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UPDATED GEOLOGY OF THE ST. ALBAN'S MAP AREA (NTS 1M/13), DUNNAGE AND GANDER ZONES

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ABSTRACT

In the eastern and central portions of the St. Alban's map area (1M/13), south coast of Newfoundland, a 1:50 000-scale bedrock mapping project has further defined the lithological units in the area and incorporated new detailed airborne geophysical surveys. The new magnetic and radiometric data are used in combination with bedrock mapping to refine and update the geology of the St. Alban's map area, which includes the boundary between the Gander Zone and Exploits Subzone of the Dunnage Zone. The Day Cove Thrust, part of the Bay d'Espoir ductile shear zone, separates the Baie d'Espoir Group (Dunnage Zone) from the Little Passage Gneiss. This gneiss is assigned to the Gander Zone and is intruded by syn- to late tectonic intrusions. Biostratigraphy and U–Pb geochronology constrain the age of the marine metasedimentary and metavolcanic rocks of the Baie d'Espoir Group to Early to Middle Ordovician. The protolith age of the Little Passage Gneiss is unknown, but its metamorphic peak age overlaps with the intrusive age of the syntectonic Gaultois Granite during the Silurian Salinic orogeny. The Baie d'Espoir Group has experienced two periods of deformations and at least one phase of metamorphism, ranging from greenschist to epidote–amphibolite facies. The cleavage of the first deformation phase (D_1) is subparallel to bedding and related to isoclinal folding, whereas the second phase (D_2) is related to recumbent folds and cleavage development. Regional trends related to the second deformation phase in the Dunnage Zone are subparallel to foliation and gneissosity of rocks in the Gander Zone. The overall southwest orientation is subparallel to the Day Cove Thrust supporting the interpretation that the second deformation phase is related to tectonic activity and mylonitization at the thrust.

Several sulphide- and gold-mineralized quartz veins and base-metal massive sulphides occur within the Baie d'Espoir Group. The Isle Galet Formation has been a major focus of exploration activity in the area for its base metal, Sb, As and Au potential, but also quartz veins within the St. Joseph's Cove Formation can contain galena, chalcopyrite, and stibnite. New gold and silver anomalies have been identified as a result of this mapping project.

INTRODUCTION

The eastern and central portions of map area NTS 1M/13 were mapped at a 1:50 000 scale in the summer of 2016, following the release of a new, high-resolution airborne geophysical survey of the area (Kilfoil, 2016). The results of the new magnetic and radiometric data are the basis for a multi-year mapping project in the St. Alban's map area. This project builds on previous mapping in the region (*e.g.*, Colman-Sadd, 1976a) and will generate a detailed GIS-integrated map with associated databases and will be a valuable asset for mineral exploration and land-use planning.

The St. Alban's map area along the south coast of Newfoundland includes part of the boundary between two of Newfoundland's major tectonostratigraphic subdivisions, the Gander and Dunnage zones (Williams *et al.*, 1988, Figure 1). The metasedimentary and metavolcanic sequences of the Ordovician Baie d'Espoir Group make up most of the map area and are assigned to the Exploits Subzone of the Dunnage Zone (Figure 2). The Day Cove Thrust separates the greenschist- to epidote–amphibolite-facies rocks of the Baie d'Espoir Group from the amphibolite-facies rocks of the Little Passage Gneiss to the southeast, considered part of the Gander Zone (Colman-Sadd and Swinden, 1984). The Little Passage Gneiss is mainly paragneiss, and is intruded by the megacrystic Gaultois Granite. Biotite–muscovite granite of the Northwest Brook complex intrudes both Little Passage Gneiss and Gaultois Granite. Garnetiferous pegmatite and aplite dykes intrude the Gander Zone, and can be over 100 m wide in places. Regional structural trends are subparallel to the Day Cove Thrust and are preserved as cleavage, schistosity and gneissosity in metasedimentary and igneous rocks.

PREVIOUS WORK

The bedrock geology of NTS 1M/13 map area was last mapped at a 1:50 000 scale in the 1970s (*e.g.*, Colman-Sadd, 1974, 1976a, b), following preliminary surveys of the area

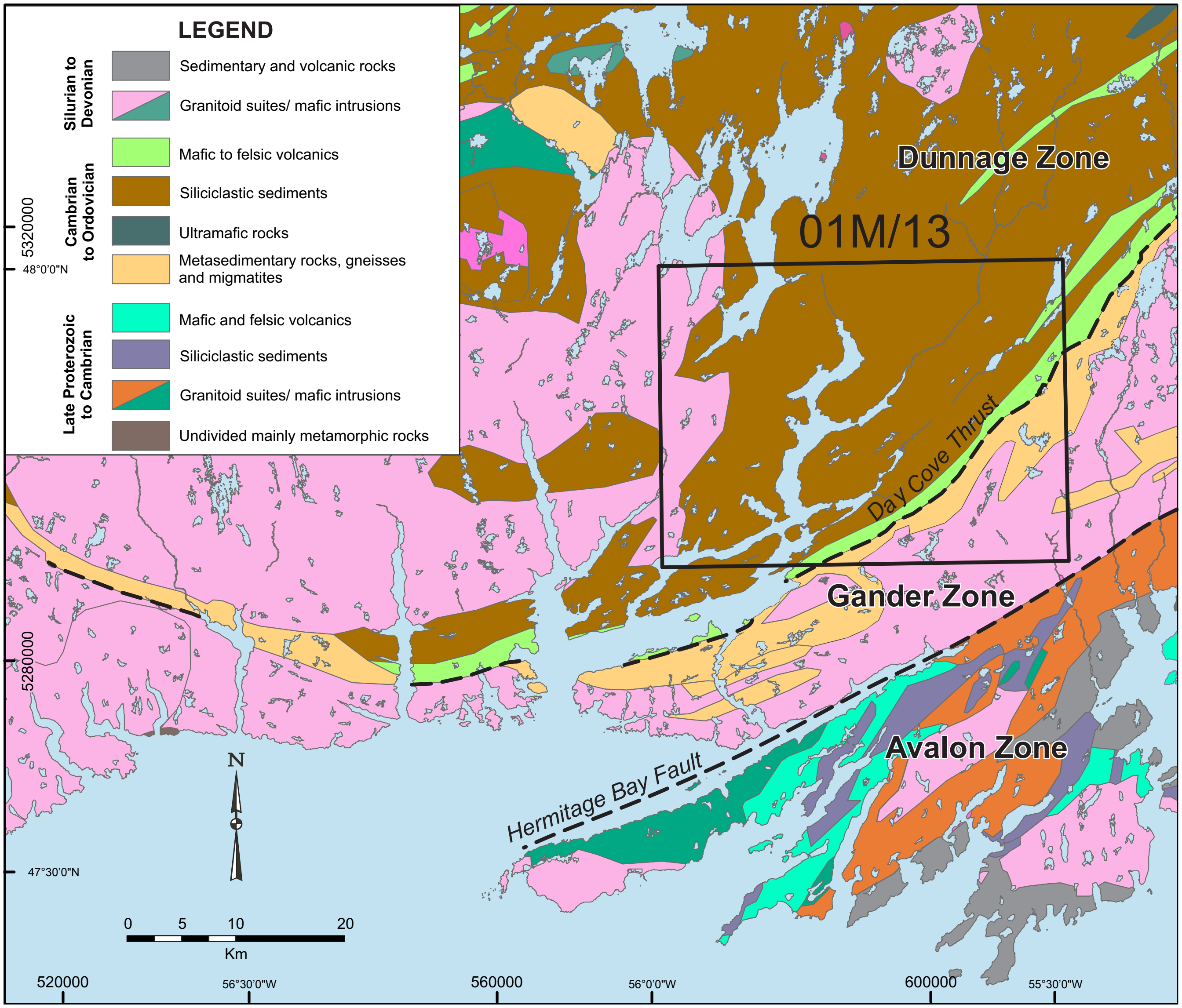

Figure 1. *Simplified regional geology of the south coast of Newfoundland modified after Colman-Sadd* et al. *(1990) and information from GSNL geoscience atlas, showing the location of NTS map area 01M/13 and approximate locations of boundaries between the tectonostratigraphic zones of Newfoundland.*

(Jewell, 1939; Moore, 1953). The St. Alban's area was also included in a 1:253 440 (1 inch to 4 miles) map of the Belloram area (Anderson, 1965). Piasecki (1988) did a detailed structural study along the coast of the Bay d'Espoir region from Hermitage Bay to Bonne Bay, including parts of map area 1M/13. This was followed by the Meelpaeg transect of the Lithoprobe project (deep seismic reflection profiles, Quinlan *et al.*, 1992), and the geology along the transects has been studied in detail in addition to the geophysical studies (*e.g.*, Williams *et al.*, 1989). Regional geochemical studies of the NTS map area 1M include a stream-sediment survey (McConnell and Honarvar, 1989) and a lake-sediment survey (Davenport *et al.*, 1990). The map area is further included in a 1:250 000-scale surficial geology map (Liverman and Taylor, 1994). More recently, the area has also been the focus of a regional till-sampling project (Brushett and Amor, 2016).

Commercial exploration activity has been ongoing for several decades with a focus on the Isle Galet Formation within the Baie d'Espoir Group for 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). A number of the targets have been drilled more recently in the Little River area

(Woods, 2010, 2011) and at the True Grit occurrence in the St. Joseph's Cove Formation (Breen, 2005). The mineral potential of this area is very high and the new geophysical observations (Figure 3) coupled with new bedrock mapping highlight the areas where exposure is limited.

REGIONAL GEOLOGY

The Dunnage Zone of the Appalachian orogen is considered to be remnants of the Iapetus Ocean, and is subdivided into the Notre Dame Subzone in the west and the Exploits Subzone in the east in Newfoundland (*e.g.*, Williams *et al.*, 1988). The boundary of the Exploits Subzone and Gander Zone (Gander Lake Subzone) is marked by the occurrence of ophiolites in the Gander River Ultrabasic Belt (GRUB line, *e.g.*, Blackwood, 1982) in north central Newfoundland. Extending the boundary to south coast of Newfoundland is more problematic because no ophiolite complexes marking the boundary are recognized in the area. One small serpentinite body was recognized in the St. Alban's area by Colman-Sadd (1975), however, this 500-m-long body lies entirely within the Dunnage Zone, not along the boundary to the Gander Zone. Instead, in the St. Alban's map area, the boundary is proposed as the contact of Ordovician low-grade metamorphosed volcano-sedimentary sequences of the Baie d'Espoir Group, Dunnage Zone, with the amphibolite-facies Little Passage paragneiss, Gander Zone (Colman-Sadd and Swinden, 1984; Williams *et al.*, 1988). The Day Cove Thrust is interpreted as part of the Bay d'Espoir shear zone, where rocks of the Baie d'Espoir Group have been thrust over the Little Passage Gneiss subparallel to the regional strike (Colman-Sadd, 1976b; Piasecki, 1988). The gneiss is intruded by two suites of syn- to late-tectonic intrusions, the Gaultois Granite and the Northwest Brook complex. The metasedimentary and metavolcanic rocks of the Baie d'Espoir Group of the Dunnage Zone are divided into the Salmon River Dam Formation, the St. Joseph's Cove Formation, the Riches Island Formation, and the Isle Galet Formation (Colman-Sadd, 1976b), and are intruded by the North Bay Granite Suite in the western parts of the map area.

The biostratigraphic age of the Baie d'Espoir Group were first defined by the occurrence of deformed brachiopods (Early to Middle Ordovician; Colman-Sadd, 1976b), and a trilobite pygidium further defined the deposition age to Late Arenig (Boyce *et al.*, 1993), equivalent to Dapingian in the current International Chronostratigraphic Chart (*ca.* 470 to 467 Ma, www.stratigraphy.org). To the north of the study area, the felsic metavolcanic Twillick Brook member of the St. Joseph's Cove Formation was dated by U–Pb (TIMS, multigrain zircon) to 468 ± 2 Ma (Colman-Sadd *et al.*, 1992). In central Newfoundland, the mineralized Mosquito Hill porphyry, interleaved with rocks assigned to the Baie d'Espoir Group by Colman-Sadd (1985), was dated recently to 494 ± 14 Ma and 477 ± 8 Ma (U–Pb zircon LA-ICPMS, Sandeman *et al.*, 2013), older than the Dapingian biostratigraphic ages reported in the St. Alban's area (above) and from the Coy Pond Complex (Williams *et al.*, 1992). An unmineralized dacite dyke crosscutting a mélange below the Mosquito Hill porphyry was dated to 464 ± 7 Ma as part of the same study. In the same area, brachiopods of Darriwillian age (*ca.* 467 to 458 Ma) occur within a limestone conglomerate that was originally assigned to the Spruce Brook Formation of the Mount Cormack Subzone of the Gander Zone (Colman-Sadd and Swinden, 1984). However, precise stratigraphic relations between this conglomerate and the Spruce Brook Formation are unexposed, and detrital studies suggest that the conglomerate is younger (Colman-Sadd *et al.*, 1992). Another felsic volcanic unit within the Baie d'Espoir Group that hosts the Katie occurrence yielded 471.1 ± 1.4 Ma (U–Pb TIMS single grain zircon, J. Hinchey, personal communication, 2016). While the age constraints for the Baie d'Espoir Group broadly overlap as Late Cambrian to Middle Ordovician, discrepancies between biostratigraphic ages and U–Pb geochronology complicate the stratigraphy within the Baie d'Espoir Group. Further, none of the U–Pb constraints are from the current map area and the timing and stratigraphic relations between the four formations within the St. Alban's map area remain unclear. Colman-Sadd (1980) suggested that they are relative time equivalents formed at different water depth (relatively deep and distal for St. Joseph's Cove Formation, shallower shelf for Riches Island and Isle Galet formations), but deformation and metamorphism destroyed many primary sedimentary features. Age constraints for rocks of the Gander Zone are also limited to equivalent units in the Gaultois map area to the south. The metamorphic peak of the Little Passage Gneiss (423 +5/-3 Ma) and the intrusive age of the Gaultois Granite (421 ± 2 Ma) overlap within error and are interpreted to be part of the Silurian Salinic orogeny (U–Pb TIMS, multi-grain zircon, Dunning *et al.*, 1990). The protolith age of the Little Passage Gneiss remains unknown. The selection of targets for precise geochronological dating is a major part of this bedrock mapping project.

GEOLOGY OF THE ST. ALBAN'S MAP AREA

Below is a description of the lithological units in the St. Alban's map area (NTS 1M/13). All units described here are shown on Figure 2. Most rock types have been described previously (*e.g.*, Colman-Sadd, 1976b), with the exception of Unit 14, which was not previously mapped.

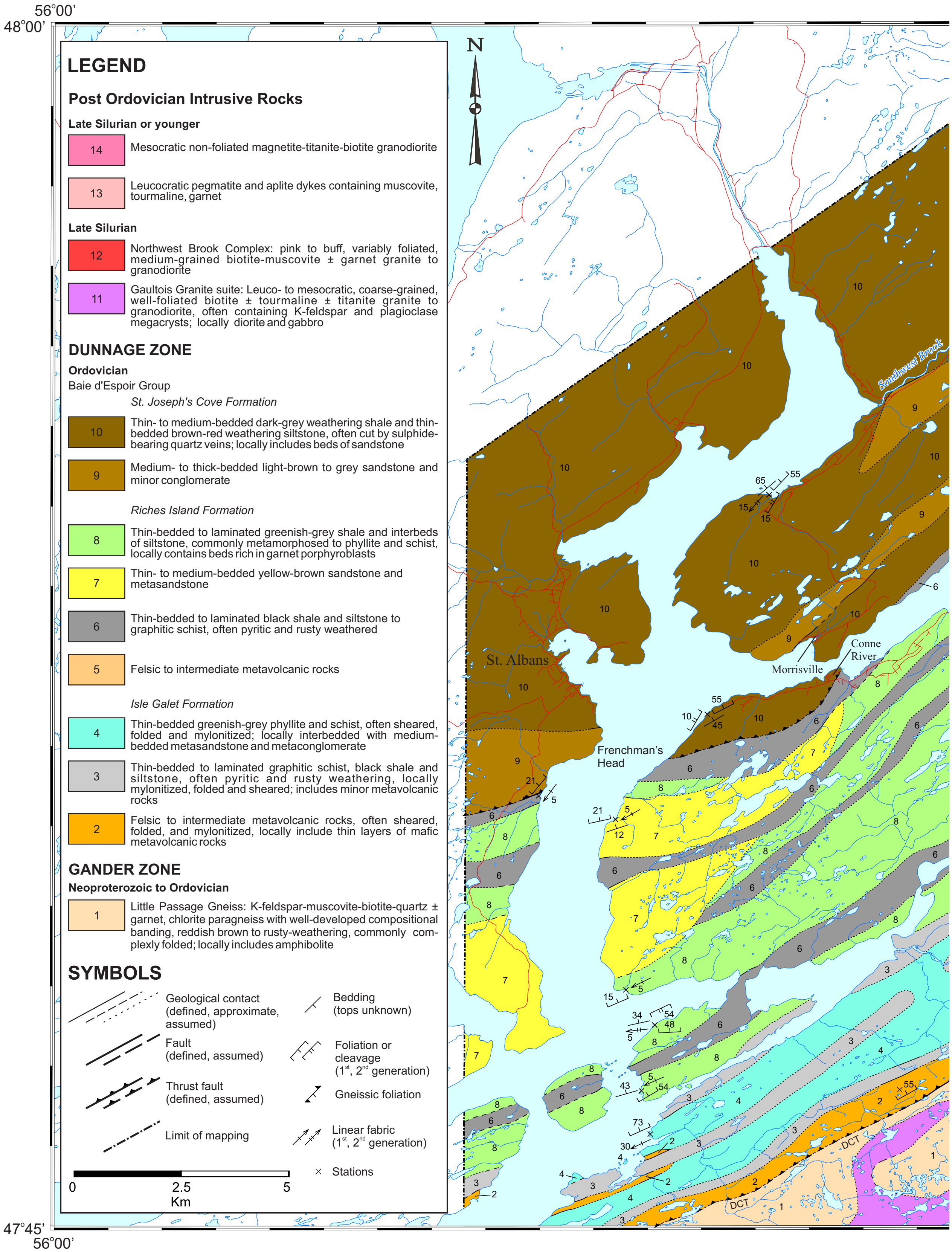

Figure 2. *Geological map of the central and eastern parts of the St. Alban's map sheet, including parts of the Bay d'Espoir coast, with selected structural observations,* see *details in text. DCT – Day Cove Thrust.*

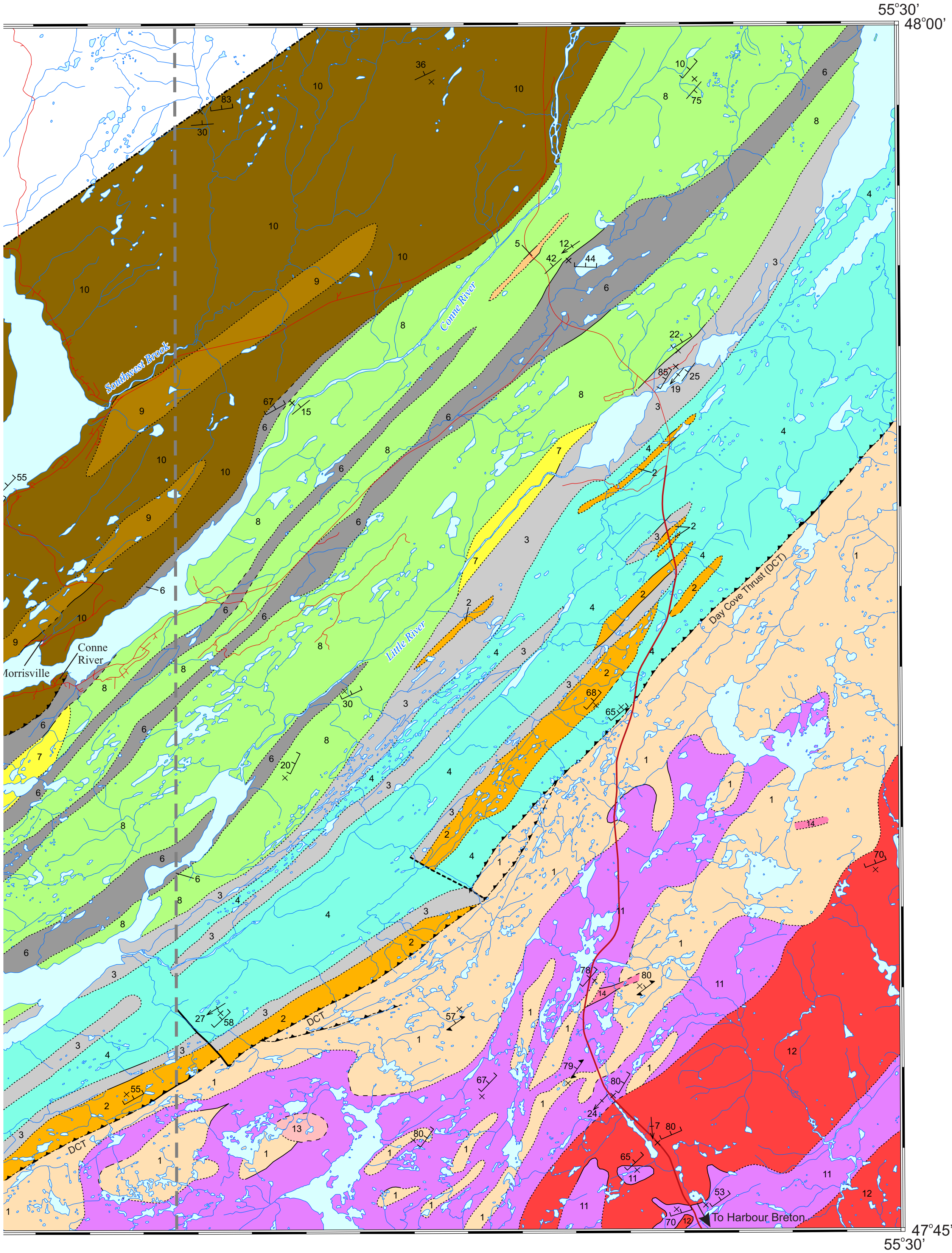

Figure 2. *Continued.*

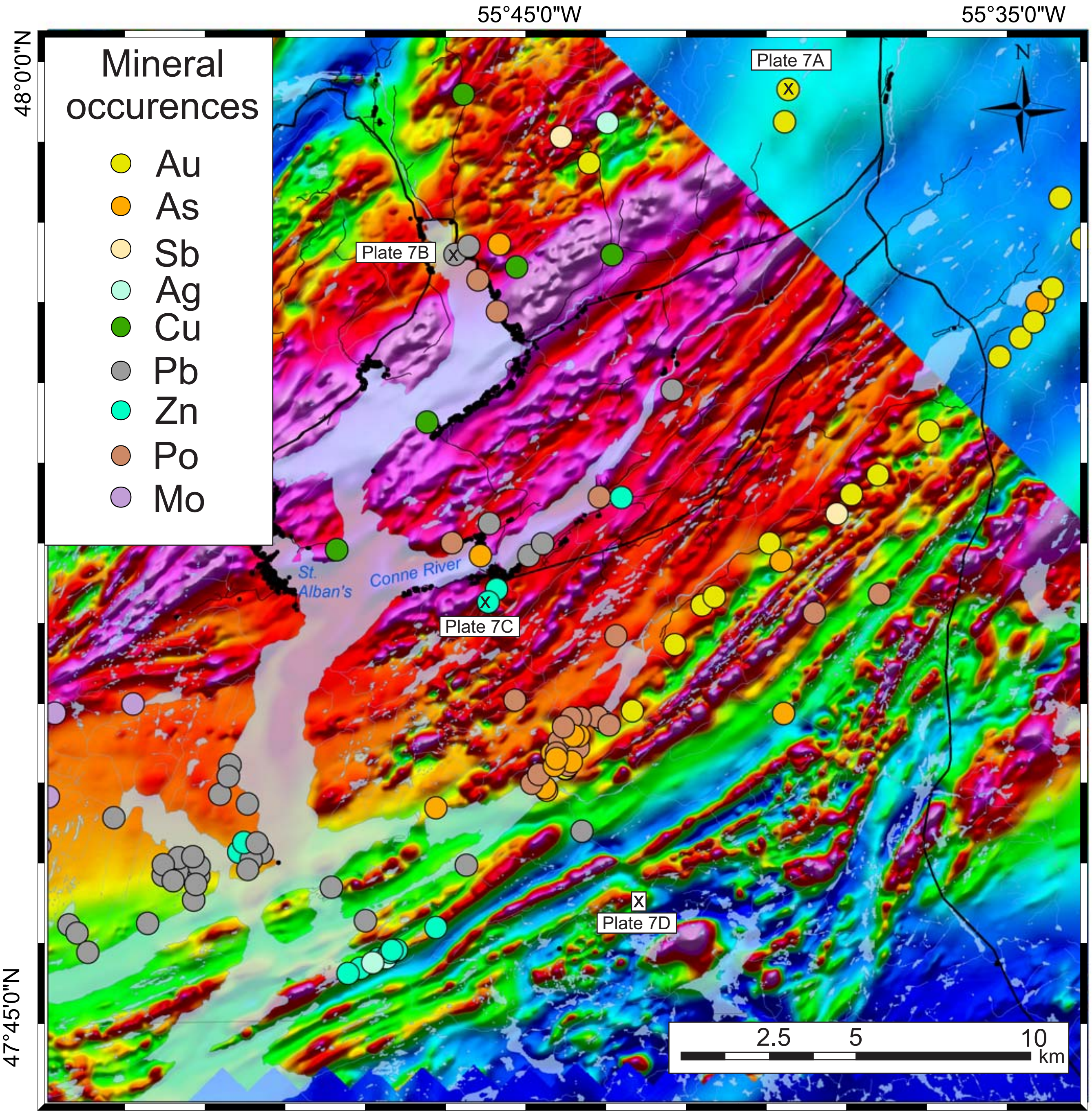

Figure 3. *Compilation for part of the St. Alban's map sheet of residual magnetic intensity of the recent geophysical survey (Kilfoil, 2016) and regional magnetic survey of Newfoundland with known mineral occurrences, data based on information of the Geoscience Atlas of the GSNL.*

GANDER ZONE

Little Passage Gneiss (Unit 1)

The Little Passage Gneiss consists mainly of banded, K-feldspar–muscovite–biotite–quartz ± garnet semipelitic to psammitic paragneiss commonly preserving well-developed compositional banding and locally migmatitic textures. The light-coloured bands are dominantly quartz, with lesser K-feldspar and few plagioclase, and vary in thickness from 0.5 cm to 2–4 cm (Plate 1). Dark bands are rich in biotite, commonly chloritizied and varying degrees of muscovite. Garnet porphyroblasts occur throughout the unit and are typically 0.2 to 1 cm in diameter. Staurolite, sillimanite and

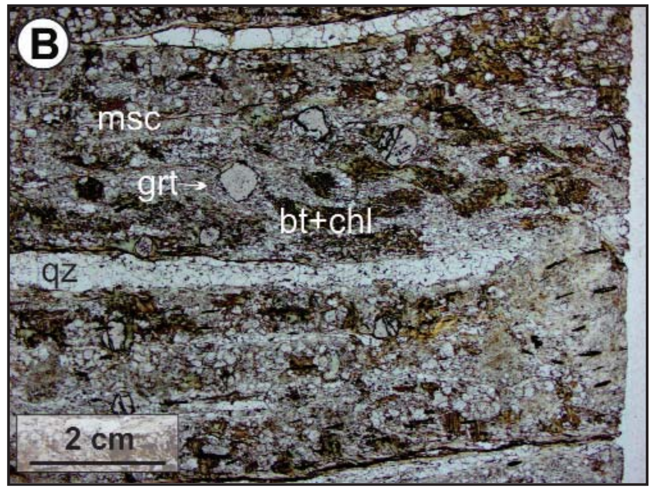

Plate 1. *A) Representative photograph of Little Passage Gneiss with compositional layering of quartz-rich and biotite-rich layers that are locally folded, as shown here. Rocks commonly show a rusty weathering, which is, combined with compositional layering, a distinctive feature of these rocks in the field; B) Photomicrograph of compositional layering of Little Passage Gneiss. Bands of recrystallized quartz (qz) between muscovite (msc) and biotite (bt, brown), partly altered to chlorite (chl, green), with garnet porphyroblasts (grt).*

amphibole occur as accessory phases. Reddish brown to rusty weathering, likely related to alteration of Fe-rich biotite and opaque phases, occurs throughout the unit. The banding in the gneiss commonly has complex folds that become tighter close to the Day Cove Thrust. A mylonitic foliation is developed in proximity to the thrust and defines the shear zone. Locally, this unit contains boudins of amphibolite gneiss that are typically 2–5 m long and 1–2 m wide, but have been described to occur up to 20 m thick (Colman-Sadd, 1976b). On the residual magnetic field and the various derivatives of the magnetic field, the Little Passage Gneiss generally shows high signatures, likely a result of disseminated magnetite. In areas with poor to no exposure the magnetic field data has been used to refine the boundaries between this unit and the Gaultois Granite (Unit 11).

DUNNAGE ZONE

Baie d'Espoir Group (Units 2 to 10)

The metasedimentary and metavolcanic rocks of the Baie d'Espoir Group are part of the Exploits Subzone of the Dunnage Zone, which are considered back-arc and intra-oceanic arc rocks formed along the eastern margin of the Iapetus Ocean (*e.g.*, Colman-Sadd, 1980; van Staal *et al.*, 1998). The Baie d'Espoir Group may be correlative with the Davidsville Group, which consists of similar rocks, along strike, in north-central Newfoundland (Colman-Sadd, 1980). The subdivisions of the Baie d'Espoir Group in the St. Alban's map area (Colman-Sadd, 1976a, b) are, from east to west: Isle Galet Formation, Riches Island Formation, St. Joseph's Cove Formation and Salmon River Dam Formation. The last formation in the western part of the map area was not studied extensively during the field season, but consists dominantly of thick-bedded brown sandstone and siltstone (Colman-Sadd, 1976b). All units of the Baie d'Espoir Group are crosscut by quartz veins ranging from 1 to 20 cm in width, which are commonly syntectonically folded and locally rich in sulphides.

The Isle Galet Formation (Units 2–4) is situated close to the Day Cove Thrust, and relative to the other formations in the group is highly deformed. The contact between Isle Galet Formation and Riches Island Formation (Units 5–8) is defined by a graphitic schist layer (Unit 3) that can be traced throughout the survey area (Colman-Sadd, 1976b) and is conformable where documented. Along the western coast of Bay d'Espoir, a tectonic contact is well exposed between the St. Joseph's Cove Formation (Units 9 and 10) and Riches Island Formation (Figure 3). Sandstone of the St. Joseph's Cove Formation (Unit 9) is thrust over a dark-grey to graphitic phyllite of the Riches Island Formation (Unit 8) along the Big Rattling Brook Thrust (Colman-Sadd, 1974), and the contact is also marked by a contrast in the residual magnetic intensity. On the eastern shore around the town of Conne River, the contact is mostly obscured, but can be traced using the magnetic intensity and the first appearance of graphitic phyllite, a lithology not found in the St. Joseph's Cove Formation. Farther inland, along the shore of Conne River, the residual magnetic signature is the main tracer for the contact between the two formations, along with a few subcrops of graphitic phyllite as the contact is masked by the heavenly wooded terrane.

Isle Galet Formation (Units 2 to 4)

The Isle Galet Formation is a metasedimentary and metavolcanic succession in tectonic contact with the Little Passage Gneiss and consists of three units. This formation is strongly cleaved and metamorphosed to greenschist and epidote-amphibolite facies. Schistocity and mylonitic fabrics are developed close the Day Cove Thrust in the southeast of the Isle Galet Formation. Most of the primary sedimentary structures are destroyed by pervasive deformation. The main rock types are phyllites, schists, and metavolcanic layers. Black phyllites and schists, rich in graphite, form marker horizons and can be traced in the field and in the magnetic signature. In many cases, where the different rock types are interbedded, the most dominant rock type is mapped. Exploration in the region has focused on the antimony, arsenic and gold potential of this formation in recent decades.

Unit 2 includes all metavolcanic rocks of the Isle Galet Formation. Felsic to intermediate layers are easy to distinguish due to their light-coloured weathering, are fine-grained, and have few K-feldspar porphyroclasts (Plate 2A). Fresh surfaces are white to light brown and the groundmass is dominantly quartz and muscovite. Locally, the rocks contain lithic fragments or are rich in porphyroclasts. Colman-Sadd (1976b) also reports lenses of lapilli tuff. Commonly, mafic rocks occur as thin layers within the felsic metavolcanic rocks and are combined with the latter; they can also be found as thin layers within the metasedimentary units. The mafic metavolcanic rocks are dark greenish-grey and metamorphosed to amphibolite grade. Foliation is defined by quartz bands and preferred orientation of muscovite. The residual magnetic resonance of this unit is intermediate to low.

Unit 3 includes thin-bedded to laminated graphitic schists, black shales and siltstones, which are generally more deformed than similar rocks of the Riches Island Formation. Commonly, thin layers of metavolcanic rocks are interbedded with graphitic schists that usually contain pyrite and are rusty altered. This unit is more common than previously mapped for this formation. The high magnetic signature makes tracing the unit possible (*see* Figure 3). The contact between the Isle Galet and Riches Island formations is defined by graphitic schist that can be traced from the coast to Little River Pond (Colman-Sadd, 1976b) and is conformable where exposed along the coast line.

Other siliciclastic metasediments, ranging from greenish-grey phyllites and schists to metasandstones form Unit 4 and have the greatest areal extent. Thin-bedded phyllites and schists consist dominantly of fine-grained muscovite and quartz, and include biotite, chlorite, feldspars and garnet. Medium-bedded metasandstones, dominantly quartzites, rarely form massive sections, but occur interbedded with thin-bedded phyllites and schists. Locally, poorly sorted metaconglomeratic beds, 10 to 30 cm thick, occur within this unit (Plate 2B), as do unseparated volcanic rocks (*see* Unit 2 above). Preserved primary bedding is evident when there are grain-size contrasts between layers; otherwise, the penetrative cleavage and schistocity overprint and obscure the original sedimentary features. This unit can be distinguished from Unit 3 by a lower signature in the residual magnetic intensity.

Riches Island Formation (Units 5 to 8)

The Riches Island Formation occurs to the northwest of the Isle Galet Formation and consists dominantly of mudstone and siltstone that are commonly metamorphosed to phyllite and occasionally to schist. Similar to the Isle Galet Formation, black shale and graphitic schists are easily distinguishable. Coarser grained siliciclastic units generally

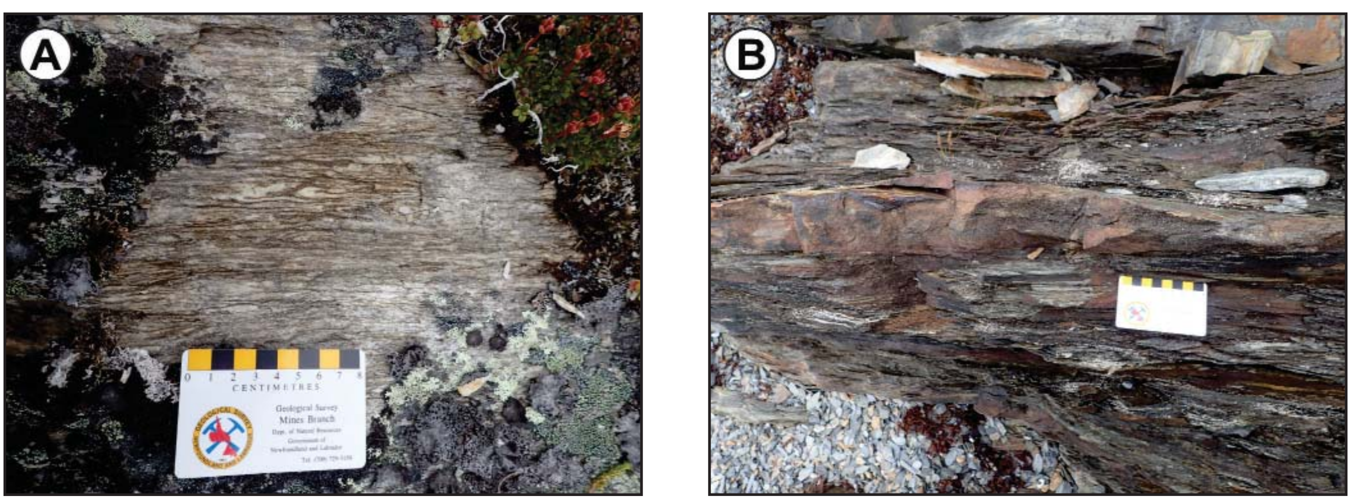

Plate 2. *Representative photographs of the Isle Galet Formation. A) Metavolcanic felsic rock (Unit 2) with foliation and small-scale isoclinal folds; B) Lens of strongly foliated metaconglomerate within green-grey to brown-altered schists (Unit 4).*

occur as metasandstone and rare metavolcanic rocks are interlayered. The different rock types are interbedded at a small scale locally, and are not mappable as separate units. Unit 8 contains brachiopods and trilobites of likely Early Ordovician age (Plate 3A, Late Arenig, Boyce *et al.*, 1993 – Dapingian).

Unit 5 comprises dominantly metamorphosed and deformed felsic to intermediate metavolcanic rocks. The light-grey metarhyolite to medium-grey meta-andesite is fine grained to aphanitic and locally porphyritic. Phenocrysts are quartz and feldspar, locally radiating amphibole, and typically form 5 to 10% of the rock; disseminated pyrite is common. The rocks show a foliation parallel to the regional trend, defined by alignment of biotite and muscovite.

Unit 6 includes thin-bedded to laminated black shale to graphitic slate and schist, depending on degree of metamorphism. With a stronger metamorphism, closer to the Day Cove Thrust, this unit is a lustrous dark grey. The dominant rock type in this unit is fine grained, organic rich and contains disseminated pyrite and is rusty weathered. The unit has a high magnetic resonance signature that can be traced through less accessible areas (*see* Figure 3). The first occurrence of graphitic phyllite is used to define the contact between St. Joseph's Cove Formation and Riches Island Formation.

Unit 7 consists of coarser grained siliciclastic rocks that are dominantly metamorphosed, thin- to medium-bedded arenaceous sandstone. The sandstone can also occur thickly bedded and is fine to medium grained. The composition is dominantly lithic arenite and lesser quartz arenite and feldspathic arenite. Quartz grains are typically unstrained and the fabric is defined by alignment of muscovite and biotite. Magnetic signature of this unit is generally weaker than that of Units 6 and 8, and can be used to trace this unit.

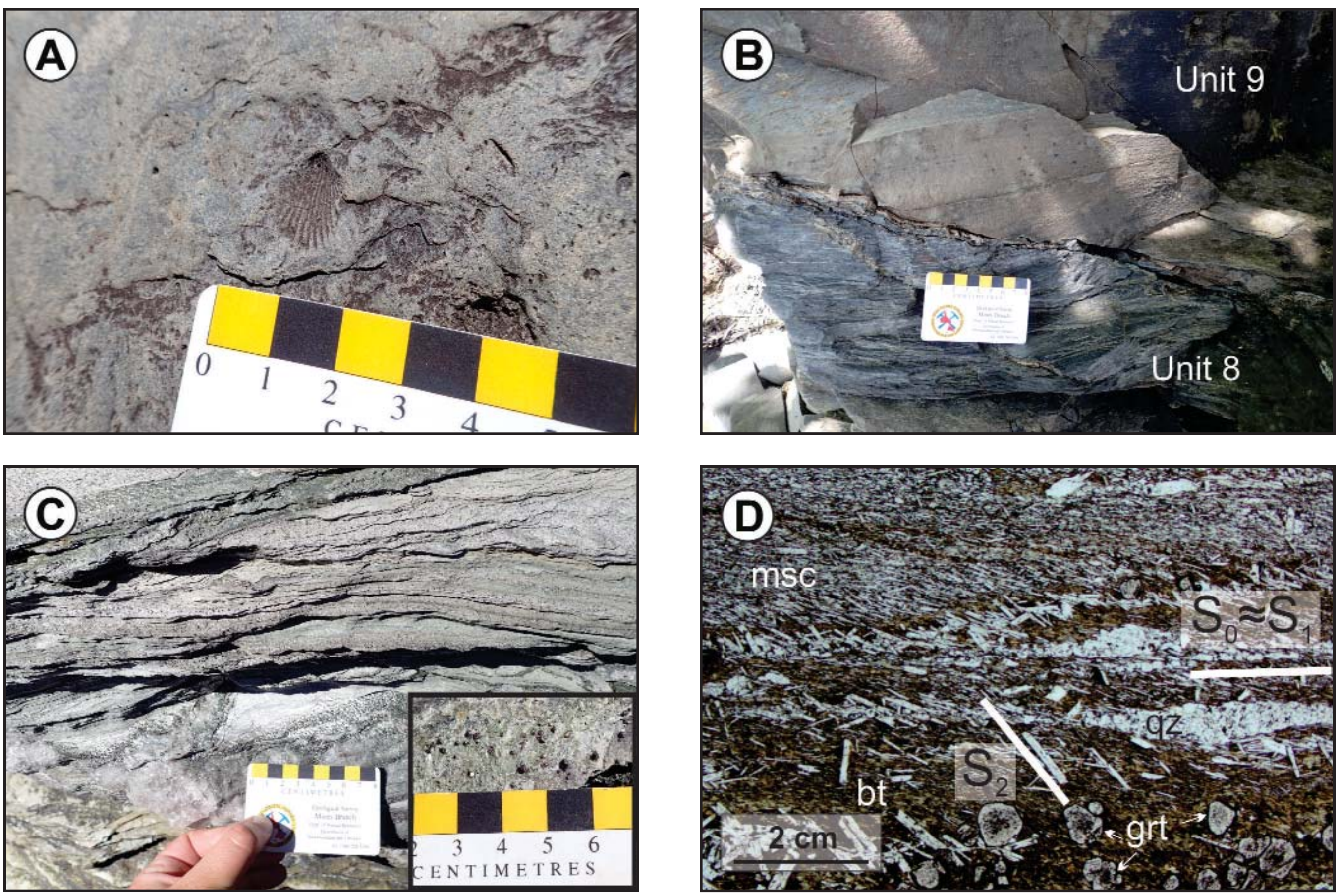

Plate 3. *Representative photographs and microphotographs of the Riches Island Formation. A) Deformed brachiopod shell found within metasiltstone (Unit 8) along shore of Conne River (UTM E598168, N5308452). The shell is Lower Ordovician in age and is from the same location described by Colman-Sadd (1976b) and Boyce* et al. *(1993); B) Tectonic contact between sandstone of St. Joseph's Cove Formation (Unit 9) and phyllite (Unit 8) of Riches Island Formation, close to Big Rattling Brook; C) Layers rich in porphyroblastic garnet within the schists (coticule layers), insert shows close up of garnet grains, likely spessartine; D) Photomicrograph of garnet (grt)-rich layer, here mainly concentrated in biotite (bt)-rich layer. Quartz (qz) veins and muscovite (msc) and define the S_1 and S_2 fabric, respectively.*

Unit 8 dominantly comprises thin-bedded to laminated greenish-grey shale interbedded with lesser dark-brown thin-bedded siltstone, which are commonly metamorphosed to greenish phyllite and pelitic to semipelitic schists. Along the coast, biotite–muscovite–quartz phyllite and schists are the dominant rock types and semipelitic schists rich in garnet (likely spessartine) form coticule layers (Plate 3C, D). Farther inland, around the Harbour Breton highway, shales and siltstone with a pervasive cleavage are more common. They are composed of biotite, muscovite, quartz and feldspar; garnet is rare. Relict primary bedding is locally preserved, but all other sedimentary structures have been obliterated. Cleavage and schistocity are defined by alignment of biotite and muscovite. This unit is locally cut by intrusive granite dykes that may be correlative of the North Bay Granite Suite in the western part of the map area.

St. Joseph's Cove Formation (Units 9 and 10)

The St. Joseph's Cove Formation consists of variable interbedded shale and siltstone beds and lesser sandy to conglomeratic beds. In contrast to the Isle Galet and Riches Island formations, primary sedimentary structures are readily preserved, such as parallel bedding, lamination, ripple structures, load clasts or rip-up clasts. This formation is poorly exposed inland, and therefore, its extent is largely interpreted from geophysical signatures and previous mapping. The shale–siltstone unit (Unit 10) has high intensities in the magnetic signature, while the sandstone belts (Unit 9) show an intermediate response in the residual magnetic field.

Unit 9 is a medium- to thick-bedded, light-grey to light-brown, arenaceous sandstone in several-hundred-metre-wide belts along parts of Southeast Brook, and east of Morrisville on the eastern shore of Bay d'Espoir. Sandstone outcrops along the road leading to Morrisville and can be traced to the western shore to Frenchman's Head. The composition is mostly lithic arenite. This unit also includes light- to medium-grey, matrix-supported, polymictic conglomerate beds up to a few metres thick. The dominantly white to light-grey clasts are poorly sorted, subrounded to rounded, and typically range from 2 mm to 2 cm in diameter. The conglomerates are likely locally sourced, because they also contain clasts consisting of shale. The extent of the unit is traced inland, based on its less intense magnetic signature compared to the shale–siltstone succession (Unit 10).

Unit 10 forms most of the St. Joseph's Cove Formation and comprises successions of parallel-laminated dark-grey shales up to 60 cm thick, interbedded with thin- to very thin-bedded brown to red siltstones. The fine-grained shales are dominantly muscovite, quartz, biotite, and also contain pyrite. The shales commonly contain fine-grained opaque minerals, which could explain the observed high magnetic intensity in this unit. The siltstone beds are richer in quartz than muscovite and locally contain feldspar and calcite. This unit preserves the relation between bedding and the two deformation fabrics: the first pervasive slaty cleavage is subparallel to bedding, while the second cleavage, commonly developed as crenulation cleavage, cuts the first fabric at an angle (Plate 4). Unit 10 also contains numerous quartz veins that can be up to 20 cm thick and are commonly syntectonically folded. Many of these veins have been found to contain sulphides including arsenopyrite, galena, and stibnite (*see* Mineralization). This unit has been interpreted as distal basin flysch having coarser siltstone repre-

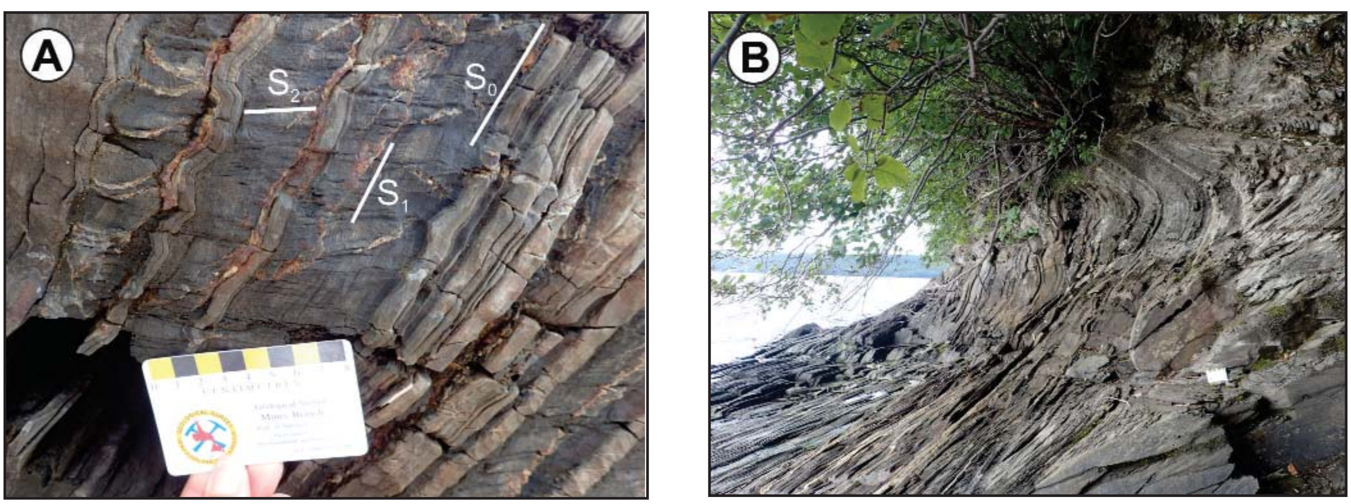

Plate 4. *Representative photographs of St. Joseph's Cove Formation. A) Typical interbedding of medium- to dark-grey shale with light-brown siltstone (Unit 10). Both are folded, but two cleavages are dominantly developed in the less competent shale layers. The first cleavage (S_1) is subparallel to the bedding (S_0), while the second cleavage (S_2) crosscuts bedding at a high angle; B) Recumbent fold within Unit 10 of St. Joseph's Cove Formation, scale card is 8 cm.*

senting turbidites (*e.g.*, Colman-Sadd, 1976b). The shape of the sand and conglomerate beds of Unit 9 suggests that they potentially were channel fills within the turbidite fans of Unit 10.

SYN- to POSTTECTONIC INTRUSIONS (UNITS 11 TO 14)

Gaultois Granite (Unit 11)

This unit consists of laterally extensive feldspar-megacrystic, lineated and foliated intrusions that have a U–Pb zircon age of 421 ± 2 Ma (*see* Dunning *et al.*, 1990, Gaultois map area; Plate 5). It occurs in the southeastern corner of this map area and stretches into the La Hune NTS 11P/10 map area in the southwest. Despite the units' granite identifier, compositions range widely from granite to granodiorite and tonalite and the heterogeneity in composition indicates a suite of intrusions rather than one intrusive body. In this report, when addressing the intrusions as a group, the formal name 'Gaultois Granite' is used, but actual rock types are referred to as Gaultois granodiorite, tonalite or granite as appropriate. Feldspar megacrysts, dominantly plagioclase, up to several centimetres in diameter are ubiquitous and occur in medium- to coarse-grained quartz, feldspar and biotite. Plagioclase is partly sericitized and biotite is commonly altered to chlorite. Accessory minerals are garnet, tourmaline, titanite, apatite, and epidote. The

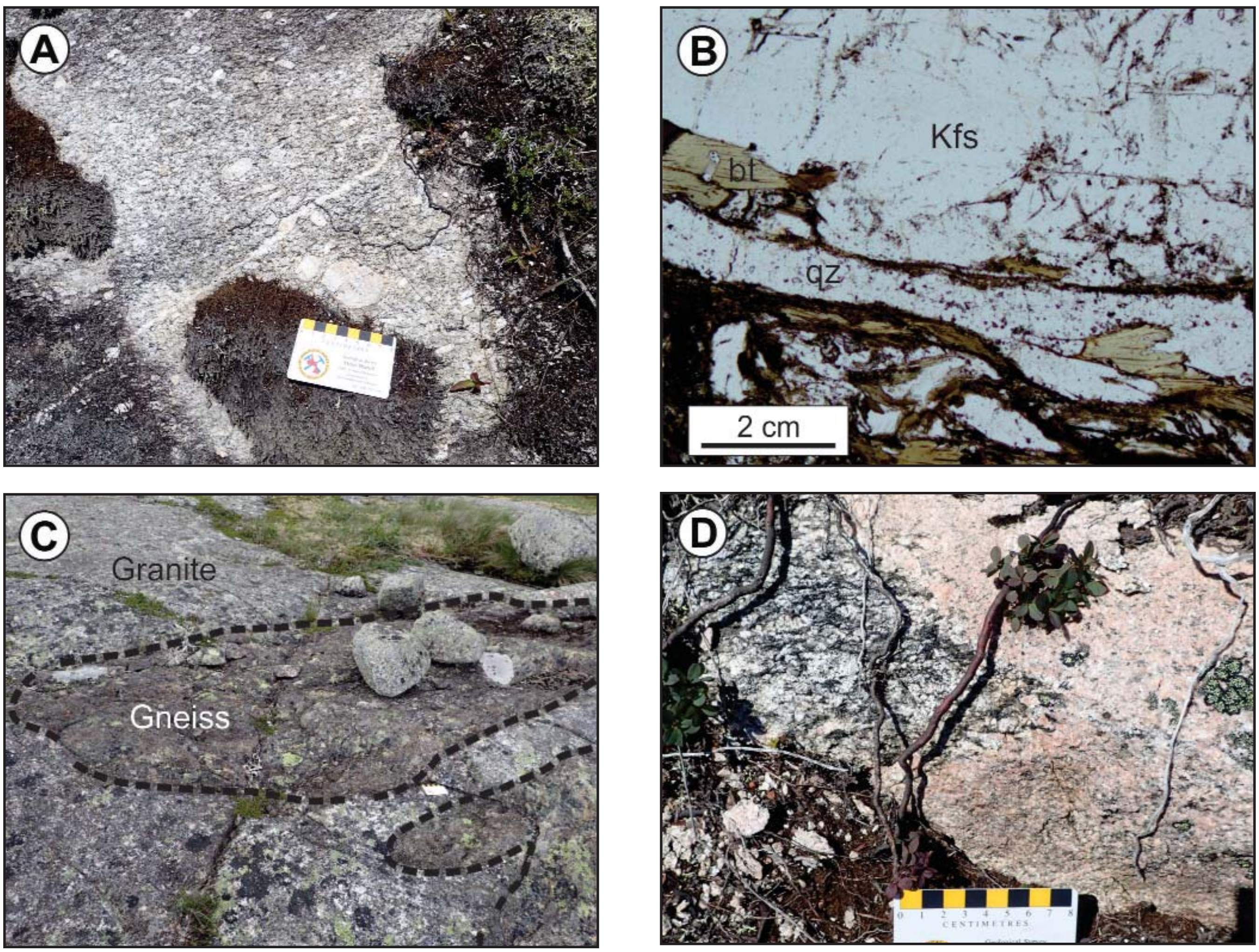

Plate 5. *Representative photographs of intrusive rocks. A) Biotite-rich Gaultois Granite with megacrysts up to several centimetres long, regional foliation is defined by elongated biotite grains and flattening of quartz; B) Photomicrograph of Gaultois Granite with elongated biotite (bt) and recrystallized quartz (qz) and K-feldspar (Kfs) defining the foliation; C) Rafts of strongly folded Little Passage Gneiss within megacrystic Gaultois granodiorite, showing the intrusive relationship between gneiss and granite, scale card is 8 cm; D) Northwest Brook complex granite (light pink) intruding a megacrystic Gaultois granodiorite. Foliation in the Northwest Brook complex granite is defined by muscovite and biotite, but less distinct than in rocks from the Gaultois Granite.*

absence of magnetite is interpreted to reflect the 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 (Plate 5A, B). Locally, the composition is more mafic dioritic to gabbroic, lacking K-feldspar and dominantly consisting of amphibole and plagioclase. Other accessory minerals include biotite, titanite, and pyrite. Small inclusions of mafic intrusive rocks occur in several places throughout the Gaultois Granite. The Gaultois Granite is restricted to the Gander Zone to the southeast of the Day Cove Thrust. 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 (Plate 5C).

Northwest Brook Complex (Unit 12)

The Northwest Brook complex is preserved only in the Gander Zone in the southeast part of the map area. It is distinguishable from the Gaultois Granite by its composition, and is dominantly a biotite–muscovite granite to granodiorite and minor syenite. The unit is pink to buff medium grained, equigranular; and rarely preserves megacrysts. It is weakly foliated and the fabric is defined by the preferred orientation of mica and elongated quartz grains. K-feldspar is commonly sericitized, garnet and tourmaline occur locally. This unit intrudes the Gaultois Granite and Little Passage Gneiss as dykes and dykelettes (Plate 5D) and is the dominant rock type in the southeastern most corner of the map area where it occurs as massive intrusive bodies.

Unnamed Leucocratic Garnetiferous Granite (Unit 13)

This muscovite–garnet–tourmaline granite typically occurs as pegmatites and aplites in many outcrops of Gaultois Granite, Northwest Brook complex and Little Passage Gneiss (Plate 6A). Dykes and veins occur parallel to and crosscutting the main foliation found in Units 11 and 12, but they themselves are not foliated. Most are not mappable at the scale of the map with the exception of two areas where dykes are preserved up to 150 m wide.

Unnamed Non-foliated Coarse Granodiorite (Unit 14)

This is a new, informal defined unit, which is an unfoliated, biotite–titanite granodiorite (Plate 6B). Accessory phases include magnetite and several opaque minerals. In regional-scale geophysics, Unit 14 has a strong high in the residual magnetic signal and occurs within a zone of alternating Little Passage Gneiss and Gaultois Granite. This area is relatively low lying compared to surrounding peaks of Gaultois Granite. The high content of magnetite, observed in hand sample, likely attributes to the observed magnetic high. In contrast to the surrounding Gaultois Granite, is does not show foliation or other signs of strong deformation and is likely a younger posttectonic intrusive rock.

PRELIMINARY STRUCTURAL AND METAMORPHIC RESULTS

The most obvious structural feature of the St. Alban's map area is the boundary between the Little Passage Gneiss and the Baie d'Espoir Group. The contact has been interpreted as thrust by Colman-Sadd (1976a) that brings younger rocks of the Baie d'Espoir Group in tectonic contact with the Little Passage Gneiss, and has been suggested as the boundary between Dunnage and Gander zones (Colman-Sadd and Swinden, 1984). This interpretation is supported by detailed work by Piasecki (1988) along the coast of Bay d'Espoir, who reports mylonitic fabrics indicating a

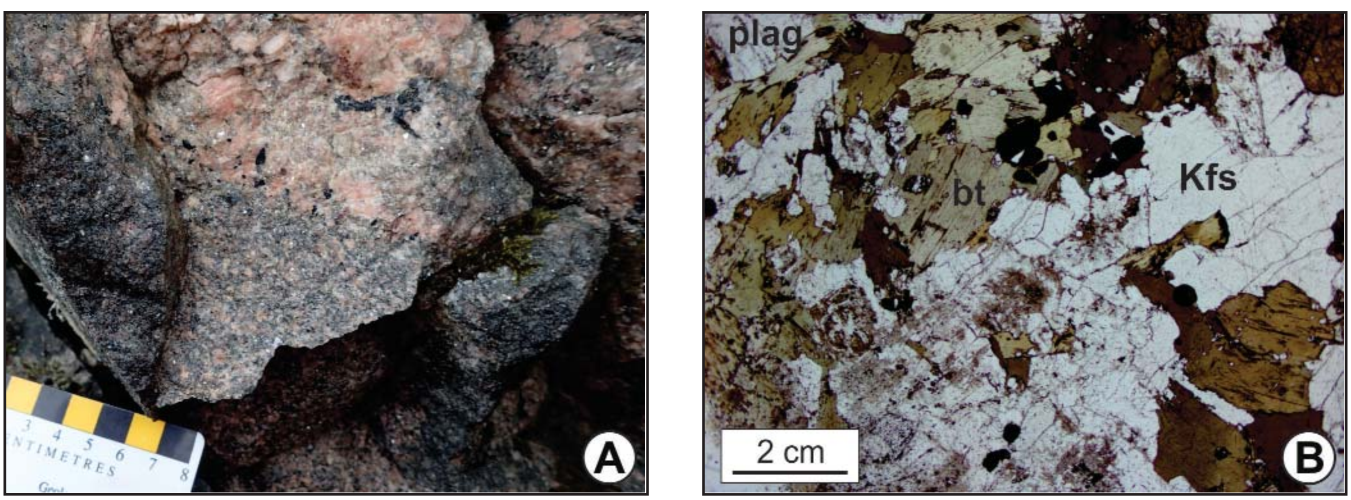

Plate 6. *A) Photograph of a garnet–tourmaline pegmatite cutting Gaultois granodiorite; B) Photomicrograph of the unfoliated granodiorite (Unit 14) with randomly orientated biotite (bt) grains surrounded by K-feldspar (Kfs) and plagioclase (plag).*

major ductile shear zone, where the highest strain rocks coincide with the Day Cove Thrust. The fabrics include stretching lineations, S-C foliations, shear bands, and rotated porphyroclasts, features that can also be observed inland indicating that the Day Cove Thrust is a major tectonic boundary. Piasecki (*op. cit.*) documents the mylonitic zones extending for at least 4 km in the Little Passage Gneiss and for up to 3 km in the Baie d'Espoir Group along the coastal section. The width of the shear zone is difficult to determine inland due to limited outcrop, but similar widths to the coastal sections are likely. In the St. Alban's map area, the Day Cove Thrust is identified by a topographic depression and a change in lithology. The shear zone affects different units in the map area. In the southernmost part of the thrust, felsic metavolcanic rocks of Unit 2 (of the Isle Galet Formation) occur to the northwest of a topographic depression, and Little Passage Gneiss can be found to the southeast. However, farther north, mylonizied schist of Unit 4 (of the Isle Galet Formation) occur closest to the thrust zone. The contact to the banded Little Passage Gneiss is poorly exposed here, and coincides with zones of low ground and bogs. Close to the eastern border of the St. Alban's map sheet, mylonizied phyllite and layers of mafic metavolcanic rocks occur on the Isle Galet Formation side of the Day Cove Thrust.

It is also worth noting that rocks of the Gaultois Granite and the Northwest Brook complex only occur within the Little Passage Gneiss, possibly indicating separate histories of the two terranes until the Late Silurian. The Day Cove Thrust is traceable in the geophysics as a negative magnetic response signature and is also visible as relative low in the radiometric maps. Further, the contrasting appearance of mostly regularly layered metasediments of the Baie d'Espoir Group on one side and the more complex relation between gneiss and intrusive rocks on the other side of the Day Cove Thrust are noticeable on magnetic and radiometric geophysical surveys. The anastomosed pattern of the shear zone, which was recognized by Colman-Sadd (1976a, b), is also evident in the geophysical survey.

The regional trends of gneissic layering of the Little Passage Gneiss and foliation in Gaultois Granite are subparallel and have a southwest strike and variable dips toward the northwest (*see* selected structural measurements in Figure 3). Foliation in the Northwest Brook complex, where developed, is also following this regional trend supporting the interpretation of syn- to late tectonic emplacement of the intrusions.

The rocks of the Baie d'Espoir Group have been deformed and folded during two deformation events recognized by Colman-Sadd (1976b), which have been studied in further detail by Piasecki (1988). The first and second deformation events (D_1 and D_2) are best preserved in the St. Joseph's Cove Formation, where both primary bedding structures and cleavages, are preserved (Plate 4A). The first cleavage (S_1) is generally subparallel to the bedding, defined by muscovite and chlorite, and developed synchronous with regional-scale isoclinal folding (F_1). A second cleavage (S_2) is developed in many cases and related to large-scale recumbent folding (F_2; Plate 4B).

In the Riches Island Formation, D_1 and D_2 present a strongly developed foliation proximal to the shear zone, and cleavages becoming schistocities. The first cleavage is penetrative and parallel to bedding; a second crenulation cleavage is typically almost horizontal and dips gently to northwest. Where the second deformation becomes more intense toward the Day Cove Thrust, folds are tight to isoclinal with a penetrative schistocity, and the D_1 event is sometimes obscured by a strong overprint of D_2. The Isle Galet Formation preserves the strongest deformation in the map area. S_2 is a pervasive schistocity here that is mylonitized closest the Day Cove Thrust and mostly obscures S_1. Mineral stretching lineation L_2 are particularly well developed on the S_2 planes of Isle Galet Formation schists, but can be found in Riches Island and St. Joseph's Cove formations, as well. Colman-Sadd (1976b) interpreted D_1 to be related to movement while sediments were only partly consolidated, while D_2 and related structures, including the local and regional recumbent folds, developed by tectonic activity during the Salinic orogeny. Trends of the primary foliation of the granitoids and the gneissocity in the Little Passage Gneiss having similar attitudes and orientations as the S_2 cleavage and schistocity in the metasediments define an overall southwest orientation, subparallel to the Day Cove Thrust. The Late Silurian crystallization age of the syntectonic Gaultois Granite gives some constraints on the timing of the shearing event (D_2). Minor northwest–southeast faults crosscut through the Day Cove Thrust and the adjacent Isle Galet Formation and are well distinguishable in the geophysical signature and also in topography. They are probably late tectonic, and occurred after the main thrusting in the ductile shear zone.

The Baie d'Espoir Group experienced at least one metamorphic event that ranges in intensity from greenschist- to epidote–amphibolite-facies conditions (Colman-Sadd, 1980). Metamorphic minerals in the St. Joseph's Cove Formation are chlorite, muscovite and biotite. Along the coast of Bay d'Espoir, phyllite and schist of the Riches Island Formation commonly contain layers rich in porphyroblastic garnet (Plate 3C, D). The metamorphic history of the area has not been studied in great detail, but the presence of garnet-rich beds indicates higher metamorphic grades than in the St. Joseph's Cove Formation. Colman-Sadd (1980) suggests that metamorphism peaked between the two deformation phases. Colman-Sadd (*op. cit.*) also describes contact metamorphism related to the emplacement of the North Bay Granite Suite in the western part of the map area. The Little Passage Gneiss has been metamorphosed to amphibolite-facies conditions, is rich in garnet and locally contains staurolite and sillimanite. The metamorphic peak of a migmatite phase within a tonalitic gneiss was dated to 423 +5/-3 Ma (Dunning *et al.*, 1990) overlapping with the intrusion of the Gaultois Granite and related to the Salinic orogeny.

MINERALIZATION

The Bay d'Espoir area has seen strong exploration activity for several decades, especially within the Exploits Subzone of the Dunnage Zone. Initial interests were the stratabound base-metal-rich sulphide mineralization within volcanic layers of the Isle Galet Formation, common in the Barasway de Cerf region in the southern part of the map area (*e.g.*, Dunlop, 1953; Saunders and Prince, 1977). Most exploration efforts, however, have been focused on structurally controlled quartz veins for the gold, antimony, and arsenic potential of the Little River area and its northeast extension (Figure 3). Evans (1996) gives a comprehensive review of exploration, prior to the 1990s, for gold in the St. Alban's area and other parts of central Newfoundland. Trenching and drilling projects found gold mineralization, *e.g.*, the Wolf Pond zone (*e.g.*, McHale and McKillen, 1989), hosted both by quartz veins and disseminated throughout the host rock. Gold mineralization is commonly found closely related to the metavolcanic units of the Isle Galet Formation. Gold can occur as free gold, but is more commonly associated with arsenopyrite or stibnite. The area continues to be of interest for mineral exploration and the Little River area (*e.g.*, Woods, 2010, 2011) and the True Grit area within the St. Joseph's Cove Formation (Plate 7A) have been drilled more recently (Breen, 2005). Several assays from known and previously unknown mineralized zones

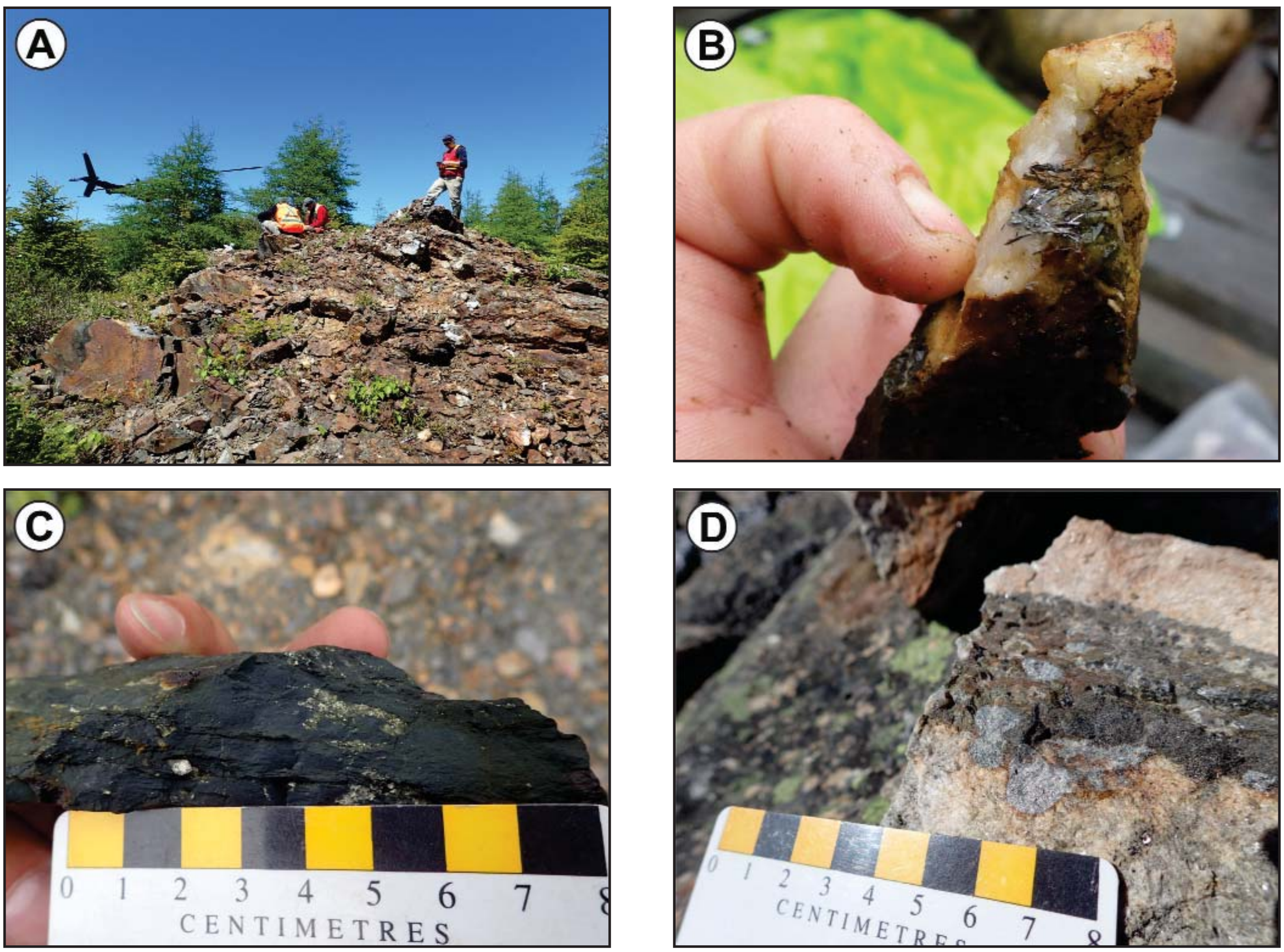

Plate 7. *Photograph of selected mineralization styles. A) Gossan zone in altered shales around structurally controlled quartz veins that are often sulphide bearing, St. Joseph's Cove Formation, True Grit occurrence; B) Stibnite crystals within quartz vein crosscutting shales of the St. Joseph's Cove Formation at Pardy Head; C) Pyrite within black shale of Riches Island Formation; D) Arsenopyrite associated with an aplite vein in Little Passage Gneiss.*

were collected for potential metal contents. Preliminary results indicate elevated gold, silver, antimony, and arsenic contents in some of the sampled quartz veins, locally together with elevated base-metal contents (Westhues, 2017). Most significantly, three samples from the St. Joseph's Cove Formation (at Pardy Head and along the shore of Southwest Brook) contain up to *ca.* 7000 ppb gold, associated with stibnite and arsenopyrite (Plate 7B). This significant grade in a grab sample indicates the potential of this formation for Au mineralization outside of the known True Grit and Golden Grit occurrences. Also the Riches Island Formation contains several quartz veins with visible galena and/or chalcopyrite. A number of molybdenum and lead occurrences are reported in the western parts of this formation, close to the North Bay Granite Suite. An assay from the known galena–barite occurrences around Hardy Cove has anomalous contents of silver of 22 ppm. The graphitic schists and black shales commonly contain pyrite (Plate 7C), which may be the source for abundant sulphides in the formations of the Baie d'Espoir Group. Mineralization within in the Gander Zone is less documented and mostly consists of disseminated pyrite within the Gaultois Granite and the Little Passage Gneiss. In a few locations, other sulphides such as arsenopyrite, occur in crosscutting veins (Plate 7D).

CONCLUSIONS

The Dunnage and the Gander zones are separated by a major ductile shear zone along the south coast of Newfoundland, related to the formation of the Appalachian orogen. In the St. Alban's map area, Ordovician marine metasediments and metavolcanic rocks of the Baie d'Espoir Group (Dunnage Zone) experienced two deformation stages, the second stage related to tectonic activities during the shearing event. Foliation in granitoids in the Gander Zone show similar orientations to the S_2 shearing in the Dunnage Zone. The tectonic activity in this region is likely related to the Silurian Salinic orogeny, but the timing in this area is less constrained than in other parts of Newfoundland. A detailed geophysical survey provided information for bedrock mapping and helped to align units in inaccessible areas. The area is known for gold and base-metal mineralization, with most recent exploration activity focusing on the gold prospects. Preliminary results show elevated Au contents in previously known and newly reported locations.

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