GS-9 Geological investigations in the Farley Lake area, Lynn Lake greenstone belt, northwestern Manitoba (part of NTS 64C16)

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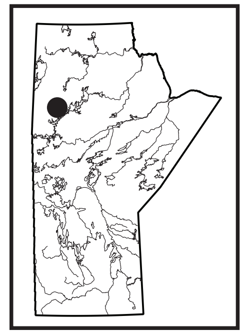

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Summary

The multiyear bedrock mapping project in the Paleoproterozoic Lynn Lake greenstone belt of northwestern Manitoba aims to further define the geological and geodynamic evolution of this belt, and to identify key factors controlling the formation of its diverse mineral deposits (e.g., orogenic Au, volcanogenic massive-sulphide Cu-Zn, magmatic Ni-Cu-PGE). In the 2016 field season, the Farley Lake area was targeted for detailed geological mapping at a scale of 1:20 000, in part to support ongoing re-evaluations of the Farley Lake Au deposit. The preliminary results of this mapping indicate that the area contains a variety of volcanic rocks comprising basalt, andesite, dacite and rhyolite (BADR) and related volcaniclastic rocks, along with subordinate sedimentary rocks. The BADR sequence is overlain by reworked volcaniclastic and epiclastic rocks, as well as banded iron formations, suggesting deposition in a setting comparable to modern volcanic arcs or back-arc basins. These supracrustal rocks were crosscut by various intrusive suites and then cut by Mesoproterozoic Mackenzie dikes.

The preliminary mapping results summarized in this report have several implications for mineral exploration: 1) banded iron formations and graphitic sedimentary rocks of unit 4 are isoclinally folded and metamorphosed to middle-amphibolite facies, resulting in numerous potential traps (structural and chemical) for Au-bearing fluids, and are thus favourable for Au mineralization; 2) reduced I-type and ilmenite-series granodiorite (unit 7b) may have played an important role in Au mineralization; 3) oxidized I-type and magnetite-series granitoid (unit 6) and evolved I-type leucogranite (unit 7a) may have potential, respectively, for porphyry Cu (Mo) and rare-metal (rare-earth elements, Nb, Ta) mineralization; 4) gabbroic intrusions of unit 5 contain potential magmatic Ni-Cu-Co-(Pt) mineralization that requires further evaluation.

Introduction

The Manitoba Geological Survey (MGS) continued bedrock mapping in 2016 in the Lynn Lake greenstone belt (LLGB) of northwestern Manitoba (Figure GS-9-1) in order to investigate its geological and geodynamic evolution, and to study metallogeny and key factors controlling the formation of various types of mineral deposits (e.g., orogenic Au, volcanogenic massive-sulphide Cu-Zn, magmatic Ni-Cu-PGE). This study involves new bedrock geological mapping, coupled with lithogeochemical characterization, radiogenic-isotope analysis and GIS compilation. In the 2016 field season, the area of the Farley Lake Au deposit was the focus of detailed mapping by the MGS at a scale of 1:20 000. This deposit is hosted in the regionally extensive Agassiz metallotect (Figure GS-9-1; Fedikow and Gale, 1982; Singh et al., 1989; Fedikow, 1992; Park et al., 2002) of the northern LLGB (Gilbert et al., 1980; Syme, 1985; Gilbert, 1993; Peck et al., 1998; Zwanzig et al., 1999; Beaumont-Smith et al., 2000), which has good potential for several types of mineral deposits in addition to Au. Gabbroic intrusions (e.g., White Owl Lake intrusion) in the map area are petrologically similar to the Lynn Lake gabbroic intrusion that hosts the Lynn Lake magmatic Ni-Cu-Co mine (Pinsent, 1980; Jurkowski, 1999; Yang and Beaumont-Smith, 2015a, b). In addition, the Brooks Bay volcanogenic massive-sulphide (VMS) deposit (Cu-Au; Milligan, 1960; Gilbert, 1993; Ferreira, 1994) occurs east of Brooks Bay on Barrington Lake, about 5 km east-northeast of the mapping area.

This report presents preliminary results of 2016 mapping, covering an area of ~85 km^2 around the Farley Lake Au deposit, and discusses key aspects of the deposit geology. The associated preliminary map (Yang and Beaumont-Smith, 2016) provides new data and updates the geology from previous mapping.

In the 2016 field season, 45 whole-rock samples were collected from the Farley Lake area for geochemical analysis, including 12 for thin-section preparation and 3 for zircon U-Pb age determination. The geochronology work will be done as a part of the Targeted Geoscience Initiative 5 program through collaboration between the MGS and the Geological Survey of Canada (GSC).

Regional geological setting

The LLGB (Bateman, 1945) is an important tectonic element of the internal Reindeer zone of the Trans-Hudson orogen (Stauffer, 1984; Lewry and Collerson, 1990), which is the largest Paleoproterozoic orogenic belt of Laurentia (Hoffman, 1988; Corrigan et al., 2007, 2009). The LLGB is bounded to the north by the Southern Indian domain, a mixed metasedimentary and metaplutonic domain; to the south, it is bounded by the Kisseynew metasedimentary domain (Gilbert et al., 1980; Syme, 1985; Zwanzig et al., 1999; Beaumont-Smith and Böhm, 2004). Similar Paleoproterozoic greenstone belts also

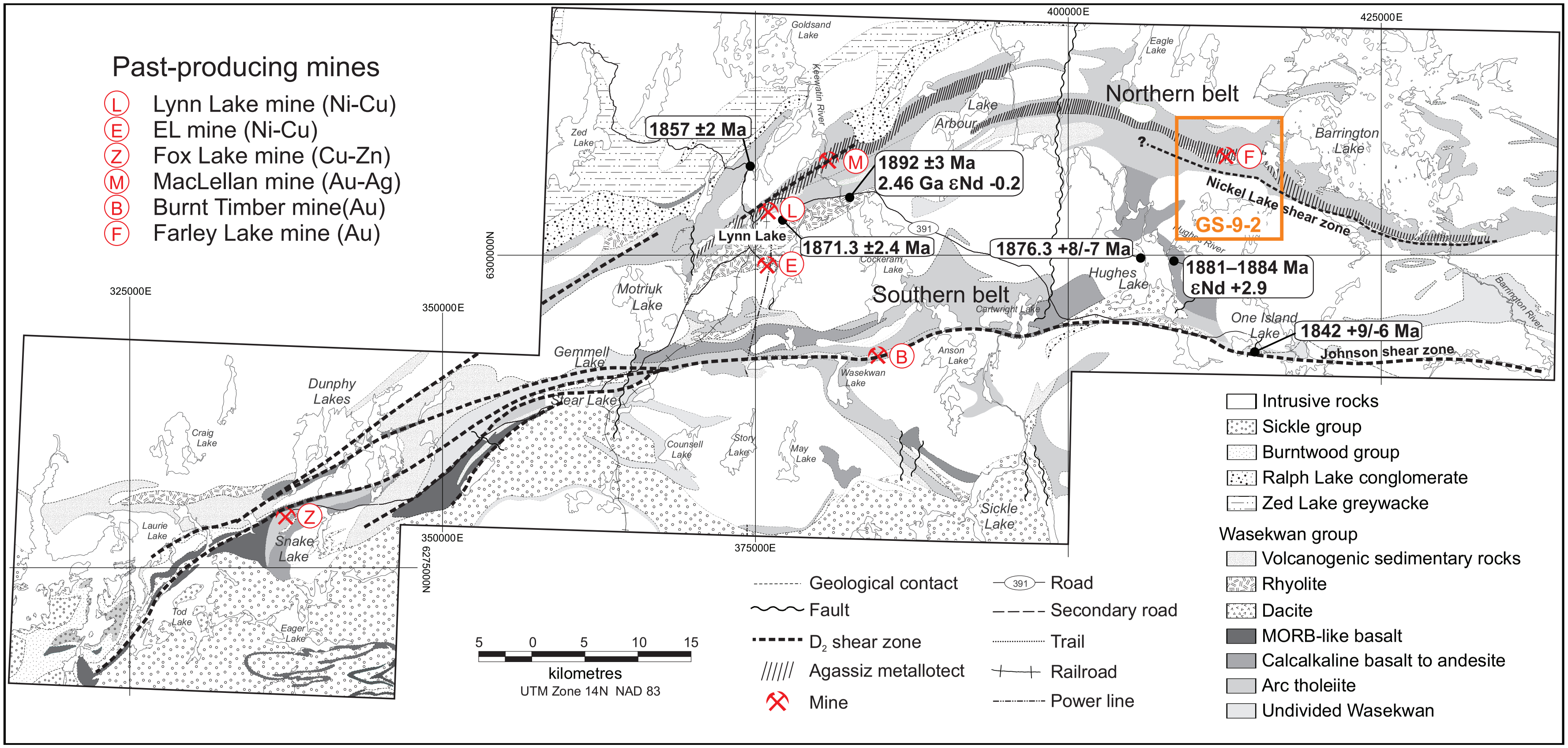

Figure GS-9-1*: Regional geology with zircon U-Pb ages and Nd isotopic compositions of the Lynn Lake greenstone belt (modified and compiled from Gilbert et al., 1980; Manitoba Energy and Mines, 1986; Gilbert, 1993; Zwanzig et al., 1999; Beaumont-Smith et al., 2000, 2006; Turek et al., 2000; Beaumont-Smith and Böhm, 2002, 2003, 2004; Beaumont-Smith, 2008; Beaumont-Smith, unpublished data, 2006). The detailed mapping area is indicated by the box and includes the Farley Lake Au deposit (labelled). Abbreviation: MORB, mid-ocean–ridge basalt.*

occur to the east (Rusty Lake belt), to the west (La Ronge belt) and to the far south (Flin Flon belt; e.g., Ansdell et al., 1999; Park et al., 2002; Ansdell, 2005; Corrigan et al., 2007, 2009; Hastie, 2014; Glendenning et al., 2015).

The LLGB consists of two east-trending, steeply dipping belts that contain various supracrustal rocks of the Wasekwan group (Bateman, 1945; Gilbert et al., 1980), along with younger molasse-type sedimentary rocks of the Sickle group (Figure GS-9-1; Norman, 1933). The southern and northern belts are separated by granitoid plutons of the Pool Lake intrusive suite (Figure GS-9-1; Gilbert et al., 1980; Baldwin et al., 1987), which are divided into pre- and post-Sickle intrusions based on their temporal relationships to the Sickle group. In the central and southern parts of the LLGB, the Sickle group overlies the Wasekwan group and felsic–mafic plutonic rocks of the Pool Lake intrusive suite along an angular unconformity. The minimum depositional age of the Sickle group is ca. 1830 Ma, based on detrital zircon U-Pb ages (Beaumont-Smith et al., 2006). Cutting the entire belt are the much younger Mackenzie dikes (ca. 1267 Ma; Baragar et al., 1996).

The northern Lynn Lake belt consists of subaqueous, tholeiitic, mafic metavolcanic and metavolcaniclastic rocks interpreted as an overall north-facing, steeply dipping succession that occupies the upright limb of a major antiformal structure (Gilbert et al., 1980). Included in the northern belt is the Agassiz metallotect (Fedikow and Gale, 1982; Fedikow, 1986, 1992), a relatively narrow, stratigraphically and structurally distinct entity consisting of ultramafic flows (picrite), banded oxide-facies iron formation and associated exhalative and epiclastic rocks (Ma et al., 2000; Ma and Beaumont-Smith, 2001; Park et al., 2002). The Agassiz metallotect contains Au mineralization (Figure GS-9-1) and intense deformation fabrics (Beaumont-Smith and Böhm, 2004).

The northern belt is unconformably overlain to the north by marine conglomerate and turbiditic sedimentary rocks, known as the Ralph Lake conglomerate and Zed Lake greywacke, respectively (Gilbert et al., 1980; Manitoba Energy and Mines, 1986; Zwanzig et al., 1999). This clastic succession is derived largely from the supracrustal rocks of Wasekwan group and older plutonic rocks, with the majority of the detrital zircons returning Wasekwan ages (ca. 1890 Ma; Beaumont-Smith and Böhm, 2004).

The southern belt consists largely of subaqueous tholeiitic to calcalkalic metavolcanic and metavolcaniclastic rocks, including minor amounts of metabasalt with geochemical signatures comparable to modern mid-ocean–ridge basalt. The tholeiitic to calcalkalic rocks include older (ca. 1890 Ma) contaminated-arc rocks, as well as younger (ca. 1855 Ma) juvenile-arc volcanic rocks (Peck and Smith, 1989; Zwanzig et al., 1999; Zwanzig, 2000; Beaumont-Smith and Böhm, 2003, 2004). Structural analysis of the LLGB suggests that it is highly transposed (Beaumont-Smith and Rogge, 1999; Beaumont-Smith and Böhm, 2002), calling into question previous stratigraphic and structural interpretations.

Significant differences in the geology and geochemistry of the northern and southern belts reflect this complex structural scenario and/or regional differences in tectonic setting (Syme, 1985; Zwanzig et al., 1999). This complexity leads to the suggestion that the term 'Wasekwan group' should be abandoned because it contains the diverse volcanic assemblages structurally juxtaposed in the evolution of LLGB (see Zwanzig et al., 1999) and thus may represent a tectonic collage similar to that described in the Flin Flon greenstone belt (e.g., Stern et al., 1995). However, this report and accompanying preliminary map (Yang and Beaumont-Smith, 2016) retain the term 'Wasekwan group' to maintain consistency with previous LLGB-related literature.

Geology of the Farley Lake area

The Farley Lake area is situated in the northern belt of the LLGB (Figure GS-9-1) and consists mostly of Wasekwan group supracrustal rocks intruded by plutons of the Pool Lake intrusive suite (Figure GS-9-2). Following the convention of previous workers (e.g., Beaumont-Smith and Böhm, 2004), the intrusions cutting the Wasekwan group (i.e., the Pool Lake intrusive suite of Gilbert et al., 1980) and those cutting the Sickle group are called, respectively, the pre-Sickle and post-Sickle (e.g., Milligan, 1960) suites; both are cut by a late intrusive suite (Yang and Beaumont-Smith, 2015a, b), identified in the area of the MacLellan Au mine. A diabase dike of the Mackenzie swarm (ca. 1267 Ma; Baragar et al., 1996) cuts across the southwest corner of the map area, as indicated by regional aeromagnetic data.

Eight map units, including 17 subunits, were defined during the course of bedrock mapping and are listed in Table GS-9-1. These map units are described in the following sections and shown in Figure GS-9-2 (see Yang and Beaumont-Smith, 2016). The supracrustal rocks in the LLGB were metamorphosed to greenschist to amphibolite facies (Gilbert et al., 1980; Beaumont-Smith and Böhm, 2004; Yang and Beaumont-Smith, 2015a); however, for brevity, the prefix 'meta' is omitted in parts of this report.

Felsic volcanic and volcaniclastic rocks (unit 1)

Felsic volcanic and volcaniclastic rocks of unit 1 are sparsely exposed in the area west of Simpson Lake, and were intruded by granodiorite (unit 6a) of the pre-Sickle intrusive suite (Figure GS-9-2). The lower part of this unit is truncated by the granodiorite because it lacks the gneissic rhyolite when compared to the stratigraphic section established in the Keewatin River area to the west (Yang and Beaumont-Smith, 2015a, b); the upper portion is inferred to occur in structural contact with volcaniclastic rocks of unit 2. Limited exposures of dacite in the

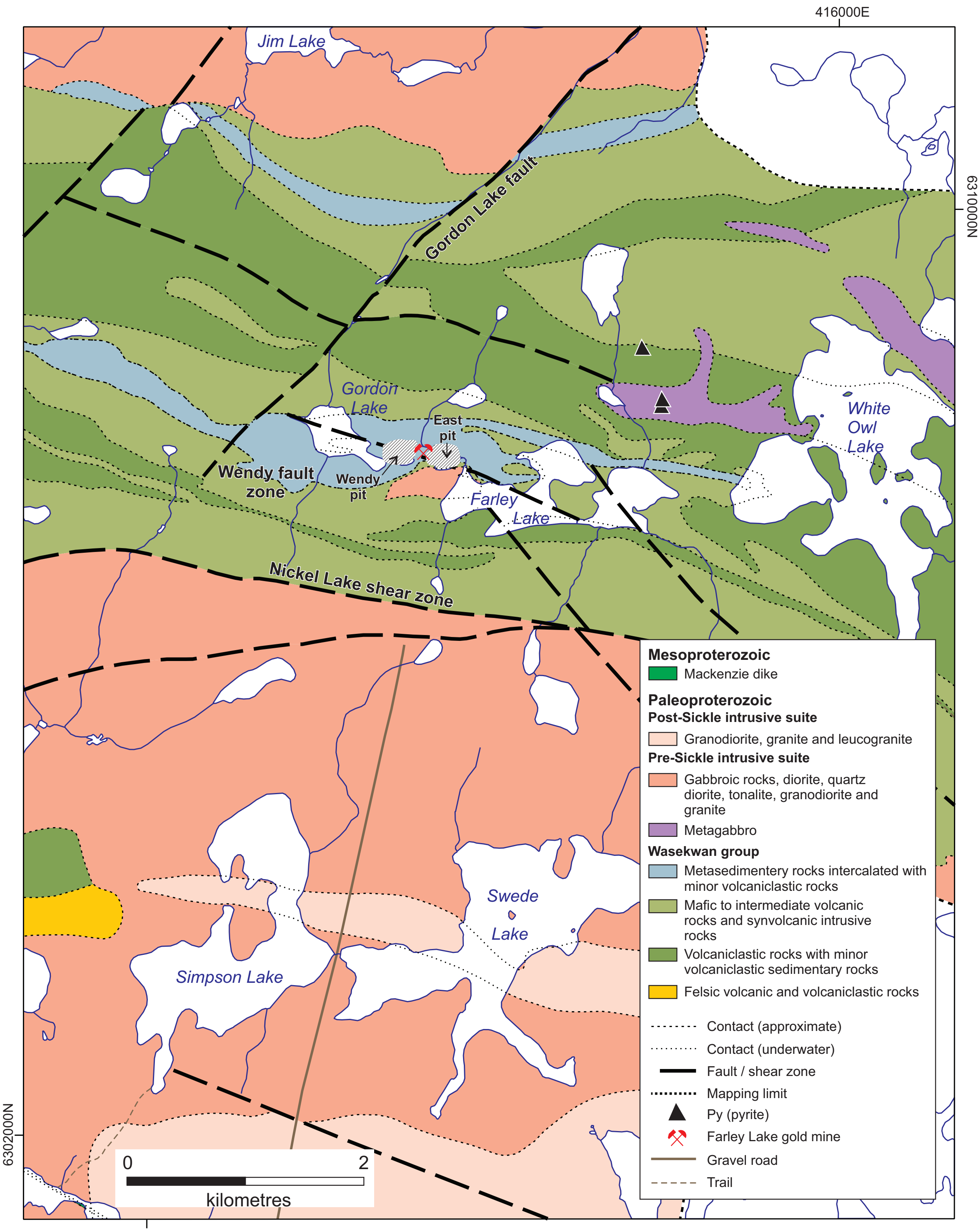

***Figure GS-9-2**: Simplified geology of the Farley Lake area, Lynn Lake greenstone belt, northwestern Manitoba (modified from Yang and Beaumont-Smith, 2016).*

Table GS-9-1: Lithostratigraphic units of the Farley Lake area, Lynn Lake greenstone belt, northwestern Manitoba.

Unit[1]	Rock type	Affiliation
8	Diabase of Mackenzie dike swarm (1267 Ma[2])	Mackenzie dike swarm
	Intrusive contact	
7	Granodiorite, granite and leucogranite	Post-Sickle intrusive suite
7a	Granite and leucogranite	
7b	Granodiorite	
	Intrusive contact	
6	Gabbroic rocks, diorite, quartz diorite, tonalite, granodiorite and granite (1876 +8/–6 Ma[3]), and associated pegmatic and aplitic dikes	Pre-Sickle intrusive suite
6a	Tonalite, granodiorite and granite, and associated pegmatic and aplitic dikes	
6b	Diorite, quartz diorite and minor gabbroic rocks	
5	Metagabbro	
	Intrusive contact	
4	Sedimentary rocks intercalated with minor volcaniclastic rocks	Wasekwan group
4a	Argillite, metasiltstone and metagreywacke	
4b	Banded iron formation	
4c	Volcaniclastic mudstone, volcaniclastic siltstone and volcaniclastic sandstone	
	Structural contact	
3	Mafic to intermediate volcanic rocks and synvolcanic intrusive rocks	
3a	Diabase and leucogabbroic dikes	
3b	Porphyritic basaltic andesite	
3c	Plagioclase-phyric basalt and aphyric basalt	
3d	Mafic autobreccia	
	Structural contact	
2	Volcaniclastic rocks with minor volcaniclastic sedimentary rocks	
2a	Felsic lapilli tuff and tuff	
2b	Intermediate lapillistone, lapilli tuff and tuff	
2c	Mafic lapillistone, mafic lapilli tuff, tuff and minor mafic mudstone	
2d	Mafic tuff breccia and breccia	
	Structural contact	
1	Felsic volcanic and volcaniclastic rocks: rhyolite, dacite and felsic to intermediate volcaniclastic rocks	
1a	Rhyolite and dacite (1884–1881 Ma[4, 5])	
1b	Felsic to intermediate volcaniclastic rocks	
	?	

[1] on Preliminary Map PMAP 2016-X01 (Yang and Beaumont-Smith, 2016)
[2] Baragar et al. (1996)
[3] Baldwin et al. (1987)
[4] Manitoba Geological Survey (2006)
[5] Beaumont-Smith, unpublished data, 2006

south wall of the flooded East pit at the Farley Lake mine are assigned to unit 1 and are similar to dacite located about 3.7 km south of Simpson Lake, which returned a U-Pb zircon age of ca. 1884–1881 Ma (Manitoba Geological Survey, 2006; Beaumont-Smith, unpublished data, 2006).

Rhyolite flows (subunit 1a; Table GS-9-1) are an important component of unit 1. These rocks preserve primary fabrics (i.e., flow banding, porphyritic texture) despite being strongly foliated and recrystallized. The rhyolite weathers light grey to buff and is medium grey on fresh surfaces. It is very fine to fine grained, with equant quartz (0.5–1.5 mm) and locally subhedral to euhedral K-feldspar (0.5–2.0 mm) phenocrysts embedded in very fine grained, dominantly felsic groundmass. Locally, sparse muscovite porphyroblasts up to 3.5 mm are evident along foliation planes. Disseminated pyrite grains (1–2 mm) occur locally.

Interflow felsic volcaniclastic layers contain up to 20% fragments (2–20 mm), comprising feldspar and quartz crystals, and lithic (very fine grained rhyolitic) fragments. These felsic volcaniclastic rocks consist dominantly of felsic lapilli tuff (subunit 1b) that contains very fine to fine-grained rhyolitic to dacitic fragments (subangular to irregular shape; 4–10 mm) and feldspar and quartz crystal fragments (2–3 mm). The matrix contains lithic fragments (1–2 mm), as well as plagioclase, K-feldspar, quartz, muscovite and biotite.

Bedded felsic to intermediate tuff (unit 1c) occurs in the upper part of unit 1 and is characterized by compositional banding and/or laminae, relative homogeneity of each layer and the presence of crystal (quartz+feldspar) and lithic fragments. Locally, euhedral garnet porphyroblasts (up to 6 mm) are evident along foliation planes. Silicification and epidote alteration are locally pervasive.

Volcaniclastic rocks with minor volcaniclastic sedimentary rocks (unit 2)

Rocks of unit 2 are widespread in the map area (Figure GS-9-2) and consist mostly of mafic volcaniclastic rocks, with minor volcaniclastic sedimentary rocks and intermediate to felsic volcaniclastic rocks. The volcaniclastic rocks of unit 2 include mafic breccia, tuff breccia, lapillistone, lapilli tuff and tuff, and minor intermediate to felsic lapillistone, lapilli tuff and tuff (Table GS-9-1).

Felsic (subunit 2a) to intermediate (subunit 2b) lapilli tuff and tuff are subordinate in unit 2. They contain volcanic fragments ranging from <2 to 60 mm across. Several fragment types are recognized on the basis of mineralogy. Fragments in felsic rocks have abundant feldspar, quartz and biotite but normally contain little or no amphibole. In intermediate rocks, the fragments contain either plagioclase and biotite (±amphibole) or little or no quartz (GS-9-3a).

Mafic volcaniclastic rocks are characterized by the presence of mafic lithic fragments in a chloritic matrix. Epidote alteration is common. In places, dark green amphibole porphyroblasts (up to 5–10 mm) are concentrated in foliation planes in mafic tuff and lapilli tuff. Some outcrops of mafic tuff and lapilli tuff contain 2–4% euhedral magnetite porphyroblasts (1–3 mm), resulting in very high magnetic susceptibility (MS; values of up to 53.9×10^{-3} SI). Subunit 2c consists of mafic volcanic mudstone, lapilli tuff, tuff and lapillistone; subunit 2d consists of mafic tuff breccia and breccia (Table GS-9-1). The volcanic mudstone (subunit 2c) weathers light greenish brown to light grey (Figure GS-9-3b) and is very fine grained, with notable disseminated pyrrhotite and pyrite. Locally, these sulphides form discontinuous layers that are transposed into the main foliation.

Mafic tuff, lapilli tuff and lapillistone (subunit 2c) are abundant in outcrop. The mafic tuff is generally strongly foliated and texturally homogeneous, and consists of varied amounts of fragments comprising plagioclase (up to 50%; 0.2–0.5 mm) and chloritic amphibole pseudomorphs (after pyroxene) in a tuffaceous matrix (Figure GS-9-3c). Magnetite and amphibole porphyroblasts are evident in places. Lapilli-sized fragments make up <25% of the rocks of subunit 2c but locally can be up to 90% (i.e., lapillistone; Figure GS-9-3d). The lapilli tuff to tuff breccia contains very fine grained rhyolitic fragments, together with plagioclase and basaltic fragments that are aligned in the foliation (Figure GS-9-3e).

The mafic tuff breccia and breccia (subunit 2d) consists of more than 80% plagioclase-phyric basalt clasts, with local aphyric basalt clasts, from 7 to 35 cm long in a lapilli tuff and tuff matrix (Figure GS-9-3f). The irregular basaltic fragments are subrounded to subangular and are normally elongated along the generally east to southeast-trending foliation. Some of the aphanitic basalt fragments display epidote alteration and others show reaction rims with very fine-grained assemblages of chlorite, epidote, sericite and albite. Locally, rare pyrrhotite and pyrite disseminations are evident in both the basaltic fragments and the matrix, suggesting that the basaltic magmas may have been sulphide saturated. As previously noted by Park et al. (2002) in the MacLellan mine area, unit 2 mafic volcaniclastic rocks may be mistakenly identified as massive basalt (either porphyritic or aphanitic) due to the presence of very large fragments or portions lacking fragments. Absent from the map area are chert and thin layers of banded iron formation, as well as fragments of similar rocks, which are common in comparable mafic volcaniclastic rocks in the area of the MacLellan Au mine (Ma et al., 2000; Yang and Beaumont-Smith, 2015a).

Mafic to intermediate volcanic rocks and synvolcanic intrusive rocks (unit 3)

The volcanic succession of unit 3 in the Farley Lake area is dominated by plagioclase-phyric and aphyric basalts with subordinate porphyritic basaltic andesite, mafic autobreccia and synvolcanic diabase and leucograbbroic dikes (Table GS-9-1; Figure GS-9-2). High-Mg picritic basalt and pyroxenite, an important part of the Agassiz metallotect (Fedikow and Gale, 1982; Ma et al., 2000; Park et al., 2002; Yang and Beaumont-Smith, 2015a, b), were not encountered in this year's mapping.

Diabase (Figure GS-9-4a) and leucogabbro (Figure GS-9-4b, c) occur as dikes assigned to subunit 3a, which are interpreted as synvolcanic intrusive rocks on the basis of a lack of chilled margins along some of the sharp contacts with the unit 3 basalt. Chilled margins, however, are not uncommon for synvolcanic dikes else (e.g., Anderson, GS-2, this volume). The diabase dikes weather greenish grey to medium grey and are medium to dark green on fresh surfaces; they are very fine to medium grained, porphyritic and deformed. Plagioclase laths (up to 5 mm) occur in a fine-grained groundmass of plagioclase, amphibole,

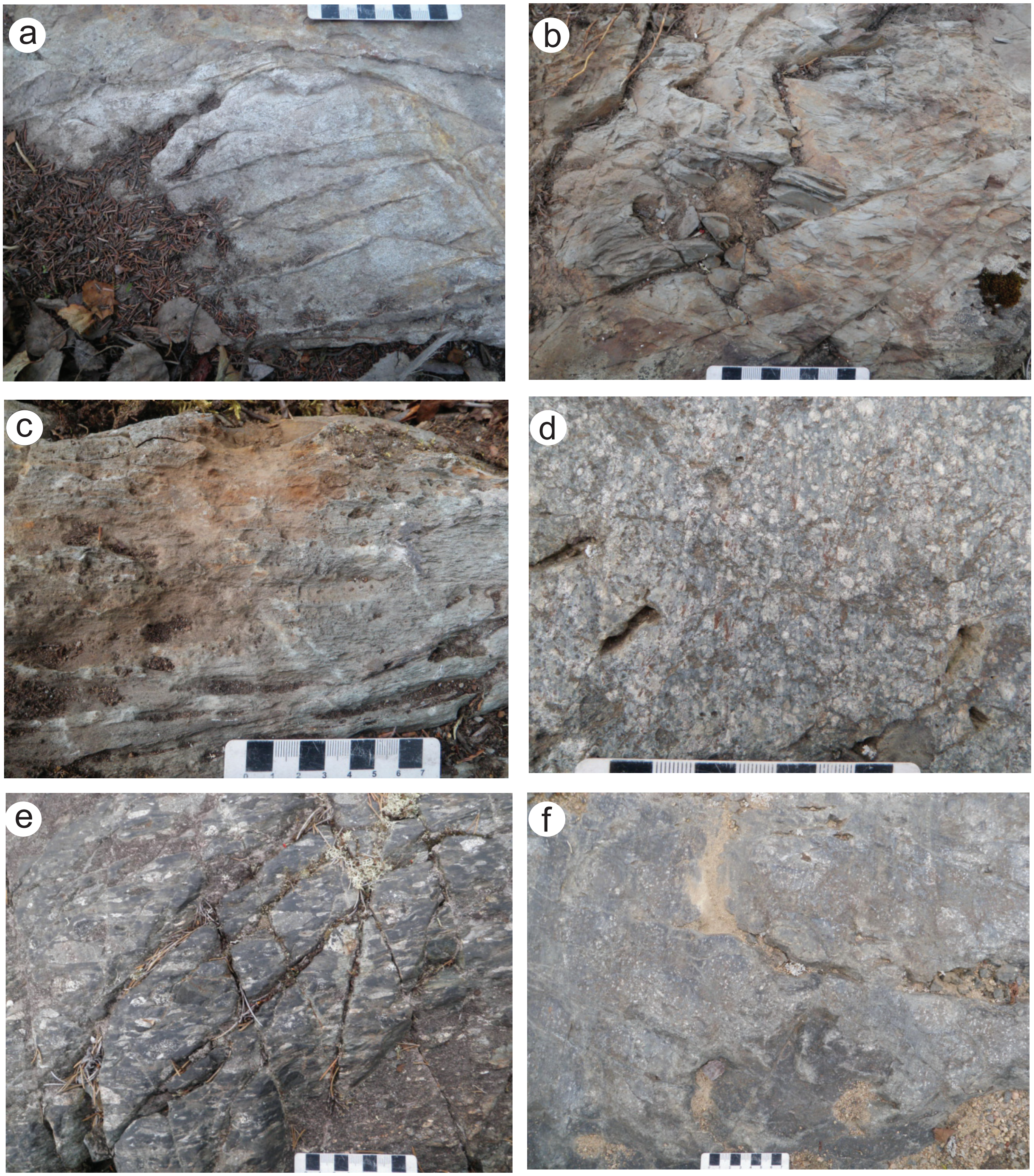

***Figure GS-9-3**: Field photographs of unit 2 volcaniclastic rocks with minor volcaniclastic sedimentary rocks of the Wasekwan group: **a)** intermediate crystal-lithic lapilli tuff (subunit 2b; UTM Zone 14N, 414891E, 6307487N, NAD 83) cut by a set of quartz veins filling S_2 foliation planes; some of the quartz veins are boudinaged; **b)** volcaniclastic mudstone with disseminated pyrrhotite and pyrite veinlets (unit 2c; UTM 414291E, 6308824N); **c)** strongly magnetic mafic tuff with 1–2 mm magnetite porphyroblasts (subunit 2c; UTM 409308E, 6308130N); **d)** mafic lapillistone with subrounded to irregular lithic and plagioclase clasts (subunit 2c; UTM 411928E, 6308577N); **e)** foliated lapilli tuff to tuff breccia with rhyolitic, plagioclase-phyric basalt and feldspar fragments in very fine grained mafic matrix (subunit 2c; UTM 411992E, 6309064N); **f)** mafic tuff breccia and volcanic breccia with plagioclase-phyric basalt blocks in lapilli tuff to tuff matrix (subunit 2d; UTM 411928E, 6308577N).*

***Figure GS-9-4**: Field photographs of mafic to intermediate volcanic rocks and synvolcanic intrusive rocks (unit 3) of the Wasekwan group: **a)** 40 cm wide diabase dike (subunit 3a; UTM Zone 14N, 410754E, 6309106N, NAD83) cutting very fine grained aphyric basalt (subunit 3c); **b)** leucograbbro dike (subunit 3a) intrudes aphyric basalt (UTM 414474E, 6309044N; note: this dike is up to 4 m in width); **c)** magnified view of the leucogabbro shown in photo b, comprising ~60% equant plagioclase phenocrysts (up to 1.2 cm) in a fine-grained groundmass of plagioclase, amphibole, chlorite and epidote; **d)** foliated plagioclase-phyric basalt with aphanitic groundmass (subunit 3c), cut by quartz veins and veinlets (UTM 415535E, 6309725N).*

chlorite and iron oxides. Generally, the diabase consists of 50–60% amphibole and 40–50% plagioclase. In contrast, the leucogabbroic rocks are enriched in larger equant plagioclase phenocrysts (up to 1.2 cm) that account for up to 65% of the rocks (Figure GS-9-4c), embedded in a fine- to medium-grained groundmass comprising plagioclase, amphibole, chlorite, epidote and iron oxide.

The plagioclase-phyric basalt (subunit 3c) weathers greenish grey and dark grey to black, and is green to dark grey on fresh surfaces (Figure GS-9-4d). This basalt comprises varied amounts of plagioclase phenocrysts and glomerocrysts (in the range 5–50% but commonly 20–30%), and rare amphibole phenocrysts (pseudomorphs after pyroxene) in a fine-grained groundmass of plagioclase, amphibole, epidote, chlorite, carbonate and iron-oxide minerals. Amphibole and magnetite porphyroblasts occur rarely in the basalt. The plagioclase phenocrysts are subhedral and commonly equant (0.5–5 mm), although some glomerocrysts or single plagioclase grains are up to 10 mm. The plagioclase-phyric basalt is commonly homogeneous and strongly foliated. In high-strain zones, relict plagioclase phenocrysts occur as finer recrystallized aggregates aligned along the foliation. Distinctly yellow-green to light greenish-grey epidote-altered domains are common. Trace disseminated pyrrhotite and/or chalcopyrite are evident in many outcrops, and pyrite is common in fractures and faults cutting basalt flows. Pillow basalts were reported by Gilbert (1993) in areas northwest and north of Gordon Lake, suggesting that some of the eruption took place in a subaqueous environment. Porphyritic basaltic andesite (subunit 3b) contains both amphibole (±biotite) and plagioclase phenocrysts, although it is similar in appearance to plagioclase-phyric basalt that commonly lacks amphibole (±biotite) phenocrysts.

Aphyric basalt is not commonly seen in the Farley Lake area, occurring as a sparse interflow unit within the more abundant plagioclase-phyric basalt. It is greyish green to dark greenish grey on weathered surfaces and dark greyish green on fresh surfaces. Epidote alteration is more commonly seen in aphyric basalt, as epidosite domains a few centimetres to a metre across, similar to those described in Gilbert et al. (1980). These epidosite domains are ovoid, angular or irregular, displaying sharp to gradational contacts with host aphyric basalt; some are fracture controlled.

In some outcrops north of White Owl Lake, mafic autobreccia (subunit 3d) occurs at the margins of aphyric basalt flows, generally in layers up to 2 m thick and containing angular to irregular fragments of dark grey to black, very fine grained basalt. As noted by Gilbert (1993), the breccia contains quartz amygdules in ovoid fragments, some of which show epidote alteration.

Sedimentary rocks with minor volcanic sedimentary rocks (unit 4)

Unit 4 sedimentary rocks are exposed mainly in the central and northern portions of the map area (Figure GS-9-2). This unit consists of argillite, mudstone and greywacke (subunit 4a), and banded iron formation (BIF; subunit 4b), with minor volcaniclastic mudstone and sandstone (subunit 4c; Table GS-9-1). The BIFs, together with the clastic sedimentary rocks, are the main hostrocks of the Farley Lake deposit (Richardson et al., 1996; Peck et al., 1998; Beaumont-Smith et al., 2000).

Thin- to thick-bedded argillite, mudstone and greywacke (subunit 4a), intercalated with BIF, are exposed in the west wall of the East pit at the Farley Lake mine (Beaumont-Smith et al., 2000). Although this subunit could not be observed at surface due to flooding, it was intersected by many exploration drillholes. Gilbert (1993) reported that the greywacke contains abraded quartz and plagioclase fragments in a finer intermediate to felsic matrix consisting of up to 55% mafic minerals (i.e., biotite and hornblende). In detailed airborne geophysical data, this subunit is expressed as relatively low magnetic domains, consistent with the presence of graphite documented in drillcore. The original bedding planes are completely transposed by the dominant regional foliation, as indicated in drillcore and in samples recovered from waste piles around the flooded open pits (i.e., East pit, Wendy pit; see Figure GS-9-2).

The BIFs (subunit 4b) are exposed north of Farley Lake, northwest of Gordon Lake and in the north-central part of the map area (Figure GS-9-2), and correlate with highly magnetic domains in detailed geophysical data. Magnetic susceptibility measurements in outcrop typically exceed 1000×10^{-3} SI. The exposed width of BIFs at Farley Lake is 450–600 m—approximately twice the true thickness of this subunit—because of fold repetition (Milligan, 1960; Gilbert, 1993; Richardson et al., 1996). This view was supported by subsequent studies by Peck et al. (1998) and Beaumont-Smith et al. (2000). At the outcrop scale, BIFs display typical alternating laminae and beds consisting of chert, mudstone, greywacke and very fine grained magnetite±hematite (Figure GS-9-5a–c). Some laminae contain abundant acicular anthophyllite porphyroblasts, whereas others contain porphyroblastic biotite. Randomly distributed euhedral magnetite crystals (1–2 mm), reddish to dark red garnet and amphibole (grunerite?) porphyroblasts are also common. This suggests that the BIFs were subjected to metamorphism up to middle-amphibolite facies. Previous studies show that finely laminated pyrrhotite-chert (sulphide-facies) units present in East pit also host important Au mineralization.

Isoclinal folds are common in outcrops of BIFs (Figure GS-9-5b), some displaying evidence for more than one phase of folding. The growth of randomly oriented amphibole porphyroblasts overprints the main (S_2) foliation, but some also display a strong preferred orientation subparallel to the regional S_3 fabric (Beaumont-Smith et al., 2000). Quartz-carbonate±sulphide veins and veinlets commonly cut the main foliation, although some of them also parallel the foliation. These vein systems host higher grade Au mineralization (up to ~30 g/t Au) at the Farley Lake mine (Peck et al., 1998) and are commonly associated with hydrothermal alteration (carbonate-silica-sericite-chlorite±actinolite±sulphide). In addition, sulphidization zones conformable with the oxide-facies BIFs also contain important Au mineralization (Richardson et al., 1996; Beaumont-Smith et al., 2000).

Thick-bedded volcaniclastic mudstone and sandstone (subunit 4c) overlie subunit 4b in the north-central part of the map area (Figure GS-9-2); contacts were not observed. The beds locally fine southward (e.g., Figure GS-9-5d). The rocks weather light grey and are grey on fresh faces. Muscovite-chlorite lithic and plagioclase clasts (0.1–1.5 mm) are dominant, although pebble-sized clasts (4–10 mm) of mafic to intermediate rocks are present in the lower part of this subunit. The volcaniclastic sandstone contains 10–25% volcanic fragments (0.1 to 2 mm); plagioclase fragments are common, with minor chloritic amphibole and biotite fragments (1–2 mm) as well as rare quartz in a fine-grained matrix of biotite, plagioclase, chlorite, lithic material and iron-oxide minerals. No magnetite porphyroblasts are evident; magnetic susceptibility values are correspondingly low (~0.5×10^{-3} SI).

Metagabbro (unit 5)

Metagabbro of unit 5 is represented by the White Owl Lake intrusion, which intrudes plagioclase-phyric to aphyric basalt (unit 3) and volcaniclastic rocks (unit 2) in the northeastern part of the map area (Figure GS-9-2). The metagabbro occurs as small stocks and a sill-like body. It

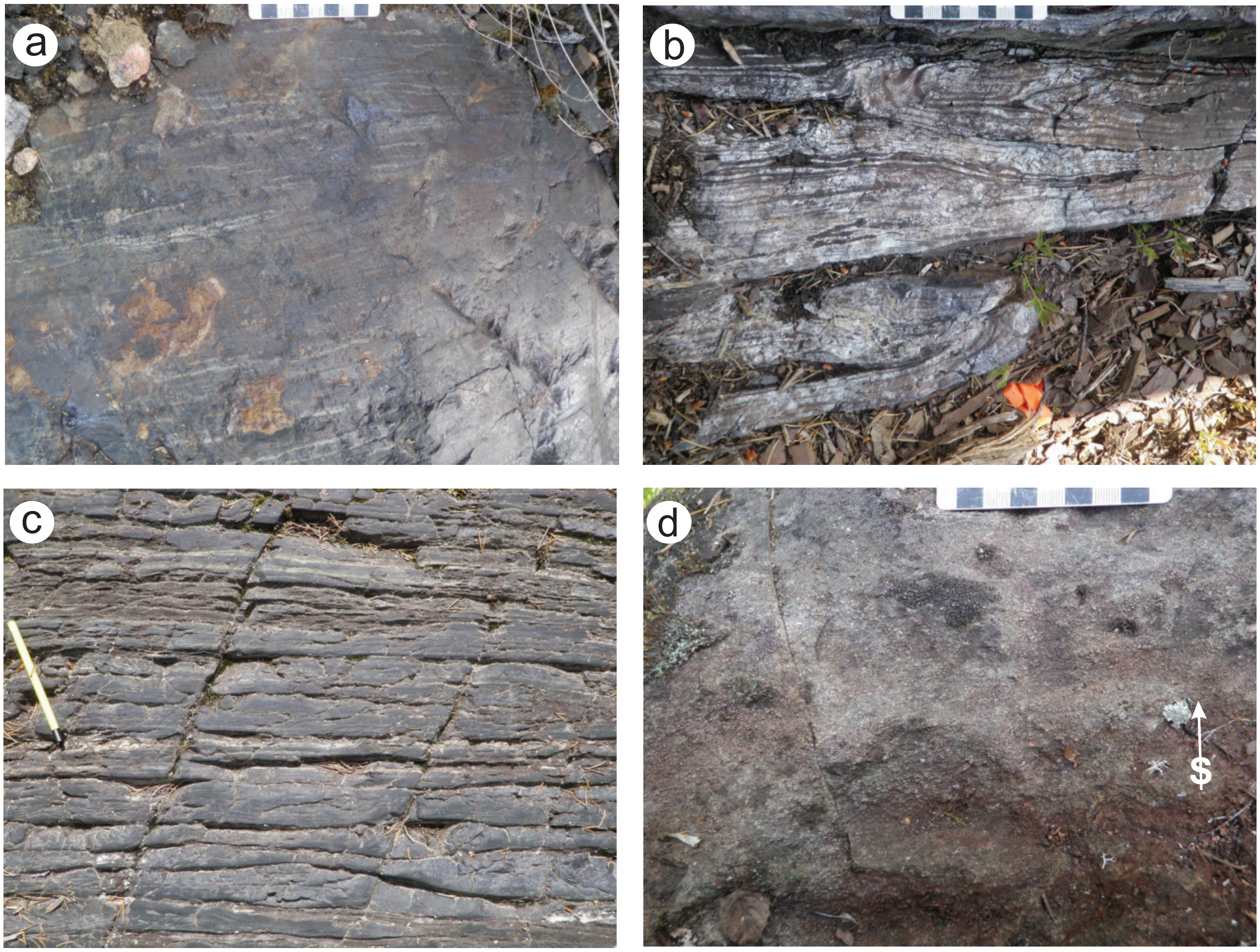

***Figure GS-9-5**: Field photographs of sedimentary rocks intercalated with minor volcaniclastic rocks (unit 4) of the Wasekwan group: **a)** banded iron formation consisting of alternating laminae of very fine grained magnetite, mudstone and chert with porphyroblastic anthophyllite bands (pale grey) and randomly distributed magnetite porphyroblasts; bedding transposed by S_2 foliation (subunit 4b; UTM Zone 14N, 412608E, 6308064N, NAD 83); **b)** laminated banded iron formation showing isoclinal folds (F_2; subunit 4b; UTM 410393E, 6308198N); **c)** silicate-facies banded iron formation with carbonaceous mudstone, chert and very fine grained magnetite laminae; mica flakes are concentrated in the mudstone layers (UTM 412038E, 6310020N); **d)** volcanic sandstone with pebbly sandstone and mudstone beds, generally fining to the south (unit 4c; UTM 411542E, 6310095N).*

weathers greenish grey and is dark greenish grey to dark grey on fresh surfaces. It is medium grained, massive and moderately to strongly foliated. The metagabbro consists of 40–50% plagioclase laths (1 to 3 mm), 45–50% amphibole (pseudomorphs after pyroxene), minor iron-oxide minerals and scattered trace pyrrhotite and chalcopyrite. The edges of both plagioclase and amphibole are diffuse. The gabbro was metamorphosed to an assemblage of chlorite, actinolite, epidote and albite, but its primary texture is well preserved and it is therefore called ‘metagabbro’. It was intruded by fine-grained granitoid dikes (unit 6) and crosscut by felsic veinlets (Figure GS-9-6a). In places, subrounded clots of epidote up to 20 cm cross are evident in the metagabbro, although epidote veins are more common. Quartz veinlets and veins (up to 15 cm wide) are common, and some of these contain pyrite. The field relationships indicate that unit 5 is part of either the pre-Sickle intrusive suite (Table GS-9-1) or the Pool Lake intrusive suite of Gilbert et al. (1980).

Pre-Sickle intrusive suite (unit 6)

Several rock types are tentatively assigned to the pre-Sickle intrusive suite (unit 6) in this report: gabbro, diorite, quartz diorite, tonalite, granodiorite, granite and associated pegmatitic and aplitic dikes This suite was dated at 1876 +8/–6 Ma by Baldwin et al. (1987) using zircon U-Pb geochronology. Unit 6 granitoid rocks and associated pegmatite and aplite dikes dominate the southern half of the map area (the Simpson-Swede lakes granitoid pluton) and, in the northern part of the area, occur immediately southeast of Gordon Lake and along the northern edge (the Jim Lake pluton; Figure GS-9-2). These plutons are divided into two subunits based on field relations and rock types: tonalite, granodiorite and granite,

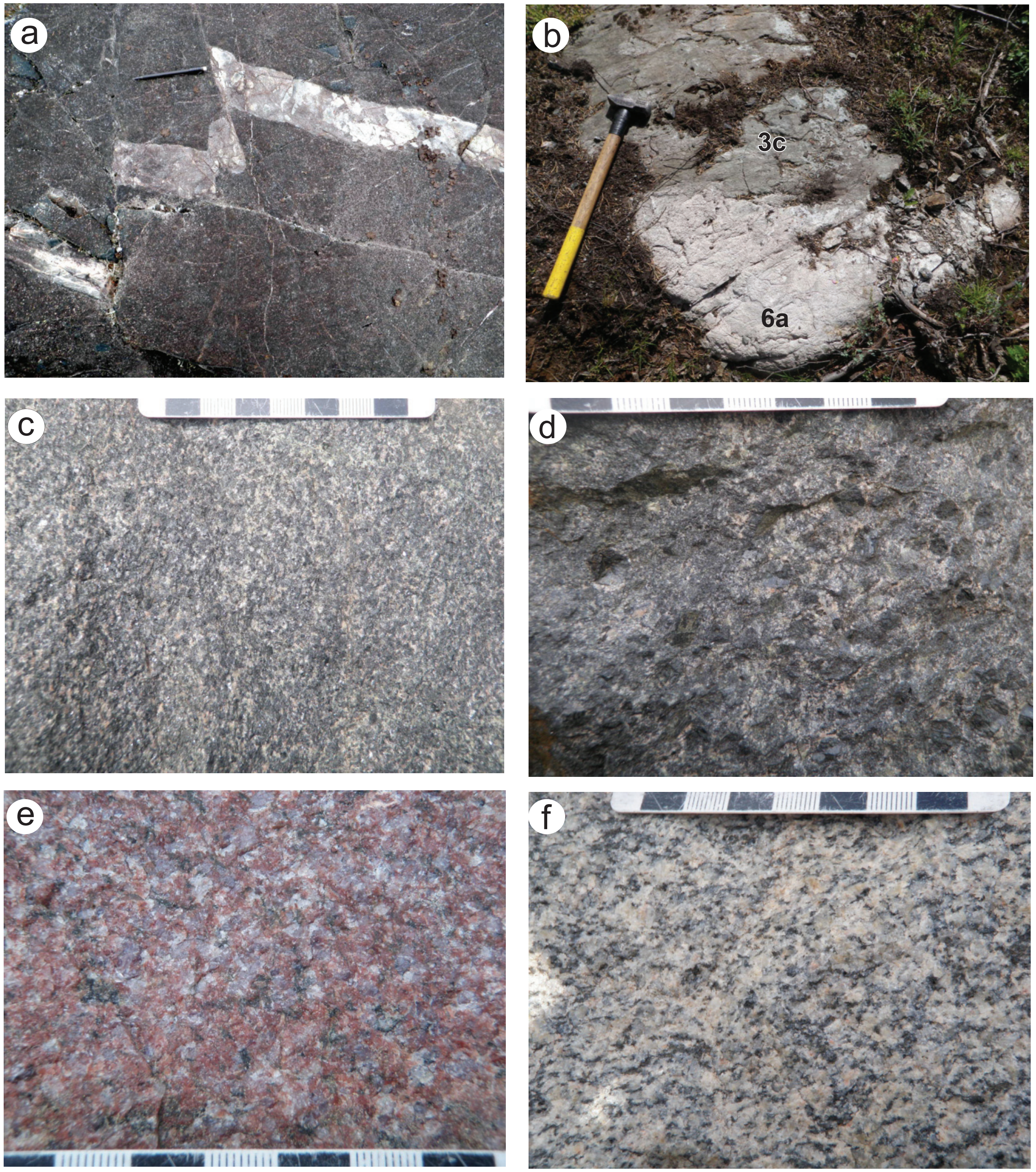

***Figure GS-9-6**: Outcrop photographs of map units 5, 6 and 7 in the area of the Farley Lake mine, Lynn Lake greenstone belt: **a**) medium-grained foliated metagabbro (unit 5) cut by a fine-grained epidote-altered granite (unit 6) dike that is offset by minor east-northeast-trending faults (UTM Zone 14N, 416624E, 6308924, NAD 83); **b**) fine- to medium-grained tonalite (subunit 6a) dikes cutting aphyric to plagioclase-phyric basalt (unit 3c; UTM 412191E, 6306575N1); **c)** medium-grained quartz diorite (subunit 6b; UTM 412074E, 6307468N); **d)** porphyritic gabbro (subunit 6b) with pseudomorphic pyroxene (now amphibole) phenocrysts (UTM 412152E, 6307453N); **e)** medium-grained leucogranite (subunit 7a; UTM 411699E, 6304064N); **f)** medium- to coarse-grained foliated granodiorite (subunit 7b; UTM 411174E, 6301508N).*

with associated pegmatitic and aplitic rocks (subunit 6a); and diorite, quartz diorite and minor gabbroic rocks (subunit 6b; Table GS-9-1).

Granitoid rocks (subunit 6a)

Granitoid rocks of subunit 6a comprise tonalite, granodiorite and granite, and minor related pegmatitic and aplitic dikes. The tonalite occurs as part of the Simpson-Swede lakes pluton. This tonalite intrudes aphyric to plagioclase-phyric basalt of subunit 3c (Figure GS-9-6b) in the area south of Farley Lake. The tonalite is fine to medium grained, grey to light grey, equigranular but moderately foliated and locally porphyritic. It consists of 15–25% quartz, 50–60% plagioclase, 15–20% amphibole and minor biotite. Chloritic alteration is common. The tonalite displays very high MS values (up to 54.6×10^{-3} SI) in a zone within 100 m of its contact; these values are much higher than the typical values for the tonalite, which range from 0.3 to 10.0×10^{-3} SI.

The dominant phase of unit 6a is medium to coarse grained, equigranular to locally porphyritic, foliated granodiorite. The granodiorite weathers greyish pink to light beige and consists of 20–30% anhedral quartz, 25–35% subhedral plagioclase laths, 20–25% K-feldspar, 5–10% biotite (±hornblende) and accessory iron-oxide minerals. It has MS values of $0.3–24.1 \times 10^{-3}$ SI, typical of the I-type granite of Chappell and White (1974) or the magnetite-series granite of Ishihara (1981). Granite is subordinate in subunit 6a and contains slightly higher K-feldspar and quartz than the granodiorite. It is also attributed to I-type or magnetite-series granite in terms of its mineral assemblage and MS values in the rage $0.2–2.5 \times 10^{-3}$ SI.

Pegmatite and/or aplite of unit 6a commonly occur as dikes that are a few centimetres to a few metres wide and consist of quartz, feldspars and minor biotite (±muscovite). These dikes are more commonly associated with granite and granodiorite than with tonalite.

Gabbroic to quartz dioritic rocks (subunit 6b)

Diorite to quartz diorite (subunit 6b) occurs as a small stock exposed on the south wall of the East pit at the Farley Lake mine; this subunit also occurs in the area southeast of Gordon Lake and around Jim Lake on the northern edge of the map area (Figure GS-9-2). The quartz diorite is light to dark grey on weathered and fresh surfaces, fine to medium grained, massive, equigranular and moderately to strongly foliated (Figure GS-9-6c). It consists of 2–10% anhedral quartz (1–3 mm), 40–50% plagioclase laths (1–4 mm) with diffuse grain boundaries, 30–40% hornblende (1–3 mm) and minor biotite. Disseminated pyrite occurs locally. In places, reddish granitic aplite veins cut the quartz diorite, which displays a relatively high MS value of 11.2×10^{-3} SI. A chlorite-altered quartz diorite sample in drillcore from the Farley Lake deposit was reported to contain 0.6 g/t Au; this quartz diorite appears to occur as a dike cutting the sedimentary rocks of unit 4, including BIFs (see Beaumont-Smith et al., 2000).

Gabbroic rocks of subunit 6b are rare, occurring as dikes cutting the quartz diorite. The gabbro is medium to coarse grained, porphyritic and dark grey on fresh surfaces (Figure GS-9-6d). It consists of 60–65% pyroxene (±amphibole), some of which occurs as phenocrysts (0.6–1.0 cm) in a fine- to medium-grained groundmass of plagioclase, pyroxene, amphibole and chlorite. A few quartz crystals occur in the gabbro, suggesting that it is silica oversaturated. The gabbro displays lower MS values ($\sim 2.15 \times 10^{-3}$ SI) than the quartz diorite.

Post-Sickle intrusive suite (unit 7)

Post-Sickle intrusive rocks of unit 7 are exposed mainly in the area south and east of Swede Lake and Simpson Lake (Figure GS-9-2). Unit 7 includes two subunits: granite and leucogranite (subunit 7a) and granodiorite (subunit 7b). The granite and leucogranite cut the granitoid rocks of unit 6 and occur as dikes to small stocks. They are light pinkish to pinkish red on fresh surfaces, medium grained, massive and equigranular. They consist of 30–35% quartz (3–5 mm), 55–65% reddish K-feldspar laths (3–5 mm) with sharp crystal edges, minor plagioclase, ~5% biotite and trace magnetite (Figure GS-9-6e). This subunit typically lacks hornblende and can be termed leucogranite when biotite content is below 5%. This evolved granite displays relatively high MS values of up to 3.98×10^{-3} SI, consistent with I-type and magnetite-series granites.

The granodiorite of subunit 7b is pinkish on fresh surfaces and weathers beige to tan. It is medium to coarse grained, foliated and equigranular to locally porphyritic. This granodiorite consists of 5–8% hornblende (partly altered to biotite), 25–27% quartz, 30–40% plagioclase, 25–30% K-feldspar and minor discrete biotite flakes (Figure GS-9-6f). In places, the feldspar laths are present as phenocrysts (locally up to 20 mm) with diffuse grain edges due to sericitic alteration. Trace sulphide minerals are locally present. This granodiorite exhibits very low MS values of 0.085×10^{-3} SI, consistent with reduced I-type and ilmenite-series granites elsewhere (cf. Yang et al., 2008).

Diabase of Mackenzie dike swarm (unit 8)

Unit 8 has not been observed at surface but is interpreted as a diabase or gabbroic dike based on aeromagnetic trends in the extreme southwestern corner of the map area (Figure GS-9-2). This northwest-trending dike cuts through the LLGB supracrustal rocks and granitoid intrusions, and is attributed to the ca. 1267 Ma Mackenzie dike swarm (Baragar et al., 1996).

Structural geology

Structural geology has been extensively investigated at both regional and deposit scales in the LLGB (Gilbert et al., 1980; Gilbert, 1993; Peck et al., 1998; Beaumont-Smith and Rogge, 1999; Beaumont-Smith and Edwards, 2000; Beaumont-Smith et al., 2000; Ma et al., 2000; Anderson and Beaumont-Smith, 2001; Ma and Beaumont-Smith, 2001; Beaumont-Smith et al., 2001; Park et al., 2002; Beaumont-Smith and Böhm, 2002, 2003, 2004; Jones et al., 2006; Yang and Beaumont-Smith, 2015a). At the belt scale, six deformation events (D_1 to D_6) were defined by Beaumont-Smith and Böhm (2002, 2004) in the LLGB. Although fabrics of the all deformation events are not necessarily observed in the Farley Lake area, this report follows the terms used by Beaumont-Smith and Böhm (2002, 2004) to describe the characteristics of their D_1 to D_6 structures.

In the Farley Lake area, the D_2 deformation structures are typically the most penetrative and manifest as a steeply north-dipping S_2 foliation, tight to isoclinal folds (F_2) with shallow plunges, and minor chevron folds. Ductile shear zones that generally define the unit contacts are thought to be related to D_2 deformation. The intensity of S_2 fabrics and tightness of F_2 folds increase toward contacts. The D_2 shear zones are characterized by dextral shear-sense indicators on horizontal surfaces and steeply plunging, generally down-dip to slightly oblique (easterly pitch) stretching lineations. The structural geometry of the Farley Lake area is overall characterized by shallowly plunging F_2 fold axes, which steepen to subvertical within D_2 shear zones.

A major D_2 shear zone—the Nickel Lake shear zone (NLSZ) identified by Beaumont-Smith and Böhm (2004)—transects the area south of the Farley Lake mine along the contact between the volcanic rocks of unit 3 and the granitoid rocks of unit 6. It is manifested by a prominent aeromagnetic lineament. A splay of this structure cuts through unit 6 (Figure GS-9-2) and other splays may include the Wendy fault at the Farley Lake deposit (Peck et al., 1998). On horizontal surfaces, a dextral shear sense is indicated by shear bands, S-C fabrics, rotated fragments and pressure shadows. The Wendy fault also exhibits a component of normal movement, suggested by the presence of imbricated clasts within the BIFs of unit 4 sedimentary rocks (Beaumont-Smith et al., 2000).

The fabrics of D_3 deformation are generally rare in the map area, represented by close to tight, S-asymmetric F_3 folds and northwest-trending, axial-planar S_3 crenulation cleavages. In contrast, F_4 folds are pervasive throughout the map area. These folds plunge steeply to the northeast and are associated with steeply dipping, northeast-striking, axial-planar S_4 crenulation cleavages. Mesoscopic structures associated with D_5 deformation include open F_5 conjugate folds, kink bands and crenulations. The D_6 deformation was brittle to ductile, represented by sinistral reactivation of D_2 shear zones (Beaumont-Smith and Böhm, 2004).

Northwest-trending faults trend through the central part of the Farley Lake mine area and extend southeast to Mac Lake (Figure GS-9-2). These faults cut D_2 shear zones, such as the NLSZ, and pre-Sickle intrusions (unit 6). The northwest-trending faults are thought to be related to the D_3 deformation event. The Gordon Lake fault (GLF) is another major fault that strikes northeast and offsets the BIFs of unit 4 at least 600 m in a left-lateral sense (Figure GS-9-2). This fault is defined by detailed aeromagnetic data and a strong topographic linear feature. The fault is interpreted to relate to the regional D_4 deformation event.

Economic considerations

The economic potential of the Farley Lake area is demonstrated by the Farley Lake Au deposit, which is related to sulphidization of oxide-facies BIFs that had been metamorphosed to middle-amphibolite facies and complexly folded. The mineralization is interpreted to result from channelling of oxidized or reduced Au-bearing fluids along D_2 shear zones (e.g., NLSZ) or D_3 and D_4 faults (e.g., GLF). In this context, structural intersections are likely the most favourable sites for Au mineralization. Gold-bearing fluids may have derived from the various intrusive suites mapped in the Farley Lake area or from metamorphic dehydration reactions at depth; the nature and potential sources of auriferous fluids are the subject of ongoing collaborative research between the GSC and MGS.

The unit 5 metagabbro intrusions saturated with sulphides (e.g., White Owl Lake intrusion) are petrologically similar to the Lynn Lake metagabbro intrusion that hosts the Lynn Lake Ni-Cu-Co deposit, suggesting that these intrusions may have potential for magmatic Ni-Cu-Co (Pt). In addition, highly evolved leucogranite of unit 7b is relatively oxidized and can therefore be classified as evolved I-type granite, with associated potential for rare metals (e.g., rare-earth elements, Nb, Ta). The potential for VMS base metals within the map area does not appear to be high, although the Brooks Bay Cu-Au deposit occurs only 5 km to the east at Brooks Bay on Barrington Lake.

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