et al.* (2016) argue that partial melting and fractional crystallization are not sufficient to achieve the observed low Nb/Ta ratios in peraluminous granites and invoke magmatic-hydrothermal processes to decrease Nb/Ta ratios: reduced F-rich fluids have increased Nb and Ta solubilities with Ta being less soluble (Zaraisky *et al.*, 2010), resulting in Ta > Nb. Even though the reasons for decoupled behaviour of the Nb and Ta and low Nb/Ta ratios are debated (Stepanov *et al.*, 2016), fractionation between the two elements is possible for peraluminous granites. These processes may be important for some of the felsic dykes and granite of the Northwest Brook Complex that have Ta concentrations well above the detection limit and low Nb/Ta ratios below 5 (Figure 7B).

The samples with stronger alteration in thin section (Gaultois granodiorite, Plate 1C and Northwest Brook Complex granite, Plate 3B) have nonetheless a very similar trace-element pattern compared to the less altered samples (Figure 4B, F). Similarly, the more altered quartz-poor Gaultois tonalite and quartz diorite have generally a similar pattern compared to the least altered tonalite (Figure 4D). However, the more altered samples must be considered with caution and are less diagnostic in determining source and generation of the melts responsible for the intrusions.

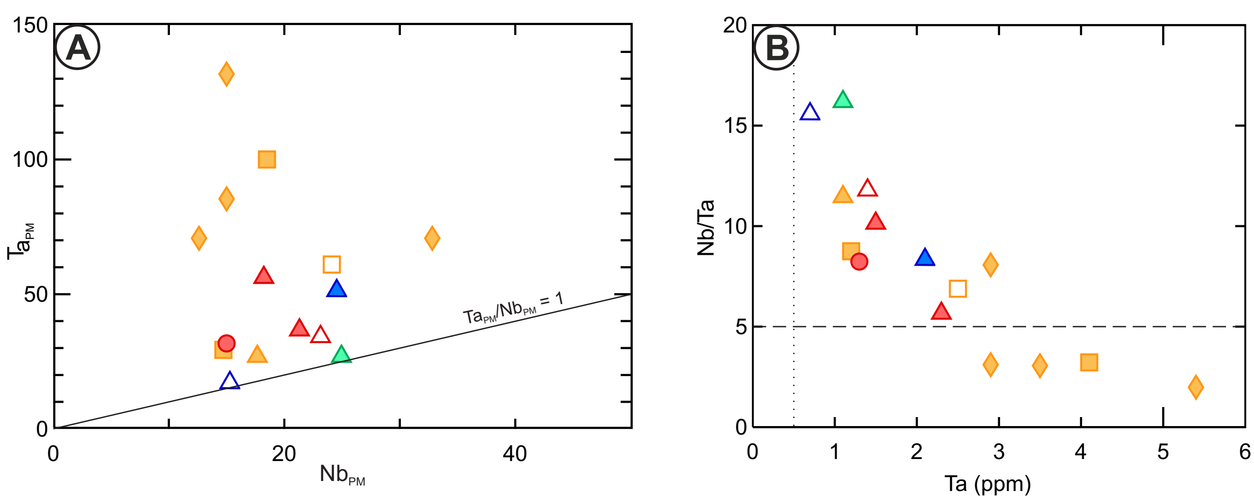


**Figure 7.** *Diagrams to illustrate decoupled geochemical behaviour of Nb and Ta. A) Nb normalized to primitive mantle ($Nb_{PM}$)* vs. *Ta normalized to primitive mantle ($Ta_{PM}$), samples with typical similar geochemical behaviour plot close to the $Nb_{PM}/Ta_{PM}$ = 1 line, and B) Ta (ppm)* vs. *Nb/Ta, dotted line is GSNL detection limit for Ta, dashed line shows boundary for "low" Nb/Ta ratio as suggested by Ballouard* et al. *(2016).*

When examining the tectonic setting of evolved magmatic rocks using geochemistry, it is important to note that the composition of granitic rocks foremost reflect their source rocks and their magma generation history (partial melting, crystallization processes, contamination, *etc.*) and not necessarily the tectonic setting. The resulting complex compositions of silicic magmatic rocks can nevertheless be used for tectonic discrimination to some extent because similar processes are potentially active in similar settings. Using major elements and mineralogy following Maniar and Piccoli (1989), the calc-alkaline and peraluminous to metaluminous character of the rocks places the intrusive rocks of the St. Alban's area into the orogenic category, specifically the continental-arc to continental-collision-granitoids (CAG to CCG). The stronger peraluminous Northwest Brook Complex two-mica granite falls into the CCG category. The trace-element patterns, such as the negative Ti, Nb, and P anomalies and the LILE enrichment on multi-element variation diagrams, are also attributed to subduction-related processes (*e.g.*, Pearce, 1996). Fluids from the subducted and altered oceanic crust and/or sediments contribute LILE to the arc magmas, whereas HFS elements of similar incompatibility are retained in the mantle wedge causing, for instance, negative Ti and Nb anomalies in the trace-element patterns. Of these, the negative Ti anomaly is the most distinct in the intrusive rocks of the St. Alban's area, whereas the Nb and also P anomalies are present to varying degrees. This is common for peraluminous magmas because increasing input of heterogeneous material during subduction, involving continental crust and continent collision, creates complex trace-element patterns (*e.g.*, higher Nb due to contamination, higher P due to higher solubility of apatite). However, all trace-element patterns of samples in this study are distinct from mid-ocean ridge or ocean-island rocks and show a clear subduction component. Further, the rocks of the Gaultois Granite suite and the North Bay Granite Suite fall within the 'volcanic arc granite' field (VAG in Figure 6B) and rocks of the Northwest Brook Complex and felsic dykes in the syn-collisional granite (syn-COLG) field of tectonic discrimination diagrams (Figure 6; after Pearce *et al.*, 1984). The latter are also stronger peraluminous, indicating increased contribution of sedimentary rocks, *e.g.*, pelite/semi-pelite, in the magma generation.

Uranium–Pb dating revealed two distinct orogenic events (Dunning *et al.*, 1990; Westhues and Hamilton, 2018). The Gaultois Granite suite (*ca.* 421 to 419 Ma), as part of the Salinic orogeny during the Late Silurian, and the North Bay Granite Suite (*ca.* 416 to 396 Ma), as part of the Early Devonian Acadian orogeny. The Northwest Brook Complex is undated, but intrudes the Gaultois Granite suite. The geochemical composition of the intrusive suites reflects the differences in timing and position within the tectonostratigraphic zones of Newfoundland. Geochemical signatures reflecting a subduction component are observed in the metavolcanic rocks of the Isle Galet and Riches Island formations (Westhues and Hamilton, 2018), even though they are related to earlier tectonic processes in the Ordovician. The St. Alban's area is clearly a region with a complex multi-event geological history.

Radiogenic isotopic studies are further helpful to understand petrogenesis and relative associations of intrusive rocks, but few data are available for the Baie d'Espoir area. Elias and Strong (1982) report initial Sr isotope ratios based on whole-rock Rb–Sr "isochrons". Rubidium and Sr are susceptible to alteration effects, and the Rb–Sr ages reported in that study are not reliable (and have since shown to differ from more robust U–Pb zircon dating, Dunning *et al.*, 1990). The initial Sr isotope ratios from that study (Elias and Strong, 1982) may highlight differences between the Gaultois Granite suite ($^{87}Sr/8^{86}Sr_i$ = 0.7103 ± 4, n=10) and North Bay Granite Suite ($^{87}Sr/^{86}Sr_i$ = 0.7053 ± 3 for East Bay Granite, n= 4, and 0.7066 ± 1 for Upper Salmon Road Granite, n=8). The few existing Sm–Nd data for Gaultois Granite suite show generally more negative initial epsilon Nd values ($\varepsilon Nd_i$ from -1.4 to -3.9, n=4) compared to the North Bay Granite Suite ($\varepsilon Nd_i$ = -1.1, n=1; Kerr *et al.*, 1995). More detailed isotopic studies of these intrusive rocks and volcanic rocks discussed in Westhues and Hamilton (2018) are in progress to further understand the geological history of the Baie d'Espoir area. Additional age dating for the Northwest Brook Complex and metavolcanic units of the Baie d'Espoir Group, along with a refinement of an age for the intrusion at the Salmon River Dam Fault, is underway.

## CONCLUSIONS

The St. Alban's map area includes the tectonic boundary between the Gander and the Dunnage zones that not only separates Dunnage metasediments from Gander gneiss, but also different intrusive suites. The *ca.* 421 to 419 Ma Gaultois Granite suite is typically a syntectonic porphyritic to megacrystic granodiorite that is a continental arc granite in relation to the Salinic orogeny in the Gander Zone. The two-mica granite of the Northwest Brook Complex (undated) shows geochemical characteristics of continental collision granite possibly late during the Salinic orogeny. The younger North Bay Granite Suite intruded the Dunnage Zone during the Acadian orogeny from *ca.* 416 to 396 Ma as a composite batholith. The units within the St. Alban's map area range from granodiorite to granite, but have overlapping geochemical characteristics of continental arc granites with a clear subduction component. The full petrogenesis and relative association with other intrusions and the volcanic rocks of the Isle Galet Formation await further mineral, chemical and isotopic studies.

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