GS2022-9

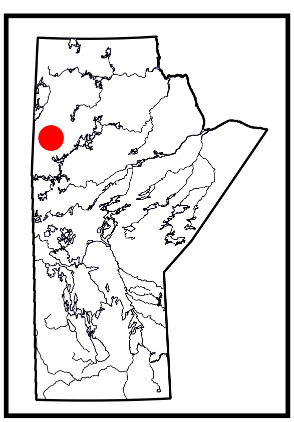
Preliminary results of bedrock geological mapping in the Fox mine–Snake Lake area, Lynn Lake greenstone belt, northwestern Manitoba (part of NTS 64C12)

by X.M. Yang

In Brief:

- Detailed bedrock mapping provides an updated geological framework for various mineralization styles
- Tectonic setting of host rocks to the Fox volcanogenic massive sulphide Cu-Zn deposit is being evaluated
- Quartz diorite intrusions of the post-Sickle intrusive suite may serve as an important guide for potential Au mineralization

Citation:
Yang, X.M. 2022: Preliminary results of bedrock geological mapping in the Fox mine–Snake Lake area, Lynn Lake greenstone belt, northwestern Manitoba (part of NTS 64C12); *in* Report of Activities 2022, Manitoba Natural Resources and Northern Development, Manitoba Geological Survey, p. 71–86.



Summary

In 2022, the Manitoba Geological Survey continued a multiyear bedrock geological mapping project in the Paleoproterozoic Lynn Lake greenstone belt, focusing on the Fox mine–Snake Lake area. The aims were to investigate the geological and structural framework of various rock units, the tectonic setting of the volcanogenic massive sulphide (VMS) Cu-Zn deposit, and the potential relationship between Au and intrusive rocks. Preliminary results of the mapping at 1:10 000 scale indicate that this area contains a variety of volcanic rocks, including basalt, andesite, dacite and rhyolite (BADR), related volcaniclastic rocks, and sedimentary rock units. Reworked volcaniclastic and epiclastic rocks overlie the BADR, suggesting deposition in a setting comparable to modern volcanic arcs to back-arc basins. This supracrustal package is cut by pre-Sickle, post-Sickle and late intrusive suites, and was involved in six regional deformation events (D_1 to D_6). The interpreted tectonic evolution of the greenstone belt includes 1) plate subduction resulting in a magmatic arc to back-arc containing volcanic, volcaniclastic and sedimentary rocks (units 1–3) and associated VMS Cu-Zn mineralization, which are cut by pre-Sickle gabbroic and granitoid rocks (units 4 and 5, respectively); 2) intra-arc extension related to rollback of a subducting slab, producing synorogenic basins filled by Sickle group sediments (unit 6) and post-Sickle granitoid rocks (unit 7); and 3) juxtaposition and/or terminal collision of the greenstone belt with adjacent domains and relaxation or collapse of the merged orogen, resulting in regional shear-zone formation and associated tectonite (unit 9), and fluid circulation triggered by adakite-like intrusions and Au mineralization in favourable structural-chemical traps, as well as emplacement of a late intrusive suite (unit 8).

Introduction

Detailed bedrock geological mapping at 1:10 000 scale, conducted in the summer of 2022 by the Manitoba Geological Survey (MGS), concentrated on the Fox mine–Snake Lake area in the southwestern part of the Lynn Lake greenstone belt (LLGB; Figure GS2022-9-1). The Fox mine produced about 12 million tons of ore grading 1.82% Cu and 1.78% Zn during the period from 1970 to 1985. It is a volcanogenic massive sulphide (VMS) deposit hosted by the Wasekwan group supracrustal rocks that consist mainly of volcanic, volcaniclastic and sedimentary rocks, informally termed the 'Fox mine succession' (Gilbert et al., 1980; Olson, 1987; Zwanzig et al., 1999). This area provides an excellent opportunity for the MGS to perform detailed bedrock geological mapping to better constrain the field relationships and nature of the supracrustal rocks, the tectonic setting of the VMS deposit, and the various intrusive suites and their associated mineral potential.

This report presents new field data on the geology, structure and metamorphism of the Fox mine–Snake Lake area, to provide an updated geological map and to discuss tectonic settings of VMS-hosted rocks and implications for Au mineralization by the post-Sickle intrusive suite. The accompanying preliminary map (Yang, 2022) was created from 162 field stations, including 165 new structural measurements, as well as compiled historical data (84 outcrops and 121 structural data points from Gilbert et al. [1980] and a handful of historical drill data), and detailed airborne magnetic data kindly provided by Alamos Gold Inc. During the course of mapping, a Terraplus Inc. KT-10 magnetic susceptibility (MS) meter with a pin was used to measure MS values of outcrops. Each rock type of a visited outcrop was measured at least five times, at different locations if possible, and the average of the measurements was recorded to represent the MS value of the outcrop. The MS data were used, together with the field observations, to constrain lithostratigraphic grouping and unit definition.

Thirty-seven whole-rock samples were collected from the map area for geochemical analysis to study geological processes, including five for Sm-Nd isotopes and one for U-Pb zircon age determina-

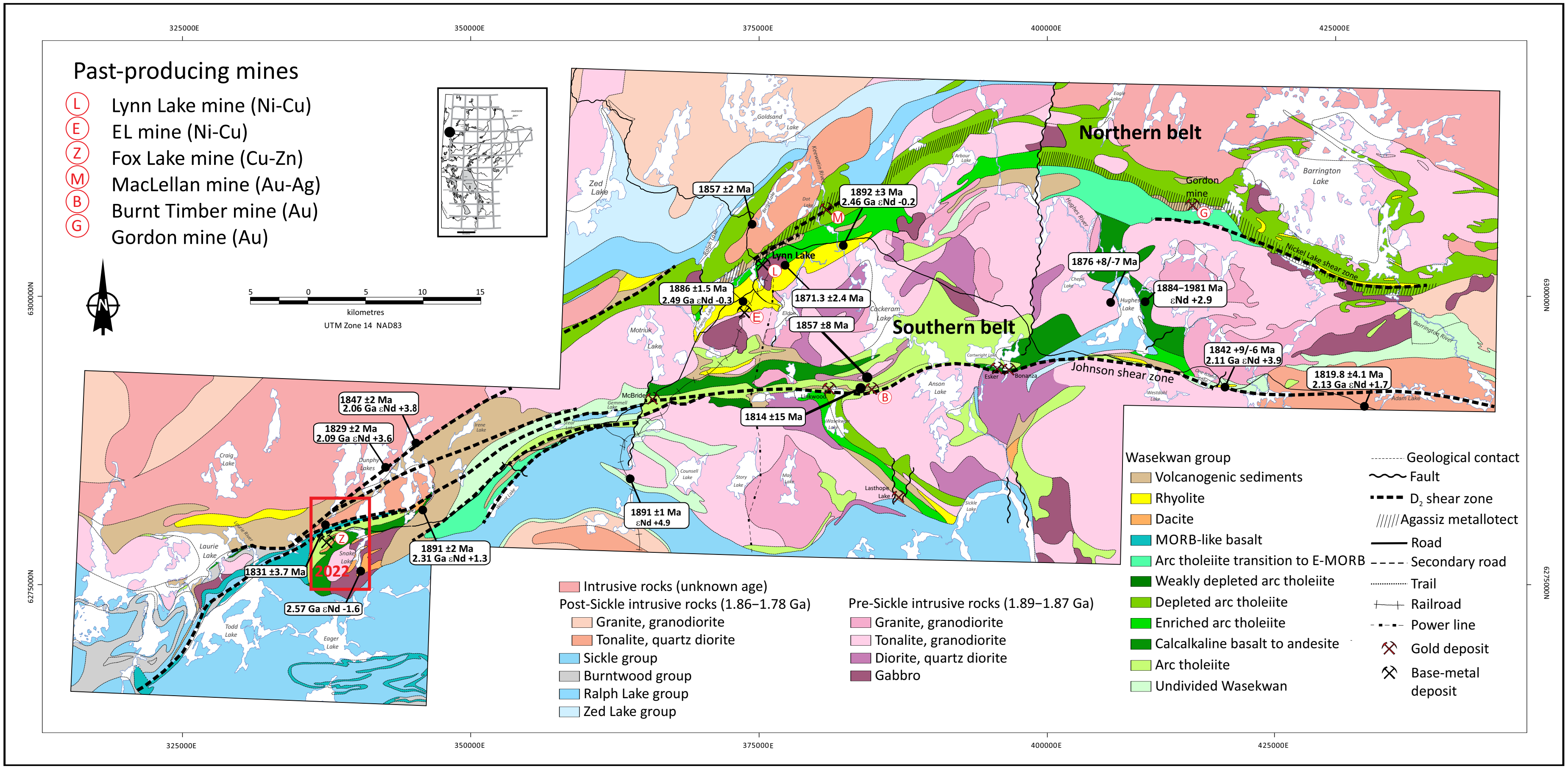


Figure GS2022-9-1: *Regional geology with U-Pb zircon ages and Nd isotopic compositions of the Lynn Lake greenstone belt (modified and compiled from Gilbert et al., 1980; Manitoba Energy and Mines, 1986; Gilbert, 1993; Zwanzig et al., 1999; Turek et al., 2000; Beaumont-Smith and Böhm, 2002, 2003, 2004; Beaumont-Smith et al., 2006; Jones et al., 2006; Beaumont-Smith, 2008; Yang and Beaumont-Smith, 2015b, 2016, 2017; Lawley et al., 2020). The 2022 mapping area is indicated by the red box. Abbreviation: MORB, mid-ocean–ridge basalt.*

tion. The results of these lab analyses are pending and will be reported in subsequent MGS publications.

General geology

The LLGB (Bateman, 1945) is a major 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; Corrigan, 2012). It is endowed with several mineral deposit types, such as orogenic Au, magmatic Ni-Cu-Co and volcanogenic massive sulphide Cu-Zn. To the north, the LLGB is bounded by the Southern Indian domain that is composed of variably migmatitic metasedimentary rocks, various granitoids and minor metavolcanic and volcaniclastic rocks (e.g., Kremer et al., 2009; Martins et al., 2019). To the south, the LLGB is flanked by the Kisseynew domain that represents a synorogenic metasedimentary basin (Gilbert et al., 1980; Fedikow and Gale, 1982; Syme, 1985; Zwanzig, 1990, 2000; Zwanzig et al., 1999; White et al., 2000; Zwanzig and Bailes, 2010; Glendenning et al., 2015; Hastie et al., 2018).

The LLGB is composed of two east- to northeast-trending, steeply dipping belts that contain various supracrustal rocks, locally known as the Wasekwan group (Bateman, 1945; Milligan, 1960; Gilbert et al., 1980; Gilbert, 1993), along with the younger Sickle group molasse-type sedimentary rocks (Norman, 1933; Milligan, 1960; Gilbert et al., 1980). The southern and northern belts are separated by granitoid plutons of the 1.89–1.87 Ga Pool Lake intrusive suite (Gilbert et al., 1980; Baldwin et al., 1987; Anderson and Beaumont-Smith, 2001; Beaumont-Smith and Böhm, 2002, 2003, 2004; Beaumont-Smith et al., 2006). 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 (Gilbert et al., 1980). The Sickle group correlates well with the 1850–1840 Ma MacLennan group in the La Ronge greenstone belt of Saskatchewan to the southwest in terms of lithological composition, stratigraphic position and contact relationships (Ansdell et al., 1999; Ansdell, 2005; Corrigan et al., 2009). Volcanic and plutonic rocks in the LLGB underwent peak metamorphism at 1.81–1.80 Ga (Beaumont-Smith and Böhm, 2002, 2003; Lawley et al., 2020).

Significant differences in the geology and geochemistry of the northern and southern belts in the LLGB may reflect regional differences in tectonic settings that were obscured by structural transposition and imbrication during multiple stages of deformation (Gilbert et al., 1980; Syme, 1985; Zwanzig et al., 1999; Beaumont-Smith, 2008). This complexity leads to the suggestion that the term 'Wasekwan group' should be abandoned because it contains disparate volcanic assemblages that were later structurally juxtaposed, and thus may represent a tectonic collage (Zwanzig et al., 1999). The concept was used in a recent geological compilation by Manitoba Agriculture and Resource Development (2021), but this report retains the term 'Wasekwan group' to remain consistent with the literature related to the LLGB.

Geology of the map area

The Fox mine–Snake Lake area is situated in the southwestern part of the LLGB (Figure GS2022-9-1) and is underlain by the Wasekwan group supracrustal rocks intruded by plutons of the Pool Lake intrusive suite (Gilbert et al., 1980). This plutonic suite is unconformably overlain by the Sickle group epiclastic rocks (Figure GS2022-9-2; Yang, 2022). The plutons that only intrude the Wasekwan group are referred to as the 'pre-Sickle suite', and those cutting both the Wasekwan group and the Sickle group are termed the 'post-Sickle suite' (e.g., Milligan, 1960); both are cut by a late intrusive suite (Yang and Beaumont-Smith, 2015a, 2015b, 2017; Yang, 2019, 2021).

Nine map units, including 13 subunits, were defined in the map area and grouped into six affiliations: Wasekwan group, pre-Sickle intrusive suite, Sickle group, post-Sickle intrusive suite, late intrusive suite, and tectonite (Table GS2022-9-1). These map units are shown in Figure GS2022-9-2 and described in the following sections. The supracrustal rocks in the LLGB were mostly deformed and metamorphosed to greenschist and amphibolite facies (Gilbert et al., 1980; Gilbert, 1993; Beaumont-Smith and Böhm, 2004; Yang and Beaumont-Smith, 2015a, 2016, 2017; Yang, 2019, 2021); however, this report omits the prefix 'meta' for brevity.

Wasekwan group (units 1 to 3)

Supracrustal rocks of the Wasekwan group exposed in the map area are divided into the three lithological units and described below.

Volcaniclastic rocks with minor volcanic rocks and sedimentary rocks (unit 1)

Unit 1 is exposed mainly in the northeastern and southwestern (e.g., Snake Lake), west-central (e.g., Mukasew Lake) and southeastern parts of the map area (Figure GS2022-9-2; Yang, 2022). This unit consists of a range of lithologies from mafic to felsic volcanic and volcaniclastic rocks that, in places, appear to have been reworked by sedimentary processes and deposited as volcanic mudstone to sandstone. Locally, some of the unit 1 rocks occur as garnet-biotite schist and amphibolite due to deformation and metamorphism.

Outcrops of foliated dacite and rhyolite (subunit 1a) with minor andesitic rocks and related volcaniclastic rocks occur mainly in the central, west-central and southeastern portions of the map area (Figure GS2022-9-2). These felsic–intermediate rocks are very fine grained, pale grey to white on weathered surfaces and light to medium greyish red or grey on fresh surfaces. Primary features (e.g., flow banding, porphyritic texture) are preserved, despite these rocks being foliated and recrystal-

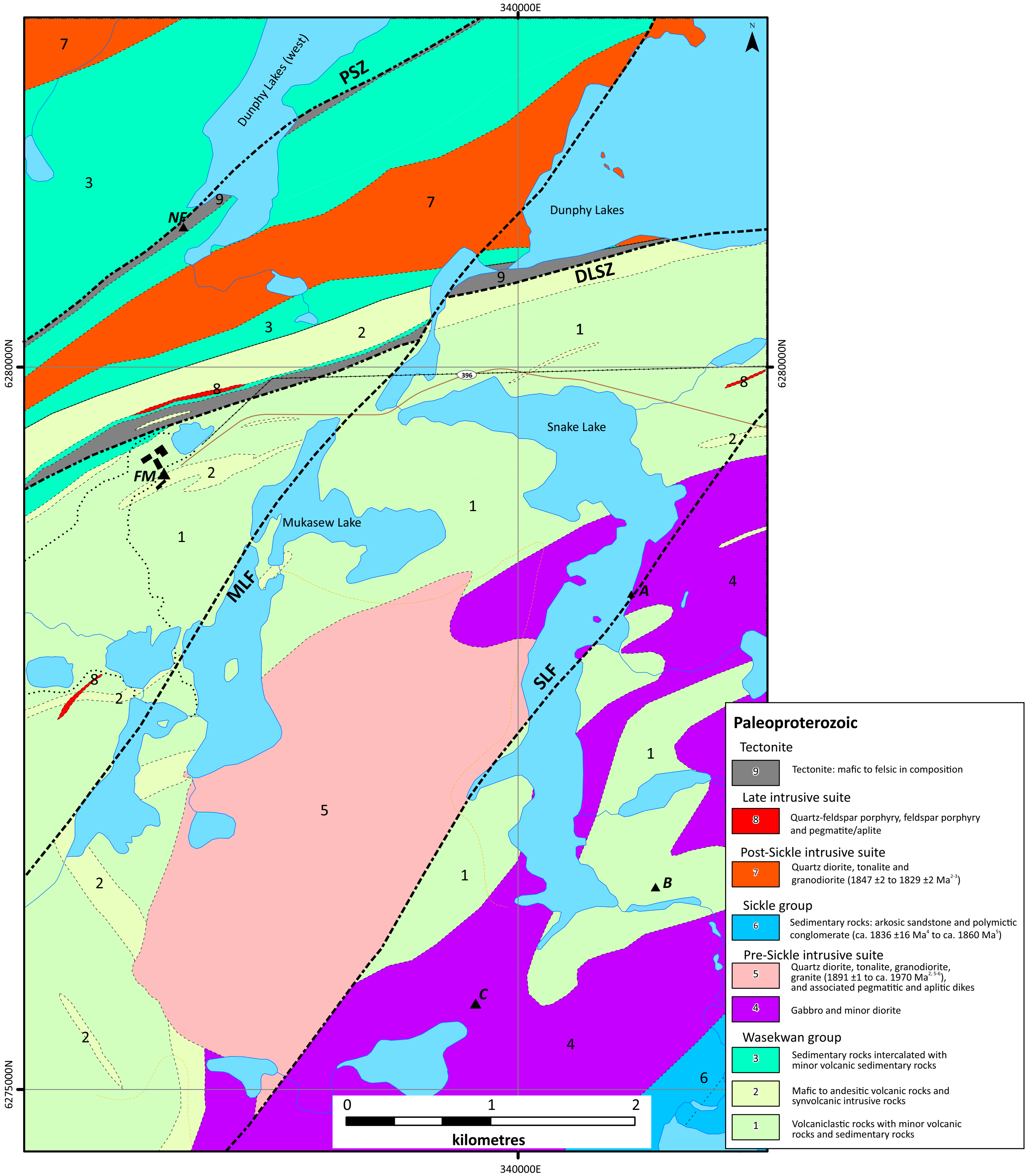


Figure GS2022-9-2: *Simplified geology of the Fox mine–Snake Lake area, Lynn Lake greenstone belt, northwestern Manitoba (simplified from Yang, 2022). Coarse dashed lines indicate a shear zone or fault: DLSZ, Dunphy Lakes shear zone; MLF, Mukasew Lake fault; PSZ, Pumphouse shear zone; SLF, Snake Lake fault. Black triangles indicate a mineral deposit or occurrence: FM, Fox mine (Cu-Zn volcanogenic massive sulphide deposit); NF, North Fox occurrence (Cu-Zn); A, BAG occurrence (Cu); B, GAL occurrence (Cu-Zn-Au-Ag); C, unnamed occurrence (Zn). Superscript numbers following U-Pb zircon ages in legend correspond to references in footnote of Table GS2022-9-1.*

Table GS2022-9-1: Lithostratigraphic units of the Fox mine–Snake lake area, Lynn Lake greenstone belt.

Unit[1]	Rock type	Affiliation
9	Tectonite: mafic to felsic	Tectonite
8	Quartz-feldspar porphyry, feldspar porphyry and pegmatite/aplite	Late intrusive suite
	Intrusive contact	
7	Quartz diorite, tonalite and granodiorite (1847 ±2 to 1829 ±2 Ma[2-3])	Post-Sickle intrusive suite
	Intrusive contact	
6	Sedimentary rocks: arkosic sandstone and polymictic conglomerate (ca. 1836 ±16 Ma[4] to ca. 1860 Ma[5])	Sickle group
6a	Arkosic sandstone, quartz pebbly sandstone	
6b	Polymictic conglomerate with minor pebbly sandstone	
	Structural contact	
5	Quartz diorite, tonalite, granodiorite, granite (1891 ±1 Ma to ~1870 Ma[2, 5-6]) and associated pegmatitic and aplitic dikes	Pre-Sickle intrusive suite
4	Gabbro and minor diorite	
	Intrusive contact	
3	Sedimentary rocks intercalated with minor volcanic sedimentary rocks	Wasekwan group
3a	Argillite, siltstone and greywacke	
3b	Mafic to intermediate tuffaceous sandstone to tuff	
3c	Volcanic mudstone, siltstone, volcanic sandstone and minor volcanic conglomerate	
	Structural contact	
2	Mafic to intermediate volcanic rocks and synvolcanic intrusive rocks	
2a	Diabase and gabbro	
2b	Porphyritic basaltic andesite	
2c	Plagioclase-phyric basalt and aphyric basalt	
2d	Pillow basalt	
	Structural contact	
1	Volcaniclastic rocks with minor volcanic rocks and sedimentary rocks	
1a	Felsic (1891 ±2 Ma[2]) to intermediate volcanic and volcaniclastic rocks	
1b	Intermediate lapillistone, lapilli tuff and tuff	
1c	Mafic lapillistone, lapilli tuff, tuff, amphibolite, minor mafic mudstone and derivative garnet-biotite schist	
1d	Mafic tuff breccia and volcanic breccia	
	?	

[1] Yang (2022)
[2] Beaumont-Smith and Böhm (2003)
[3] Turek et al. (2000)
[4] Lawley et al. (2020)
[5] Beaumont-Smith et al. (2006)
[6] Baldwin et al. (1987)

lized. Amphibole-(plagioclase-)–phyric basaltic andesite (Figure GS2022-9-3a) does not contain any quartz phenocrysts, but porphyritic dacite (Figure GS2022-9-3b) and rhyolite contain equant or subrounded quartz (1–2 mm) and locally subhedral to euhedral feldspar (0.5–1.5 mm) phenocrysts embedded in a very fine grained to aphanitic groundmass.

Intermediate lapillistone, lapilli tuff and tuff (subunit 1b), typically displaying millimetre- to centimetre-scale layers, likely represent beds, although foliated and locally folded. Lapilli tuff contains elongated fragments of various lithologies (e.g., rhyolite, porphyritic andesite, aphanitic basalt) embedded in a fine-grained matrix consisting of amphibole, biotite, chlorite, epidote, plagioclase and aphanitic material (Figure GS2022-9-3c). Alternating dark grey and pale yellow-grey layers, about 0.5–1 cm thick, are common and represent mafic and intermediate–felsic intercalations. Lapilli tuff appears to grade laterally to fine-grained tuff that contains interbedded mafic and felsic laminae (~0.5–2 mm). Some tuff and lapilli tuff contain

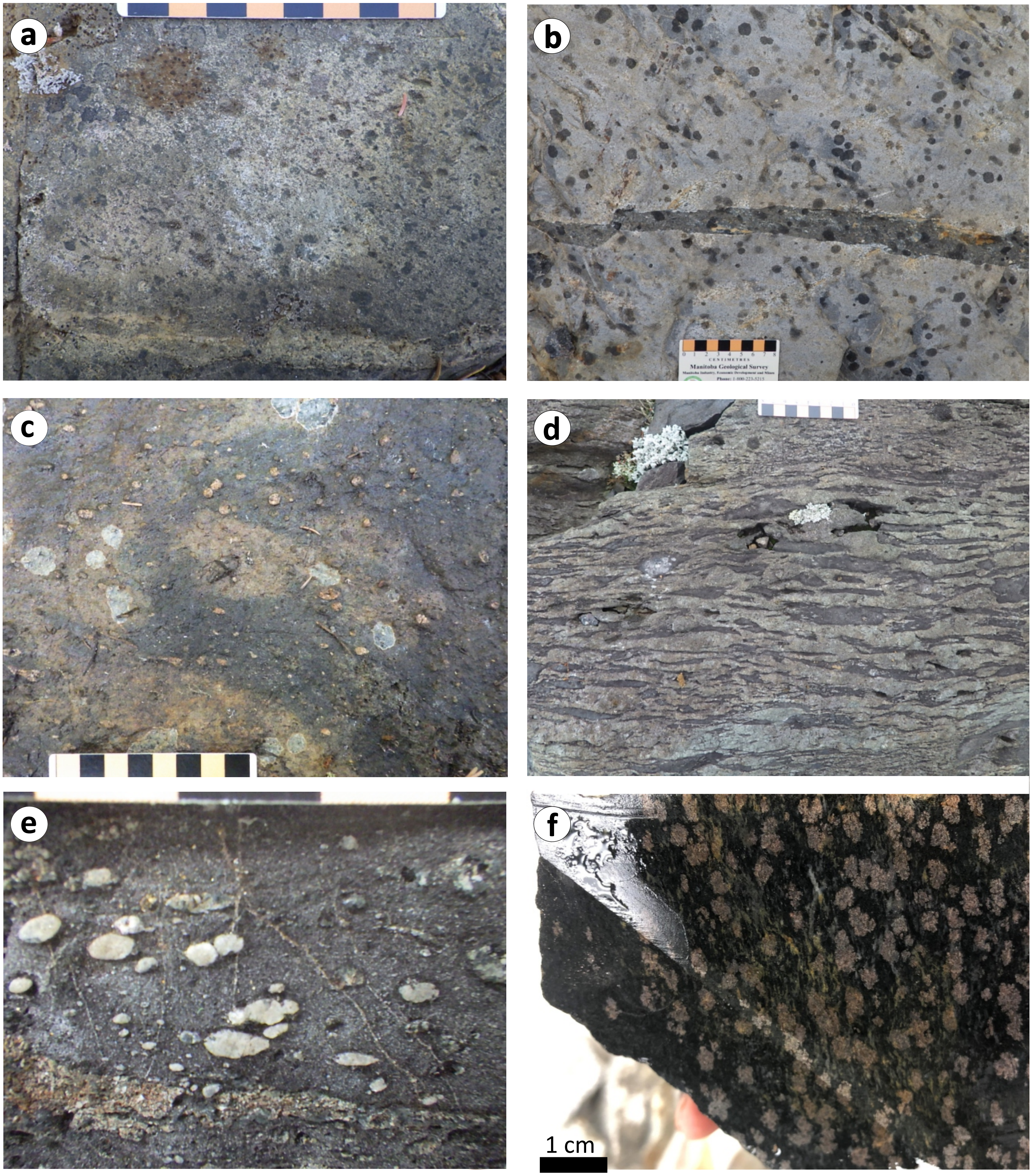


Figure GS2022-9-3: *Field photographs of unit 1 volcaniclastic rocks with minor volcanics and sedimentary rocks of the Wasekwan group in the Fox mine–Snake Lake area:* ***a)*** *amphibole- and plagioclase-phyric basaltic andesite (subunit 1a; UTM Zone 14N, 337470E, 6279101, NAD 83);* ***b)*** *foliated, massive, quartz-phyric dacite cut by a mafic dike up to 4 cm wide (subunit 1a; UTM 337235E, 62777767N);* ***c)*** *foliated andesitic tuff to lapilli tuff containing felsic lithic fragments (subunit 1b; UTM 337147E, 6276091N);* ***d)*** *strongly foliated mafic tuff breccia and breccia with basaltic to andesitic fragments transposed along S_2 foliation (subunit 1d; UTM 341041E, 6279766N);* ***e)*** *some fragments in the mafic volcanic breccia contain stretched oval to subrounded quartz amygdules (same locality as photo d);* ***f)*** *cut slab of sample 111-22-107A01 taken from an outcrop of foliated, medium- to coarse-grained, porphyroblastic garnet amphibolite containing disseminated pyrrhotite (subunit 1c; UTM 336356E, 6278815N) and showing garnet crystals, 5–6 mm in size, that display diffusive grain boundaries and are aligned, together with amphibole and minor plagioclase, in the matrix along S_2 planes. Divisions on scale card are 1 cm.*

reddish garnet porphyroblasts (1–2 mm) that occur preferably in mafic-rich bands or layers and are aligned along S_2 foliation planes.

Mafic volcaniclastic rocks are grouped into two subunits based on size, relative proportion of fragments and composition: subunit 1c includes lapillistone, lapilli tuff, tuff, minor mafic mudstone, and amphibolite and garnet-biotite schist; and subunit 1d includes mafic tuff breccia and breccia (Table GS2022-9-1).

Subunit 1c is characterized by the presence of mafic lithic fragments in an amphibole (and chloritic) matrix. Minor greenish grey, very fine grained, thinly bedded mafic mudstone is included in this subunit. Dark green, acicular actinolite porphyroblasts (up to 5–10 mm), concentrated in foliation or fracture planes in mafic tuff and lapilli tuff, are interpreted to have formed by retrograde greenschist-facies metamorphism. The mafic lapilli tuff and tuff (subunit 1c) are generally moderately to strongly foliated and range from texturally variable to relatively homogeneous. These rocks consist of varied amounts of aphyric lithic fragments and crystal fragments (e.g., plagioclase, chloritic amphibole pseudomorphs after pyroxene) in a fine-grained mafic-tuff matrix. Mafic lapilli-sized fragments make up <25% of subunit 1c but can locally account for up to 80% of the rock, which is then termed mafic lapillistone.

Subunit 1d consists of moderately to strongly foliated mafic tuff breccia and breccia, with various lithic fragments, including plagioclase-phyric basalt, plagioclase-amphibole–phyric basalt, aphyric basalt, lapilli tuff, very fine grained andesite, and minor rhyolite clasts ranging from 8 to 30 cm in length, embedded in a lapilli tuff and tuff matrix. The basaltic fragments are subrounded to subangular, varying in shape from irregular to rarely ellipsoidal, and have been stretched along the generally east-northeast-trending foliation (S_2). In high-strain zones, lithic fragments are sheared and flattened, although the margins of some of the fragments are still discernible (Figure GS2022-9-3d). Some basalt fragments display epidote alteration and others show reaction rims with fine-grained assemblages of chlorite, epidote, sericite and albite. Locally, basalt fragments contain well-preserved quartz amygdules (Figure GS2022-9-3e), and porphyritic fragments display plagioclase and amphibole (after pyroxene) phenocrysts.

Some of the unit 1 volcaniclastic rocks can be classified as garnet-biotite schist because of well-developed schistosity and mineral assemblage (e.g., biotite+plagioclase+garnet+chlorite, quartz and minor magnetite), and others are better termed amphibolite as it is massive rock and contains reddish garnet porphyroblasts in finer amphibole matrix (Figure GS2022-9-3f). The mineral assemblage (i.e., garnet+hornblende±plagioclase) of this garnet amphibolite suggests that its mafic protolith may have experienced middle to upper amphibolite-facies metamorphism at about 5–6 kb and 650–700°C (e.g., Winkler, 1967; Winter, 2014).

Mafic to intermediate volcanic rocks and synvolcanic intrusive rocks (unit 2)

Unit 2 rocks occur mainly south of Dunphy Lakes and in the southwestern part of the map area (Figure GS2022-9-2). This unit consists dominantly of plagioclase-phyric and aphyric basalts and pillow basalt, with subordinate porphyritic basaltic andesite and synvolcanic diabase and gabbro dikes (Table GS2022-9-1).

Synvolcanic diabase and gabbro (subunit 2a) occur mostly as dikes and small plugs in unit 2 volcanic rocks and, in some cases, unit 1 volcaniclastic rocks. The gabbroic rocks are fine to medium grained, porphyritic to equigranular and moderately to strongly foliated. Equant to subhedral plagioclase phenocrysts (up to 10 mm) occur in a fine-grained groundmass of plagioclase, amphibole, chlorite and Fe oxides. Generally, subunit 2a gabbroic rocks consist of 50–60% amphibole and 40–50% plagioclase (Figure GS2022-9-4a). Trace disseminated sulphides (e.g., pyrrhotite; ~0.5–1 mm) are locally evident.

Porphyritic basaltic andesite (subunit 2b) contains amphibole (±biotite) and lesser amounts of plagioclase phenocrysts in a fine-grained groundmass (Figure GS2022-9-4b). Biotite and sericite alteration is common. It is hard to distinguish unit 2b from plagioclase-phyric basalt (subunit 2c), although the latter commonly lacks amphibole (±biotite) phenocrysts (Figure GS2022-9-4c) but commonly exhibits epidote alteration.

Massive aphyric basalt (subunit 2c) is common in the map area. Vesicles and quartz±calcite amygdules are present in some outcrops. Chlorite and epidote alteration is common in the aphyric basalt, as shown by epidote domains as veins and patches ranging from a few centimetres to a metre across.

Pillow basalt (subunit 2d) is exposed and preserved in a relatively low-strain area south and southwest of the Fox mine (Figure GS2022-9-2). Pillow size ranges from 20 to 40 cm and locally reaches up to 100 cm, with well-preserved hyaloclastite selvages up to 3 cm thick. In high-strain areas, pillows are strongly deformed and contain a penetrative foliation. Some pillow selvages are still recognizable and contain stretched vesicles and quartz amygdules transposed along S_2 foliation (Figure GS2022-9-4d). Epidote alteration as veinlets, patches or nodules was commonly observed in basalt with few plagioclase phenocrysts.

Sedimentary rocks intercalated with minor volcanic sedimentary rocks (unit 3)

Unit 3 sedimentary rocks are exposed mainly in the central and northwestern portions of the map area (Figure GS2022-9-2) and can be subdivided into three subunits (Table GS2022-9-1).

Thin- to medium-bedded quartzofeldspathic greywacke, siltstone and argillite (subunit 3a) dominate the sedimentary succession. Primary bedding (S_0) in the sedimentary rocks was transposed by the regional S_2 foliation. The medium- to coarse-grained greywacke is composed mostly of quartz, feldspar, amphibole and lithic clasts (1.5–2 mm) that are well aligned on foliation planes defined by biotite flakes and manifested by felsic-

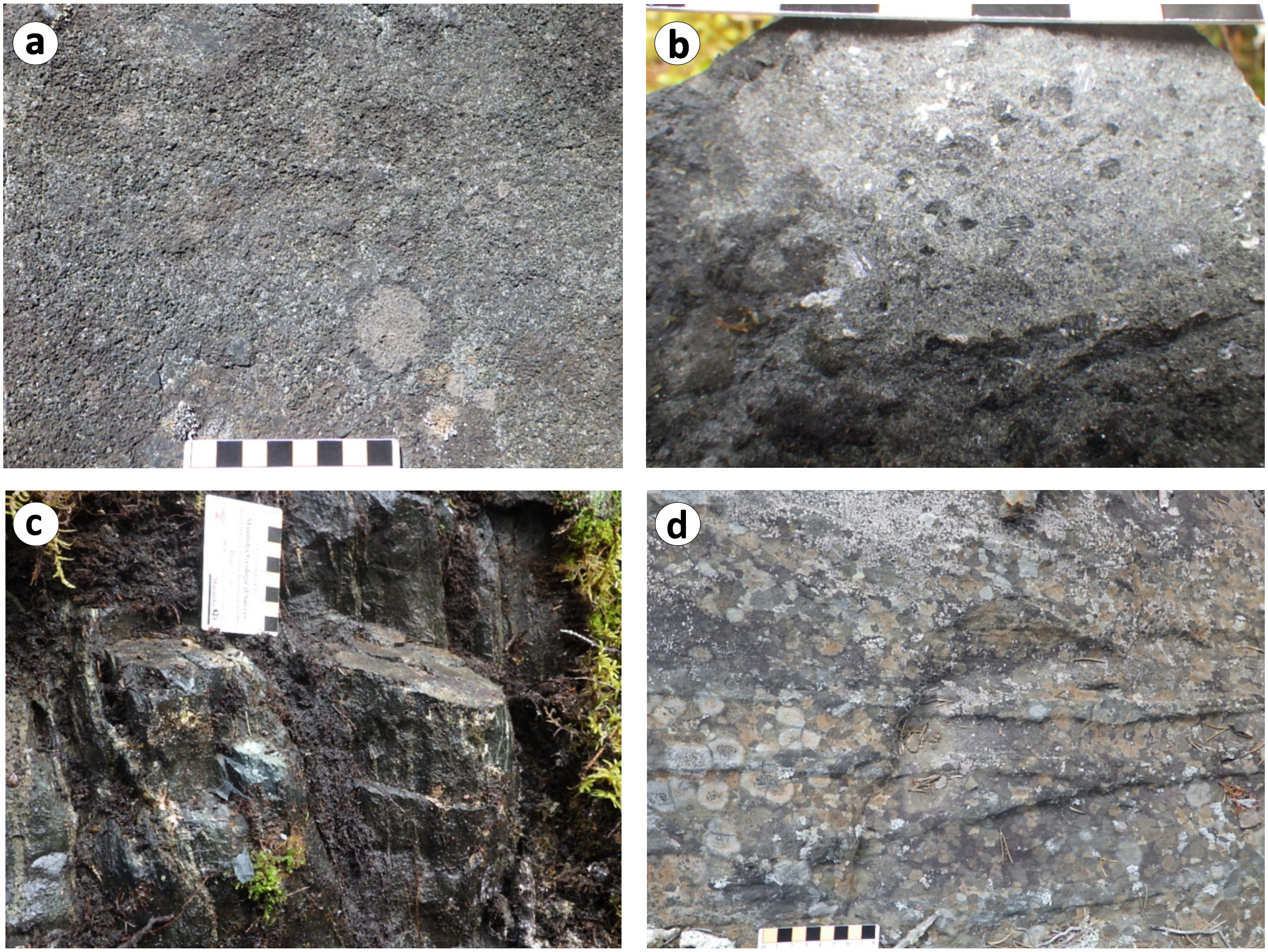


Figure GS2022-9-4: *Field photographs of mafic to intermediate volcanic rocks and synvolcanic intrusive rocks (unit 2) of the Wasekwan group in the Fox mine−Snake Lake area:* ***a)*** *synvolcanic massive gabbro (subunit 2a; UTM Zone 14N, 338119E, 6279300N, NAD 83);* ***b)*** *amphibole-phyric basaltic andesite (subunit 2b; UTM 337803E, 6274906N);* ***c)*** *strongly foliated, aphanitic to plagioclase-phyric basalt (subunit 2c; UTM 338228E, 6280088N);* ***d)*** *strongly foliated pillow basalt with partial hyaloclastite selvage, the stretched pillows aligned along S_2 foliation planes (subunit 2d; UTM 337080E, 6276502N). Divisions on scale card are 1 cm.*

and mafic-rich layering that likely reflects transposed bedding (Figure GS2022-9-5a). Scattered pyrite grains are locally evident in the greywacke and are associated with felsic and/or quartz veins and veinlets. Although strongly foliated and folded (Figure GS2022-9-5b), a unique bed of coarse-grained arkosic greywacke (subunit 3a) with relatively low MS values of 0.179 × 10^{-3} to 0.215 × 10^{-3} SI consists dominantly of quartz and feldspar with much less clay material in a matrix containing muscovite and/or biotite, and locally shows graded bedding indicative of younging to the south.

Thin to thick beds of volcanic sedimentary rocks (subunit 3c) consist of volcanic mudstone, siltstone and sandstone, and minor volcanic breccia (Table GS2022-9-1). Tuffaceous sandstone is dominated by laminated, fine- to medium-grained andesitic sandstone consisting mainly of irregular plagioclase, biotite flakes and lithic fragments in a fine sandy matrix; locally, a few large lithic fragments occur along bedding transposed by regional S_2 foliation (Figure GS2022-9-5c). Locally, subunit 3c volcanic sandstone contains fine-grained magnetite grains and displays a relatively high MS value of 1.25 × 10^{-3} (Figure GS2012-9-5d).

Minor volcanic conglomerate of unit 3c consists dominantly of felsic and intermediate–mafic volcanic clasts in a coarse-grained sandy matrix. These clasts are stretched or flattened and well aligned along S_2 planes that transposed primary bedding. Although not exposed at surface, banded iron formation was intersected by a few historical drillholes in the southeastern part of the map area. It is likely part of the unit 3 sedimentary rocks (e.g., Yang, 2019) and is correlated with highly magnetic, northeast-trending band(s) in the area that are indicated by detailed airborne magnetic data.

Pre-Sickle intrusive suite (units 4 and 5)

Pre-Sickle intrusive suite rocks consist of gabbro and minor diorite of unit 4 and granitoid rocks of unit 5 that occur as plutons

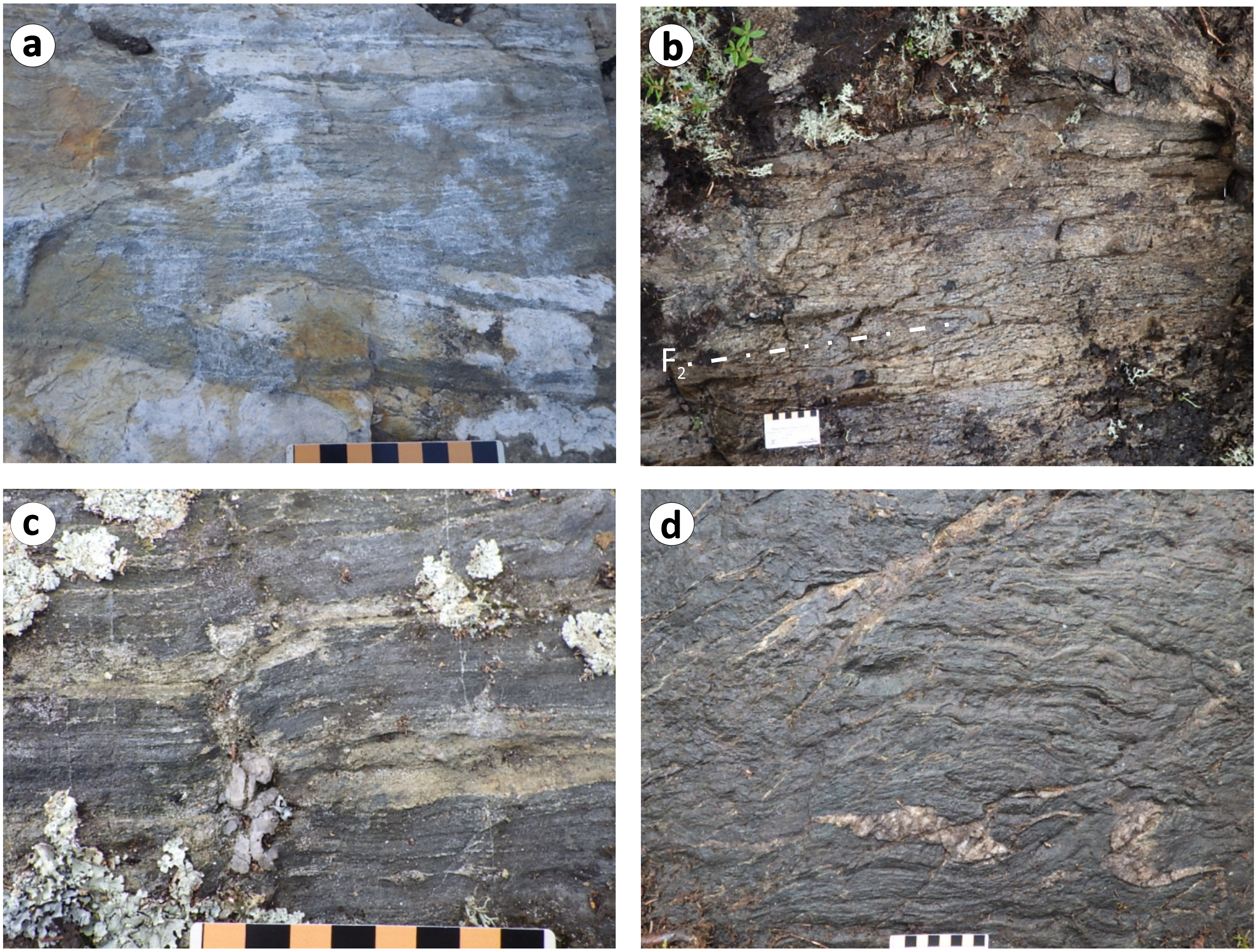


Figure GS2022-9-5: *Field photographs of sedimentary rocks intercalated with minor volcano-sedimentary rocks (unit 3) of the Wasekwan group in the Fox mine−Snake Lake area:* ***a)*** *medium-grained, foliated greywacke with alternating felsic and mafic bands or layering (subunit 3a; UTM Zone 14N, 337634E, 6280046N, NAD 83), which is intruded by fine-grained aplitic dikes (unit 8) up to 10 cm in width;* ***b)*** *strongly foliated arkosic greywacke contains a rootless isoclinal fold (F_2) formed by D_2 formation (unit 3a; UTM 338378E, 6279970N);* ***c)*** *foliated, laminated mafic to intermediate tuffaceous sandstone to tuff (subunit 3b; UTM, 364850E, 6290199N), which is cut and offset by a late quartz vein formed by the D_4 deformation event;* ***d)*** *volcanic sandstone with intermediate to mafic volcanic fragments, its bedding transposed by S_2 foliation that is foliated and folded (subunit 3c; UTM 336954E, 6281033N).*

and/or intrusions in supracrustal rocks of the Wasekwan group, which are overlain unconformably by the Sickle group epiclastic rocks.

Gabbro and minor diorite (unit 4)

Unit 4 occurs mainly in the southern and southeastern parts of the map area (Figure GS2022-9-2). This unit occurs as stock or sill-like intrusions in the Wasekwan group and is cut by unit 5 granitoids. Unit 4 gabbro is foliated, massive, equigranular and medium to coarse grained. It consists of 30–40% plagioclase laths (1–3 mm), 55–60% amphibole (pseudomorphs after pyroxene), minor Fe-oxide minerals and trace pyrrhotite±chalcopyrite (Figure GS202-9-6a). It is locally transitional to medium-grained diorite and texturally grades to very coarse grained gabbro east of Snake Lake. Notably, late quartz (-pyrite) veins cut unit 4 gabbro, resulting in channelized hydrothermal alteration manifested by light red garnets, 3–5 mm across, in the gabbro (Figure GS2022-9-6b).

Granitoid rocks (unit 5)

Unit 5 granitoids occur as a stock (herein termed the ‘Snake Lake stock’) and are exposed mainly in the southwestern part of the map area (Figure GS2022-9-2). This unit comprises quartz diorite, tonalite, granodiorite and granite, and associated pegmatitic and aplitic dikes.

Unit 5 tonalite is medium to coarse grained, massive, equigranular to locally porphyritic and weakly to moderately foliated. It consists of 20–25% quartz, 40–45% plagioclase, 5–10%

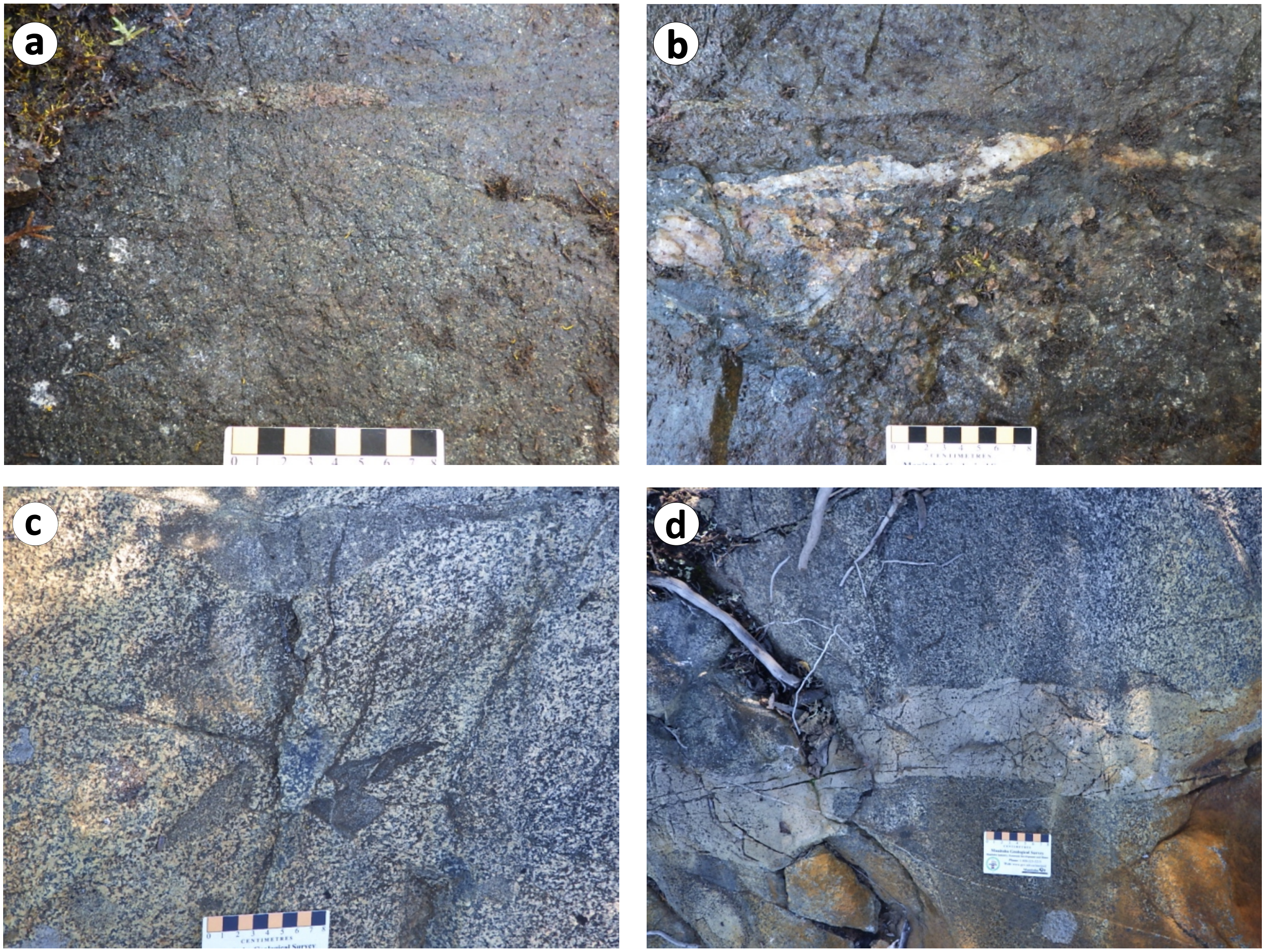


Figure GS2022-9-6: *Outcrop photographs of units 4 and 5 in the Fox mine−Snake Lake area:* ***a)*** *foliated, massive, fine- to medium-grained equigranular gabbro with elongated fragment displaying epidote alteration (unit 4; UTM Zone 14N, 341604E, 6278891N, NAD 83);* ***b)*** *unit 4 gabbro with reddish garnets along north-trending, steeply dipping quartz vein (same location as photo a);* ***c)*** *foliated, massive, medium-grained tonalite (unit 5; UTM 337853E, 6277181N) with angular xenoliths of mafic aphanitic volcanics, plagioclase-phyric basalt and porphyritic diorite;* ***d)*** *foliated, massive, medium-grained quartz diorite cut by an ~20 cm wide aplite dike (unit 5; UTM 337919E, 6277209N).*

K-feldspar, 15–25% hornblende (±biotite) and accessory Fe-oxide minerals. At the contact zone with unit 2 basaltic rocks, tonalite contains variable, angular, mafic volcanic to porphyritic xenoliths (Figure GS2022-9-6c). Some of the porphyritic variety contains ~5% quartz phenocrysts up to 1 cm across, suggesting relatively shallow emplacement into the Wasekwan group supracrustal package.

Quartz diorite occurs mostly as marginal phases of the Snake Lake stock and is fine to medium grained, massive, equigranular and moderately to strongly foliated. It consists of 5–10% anhedral quartz, 50–60% plagioclase, 20–30% hornblende and minor biotite. Granodiorite to granite occur mainly in the southwestern part of the stock, where K-feldspar is more abundant than plagioclase and biotite occurs as the dominant ferromagnesian mineral.

Pegmatite and/or aplite of subunit 5a are not uncommon in association with unit 5 granitoid rocks, which occur as dikes, a few centimetres to a few metres wide, and consist of quartz, feldspar and minor biotite (Figure GS2022-9-6d).

Sickle group (unit 6)

Sickle group sandstone (subunit 6a) and polymictic conglomerate (subunit 6b) outcrop in the southeastern corner of the map area (Figure GS2022-9-2). Subunit 6a sandstone is interpreted as stratigraphically overlying subunit 6b conglomerate (e.g., Gilbert et al., 1980). Medium- to thick-bedded arkosic sandstone and quartz pebbly sandstone of subunit 6a are fine to coarse grained and composed of feldspar, quartz, mica, lithic fragments and finer material. Up to 10% quartz pebbles (3–5 mm) are common in the quartz pebbly sandstone.

Subunit 6b conglomerate is polymictic, poorly sorted, and matrix to clast supported, and contains variably sized (2–30 cm), rounded and subrounded to irregular clasts ranging from pebble to boulder size. Generally, cobble-size clasts are more common. Clast types include mafic and felsic volcanic rocks, granitoids, vein quartz, epidotized fragments and chert in a sandy to wacke matrix.

Post-Sickle intrusive suite (unit 7)

The post-Sickle intrusive suite (unit 7) is represented by the Fox mine intrusion (1831.0 ±3.7 Ma; Turek et al., 2000) and part of the Dunphy Lakes batholith (1847 ±2 to 1829 ±2 Ma; see Beaumont-Smith and Böhm, 2003; Yang and Beaumont-Smith, 2015b). Unit 7 granitoid rocks occur mainly in the northern part of the map area (Figure GS2022-9-2).

Unit 7 comprises quartz diorite, tonalite and granodiorite. Quartz diorite is fine to medium grained, weakly to moderately deformed and composed of 5–10% quartz, 60–70% plagioclase and 15–20% amphibole (Figure GS2022-9-7a). Tonalite is medium to coarse grained, moderately foliated and contains ~20% quartz and less amphibole (Figure GS2022-9-7b). Quartz diorite and tonalite of the Fox mine intrusion display as magnetic lows on the detailed airborne magnetic imagery. These rocks have high Sr/Y and La/Yb ratios (Yang, in press), resembling post-Sickle quartz diorite at Farley Lake that exhibits geochemical characteristics of adakite-like rocks (Yang and Lawley, 2018). Granodiorite is medium to coarse grained, foliated and equigranular to locally porphyritic.

Late intrusive suite (unit 8)

Unit 8 quartz-feldspar porphyry, feldspar porphyry pegmatite and/or aplite occur mostly as dikes in the central, southwestern and northeastern portions of the map area (Figure GS2022-9-2). Unit 8 rocks do not show any relationship to pre- and post-Sickle

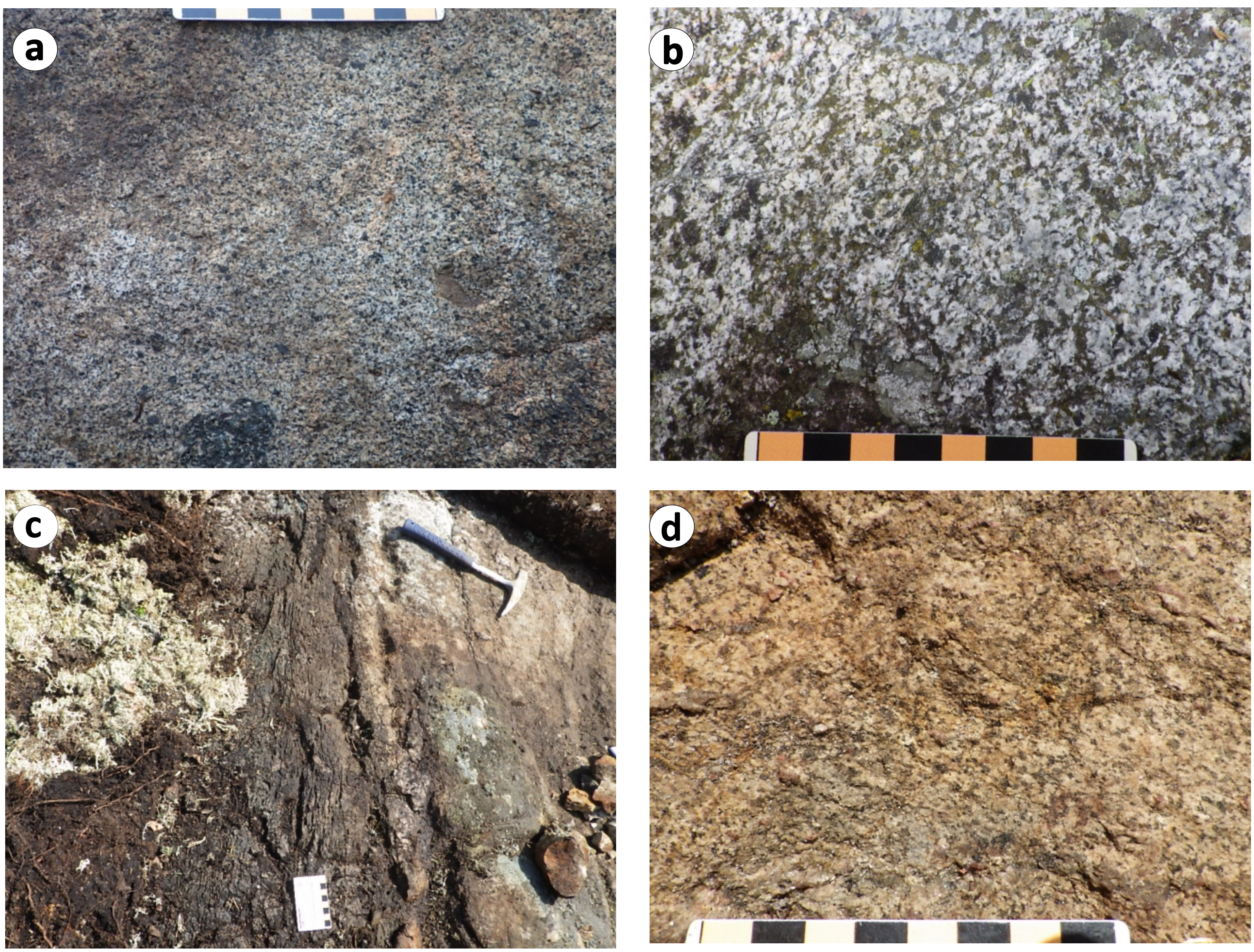


***Figure GS2022-9-7:** Outcrop photographs of units 7 and 8 intrusive rocks in the Fox mine−Snake Lake area: **a)** fine- to medium-grained, massive quartz diorite (unit 7; UTM Zone 14N, 337979E, 6280499N, NAD 83); **b)** foliated, massive, coarse-grained, equigranular tonalite (unit 7; UTM 338325E; 6282812N); **c)** quartz-feldspar porphyry (granite) dike (unit 8; UTM 341624E; 6279950N) cuts strongly foliated mafic volcaniclastic rock of subunit 1c (left side; minor malachite is present at the contact; hammer handle points to north); **d)** massive quartz-feldspar porphyry containing muscovite flakes (~1%) and minor reddish garnet grains, 5 m from the contact with unit 1 amphibolite (unit 8; UTM 341624E; 6279950N).*

intrusive suites (units 5 and 7), and are therefore assigned to the late intrusive suite. Malachite stains were noted along the contact between a quartz-feldspar porphyry dike (up to 15 m wide) and subunit 1c amphibolite, and muscovite flakes (~1%) and minor reddish garnets occur evenly in the porphyritic granite ~5 m away from the contact (Figure GS2022-9-7a, b). The presence of muscovite and garnet indicates that this quartz-feldspar porphyry is likely an S-type granite, although it has relatively high MS values of 0.404 × 10^{-3} SI due to disseminated primary pyrrhotite (e.g., Yang et al., 2019). Pegmatite and aplite of unit 8 commonly contain muscovite (±tourmaline) in addition to biotite.

Tectonite (unit 9)

Tectonite of unit 9 comprises mafic to felsic protomylonite to mylonite within the Dunphy Lakes shear zone (DLSZ) and Pumphouse shear zone (Figure GS2022-9-2), characterized by the development of intense S_2 tectonic fabrics (Beaumont-Smith and Böhm, 2002; this study). Although the protoliths of such high-strain rocks are difficult to determine in the field, some of the feldspar, quartz and lithic relicts may be partly preserved in tectonite that shows ductile deformation (Figure GS2022-9-8a, b). Mafic tectonites derived from mafic volcanic flows and/or volcaniclastic rocks are indistinguishable, particularly those that were altered to very fine grained chlorite and sericite materials. Some S-C fabrics are well

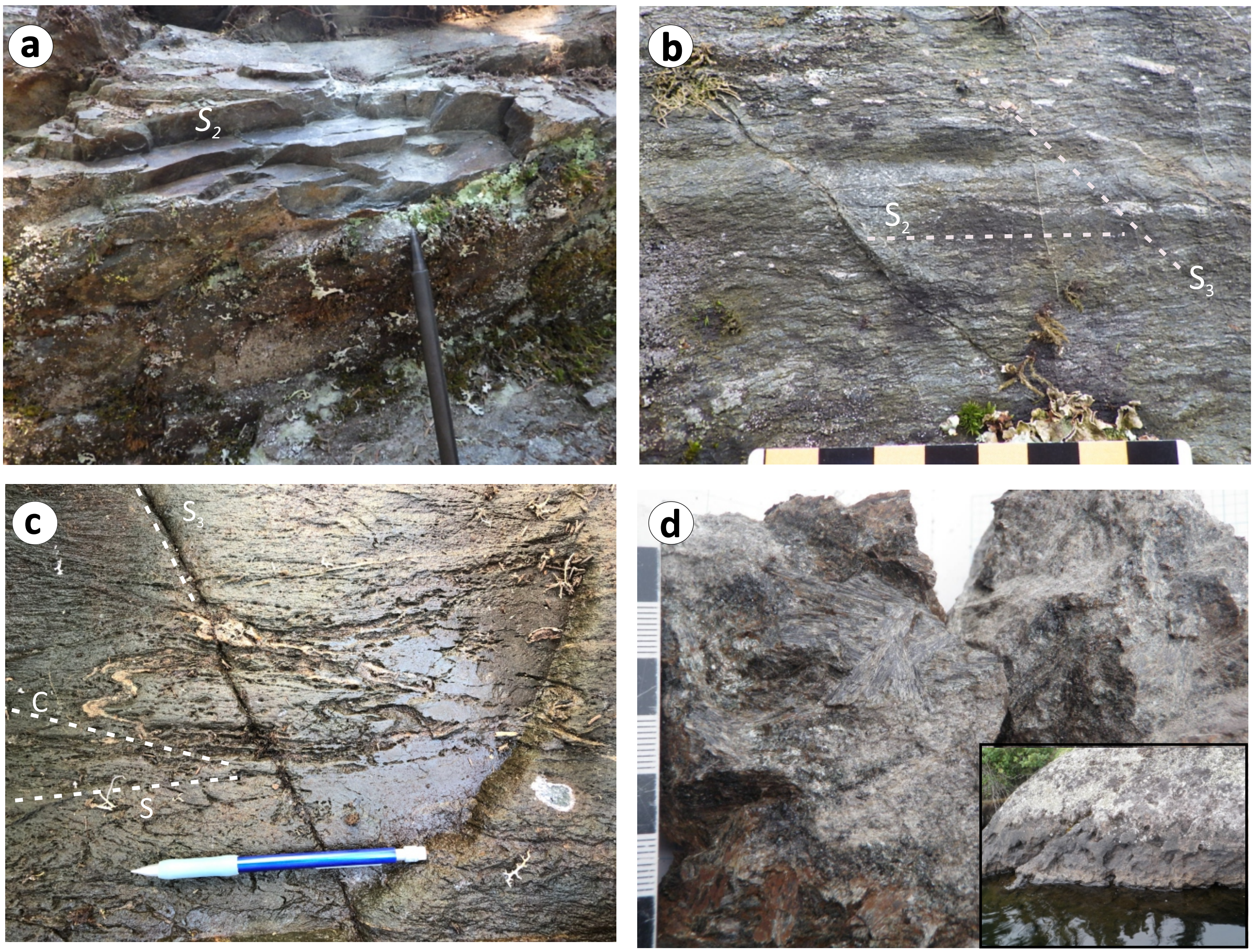


Figure GS2022-9-8: *Outcrop photographs of unit 9 tectonite in the Fox mine–Snake Lake area: **a)** shallowly dipping S_1 fabrics cut by subvertical S_2 foliation plane (indicated by the pencil) developed in mafic mylonite (unit 9; UTM Zone 14N, UTM 339887E; 6280527N, NAD83); **b)** protomylonite derived from unit 3 volcanic sandstone and conglomerate, in which relicts of quartz, feldspar and mafic to felsic volcanic fragments are preserved and aligned along S_2 foliation planes and cut by S_3 cleavages (UTM 338012E, 6281178N); **c)** S-C fabrics indicative of dextral shear in mafic mylonite, with folded quartz veins cut by S_3 fabrics (UTM 340579E, 6280688; pencil points to the east); **d)** radial aggregates of megacrystic actinolite (UTM 340421E, 6277000N) formed by retrograde greenschist-facies metamorphism, evident in a structural-breccia zone in unit 4 gabbro that is about 10–15 m wide, trends 350° and dips at about 80° to east; inset in lower right shows the gabbroic breccia at the shoreline of Snake Lake.*

developed within the DLSZ, providing a reliable shear-sense indicator (e.g., dextral shear; Figure GS202022-9-8c).

Structural geology

The LLGB was involved in six generations of regional deformation (D_1 to D_6; Beaumont-Smith and Böhm, 2002, 2004), although these structures are not necessarily encountered in one area. In the map area, D_1 fabrics are locally evident as penetrative, shallow-dipping S_1 foliation (Figure GS2022-9-8a) overprinted by vertical S_2 fabrics associated with D_2 deformation. D_1 fabrics, which are not found in the Sickle group, Pool Lake suite (Gilbert et al., 1980) or pre-Sickle intrusive suite rocks, likely formed due to the assembly of volcanic terranes (Beaumont-Smith and Böhm, 2002, 2003, 2004).

The D_2 structures are dominant and penetrative, and manifest as a steeply north-dipping S_2 foliation and tight to isoclinal folds (F_2) that have shallowly plunging hinges and associated minor chevron folds. The S_2 fabrics were observed in all map units except the late intrusive suite (unit 8). Typically, S_2 foliations dip steeply north and contain a down-dip to steeply plunging mineral and stretching lineation. Ductile shear zones that generally define map-unit contacts are commonly related to D_2 deformation, as the intensity of S_2 fabrics and tightness of F_2 folds increase toward the contacts. The D_2 shear zones are characterized by a steep south to north strain gradient culminating in a 30–50 m wide mylonitic core, dextral shear-sense indicators (e.g., Figure GS2022-9-8c) on horizontal surfaces, and steeply plunging, generally down-dip to slightly oblique (easterly pitch) stretching lineations. The northeast-trending DLSZ and PSZ are dextral transpressional shear zones formed during D_2 deformation (Beaumont-Smith and Böhm, 2002; Figure GS2022-9-2). The DLSZ appears to be the western extension of the regional JSZ, whereas the PSZ is likely the continuation of the North Star Lake shear zone (Yang, 2019; Beaumont-Smith, 2000), which could be part of a southern splay of the JSZ (Beaumont-Smith and Böhm, 2002).

The D_3 deformation is represented by close to tight, S-asymmetric F_3 folds and northwest-trending, axial-planar S_3 crenulation cleavage. F_4 folds produced by the D_4 deformation event are also 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 cleavage. The Mukasew Lake and Snake Lake faults (Figure GS2022-9-2) strike north-northeast and display sinistral movement, and are associated with D_4 deformation. Some fault breccia contains megacrystic, radial actinolite aggregates (Figure GS2022-9-8d) in the Snake Lake fault, which was likely formed during greenschist-facies metamorphism.

Economic considerations

Mafic to felsic volcaniclastic rocks, volcanic rocks characterized by coexistence of plagioclase- and amphibole-phyric varieties, and derivative volcanic sedimentary rocks in the map area suggest that the Wasekwan group (units 1–3) may have been derived from hydrous calcalkaline to tholeiitic magmas in a volcanic-arc to back-arc setting. Plotting of published geochemical data (Zwanzig et al., 1999; Beaumont-Smith, 2008) from mafic to felsic volcanic rock samples (n = 26) from the map and adjacent areas on a diagram (not shown) of Nb/Y versus σ values, based on the parameters defined respectively by Pearce (1996) and Yang (2007), indicate that volcanic rocks of units 1 and 2 are exclusively calcalkaline, consistent with their emplacement into a magmatic arc to back-arc setting. Unit 1 calcalkaline dacitic to rhyolitic rocks are geochemically similar to FII felsic rocks identified by Lesher et al. (1986) and Hart et al. (2004), suggesting the felsic rocks of unit 1 are a good but rare example of a Paleoproterozoic felsic volcanic package that could host VMS Cu-Zn deposits.

The Wasekwan group supracrustal rocks (units 1–3) were intruded by the pre-Sickle intrusive suite (units 4 and 5), post-Sickle granitoid (unit 7) and, subsequently, late intrusive suite (unit 8). Unit 4 gabbroic intrusions contain disseminated pyrrhotite and, locally, chalcopyrite, and thus need to be further evaluated for magmatic Ni-Cu-PGE minerals. Unit 7 granitoid rocks display adakite-like signatures and may have played a role in Au mineralization (Thorne et al., 2002; Yang and Lawley, 2018; Yang, 2019, 2021). The occurrences of I-type adakite-like granitoids in the map area suggests that tectonic settings may have evolved from intra-arc extension induced by slab roll-back to terrane terminal collision (Yang and Lawley, 2018).

Based on the Manitoba Mineral Inventory Cards (https://mrsearch.gov.mb.ca/Itm-cat/web/minsearch.html), the Fox VMS deposit and four mineral occurrences (Figure GS2022-9-2) suggest the presence of diverse styles of mineralization within the map area (Ferreira, 1993). Appreciable amounts of residual mineral resources are evidently present below the mined-out orebodies of the Fox mine, suggestive of high exploration potential. The North Fox occurrence on the southwestern shore of Dunphy Lakes, located about 1.76 km north of the Fox mine, contains a sulphide zone up to 18.8 m in width (pyrrhotite+arsenopyrite+chalcopyrite+pyrite; Ferreira, 1993) hosted in sedimentary rocks and minor volcanic sedimentary rocks that were strongly deformed and mylonitized to be termed tectonite (unit 9). The BAG occurrence (labelled A on Figure GS2022-9-2) shows disseminated pyrite and chalcopyrite in siliceous anthophyllite-corderite-biotite±garnet porphyroblastic schist (Stewart and Brewer, 1984), similar to the alteration zone of the Fox VMS deposit (Obinna, 1974; Lustig, 1979). This metamorphic mineral assemblage may have been derived from a primary chlorite±sericite hydrothermal alteration associated with VMS mineralization overprinted by middle- to upper-amphibolite–facies metamorphism. Felsic rocks similar to those of the Fox deposit occur southeast of Snake Lake, where chip samples collected from exploration trenches south of the pond on the GAL occurrence (labelled B) contain mineralization with up to 61.7 g/t Au, 2011 g/t Ag, 22% Cu and 7.7%

Pb (https://manitoba.ca/iem/geo/gis/mds/m64c_12_009.pdf). At an unnamed occurrence (labelled C), historical drilling intercepted mineralization, including a 1.6 m pyrrhotite zone containing trace Zn and Ni (Assessment File 91016, Manitoba Natural Resources and Northern Development, Winnipeg), hosted in unit 1 felsic volcanic rocks cut by intrusions of units 4 and 5.

Acknowledgments

The author thanks M. Fahim for providing enthusiastic field assistance, and C. Epp and P. Belanger for thorough logistical support, cataloguing and processing of the samples. Thanks go to L. Chackowsky and H.O. Adediran for assistance with GIS and drafting of the preliminary map and Figure GS2022-9-2, respectively. Alamos Gold Inc. is thanked for generously providing detailed geophysical data. B.R. King at Oakridge Environmental Ltd. kindly provided underground drilling data from the Fox mine. Willeson Metals Corp. is acknowledged for allowing field crew to enter their property. Nutrien and its contractors (Strilkiwski and Arcadis) are thanked for permitting use of the access road passing through their property. Constructive reviews by K.D. Reid and C.O. Böhm, technical editing by R.F. Davie and report layout by C. Steffano are gratefully acknowledged.

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