GS-5 Preliminary results of bedrock mapping at Bigstone Lake, northwestern Superior province, Manitoba (parts of NTS 53E12, 13)

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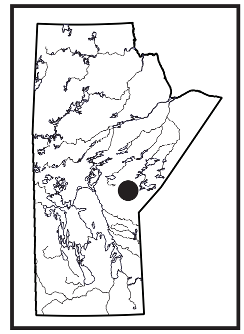

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Summary

The Manitoba Geological Survey (MGS) began 1:20 000 scale mapping of the Bigstone Lake area in the summer of 2016 as part of a renewed study of supracrustal rocks in the Bigstone–Wass–Knight lakes area. Results of this field season, building partly on previous work, included: 1) delineation of several ultramafic cumulates and related flows in the lower part of the greenstone belt stratigraphy, with potential for Ni-sulphide mineralization; 2) recognition of shallowing water depth during emplacement of the volcanic stratigraphy, with potential for precious-metal–rich volcanogenic massive sulphide (VMS) deposits in the uppermost portions of the volcanic stratigraphy; 3) possible evidence of a major unconformity between rocks of the Hayes River and Island Lake groups; 4) definition of several regional alteration zones, including mineral assemblages known elsewhere to occur in association with base-metal and/or shear-hosted gold deposits; and 5) recognition of a complex structural history, including regional isoclinal and open folding followed by episodes of late shearing, with implications for understanding potential controls on vein-hosted precious-metal mineralization in the region.

Introduction

The Bigstone Lake area in east-central Manitoba (Figure GS-5-1) contains a wide range of Archean supracrustal rock types, including ultramafic, mafic and felsic volcanic packages (Neale et al., 1986; Herd et al., 1987), and is considered to have potential for several types of mineral deposit. It includes a documented gold occurrence, with reported values up to 72.3 g/t Au (Assessment File 94359, Manitoba Growth, Enterprise and Trade, Winnipeg), along with features potentially related to the formation of VMS deposits (e.g., zones of sphalerite and chalcopyrite mineralization, sodium depletion and chlorite alteration; Assessment File 94359).

This document summarizes the results of field work undertaken in 2016 at Bigstone Lake. The work is part of a project intended to

- document the supracrustal rocks of the Bigstone, Wass and Knight lakes area through systematic shoreline mapping, supplemented by geochemical and geochronological analyses;
- investigate regional stratigraphic and structural relationships between the Hayes River and Island Lake groups, including their contained mineral occurrences; and
- provide a revised assessment of mineral potential in this part of the Superior province.

The Bigstone Lake area has been subject to sporadic precious- and base-metal exploration activity since 1920, including airborne and ground-loop electromagnetic surveys, and has been tested by a total of 91 drillholes collared mostly along the southeastern shoreline. The largest exploration campaign was conducted by Noranda Exploration Co. Ltd., from 1982 to 1986; the last submitted assessment report for this work recommended continued drill testing of Zn and Au mineralization (Assessment File 94359). Since 1986, no work has taken place at Bigstone Lake, apart from brief visits to a few outcrops as part of a regional geochemical sampling program undertaken in

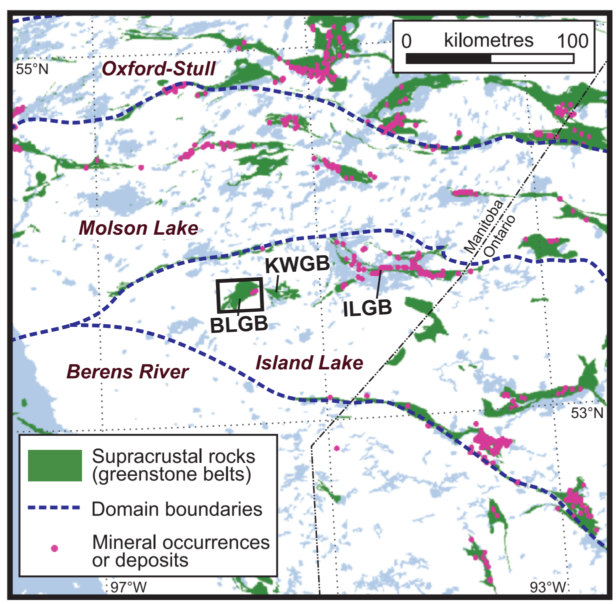

***Figure GS-5-1:** Simplified geological domains of the northwestern Superior province, showing the locations of selected greenstone belts (labelled) and the 2016 mapping area (outlined). Domain names are in italics and are labelled as shown in Pilkington and Thomas (2001). Mineral occurrences shown are mostly Au, Cu, Ni, Ag or Zn; occurrences shown in the Island Lake greenstone belt include two known gold deposits. Abbreviations: BLGB, Bigstone Lake greenstone belt; KWGB, Knight and Wass lakes greenstone belt; ILGB, Island Lake greenstone belt.*

1999 by Hudson Bay Exploration and Development Co. Ltd. (Assessment File 73614).

Geological mapping at Bigstone Lake was carried out in 1939 by MGS geologist R. McIntosh at 1:63 360 scale (McIntosh, 1941), in 1974–1975 by geologists of the Geological Survey of Canada at 1:63 360 scale (Ermanovics, 1975; Ermanovics et al., 1975; Herd and Ermanovics, 1976) and in 1984–1985 by MGS geologist K. Neale at 1:20 000 scale (Neale, 1984, 1985; Neale et al., 1986). Mapping by Neale (1984–1985) was mostly limited to the eastern third of the 2016 mapping area. Detailed mapping at 1:10 000 scale was also undertaken in 1985 by Noranda geologists over a small portion of the southeastern shoreline. The results of these mapping programs were used to inform the geological boundaries outside of the mapping area shown in Figure GS-5-2a, particularly in areas inland.

Seven weeks of shoreline mapping at 1:20 000 scale was carried out during the summer at Bigstone Lake. A total of 670 stations were described, with 119 samples collected for geochemical, petrographic or geochronological analyses. Despite high water levels, excellent exposures were encountered at several locations, mostly along the central island chains. Inland access was particularly difficult in the recently burned area along the southeastern shore of Bigstone Lake (near the sphalerite occurrence labeled in Figure GS-5-2b) and in densely forested areas around the southwestern tip of Bigstone Lake.

Regional geology

The Bigstone Lake greenstone belt (BLGB) is located in the northwestern Superior province, approximately 70 km west of the Island Lake greenstone belt, and is contiguous with supracrustal rocks at Knight and Wass lakes (Figure GS-5-1). Archean supracrustal rocks of the Bigstone, Knight, Wass and Island lakes areas share a generalized stratigraphy consisting of rocks of the Hayes River group overlain by rocks of the Island Lake group. The Hayes River group is an arc-derived sequence of mafic and minor ultramafic flows and intrusions transitioning to felsic flows and pyroclastic rocks, which were (in the Island Lake region) emplaced between ca. 2900 and 2861 Ma (Stevenson and Turek, 1992). The Island Lake group is a sedimentary (±volcanic) sequence of basal conglomerate and marine turbidites, which were deposited ca. 2749–2729 Ma (Neale, 1985; Herd et al., 1987; Stevenson and Turek, 1992). Late (post-Hayes River group) volcanic units are included in the Island Lake group described by Herd et al. (1987), whereas Neale (1985) assigned them to a (possibly unrelated) late supracrustal group. The supracrustal units were intruded by granitoid plutons ranging in age from ca. 2729 to 2699 Ma (Turek et al., 1986).

Local geology

Units documented during the 2016 field season are described here from oldest to youngest interpreted age. All of the rocks have been metamorphosed to upper-greenschist to lower-amphibolite facies; in the interest of brevity, the 'meta' prefix is not used in this report.

Lower stratigraphic sequence (Hayes River group)

The oldest and lowermost supracrustal units of the BLGB define the outer limbs of a belt-scale syncline (Figure GS-5-2). The sequence consists mostly of mafic to ultramafic intrusions and flows, with subordinate felsic volcanic units and interflow sedimentary packages.

Lower mafic volcanic flows

Basalt of the lower sequence is the most abundant rock type in the BLGB, occurring along the outer belt margins in flow packages up to 5 km in apparent thickness (Figure GS-5-2a). Variolitic pillowed flows make up two thirds of the unit and are typically grey-green on fresh and weathered surfaces, aphyric and highly strained. On average, pillows 20–80 cm thick are elongated (~4:1 aspect ratios) along the regional S_3 fabric, with significant local variations (up to 15:1) reflecting strain partitioning. Pillow selvages 0.5–3 cm thick are generally well-preserved and varioles 0.2–2 cm across, which coalesce toward pillow centres, make up between 50 and 80% of most outcrops. Massive, sparsely plagioclase-phyric basalt makes up the remaining third of the lower sequence mafic flows. Where least strained, the massive basalt contains ~20% plagioclase phenocrysts <0.5 mm long and appears to transition into the gabbro unit described below.

Concentric pillow fractures, finely bedded interpillow hyaloclastite, coarse interflow hyaloclastite-breccia layers, quartz-filled pillow shelves and rare quartz-filled amygdules up to 2 cm across were also documented in the flows. Shelves, amygdules and well-developed cusps consistently indicate younging toward the belt centre (as summarized in Figure GS-5-2b).

Subordinate components of the lower mafic flow unit, which are too small to display as separate units, include interflow oxide-facies iron formation in layers <50 cm thick, mafic crystal-rich tuff (locally containing zoned plagioclase up to 1 cm across) in rare beds up to a few metres thick and rhyolite dikes <3 m thick. The rhyolite dikes are most abundant along the southeastern limb of the BLGB, and are interpreted to be cogenetic with the felsic volcanic and volcaniclastic units described below.

Felsic volcanic and volcaniclastic units

Felsic igneous rocks are intercalated with the lower mafic volcanic flows in the eastern half of the BLGB, both north and south of Bigstone Lake (Figure GS-5-2a). Rhyolite to rhyodacite flows or domes make up about

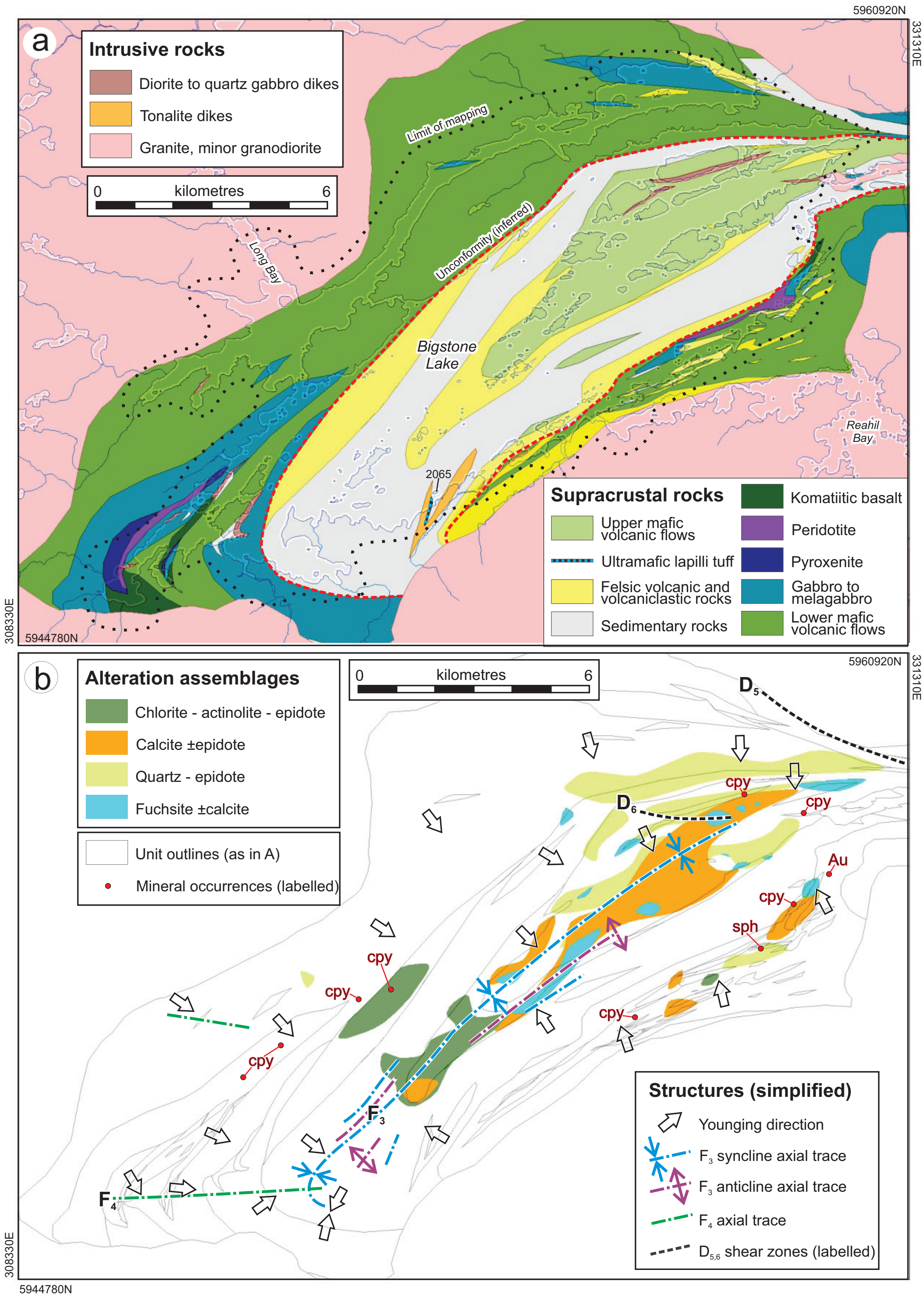

Figure GS-5-2: *Geology of the Bigstone Lake area simplified from Preliminary Map PMAP2016-4 (Rinne et al., 2016).* ***a)*** *Major units mapped during the 2016 field season. Units outside of the mapping limit are based mostly on historical drill data (1938–1986) and inland traverses by McIntosh (1941), Ermanovics et al. (1975) and Neale (1984, 1985). The inferred unconformity (dashed red line) separates the lower stratigraphic units (Hayes River group) from the upper units (possibly belonging to the Island Lake group; see text). Station 2065 (labelled) is discussed in the text.* ***b)*** *Alteration assemblages and simplified structural trends. Mineral occurrences (labelled in red) are: cpy, trace amounts of chalcopyrite in outcrop; sph, sphalerite occurrence sampled by Neale (1985); Au, Diamond Queen gold vein. UTM co-ordinates are in NAD83, zone 15N.*

half of the felsic rocks in the lower stratigraphy and are most common in the lower pillow basalt southeast of Bigstone Lake. Contacts with the basalt are sharp, irregular or slightly undulating, and are generally transposed parallel to the dominant S_3 fabric. The rocks are aphanitic, massive or rarely flow banded, with light beige weathered surfaces and grey fresh surfaces. Weathered surfaces are commonly weakly gossanous, reflecting up to 5% very finely disseminated pyrite and pyrrhotite.

Volcaniclastic rocks make up the remainder of the lower felsic units, ranging from coarse volcanic conglomerate to volcanic mudstone. The rocks have pale tan to light grey-beige weathered surfaces and grey fresh surfaces. Where clasts are visible, the rocks are monomictic, with about 70% light grey, fine- to medium-grained plagioclase- and quartz-phyric clasts up to 40 cm long in a grey lapilli-tuff matrix that locally contains euhedral plagioclase crystals. The clasts are inferred to have been subangular prior to strong flattening.

Gabbro to melagabbro

Mafic intrusive rocks occur throughout the lower sequence and are most abundant in the southwestern part of the BLGB; contacts were not observed. The rocks are fine- to medium-grained, dark green to grey-green and equigranular. The gabbro is mostly homogeneous in outcrops, although a few contain subtle, decimetre-scale planar variations in plagioclase and pyroxene contents, interpreted as intrusive flow banding.

The gabbro contains an average of 40% plagioclase with gradational variation between outcrops, some of which contain as little as 15% plagioclase (i.e., melagabbro). The rocks also consist of chlorite and actinolite after pyroxene, and contain trace amounts of very finely disseminated pyrite and chalcopyrite. In a few outcrops, secondary actinolite occurs in radial or plumose aggregates locally resembling pseudo-spinifex texture; this is interpreted as a metamorphic texture. One outcrop of gabbro, located along the northernmost shoreline of Bigstone Lake, contains actinolite-replaced hornblende crystals up to 7 cm long. This pegmatitic texture is interpreted as a primary igneous feature, possibly resulting from local segregation of volatiles.

Pyroxenite

Pyroxenite was documented at four stations in the southwestern end of the BLGB, in broad spatial association with gabbro and melagabbro (Figure GS-5-2a); however, contacts were not observed. The rocks are homogeneous, dark grey-green to black on fresh and weathered surfaces and contain 90–95% subhedral pyroxene crystals 0.5–1.5 mm across (partially actinolite-replaced), with 5–10% interstitial plagioclase. The rocks are nonmagnetic and contain trace amounts of very finely disseminated pyrite and pyrrhotite.

Peridotite

Peridotite cumulates occur in both the southwestern and eastern portions of the BLGB (Figure GS-5-2a). Contacts were not observed, although some fine-grained outcrops may be transitional to adjacent outcrops of komatiitic basalt. The peridotite is grey-green to pale green on weathered surfaces, distinctly blue-grey on fresh surfaces, serpentinized and moderately magnetic. Round, relict (serpentinized) olivine cumulus crystals 0.5–3 mm across make up ~70% of the rock; the intercumulus contains pyroxene (+secondary actinolite and serpentine) and very finely disseminated magnetite. Pyroxene oikocrysts up to 8 mm across were noted in southwestern outcrops (Figure GS-5-3a) and sparse pyroxene cumulus crystals measuring up to 1.5 cm occur in eastern outcrops. The locations of the peridotite units, in conjunction with the gabbro-melagabbro and pyroxenite units described above, broadly correspond to regional aeromagnetic anomalies in the BLGB.

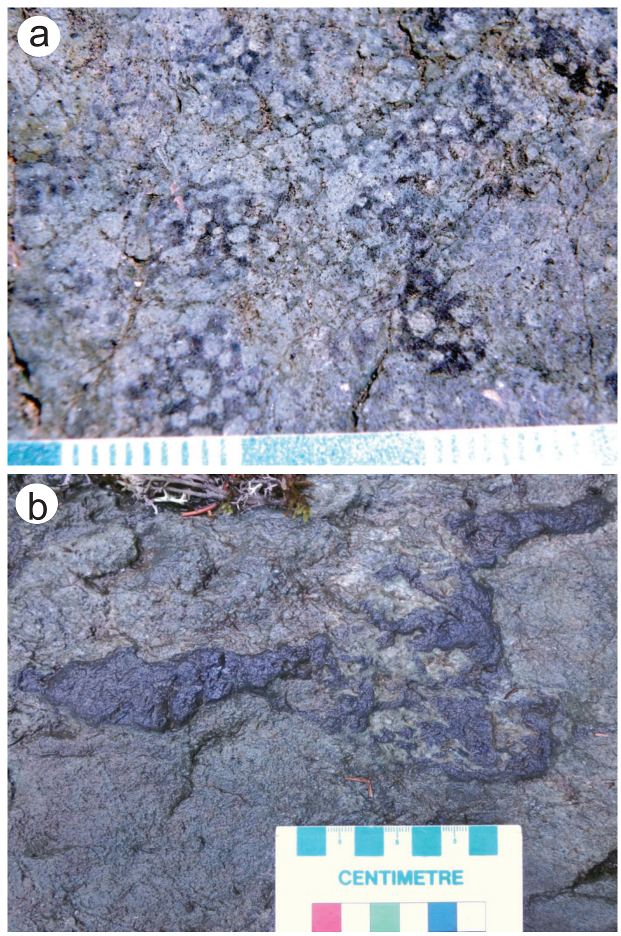

***Figure GS-5-3:** Outcrop photographs of ultramafic units in the lower stratigraphic sequence of the Bigstone Lake greenstone belt, showing **a)** serpentinized peridotite cumulate with pyroxene oikocrysts partially replaced by magnetite; **b)** amoeboid fragment of magnetite-olivine cumulate in pillowed komatiitic basalt, interpreted as a partially assimilated ultramafic xenolith.*

Komatiitic basalt

Ultramafic flows were identified at ten stations in the southwestern and eastern parts of the BLGB (Figure GS-5-2a); contacts were not observed. The rocks are mostly grey-green on weathered surfaces; fresh surfaces are dark grey-green (where least altered) to blue-grey (where serpentinized). They are very fine-grained and strongly foliated, with weakly preserved pillow selvages <3 cm thick noted in three locations. Most outcrops contain trace amounts of very finely disseminated pyrite and/or pyrrhotite.

One outcrop of pillowed komatiitic basalt contains amoeboid xenoliths of fine-grained, serpentinized and magnetite-bearing dunite cumulates up to 20 cm long (Figure GS-5-3b). These xenoliths are interpreted as partially assimilated fragments entrained from either a parent magma chamber or the adjacent footwall, implying emplacement with or after the peridotite cumulates.

In the absence of primary textures such as spinifex, the mafic–ultramafic character of the komatiitic basalt is inferred mostly on the basis of its darker colour on fresh surface. Pending geochemical analyses may help to resolve its composition and possible cogenetic relationship with adjacent ultramafic units.

Upper stratigraphic sequence (Island Lake group?)

The upper sequence of rocks forms the core of the regional syncline of the BLGB and consists primarily of sedimentary and felsic volcaniclastic rocks that are overlain by a package of mafic volcanic flows (Figure GS-5-2a, b). The upper sequence rocks were interpreted by Herd et al. (1987) as part of the Island Lake group, whereas Neale (1985) assigned the rocks to a separate group. The contact between the upper and lower sequences was not observed. Pending geochemical and geochronological analyses may confirm or refute a stratigraphic correlation with the Island Lake group.

Sedimentary rocks

The sedimentary unit broadly traces the limbs of the regional syncline (Figure GS-5-2a, b) and contains several rock types, described below in order of decreasing abundance.

Feldspathic greywacke–mudstone turbidite

Planar-bedded greywacke–mudstone turbidites make up about 90% of the sedimentary unit. Sharp, conformable contacts with both mafic and felsic volcanic units were documented at several locations, some containing rip-up fragments of the underlying unit. The turbidites are grey to dark grey on weathered and fresh surfaces. Well-preserved beds are typically 5–40 cm thick, with fine- to medium-grained greywacke fining to darker grey mudstone tops. Pebbly sandstone bases (locally pebble conglomerate) are common, containing well-rounded, plagioclase-phyric lithic clasts and <5% rounded quartz clasts. Bedding planes are generally transposed parallel to the major S_3 fabric and younging directions—indicated by normally graded beds, along with rare load casts and flame structures—define early isoclinal folds, which are overprinted by later open folds (see 'Structural geology' section).

Laminae to thin beds of mafic mudstone (tuff?) and felsic tuff to lapillistone were documented together in a few thin-bedded turbidite outcrops near the centre of Bigstone Lake, and are interpreted to indicate coeval submarine sedimentation and volcanism, possibly from bimodal volcanic centres.

Polymictic conglomerate

A package of coarse conglomerate occurs along the northwestern (stratigraphically lower) margin of the main sedimentary unit and is estimated to be at least 400 m thick. Contacts with the lower mafic volcanic flows were not observed, with the possible exception of one outcrop in which the contact was very highly strained. The conglomerate is grey-tan on weathered surfaces, grey to dark grey on fresh surfaces, poorly sorted, crudely bedded and mostly matrix-supported (Figure GS-5-4a). Well-rounded clasts 0.5–25 cm long, which make up ~70% of the rock, include (in decreasing order of abundance): grey, fine-grained feldspathic greywacke with sparse quartz grains; light grey, fine-grained, plagioclase-phyric fragments of felsic-intermediate composition; dark grey mudstone; light tan to pink, medium-grained granitoid clasts (among the largest clasts); light tan, felsic quartz crystal-rich tuff breccia; grey-green, fine-grained, aphyric mafic clasts (among the smallest clasts and mostly subangular); and white, laminated quartz (interpreted as eroded quartz-vein fragments).

The conglomerate matrix consists of medium-grained feldspathic greywacke. The larger, rounded clasts may be derived from the stratigraphically adjacent felsic volcanic and volcaniclastic units, whereas the subangular mafic clasts are possibly derived from the underlying basalt flows.

Coarse conglomerate was not mapped elsewhere in the sedimentary unit, apart from one location near the southern shore of Bigstone Lake that was briefly described by Herd and Ermanovics (1976; station 2065 labelled in Figure GS-5-2a). The rock is clast-supported, with subangular clasts up to 40 cm long of medium-grained granitoid, gabbro, pyroxenite and thin-bedded greywacke (Figure GS-5-4b). A pre-S_3 metamorphic foliation is preserved in (and randomly oriented between) several of the clasts, suggesting that the material was derived from a previously metamorphosed and at least partially supracrustal basement. These rocks are similar to conglomerate

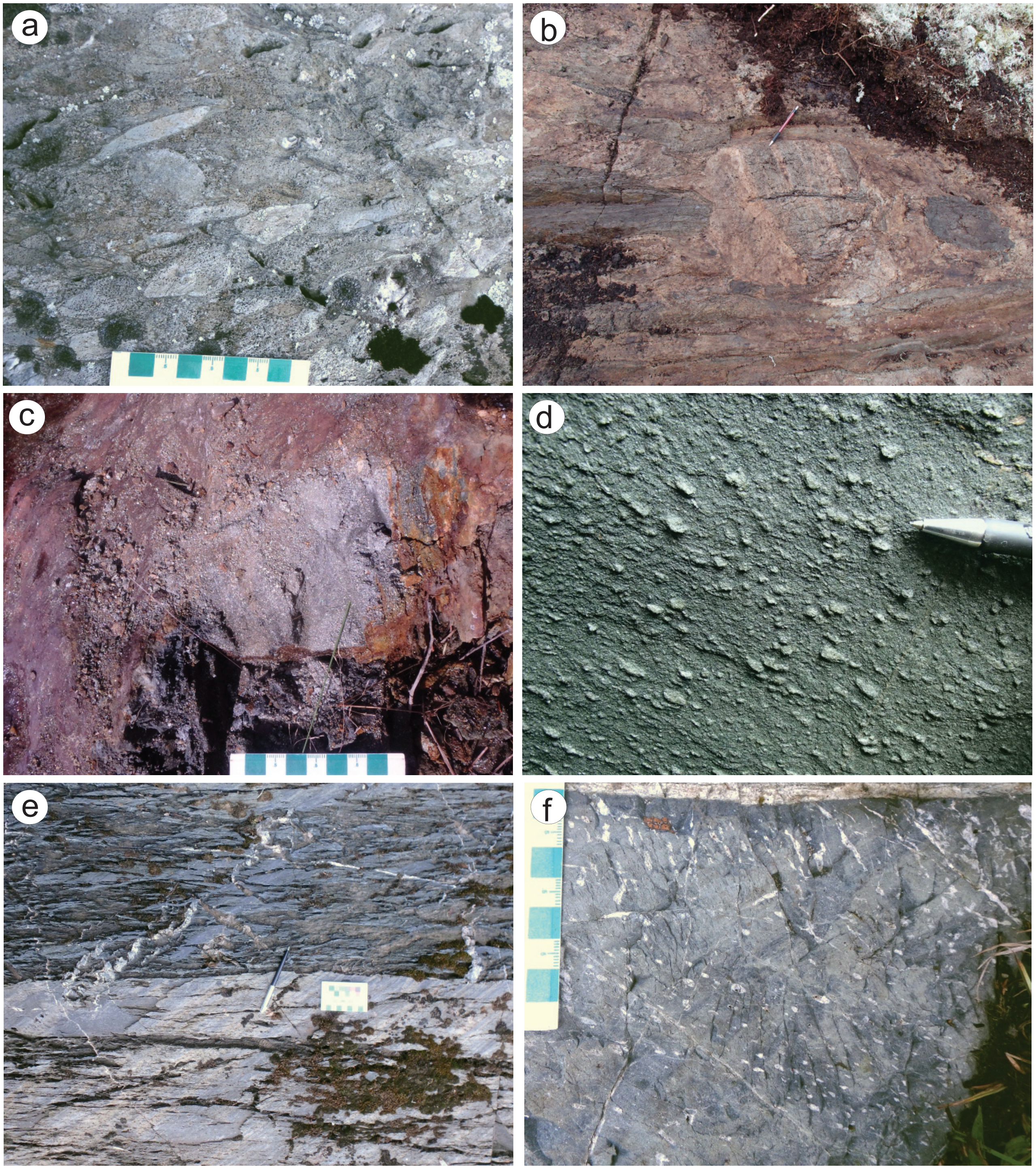

***Figure GS-5-4:** Outcrop photographs of upper stratigraphic units of the Bigstone Lake greenstone belt, showing **a)** a coarse, heterolithic conglomerate with well-rounded and elongated clasts; **b)** a coarse, heterolithic breccia with clasts that contain a predepositional foliation; **c)** sulphide-facies iron formation; **d)** a unit tentatively identified as an ultramafic lapilli tuff; **e)** a sharp, strongly foliated contact between felsic lapilli tuff (bottom) and calcite-altered basalt (top); **f)** quartz-filled pipe vesicles in quartz-epidote–altered basalt.*

at the base of the San Antonio assemblage in the Rice Lake belt further south in the Superior province, which is interpreted to represent a landslide facies deposited near a basin-bounding fault scarp (Weber, 1971; Anderson, 2008).

The unconformity between the Hayes River and Island Lake groups is presumed to mark the base of the sedimentary unit at Bigstone Lake (as indicated in Figure GS-5-2a), but it has not been documented. If the above-described conglomerate is a scarp breccia analogous to the base of the San Antonio assemblage, it should immediately overlie the unconformity. Its apparent location above the inferred unconformity may indicate a structural window (e.g., the exposed core of an F_3 anticline). Alternatively, the Hayes River group at Bigstone Lake locally includes an uppermost turbidite sequence and the unconformity at the base of the upper stratigraphic sequence lies somewhere within the sedimentary unit in Figure GS-5-2a.

Minor sedimentary subunits

Minor (<5%) subunits of the sedimentary unit include: sulphide-facies iron formation, mostly occurring as variably pelitic/argillaceous mudstone beds <3 m thick that contain up to 60% pyrite, pyrrhotite and trace amounts of a very fine-grained mineral tentatively identified as sphalerite (e.g., Figure GS-5-4c); oxide-facies iron formation (as laminae to beds <15 cm, containing chert and magnetite); pelitic mudstone (laminae to beds up to a few metres wide, containing garnet and rare cordierite porphyroblasts <4 mm across); mafic mudstone (occurring as rare chloritic laminae in between some turbidite beds); and chert beds up to 2 cm thick.

Felsic volcaniclastic rocks

Felsic volcaniclastic rocks of the upper stratigraphic sequence are located mostly along the upper and lower contacts of the sedimentary unit (Figure GS-5-2a).

Felsic tuff, lapilli tuff and tuff breccia

Fine- to medium-grained fragmental rocks interpreted to represent pyroclastic deposits make up 75% of the upper felsic unit. Contacts with sedimentary rocks within the upper stratigraphy are sharp, planar and highly strained. Where least altered, the rocks are pale tan or beige-grey on weathered surfaces and grey on fresh surfaces. Most outcrops are massive to weakly bedded, and contain between 40 and 80% rounded fragments 0.5–2.5 mm across in a very fine-grained tuff matrix (i.e., tuff to lapilli tuff). A few outcrops contain <15% angular, light beige, plagioclase-phyric felsic fragments up to a few centimetres long within a lapilli-tuff matrix (i.e., lapilli-tuff breccia). Plagioclase crystal-rich tuff is a less common component, occurring mostly as thin (centimetre- to decimetre-scale) horizons within outcrops dominated by tuff to volcanic conglomerate. Subtly darker grey-beige, wispy, flattened fragments up to 1 cm long were noted in several highly strained outcrops near the centre of Bigstone Lake; these may be fiamme, though their identification is tenuous.

Felsic volcanic breccia and volcanic conglomerate

Coarse pyroclastic rocks make up 25% of the felsic unit and are commonly in gradational contact (both normal and reverse) with felsic tuff-breccia units. The rocks are light beige-grey on weathered surfaces, grey on fresh surfaces, and contain between 10 and 60% felsic fragments up to 70 cm long in a felsic tuff matrix. The fragments are typically very strongly elongated parallel to the S_3 foliation. Where least deformed, the fragments are angular, light beige-grey, and are either aphyric and aphanitic or finely plagioclase±quartz-phyric. Trends in clast-size distribution will be analyzed to identify possible volcanic centres.

Ultramafic lapilli tuff

A small cliff-face exposure of ultramafic lapilli tuff was identified along the southern shore of Bigstone Lake (Figures GS-5-2a, 4d). The unit is approximately 5 m thick, occurring in apparent conformable contact with adjacent greywacke. The rock is light olive-green on weathered surface, dark green on fresh surface, very soft (easily smeared with a finger) and has a smoothly sculpted weathered surface. It contains 20% grey-green lapilli <2 cm, poorly sorted and supported in a fine tuff matrix. This rock is similar to ultramafic volcaniclastic and sedimentary rocks of alkaline affinity at Knee Lake (Anderson, GS-2, this volume); geochemical analyses of this distinctive unit are pending.

Upper mafic volcanic flows

Pillow-basalt flows of the upper sequence form the uppermost stratigraphic unit recognized at Bigstone Lake (Figure GS-5-2a). This unit occurs in conformable contact with the underlying felsic pyroclastic rocks (Figure GS-5-4e). Least-altered portions of the upper flows are identical to the lower mafic flow unit, in terms of colour, composition and overall pillow geometry. However, unlike the lower flows, vesicles 0.5–8 mm across are present (up to 20%) throughout and are most abundant near pillow margins, locally coalescing into pipe vesicles near pillow selvages (e.g., Figure GS-5-4f); these may indicate shallower water depth compared to the lower flows. In addition, the upper flows do not contain the thick, extensive sills of ultramafic–mafic intrusive rock that characterize the mafic flow unit in the lower sequence.

Most of the upper mafic flow sequence has been altered to assemblages containing calcite, quartz, epidote and/or fuchsite (Figure GS-5-2b; see ‘Alteration’ section).

This has resulted in a lighter colour on most of the outcrops; calcite-altered zones in particular correspond to areas previously mapped as andesite flows (e.g., Neale et al., 1986).

Intrusive rocks

Tonalite dikes

Tonalite dikes, commonly several metres thick, intrude felsic tuff breccia and greywacke in the southern half of the belt. Along the southeastern shoreline of Bigstone Lake, the tonalite forms a mappable set of dikes up to 300 m wide that crosscut both sedimentary and felsic igneous units (Figure GS-5-2a). The rocks are light grey to white on weathered surface, grey on fresh surface, mostly fine-grained and equigranular to sparsely plagioclase-phyric, with up to 10% plagioclase phenocrysts <5 mm. The dikes contain a weak S_3 foliation.

Diorite and quartz gabbro intrusions

Diorite dikes

Intermediate porphyry dikes are common and widespread throughout the BLGB, crosscutting all major supracrustal units, along with one tonalite dike. The rocks are light grey on fresh surface, grey on weathered surface, and all contain an aphanitic to fine-grained groundmass. Compositions vary from densely plagioclase- and quartz-phyric (i.e., quartz-feldspar porphyry) to sparsely hornblende- and plagioclase-phyric diorite. The plagioclase-phyric dikes contain up to 50% subhedral plagioclase (0.5–5 mm) and up to 5% rounded quartz phenocrysts (<3 mm). The hornblende-phyric dikes contain subhedral to euhedral, relict (actinolite- and chlorite-replaced) hornblende phenocrysts <7 mm. Well-developed chill margins up to 2 cm wide are common, as are contact-parallel flow bands. In one location, the diorite occurs as a multiphase intrusive breccia, wherein hornblende-phyric diorite forms the later infill to jigsaw-fit fragments of plagioclase-phyric diorite. The porphyritic diorite dikes postdate the supracrustal units and tonalite dikes, and predate D_3.

Quartz gabbro dikes or sills

Quartz gabbro is a minor intrusive phase, tentatively grouped with the diorite dikes. In some chlorite-epidote-actinolite–altered outcrops, the rocks superficially resemble the previously described gabbro units in terms of overall colour, grain size and locally developed metamorphic textures defined by radial or pseudo-spinifex actinolite. Key distinguishing features of the quartz gabbro are the sparse (1–10%), evenly distributed quartz phenocrysts up to 3 mm and noticeably harder outcrop. A quartz-phyric gabbro sill in the upper mafic volcanic flows (the longest of the red units shown in Figure GS-5-2a) was previously mapped as massive basalt (Neale et al., 1986).

In two widely spaced locations, quartz gabbro dikes contain diffuse zones of medium- to coarse-grained pyroxenite up to a few metres wide. The origin of these features is unknown; gradational contacts between pyroxenite and gabbro are not consistent with either a xenolith or younger intrusion and ultramafic segregations (e.g., cumulate settling) would not be expected from a silica-saturated magma.

Mafic dikes

Grey-green, aphanitic and aphyric dikes are a minor but widespread component of the BLGB and are too small to display as individual map units. Most were documented in the sedimentary and felsic volcaniclastic units, and a few crosscut rhyolite and diorite dikes. The dikes are typically strongly deformed, occurring as dismembered and isoclinally folded boudins up to 30 cm wide within folded hostrocks. Based on their crosscutting relationship with diorite dikes, they are the latest intrusive phase documented in the BLGB; however, multiple (including earlier) generations of mafic dikes are possible.

Granite to granodiorite

Granitoid intrusions were examined along shorelines in the northwestern and southeastern parts of Bigstone Lake (into Long Bay and the channel into Reahil Bay; Figure GS-5-2a), and by inland traverse in the southwest. The felsic plutons bound the edges of the BLGB and their margins form many of the topographic ridges surrounding Bigstone Lake. The rocks are light beige-grey to pink on weathered surfaces and light grey to pink on fresh surfaces. Northwest and southwest of the BLGB, the rocks are mostly medium- to coarse-grained and inequigranular, with subhedral K-feldspar phenocrysts 2–9 mm across, in a medium-grained groundmass consisting of quartz, K-feldspar, plagioclase, biotite (±secondary chlorite and epidote) and trace amounts of finely disseminated pyrite. Compositions vary from syenogranite to granodiorite, with local variations in the colour of K-feldspar grains, and a few diffuse patches or bands of increasing biotite and K-feldspar contents. Southeast of the BLGB, the rocks are mostly medium-grained, equigranular, and locally quartz- and hornblende-phyric granodiorite. Gradations to tonalitic composition and gneissic banding were noted by previous workers (e.g., Ermanovics et al., 1975) outside of the mapping area. Most of the granitoid outcrops contain a weak spaced-cleavage foliation, which transitions toward the belt margins into a moderate and contact-parallel pervasive foliation defined by phenocrysts and groundmass biotite.

Contacts with basalt or komatiitic basalt were documented both north and south of the BLGB. They are sharp, undulating, strongly foliated and parallel to the regional trend of the granite contacts. Granitoid dikes or apophyses increase in abundance toward the contacts of the plutons.

The dikes are strongly foliated and isoclinally folded with the hostrocks, and in places contain well-developed chill margins. Granite outcrops in the southwest contain a few recessively weathered xenoliths of the host komatiitic basalt and granodiorite outcrops in the southeast contain small mafic xenoliths interpreted as basalt. Collectively, these field relationships point to an intrusive relationship with the supracrustal rocks of the BLGB (as opposed to the plutons representing the basement to the greenstone belt).

Structural geology

Results of the 2016 field season indicate a complex structural history, summarized below from earliest to latest. The first two deformation events (D_1, D_2) could not be documented in sufficient detail to identify regional trends; the later events (D_3–D_6) are better defined.

The earliest known generation (D_1) is preserved as a foliation in the large clasts of the possible scarp-facies heterolithic conglomerate described previously. The S_1 foliation is rotated between clasts and truncated at clast boundaries; it was therefore developed in the lower sequence prior to deposition of the conglomerate and overlying sequence. Following deposition of the turbidites was an early fold event (F_2), manifest in reversals of structural facing direction (younging projected onto the S_3 cleavage) throughout the sedimentary unit. The F_2 folds may be related to an early fabric (tentatively S_2), which is preserved as a moderate penetrative foliation along F_3 fold noses in a few turbidite outcrops and in some outcrops overprinted by an S_3 crenulation.

An S_3 planar fabric is generally the most obvious in outcrop, occurring as a dominantly northeast-trending and steeply dipping penetrative foliation. Beds and other planar features are typically transposed parallel to the S_3 fabric. The foliation is axial planar to the belt-scale F_3 folds indicated in Figure GS-5-2b. The S_3 fabric is also locally manifest as a crenulation cleavage, or in some gabbro and diorite outcrops as a spaced cleavage.

The F_3 folds are isoclinal and almost vertically plunging, with axial planes that trend mostly northeast along the length of the BLGB (Figure GS-5-2b). The folds are defined by reversals in younging direction (particularly in turbidite outcrops, alternately younging southeast and northwest), as well as centimetre- to metre-scale isoclinal folds observed throughout the BLGB, which are thought to be parasitic to the main structure.

The F_3 folds have been refolded by a later generation of steeply plunging, open F_4 folds (Figure GS-5-5a), commonly expressed as a subtle, outcrop-scale undulation of strata and S_3 foliation. The second generation folds account for the regional curvature of map units in the southwestern portion of the BLGB (Figure GS-5-2a, b). A weak, axial planar S_4 fabric was measured in several stations, with an east- to east-northeast trend and steep southward dip. It is most evident in outcrops of pebbly sandstone and conglomerate, wherein the first generation of foliation and clast flattening is overprinted by the weak S_4 foliation, refracted at clast-matrix boundaries.

Throughout the BLGB, D_5 deformation is expressed as discrete shear zones and, less commonly, Z-shaped kink bands. The shear zones are mostly a few centimetres wide, dip steeply southward and show evidence of dominantly dextral movement. Toward the east, the dominant trend of the D_5 shear zones rotates clockwise, from northeast to southeast. The regional dextral offset of the BLGB toward the southeast (the shear zone indicated at upper right in Figure GS-5-2b), interpreted by Herd et al. (1987), is tentatively attributed to the D_5 deformation event.

The youngest deformation structures in the BLGB are sinistral D_6 shear zones that are typically less than 20 cm wide and occur as a locally anastomosed network, which is dominantly east-northeast to east-southeast-trending (e.g., Figure GS-5-5b). In several locations, larger sinistral D_6 offsets may account for some west-northwest-trending topographic lineaments or shoreline trends, particularly through the larger islands of the northeastern half of Bigstone Lake (Figure GS-5-2a, b). The D_6 shear zones clearly offset D_5 shears at several locations. These structures are presumed to form a much larger and more complex network than is indicated in Figure GS-5-2b. However, a more detailed interpretation of the geometry of the late shear zones requires additional data (e.g., from detailed aeromagnetic surveys).

Alteration

Mapped alteration zones at Bigstone Lake are defined on the basis of different alteration assemblages, which are mostly developed in the upper mafic volcanic flows, felsic volcaniclastic rocks and, to a lesser extent, in the uppermost portions of the lower mafic flows (Figure GS-5-2b). The term ‘assemblage’ is used loosely in this section to describe common associations of secondary minerals that may or may not have formed at the same time; all are overprinted by D_3 structures.

Zones of strong chlorite-actinolite-epidote alteration occur mostly in the westernmost outcrops of felsic volcanic breccia and lapilli tuff, along with two outcrops of turbiditic greywacke. This dark green assemblage has replaced up to 30% of the rock in some outcrops, mostly within the pyroclastic matrix (Figure GS-5-5c), and occurs in veins up to 15 cm wide. Along the periphery of the zones outlined in Figure GS-5-2b, secondary chlorite-actinolite-epidote occurs in weak, matrix-selective, diffuse and locally discordant patches.

Broad zones of weak quartz-epidote alteration were mapped in pillow basalt in the eastern third of the Bigstone Lake area (Figure GS-5-2b). This alteration is recognized on the basis of lighter and slightly greener colour

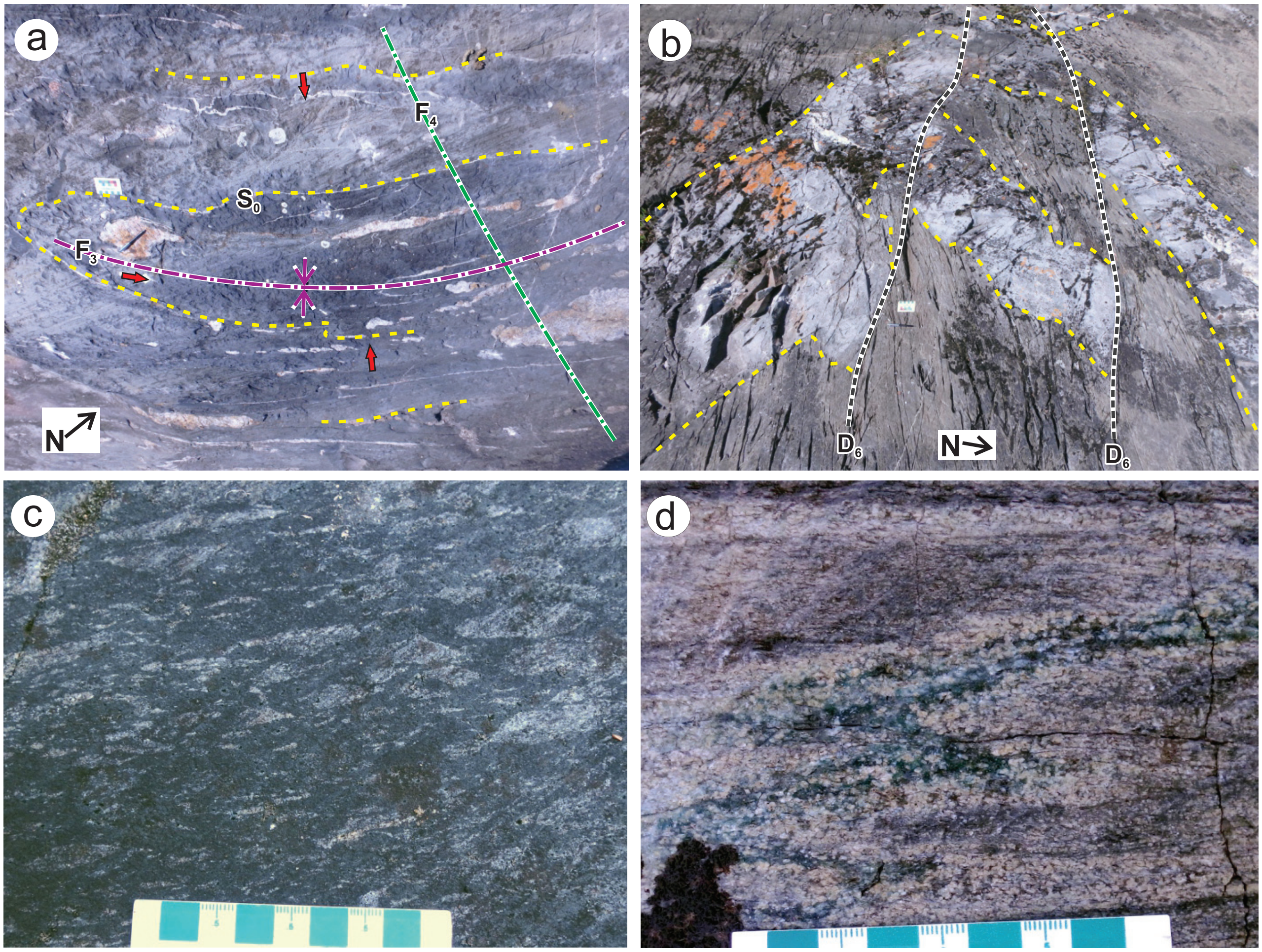

Figure GS-5-5: *Outcrop photographs illustrating alteration and structural relationships discussed in the text:* ***a)*** *turbiditic greywacke beds (some bedding planes traced in yellow) isoclinally folded about an F_3 syncline (red arrows indicate younging) and later folded about an open F_4 axial plane;* ***b)*** *calcite-altered pillow basalt and hornblende-phyric diorite (lighter dikes, outlined in yellow), strongly foliated and folded about an east-northeast-trending S_3–F_3 fabric, and offset by sinistral D_6 shears;* ***c)*** *felsic volcanic conglomerate with intense, matrix-selective chlorite-actinolite-epidote alteration;* ***d)*** *felsic lapilli tuff with discordant (and F_3-folded), matrix-selective fuchsite.*

on fresh and weathered surfaces (e.g., Figure GS-5-4f), slightly harder rock and an association with sparse quartz-epidote veins or diffuse patches up to 40 cm wide. The quartz-epidote alteration is commonly selective after pillow selvages and varioles.

Pervasive calcite alteration has locally affected several of the rock types, including pillow basalt, felsic lapilli tuff, greywacke, cumulate peridotite, rhyolite and diorite. The calcite alteration is most prevalent in the upper mafic volcanic flows, where the rocks are strongly bleached and react strongly to dilute hydrochloric acid. In several locations, gradually increasing calcite contents were traced from relatively fresh, dark grey-green pillow basalt, to strongly calcite-altered, pale grey pillow basalt. Although the calcite is dominantly pervasive, many of the calcite altered rocks contain up to 5% calcite±epidote veinlets.

Fuchsite was documented at several locations throughout the mapping area, most commonly along the periphery of pervasively calcite-altered zones (Figure GS-5-2b). The bright green alteration is typically matrix-selective in volcaniclastic rocks (e.g., Figure GS-5-5d), and variole- and selvage-selective in outcrops of pillow basalt. In a few locations, fuchsite occurs as diffuse haloes up to 20 cm thick alongside quartz-calcite-epidote-tourmaline veins; this may imply a cogenetic relationship (i.e., a hydrothermal assemblage of quartz-calcite-epidote-tourmaline-fuchsite).

Economic considerations

Several features of the BLGB indicate potential for VMS mineralization, most notably

- Occurrences of Zn and Cu mineralization in the lower and upper volcanic units, including minor Cu-Zn mineralization intersected by drilling near the northeastern corner of Bigstone Lake (Assessment File 92627), zones of Zn mineralization (1–2% Zn) in felsic volcanic rocks in the southeastern part of the lake (Assessment File 93285) and a zone of mineralization that assayed 8.1% Zn (Neale, 1985; sphalerite occurrence labelled in Figure GS-5-2b). The sample reported by Neale was described as silicified quartz porphyry. However, its marked location was revisited twice in 2016, including excursions inland, and only felsic volcaniclastic units and iron formation were encountered.

- Regional and apparently semi-conformable quartz-epidote alteration in the upper parts of the stratigraphy (Figure GS-5-2b). Similar quartz-epidote (±albite-actinolite) alteration typifies the high-temperature reaction zone in the footwall of many VMS deposits (e.g., Franklin et al., 2005).
- Laterally extensive calcite alteration in the upper volcanic flows and in the uppermost portions of the lower volcanic flows (Figure GS-5-2b). Regional carbonate alteration has also been recognized in the footwall of some shallow-water (<1.5 km) VMS deposits (e.g., Morton et al., 1990).
- Na depletions in some felsic volcanic rocks in the southeastern part of Bigstone Lake (Assessment File 94359), potentially indicating feldspar alteration in a VMS footwall environment (e.g., Date et al., 1983).
- Locally intense chlorite-actinolite-epidote alteration and veins in a few outcrops near the centre of Bigstone Lake (Figures GS-5-2b, GS-5-5c). Among other possibilities, similar features can form in proximity to seafloor sulphide deposits (i.e., chloritic alteration pipes or feeder zones; Lackschewitz et al., 2000; Franklin et al., 2005).
- Hydrothermal precipitates (iron formation, chert) throughout the volcanic strata, some of which are weakly Zn-bearing (e.g., Assessment File 73614). Such deposits, particularly where Zn- or Cu-bearing, may point to VMS-related hydrothermal venting (e.g., Franklin et al., 2005).

Most base-metal exploration at Bigstone Lake has focused on the Hayes River group basalt in the southeastern part of the lake. However, if the regional calcite and quartz-epidote alteration zones were formed in the footwall of a VMS system, then the uppermost portions of the upper volcanic flows (or their stratigraphic equivalents in the adjacent Knight–Wass lakes area) are broadly prospective for VMS deposits. Areas near zones of chlorite-actinolite-epidote alteration may also warrant further attention.

In the eastern part of the map area, visible gold is reportedly hosted in a quartz vein with pyrite and galena (Au occurrence labelled in Figure GS-5-2b; McIntosh, 1941; Assessment File 91148). A sample of quartz-carbonate veins from this area was reported to contain 72.3 g/t Au (Assessment File 94359). Archean lode-gold deposits are often associated with regional carbonate alteration (e.g., MacGeehan and Hodgson, 1982) and less commonly with fuchsite alteration (e.g., Moritz and Crocket, 1990). A structural control on the alteration zones shown in Figure GS-5-2b has not been established from field relationships. If the alteration were shown to be spatially related to D_6 shear structures, for example, this may indicate potential for shear- or fault-hosted gold mineralization. The gold occurrence was not visited during the 2016 field season; a visit is planned in 2017 to sample and document the timing and structural control on the occurrence, which may inform exploration models for gold mineralization in the area.

The peridotite and pyroxenite units identified in the BLGB, together with the few trace occurrences of chalcopyrite in the adjacent melagabbro units, suggest some potential for magmatic Ni-Cu (±PGE, Cr) deposits in the map area. Such deposits may be more likely to occur in proximity to sedimentary units (serving as possible sources of external sulphur), as is the case for the peridotite exposed along the eastern shore of Bigstone Lake. Alternatively—in the case of possible komatiite-hosted mineralization—deposits could occur at the base of the most Mg-enriched (typically lowermost) flows in the stratigraphy (e.g., Lesher and Barnes, 2008). A large area of ultramafic-bearing stratigraphy in the southwestern part of the BLGB has not been tested by drilling or surface sampling.

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