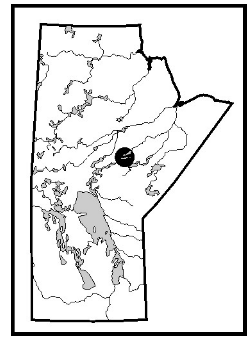
GS-7 Preliminary results from geological mapping of the Bear Lake greenstone belt, Manitoba (parts of NTS 53M4 and 63P1)

by R.P. Hartlaub[1] and C.O. Böhm



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Summary

The Bear Lake area, lying within the Superior Province in Manitoba, hosts several shear zone–bounded panels of lower- to middle-amphibolite facies, mixed volcanic and sedimentary rocks. Together, these panels make up the discontinuously exposed Bear Lake greenstone belt. The belt likely represents the westerly, strongly attenuated continuation of the Oxford Lake–Knee Lake belt, the largest contiguous greenstone belt in the northwestern Superior Province. The volcanosedimentary package at Bear Lake is most comparable to supracrustal rocks of the Hayes River Group at northern Oxford Lake and southwestern Knee Lake, but may also contain rocks of the Oxford Lake Group. At Bear Lake, the supracrustal rocks are interpreted as mafic, intermediate and felsic volcanic rocks, volcanic breccia, iron formation, conglomerate, volcaniclastic rocks and greywacke. Shear zones bounding the Bear Lake greenstone belt are east trending, contain dextral kinematic indicators and include a major northwest-southeast splay. Granite-granodiorite locally cuts the greenstone belt and makes up the majority of outcrop on the eastern half of Bear Lake. Together with planned mapping in the Utik Lake area, this study will provide an improved geological context and regional framework for base- and precious-metal exploration in this part of the northern Superior Province.

Introduction

The gold and base-metal potential of Precambrian belts of volcanic rock, also known as greenstone belts, has been well established. Within the Archean Superior Province of Manitoba and Ontario, numerous Cu- and Zn-rich, volcanic-associated massive sulphide (VMS) deposits have been discovered in these greenstone belts (Evans and Moon, 1995). Where shear zones intersect belts of volcanic and sedimentary rock, there is also significant potential for orogenic gold mineralization (e.g., Lin, 2001; Dubé et al., 2004). The strong economic potential of these belts is the impetus for a new three-year effort to re-examine the volcanic and sedimentary rocks in the Utik and Bear lakes area of the northern Superior Province in Manitoba. During the first year of the project, the Bear Lake area was remapped at 1:50 000 scale. The preliminary findings of the fieldwork at Bear Lake are summarized in this report and on a preliminary geological map (Böhm and Hartlaub, 2006). The plan for 2007 is to remap the Utik Lake area and subsequently synthesize the field and analytical results, with final geological maps of the two areas being produced in 2008.

Bear Lake is located approximately 125 km southeast of Thompson, Manitoba, in the Archean Superior Province. The lack of road access has limited the amount of geological and exploration work in the area, but previous geologists (Milligan, 1952; Allen, 1953; Milligan and Take, 1954; Weber, 1974) have noted well-exposed volcanic and volcanogenic rocks in the area. Volcanic and sedimentary rocks that are possibly coeval with those at Bear Lake are also exposed 10 km to the north at Utik Lake (Hargreaves, 1975; Hargreaves and Ayres, 1979). The volcanic sequences, informally termed the Bear Lake and the Utik Lake greenstone belts, lie along the northern margin of the Gods Lake Domain (Weber and Scoates, 1978), which is now referred to as the Oxford Lake–Stull Lake terrane (Skulski et al., 2000) and is located south of the granulite-grade Pikwitonei Domain.

The Bear Lake and Utik Lake supracrustal belts have an easterly trend that parallels the regional (Card, 1990) structure of the Superior Province. Based on regional correlation using magnetic data and field lithological descriptions, the Bear Lake greenstone belt likely forms the westerly continuation of the Oxford Lake–Knee Lake belt (Figure GS-7-1). At Knee Lake, this largest greenstone belt in the northwestern Superior Province represents a complex of two supracrustal sequences, the volcanic-dominated, ca. 2.83 Ga Hayes River Group and the sedimentary-dominated, ca. 2.71 Ga Oxford Lake Group (e.g., Syme et al., 1997; Corkery et al., 1999). Dating of the volcanic rocks at Bear Lake is one of the main focuses of this study and will, together with detailed major- and trace-element geochemistry and isotope geochemistry, facilitate correlation with other dated supracrustal rocks in the region. The volcanic and sedimentary rocks at Bear Lake are intruded by voluminous granite and granodiorite gneiss exposed in the region. A thin veneer of glacial material covers much of the area,

[1] Department of Mining Technology, British Columbia Institute of Technology, 3700 Willingdon Avenue, Burnaby, British Columbia V5G 3H2

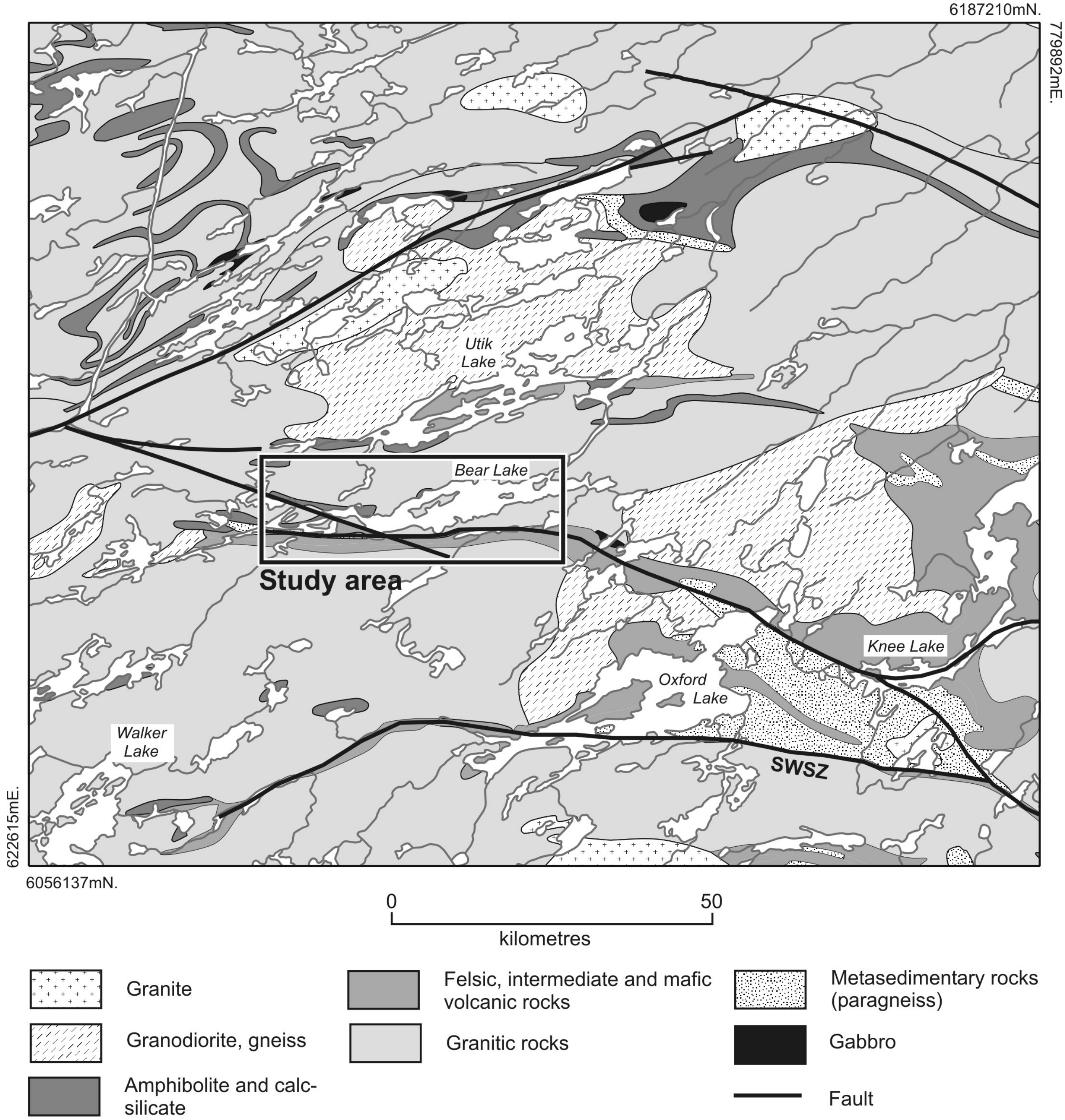

Figure GS-7-1: *Simplified, regional geology of part of the northern Superior Province in Manitoba, with the Bear Lake mapping area outlined. Abbreviation: SWSZ, Stull–Wunnummin shear zone.*

but this overburden is relatively thin on western Bear Lake.

General geology

Two main east-trending structural panels of sedimentary and volcanic rocks occur within the Bear Lake area. One panel is exposed along the northwestern end of Bear Lake and a second, thicker one occurs at southwestern Bear Lake and extends east to McKechnie Lake (Figure GS-7-2). The northwest-trending shear zone that cuts across western Bear Lake acts as the northern boundary of the southern panel. Rocks interpreted to be volcanic at Bear Lake include mafic, intermediate and felsic compositions, volcanic breccia, and volcaniclastic and tuffaceous rocks. Rare horizons of sulphide-facies iron formation are interlayered with these presumably volcanic and volcaniclastic rocks. Clastic sedimentary rocks of unclear relative age and association with the volcanic rocks include minor greywacke and pebble conglomerate. Graded bedding indicates mainly that the

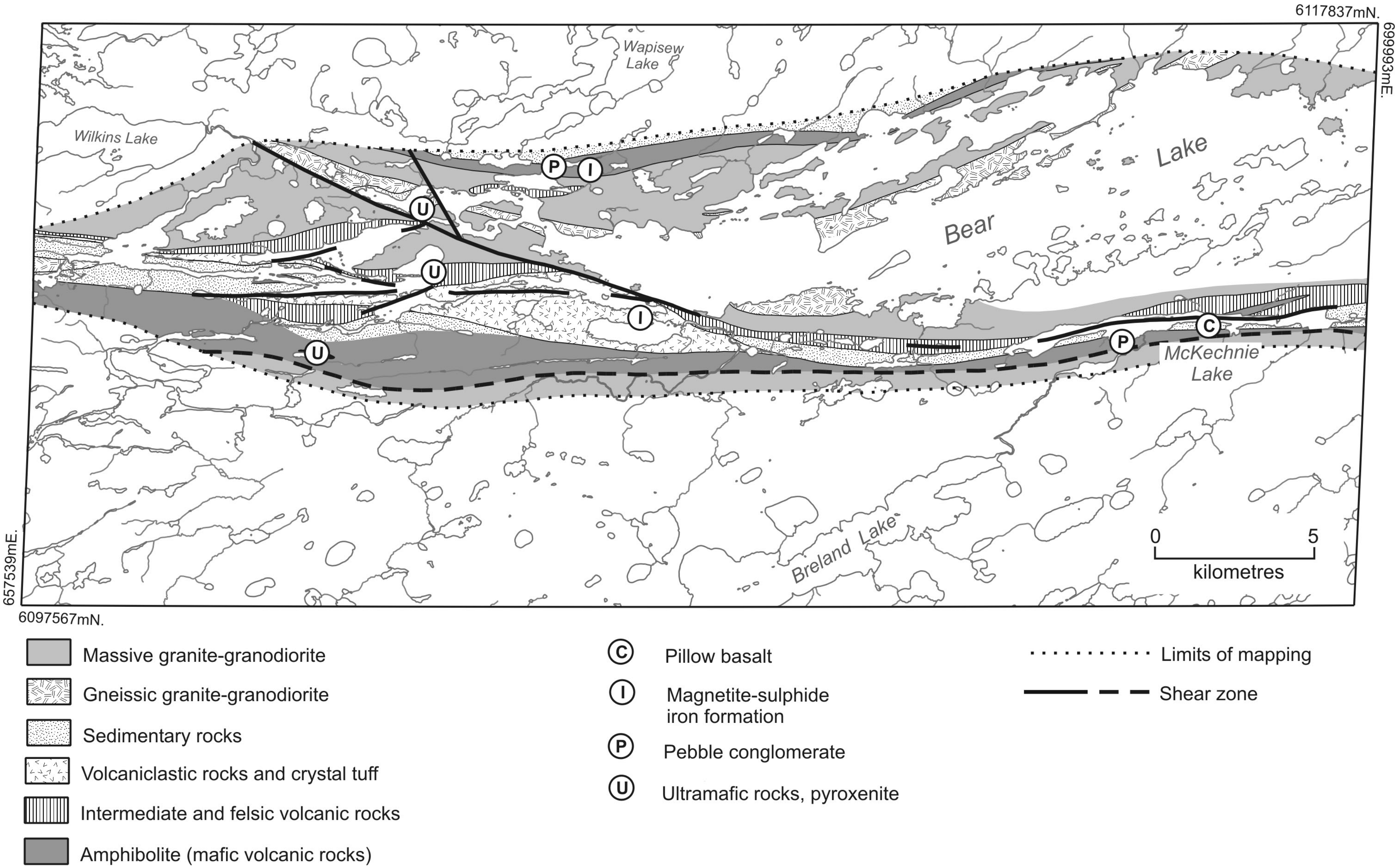

Figure GS-7-2: *Simplified geological map of the Bear Lake area.*

volcanic and sedimentary rocks consistently young to the south. The consistent south-dipping foliation and south younging direction indicate that no significant refolding of the greenstone belt has occurred. The two structural panels are partially bounded by shear zones, as well as by large volumes of granite and granodiorite gneiss (Figure GS-7-2). These felsic intrusive rocks clearly crosscut the mafic volcanic rocks in many locations and were therefore sampled for U-Pb geochronology to obtain a minimum age for volcanism. The youngest units in the area are undeformed granite, pegmatite and mafic dikes.

Supracrustal rocks

Amphibolite interpreted as mafic volcanic rocks

Black, fine- to medium-grained amphibolite is the dominant mafic rock type in both structural panels. Amphibolite occurs as massive, pillowed and layered varieties, with the massive variety the most abundant. Obviously pillowed amphibolite has been observed at two localities in the map area. Well-developed volcanic pillows, with amphibole- and garnet-rich selvages, occur at one location in the northern panel (Figure GS-7-3a, -3b). A second location was observed on McKechnie Lake. Larger exposures of pillowed basalt have been well described by Hargreaves and Ayres (1979) for a location 10 km northwest on Utik Lake. The authors interpret the common compositional layering in amphibolite exposures elsewhere in the map area as possibly representing highly flattened pillow structures. The origin of the massive amphibolite is less certain, but the local presence of pillows and their sheared equivalents suggests that the massive amphibolite may also be derived from mafic flows.

Amphibolite is locally interlayered with rocks interpreted to be intermediate and felsic volcanic and sedimentary rocks. Most of the examined amphibolite exposures contain trace pyrite, with rusty layers, locally containing abundant pyrite and pyrrhotite, along the contact between amphibolite and felsic and intermediate rocks. Epidotization of sheared or boudinaged calcsilicate layers in amphibolite is common.

Pyroxenite and ultramafic schist

Ultramafic rocks were identified at several locations on western Bear Lake. Medium- to coarse–grained, equigranular, massive to weakly foliated pyroxenite and hornblendite, which are closely associated with strongly sulphidic amphibolite interpreted as mafic volcanic rock, form several small exposures south of Mahigan River in the southwestern part of the area (Figure GS-7-2). In addition, one exposure of decimetre-sized rafts of altered pyroxenite within pegmatitic leucogranite was found at the northwest arm of Bear Lake. At west-central Bear Lake, a dark green, dense, altered amphibole- and chlorite-rich schist is interlayered with presumably intermediate volcanic rocks. This schist likely represents a hydrated and metamorphosed ultramafic extrusive rock or sill.

Felsic and intermediate rocks interpreted as volcanic rocks

Fine-grained, medium grey, compositionally layered intermediate rocks, interpreted to be volcanic, make up less than 20% of the greenstone belt at Bear Lake. These rocks are typically plagioclase±biotite-phyric and interlayered with amphibolite or rocks interpreted to be volcaniclastic.

Several thin units of felsic, quartz-feldspar-phyric rock were identified in the map area, with some of the best exposed layers located south of Bear Lake on the Piskominahikoska River (Figure GS-7-2). In this area, several 5 to 10 m thick sheets of white aphanitic felsic rock of rhyolite to rhyodacite composition are interlayered with amphibolite. These felsic rocks are locally porphyritic, with up to 30% highly attenuated plagioclase and/or quartz phenocrysts that are moderately to highly flattened (Figure GS-7-3d). A single plagioclase-phyric felsic dike that cuts tuffaceous rocks may represent a feeder to this unit.

Felsic to intermediate fragmental rock interpreted as volcanic breccia is well exposed at one location on the Piskominahikoska River (Figure GS-7-3e, -3f), and several other highly deformed breccias of probable volcanic origin were also identified. The volcanic breccia is composed of felsic and intermediate clasts in an aphanitic, light grey, felsic groundmass. Clasts are angular, 2 to 20 cm in length and texturally fine grained to aphanitic with rare plagioclase phenocrysts.

Magnetite-sulphide iron formation

Magnetite-sulphide iron formation is fine to medium grained, well layered to laminated and forms thin (1–5 cm) horizons within volcanic and volcaniclastic rocks (Figure GS-7-4a). Fine-grained pyrite is the dominant mineral in these layers and, where weathered, the rock has a brown gossanous appearance. Chert was not noted in this unit. The intercalated nature of magnetite-sulphide iron formation with presumably volcanic rocks is consistent with a proximal volcanic source for the contained metals and sulphides. Although the iron formation may be related to hydrothermal activity, no significant alteration was identified in the surrounding rocks.

Possible volcaniclastic rocks and crystal tuff

One of the most abundant units within the Bear Lake map area is a mixed package of rocks interpreted as volcanogenic sandstone and tuffaceous rocks. The terms tuff and tuffaceous are used here in a descriptive and nongenetic sense, following the granulometric classification of volcanic rocks proposed by Fisher (1966). The

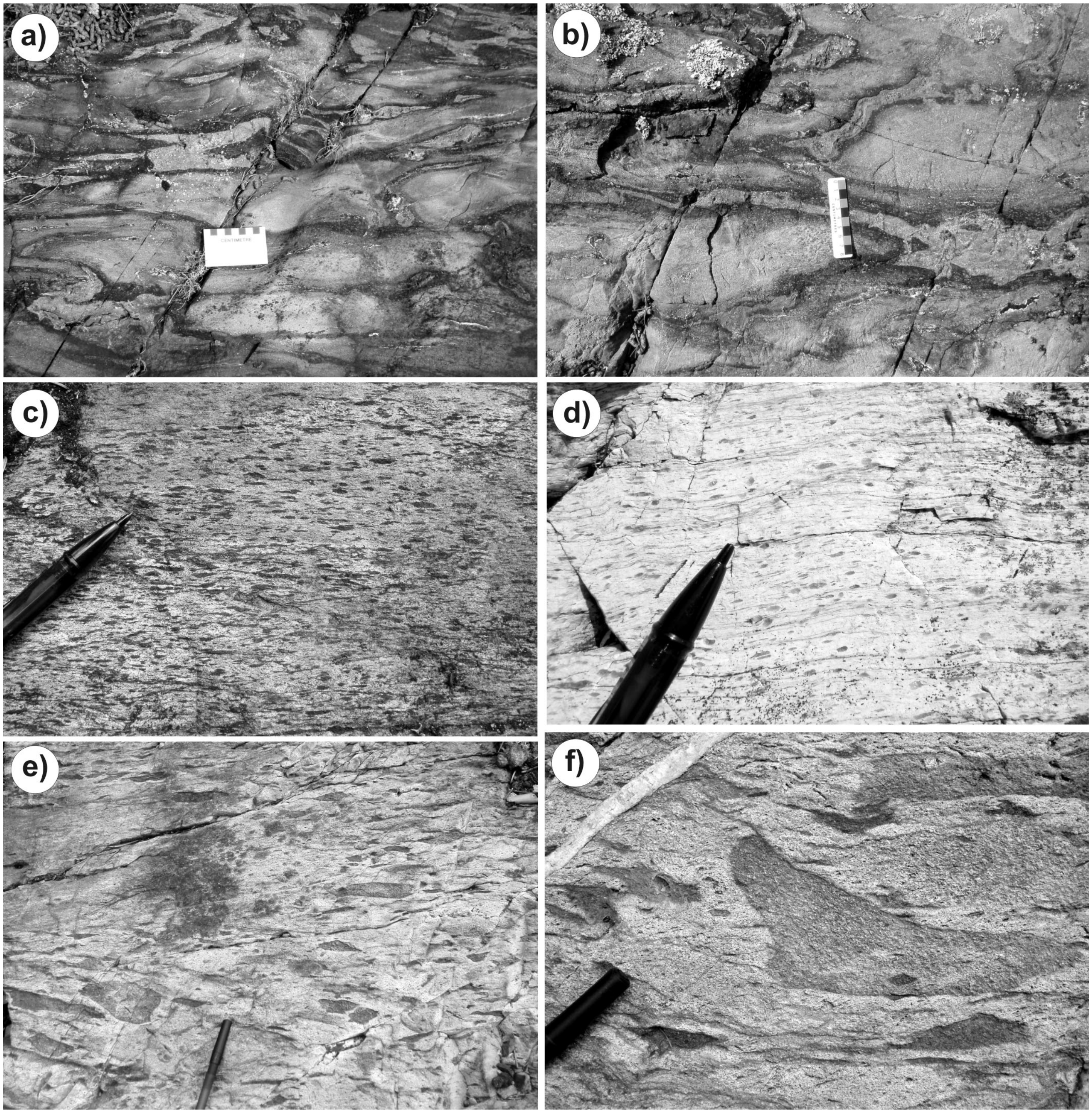

Figure GS-7-3: *Archean volcanic rocks of the Bear Lake area:* ***a)*** *metamorphosed pillows in amphibolite (station 97-06-552, UTM Zone 14, 673914E, 6112172N [NAD 83]);* ***b)*** *pillowed mafic flow; note the dark garnet- and hornblende-rich pillow selvages (station 97-06-552, UTM 673914E, 6112172N);* ***c)*** *intermediate volcanic rock with flattened hornblende phenocrysts (station 97-06-648, UTM 669257E, 6108574N);* ***d)*** *quartz-phyric felsic volcanic rock (station 97-06-685, UTM 679734E, 6106179N);* ***e)*** *volcanic breccia (station 97-06-683, UTM 679837E, 6107019N);* ***f)*** *close-up of volcanic breccia with moderately flattened clasts (station 97-06-683, UTM 679837E, 6107019N).*

clastic sedimentary rocks at Bear Lake are locally interbedded with rocks interpreted as crystal-rich tuff and felsic to intermediate volcanic rocks. The grain size of the sedimentary rocks ranges from sand to silt; graded bedding identified at numerous locations (Figure GS-7-4b) consistently indicates a southward younging direction. Interlayering of coarse sandy layers and fine silty argillite and/or tuffaceous layers (Figure GS-7-4c) is especially well developed at the western end of Bear Lake near the Mahigan River (Figure GS-7-2). Where the argillitic deposits are thickest, the rock displays a strong fissility and cleaves into thin sheets.

Preliminary petrographic thin-section examination of rocks in this unit reveals that the contained phenocrysts are primarily monomineralic quartz and/or feldspar. Although large euhedral plagioclase crystals are locally

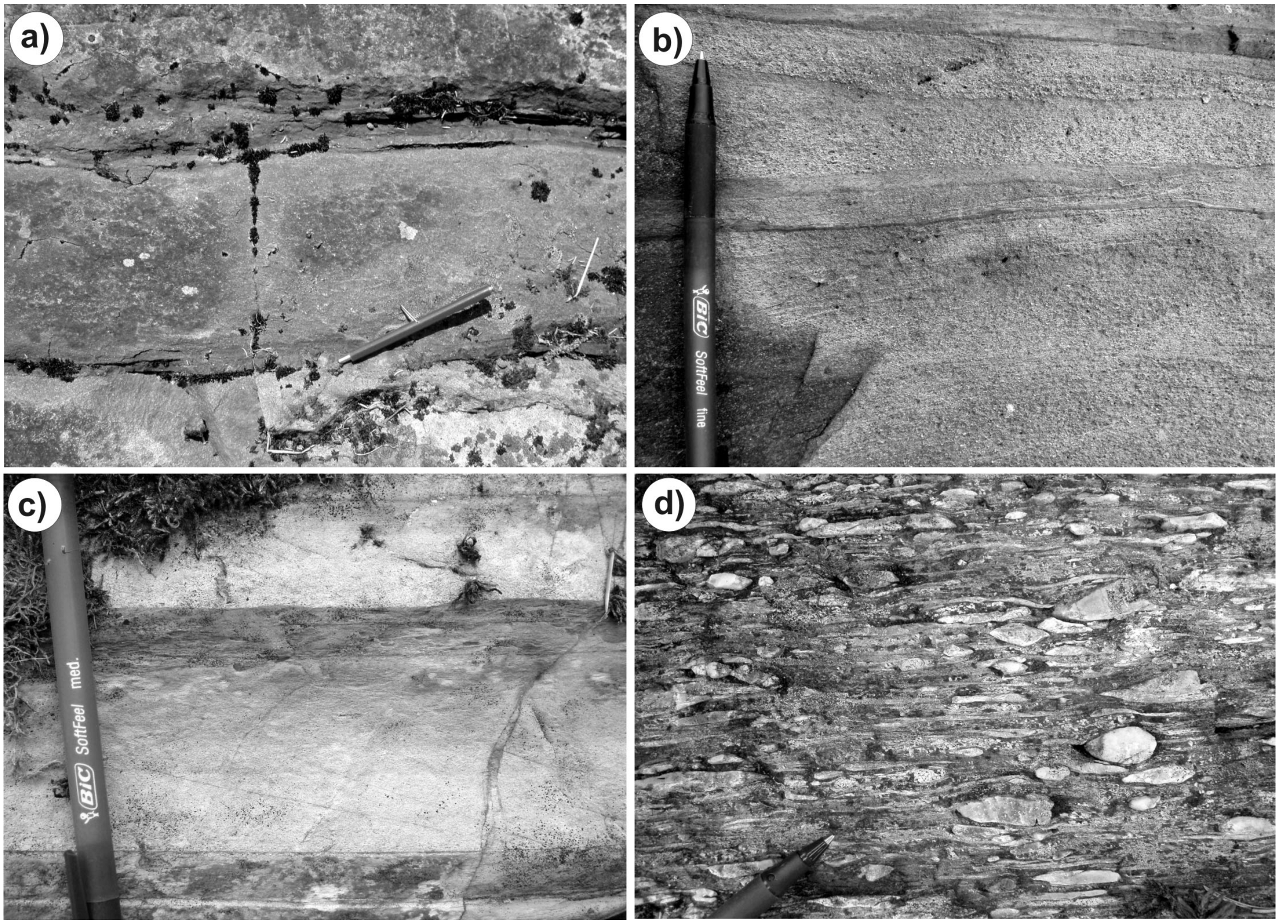

Figure GS-7-4: *Archean sedimentary rocks of the Bear Lake area:* ***a)*** *magnetite-sulphide iron formation interlayered with plagioclase-phyric felsic volcanic rocks (station 97-06-513, UTM Zone 14, 676874E, 6107574N [NAD 83]);* ***b)*** *graded bedding in volcanogenic sandstone, with younging toward the top of the photo (station 97-06-593, UTM 660057E, 6108595N);* ***c)*** *interlayering of volcanogenic sandstone and argillaceous (tuffaceous?) rock, with graded bedding indicating younging toward the top of the photo (station 97-06-652, UTM 669089E, 6107944N);* ***d)*** *pebble conglomerate from McKechnie Lake (station 97-06-209, UTM Zone 15, 311987E, 6107834N).*

well developed, the majority of grains in the volcanogenic sandstone are highly fragmented and angular.

Sedimentary rocks

Fine- to medium-grained, rusty-weathering greywacke contains 10 to 20% biotite±cordierite±sillimanite. Quartz-rich melt layers, which form up to 20% of outcrops, are common and up to a few centimetres wide. The main exposures of greywacke are north of the pillowed basalt at northwestern Bear Lake and form common interlayers, ranging from a centimetre to few decimetres wide, within felsic and intermediate tuff. Good examples of interbedding with felsic and intermediate tuff are exposed along the northern part of the Mahigan River system west of Bear Lake.

Pebble conglomerate interlayered with argillite is exposed along the southern shore of McKechnie Lake. Clasts are well rounded, highly flattened and lie within a sandstone matrix (Figure GS-7-4d). Clast length:width ratio ranges from 3:1 to 6:1. The average clast length is approximately 3 cm, with the largest clasts up to 10 cm. The predominant clast lithology is vein quartz, but quartz-phyric felsic and hornblende-phyric intermediate volcanic clasts were also identified. Flattening is more pronounced in the volcanic clasts as compared to the evidently more rigid quartz pebbles.

Intrusive rocks

Gneissic granite-granodiorite

Medium- to coarse-grained felsic intrusive rocks make up the majority of exposed bedrock in the eastern half of the Bear Lake area (Figure GS-7-2). Compositionally, these intrusive rocks are granite to granodiorite with an average of 10% biotite. Detailed petrographic analysis of this unit is included in Allen (1953). Hornblende, K-feldspar augen and pegmatitic patches are locally present. Granite-granodiorite ranges from moderately foliated to strongly gneissic and locally contains randomly oriented supracrustal xenoliths of mafic or intermediate composition. These xenoliths are likely derived from the

Bear Lake greenstone belt, as granite gneiss crosscuts amphibolite in several locations. Some outcrops display two main components: an older biotite-granodiorite gneiss and a younger anastomosing network of foliated leucogranite. Trains of angular mafic inclusions may represent dismembered dikes rather than wallrock. Many of the mafic layers have undergone dextral shear. Retrogression of mafic minerals and inclusions to chlorite±epidote is focused along late shears and fractures. Mylonitic granite with ribbon quartz, occurring within the major east- and northwest-trending shear zones, was sampled for U-Pb geochronology to obtain a maximum age constraint on these shear zones.

Massive granite

Coarse-grained, homogeneous, massive hornblende and/or biotite granite is exposed in parts of western and central Bear Lake (Figure GS-7-2). The granite is locally pegmatitic and contains no visible xenoliths, dikes or visible foliation, and is therefore assumed to be either Neoarchean post-tectonic (<2.68 Ga) or Paleoproterozoic (ca. 1.82–1.86 Ga) in age.

Gabbro dike

Gabbro dikes were identified in two exposures in the Bear Lake area. These northwest-trending dikes are fine to medium grained, straight sided, undeformed and up to 5 m thick. The dikes are brown weathering, contain >50% pyroxene and may be part of the ca. 1.88 Ga (Heaman et al., 1986) Molson dike swarm. This mafic magmatic event has been recorded all along the northwestern Superior Province margin, and is linked to nickel mineralization in the Thompson Nickel Belt (e.g., Hulbert et al., 2005).

Metamorphic and structural geology

The Bear Lake area appears to have reached lower to middle amphibolite facies metamorphic grade under moderate to low pressures. Mafic volcanic rocks (amphibolite) contain hornblende and garnet, and lack prograde chlorite. Sillimanite and cordierite were identified in initial petrographic analysis of greywacke from northwestern Bear Lake; there is, however, a general paucity of highly aluminous rock. A site originally identified by Weber (1974) to contain kyanite was re-examined and found to be located within a mixed zone of pegmatite that is likely related to the movement of high-pressure aluminous fluids rather than to regional conditions. This interpretation is supported by the presence of cordierite and weakly deformed pillowed volcanic rocks less than 1 km from the kyanite pegmatite. Rocks of the Bear Lake area have not reached minimum melt pressure and temperature conditions.

The main foliation in the Bear Lake area trends east and is steeply south dipping. Granite-granodiorite locally contains a second foliation that commonly strikes northwest, parallel to the northwest-trending, dextral shear zone that transects Bear Lake. This northwest-trending shear zone is considered to be a splay off the main east-west system of regional shear zones. Mylonitic rocks are best developed in the east-trending shear zones that run along southwestern Bear Lake. These mylonitic rocks range from moderately porphyroclastic gneiss to very fine grained recrystallized ultramylonite. Stretching lineations are generally not present or preserved. Overall, the orientation of shear zones on Bear Lake (Figure GS-7-2) roughly mirrors that of the small-scale dextral shears noted at outcrop scale.

Except for locally present disharmonic z-folds, small-scale minor fold structures are rare in the Bear Lake area. The minor z-folds have close to tight interlimb angles and steeply south-dipping axial planes, and plunge shallowly to the east or west. The orientation of these z-folds is consistent with the dextral sense of regional shearing. The timing of deformation and metamorphism is uncertain, but the main metamorphism and flattening, as well as the regional shearing, predate intrusion of the undeformed granites and mafic dikes.

Economic considerations

The main economic potential in the Bear Lake area is for volcanic-associated massive sulphide (VMS) deposits and orogenic gold deposits, with some minor potential for epithermal and paleoplacer gold mineralization. Many volcanic-associated massive sulphide deposits occur within volcanic arcs, particularly those that have undergone extension (Cathles et al., 1983; Syme and Bailes, 1993; Syme et al., 1999). In addition, orogenic gold deposits in the northern Superior Province are known to be localized near or within major transpressive shear zone structures.

Potential for VMS deposits in the Bear Lake area resides in the supracrustal rocks of the greenstone belt, within rocks interpreted as subaqueous volcanic and volcaniclastic (e.g. Bernier and MacLean, 1989). The Bear Lake greenstone belt includes a mixed package of basalt and intermediate to felsic, presumably volcanic and volcaniclastic rocks, with the most prospective portions of the volcanic supracrustal sequence being felsic volcanic rocks that make up just 5 to 10% of this sequence. The local magnetite-sulphide iron formation and volcaniclastic sedimentary rocks interlayered with this package are of particular interest because they have associated sulphides. Volcanogenic conglomerates in the map area could also hold potential for paleoplacer gold mineralization.

The potential for volcanic-associated vein and shear-zone gold (e.g., Thorpe and Franklin, 1984) is likely to be highest along the east-trending high-strain zones (and locally developed, subparallel alteration zones) that cut the sedimentary and volcanic rocks at west Bear Lake. Subsidiary fault structures branching from regional shear zones are common sites of gold mineralization (Eisenlohr et al., 1989). The shear zones along southwestern Bear Lake are along strike from, and may form part of, a major splay of the Stull–Wunnummin Shear Zone that transects the northeastern portion of Oxford Lake (Fig. GS-7-1). The Stull–Wunnummin Shear Zone and splays originating from it are commonly the locus for gold mineralization in this part of the Superior Province. At southwestern Bear Lake, the northwest-trending splay of the generally east-trending shear zone is also dextral and therefore an extensional structure (dilational), making it favourable for focusing gold-bearing metamorphic fluids. Although gold-related alteration is of limited extent in the Bear Lake area, iron-carbonate-sericite-chlorite alteration in strongly fractured zones of dominantly felsic and intermediate tuffaceous rocks along parts of the south Mahigan River seems most prospective. Chemical analyses of samples of altered and less altered supracrustal rocks are pending.

In addition to previously explored exposures of mineralized and altered felsic volcanic rocks in the Bear Lake area (e.g., Assessment Files 94568 and 94580, Manitoba Science, Technology, Energy and Mines, Winnipeg), one of the best exposures of mineralized volcanic rocks was found along the Piskominahikoska River (Figure GS-7-2, UTM Zone 14, 673914E, 6112172N [NAD 83]).

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