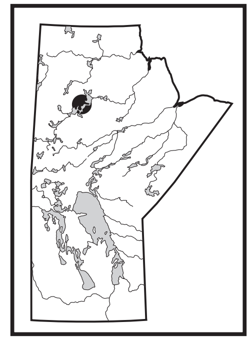
GS-8 Geological investigations of the Pukatawakan Bay belt, Southern Indian Lake, Manitoba (part of NTS 64G2)

by P.D. Kremer



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Summary

Fieldwork conducted during the summer of 2008 at Southern Indian Lake was the first in a multiseason project in collaboration with the Geological Survey of Canada under Phase 3 of the federal government's Targeted Geoscience Initiative (TGI-3). The primary focus of this project is to sample, map in detail and reassess the mineral potential of supracrustal assemblages along the northeastern extent of the Churchill River system in the Southern Indian Lake area (Pukatawakan Bay, Pine Lake, Partridge Breast Lake). The new data will provide a basis for comparing the supracrustal rocks in the Southern Indian Lake area with similar and potentially related sequences that occur along strike to the west, in both Manitoba and Saskatchewan (e.g., Lynn Lake, La Ronge and Rottenstone domains).

The Pukatawakan Bay area forms the west-central part of Southern Indian Lake in northern Manitoba. Geologically, the area consists of basement paragneiss and orthogneiss that are overlain by two distinct assemblages of polydeformed mafic volcanic rocks, each with associated sedimentary rocks and subvolcanic dikes and sills that have been subjected to three discrete folding events. A presumably younger sequence of clastic fluvial-alluvial sedimentary rocks is interpreted from field relationships to unconformably overlie the volcanic rocks. All supracrustal rocks are intruded by suites of mafic to felsic, syn- to post-tectonic intrusions.

Introduction

Southern Indian Lake is located approximately 160 km north of Thompson and forms part of the Churchill River system. The area was selected for detailed study because this portion of the Trans-Hudson Orogen (THO) has seen little mineral exploration in recent decades and has not been systematically mapped since the late 1960s (Frohlinger, 1972). The purpose of the present work is to re-examine the geology of Southern Indian Lake in detail, with particular emphasis on documenting the nature, age, affinity and mineral potential of the Pukatawakan Bay and Partridge Breast Lake areas, both of which are dominated by volcanic rocks (Figure GS-8-1). It has been suggested, on the basis of emerging stratigraphic, geochemical and geochronological data, that the historically metal-producing Lynn Lake and Rusty Lake greenstone belts in Manitoba and the La Ronge belt in Saskatchewan are coeval rather than distinct terranes (Maxeiner et al., 2001; Beaumont-Smith and Böhm, 2002; Corrigan et al., 2002, 2007). Given that the tectonostratigraphic position of volcanic rocks in the Southern Indian Lake area within the regional framework of the THO is similar to those in the Lynn Lake and Rusty Lake belts, it is possible that they represent eastward extensions, albeit tectonically and magmatically dismembered, of related or equivalent supracrustal sequences, and may therefore share similar potential for VMS-type, orogenic lode gold and magmatic sulphide mineralization.

Mapping during the 2008 field season focused on the Pukatawakan Bay belt (Corrigan et al., 2002), where an area of approximately 300 km^2 was mapped at a scale of 1:25 000 (Figure GS-8-2). Shoreline exposure was well above average due to appreciably lower than normal water levels throughout Southern Indian Lake in June and early July, providing significant amounts of clean, lichen-free outcrop. Bush traverses, designed based on orthorectified aerial photographs, followed in late July.

Sampling of representative key rock types was undertaken for thin-section, whole-rock major-and trace-element geochemical, U-Pb geochronological, Sm-Nd isotopic and assay analyses. Owing in part to significant improvements in modern analytical techniques, including lower detection limits and higher analytical precision, the samples collected will enable significant refinement of the stratigraphy and detailed determination of the nature and age of the supracrustal rocks at Southern Indian Lake, and how they fit into the regional tectonic framework. Furthermore, results from a detailed aeromagnetic geophysical survey (300 m line spacing), conducted in the spring of 2008 by the Geological Survey of Canada, were made available for the field season. The aeromagnetic survey significantly aided bedrock mapping, providing more accurate interpretations, particularly in areas with limited or no exposures.

Previous studies

The first geological investigations of Southern Indian Lake were conducted by the Geological Survey of Canada in the early 20[th] century (McInnes, 1913), followed by Wright (1953) and Quinn (1960) who conducted mapping campaigns of selected areas on Southern Indian Lake at a scale of 1:15 840. In the late 1960s, the Manitoba Geological Survey initiated a large-scale mapping program to examine the entire Southern Indian Lake area and the area to the southwest along the Churchill River to Granville

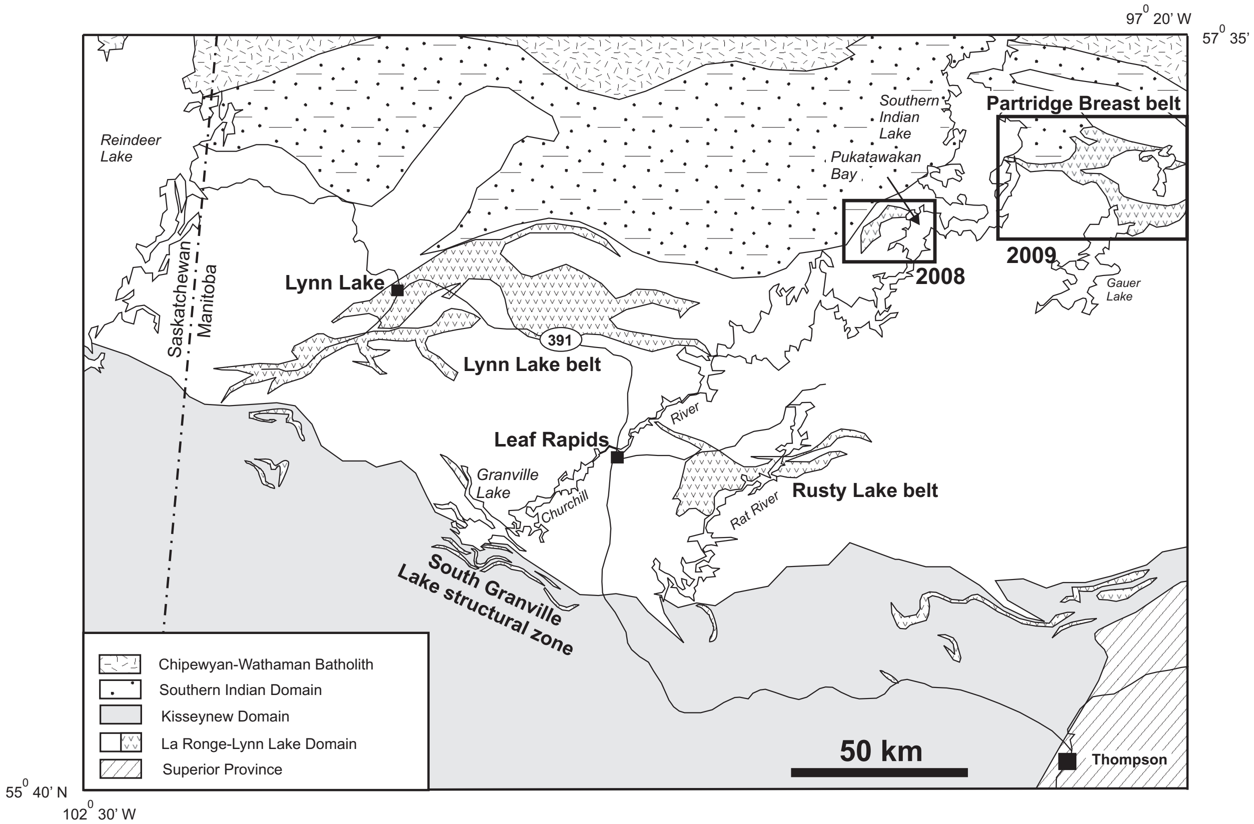

Figure GS-8-1: *Simplified regional geology of the Trans-Hudson Orogen in Manitoba. The 2008 mapping areas at Pukatawakan Bay and the proposed 2009 mapping area at Partridge Breast Lake are outlined.*

Lake. Priority was given to the project in order to map existing shoreline exposures prior to flooding as a result of construction by Manitoba Hydro of the Missi Falls control structure. An airborne INPUT electromagnetic survey was used to aid in delineating major structural trends (Haugh, 1969). The program resulted in a series of reports with accompanying maps (e.g., Campbell, 1972; Cranstone, 1972; Frohlinger, 1972; Steeves and Lamb, 1972; Thomas, 1972). In addition, prospect sampling for base metals led to the discovery of narrow copper showings around Whyme Bay. After the flooding of Southern Indian Lake, the first mapping of the supracrustal assemblages at newly established shoreline and inland exposures in the Partridge Breast Lake area was conducted by Lenton and Corkery (1981) at 1:50 000 scale. More recently, the area has been included in a program funded by the federal government’s Targeted Geoscience Initiative 3 (TGI-3) to examine and update models of the lithotectonic evolution and base-metal potential of the THO, including the Kisseynew, Lynn Lake–Leaf Rapids and Southern Indian domains in Manitoba, as well as their equivalents to the west in Saskatchewan (Corrigan et al., 1999, 2002, 2007; Corrigan and Rayner, 2002; Rayner and Corrigan, 2004).

Regional setting

The Southern Indian Domain is one of three main tectonostratigraphic terranes that form the northern flank of the Trans-Hudson Orogen in northern Manitoba (Figure GS-8-1). It is bounded to the south by the Lynn Lake–Leaf Rapids Domain, and intruded to the north by ca. 1.86-1.85 Ga (Corrigan et al., 2000) continental arc–type granite of the Chipewyan/Wathaman Batholith and related subsidiary plutons. In Manitoba, the Southern Indian Domain is largely composed of granitic and granodioritic orthogneiss and migmatitic paragneiss (conglomerate, greywacke, turbidite), and lesser volcanic rocks of previously unknown age and tectonic affinity. Along strike to the west, similar rocks appear in the Rottenstone Domain in Saskatchewan, where recent investigations (Corrigan et al., 1999) have identified two distinct sedimentary assemblages: 1) the ca. 1975–1890 Ma Milton Island assemblage, consisting of sillimanite-muscovite-biotite±garnet±graphite migmatitic greywacke, psammite and psammopelite, interpreted as a fore-arc accretionary complex north of the La Ronge–Lynn Lake arc; and 2) polymictic conglomerate, arkose and psammite of the Park Island assemblage, interpreted as part of a foreland basin. These sequences are intruded by numerous granitoid batholiths and suites of smaller stocks and plugs of varying composition.

Bedrock geology of Pukatawakan Bay

The Pukatawakan Bay belt consists of two distinct assemblages of deformed mafic volcanic and intrusive rocks with associated interlayered sedimentary rocks,

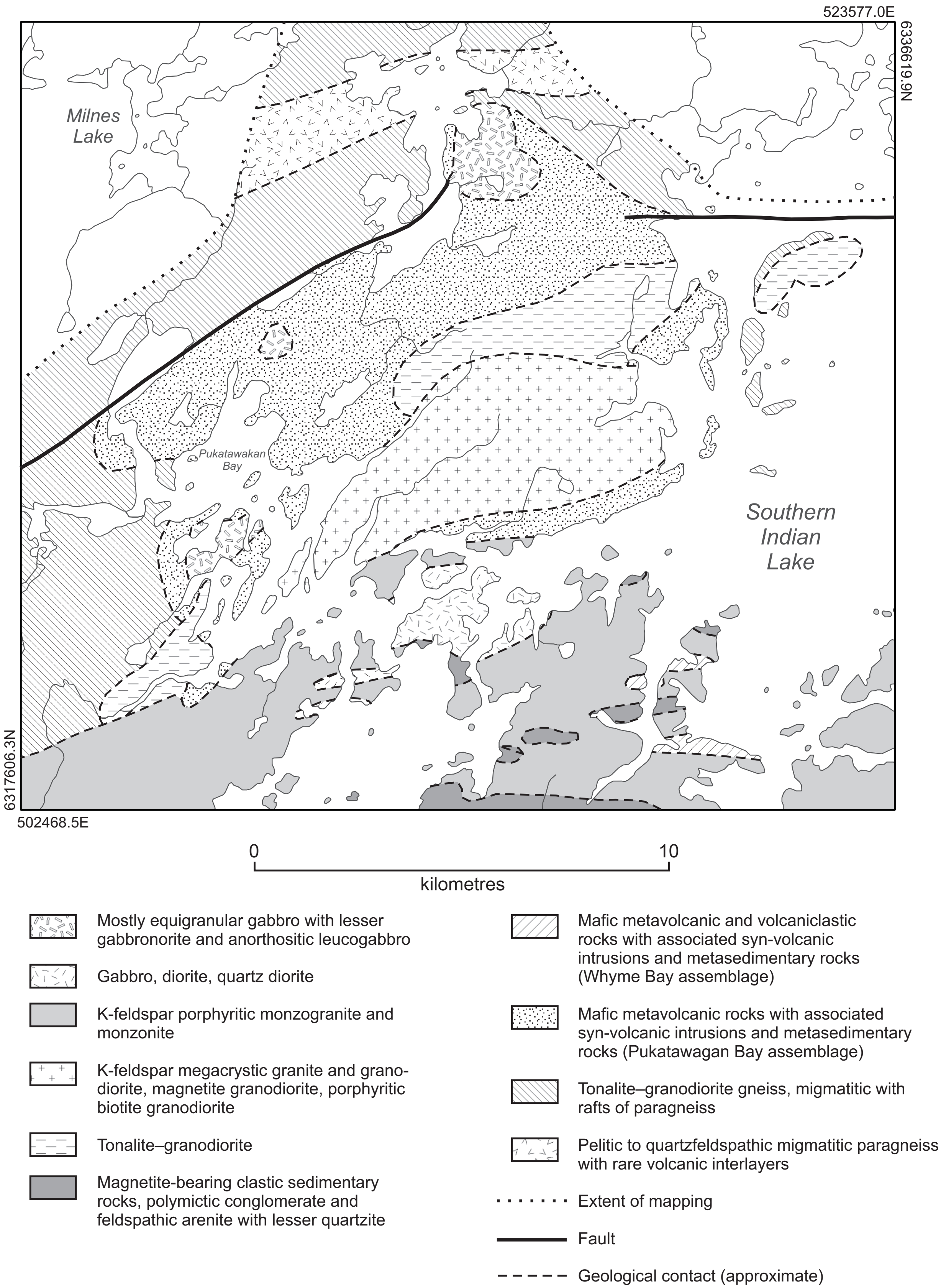

Figure GS-8-2: *Simplified geology of the Pukatawakan Bay area of Southern Indian Lake.*

herein termed the 'Pukatawakan Bay' and 'Whyme Bay' assemblages, which both overlie an older suite of mixed para- and orthogneiss. The Whyme Bay assemblage is itself unconformably overlain by fluvial-alluvial sedimentary rocks, dominated by polymictic conglomerate and well-bedded to massive arenite. The two volcano-sedimentary assemblages are both intruded and physically separated by multiple generations of voluminous, fine-grained to pegmatitic, gabbroic to monzonitic batholiths, stocks and dikes (Figure GS-8-2). All rocks, with the exception of certain late intrusions, have been metamorphosed to mid- to upper amphibolite facies; for this reason, the prefix 'meta' has been omitted from this discussion. The main rock types and relationships in the Pukatawakan Bay area are summarized in this report and outlined on Kremer (2008). The lithostratigraphy of the area is outlined in Table GS-8-1.

Ortho- and paragneiss

The oldest rocks in the Pukatawakan Bay area are an intermixed gneissic suite of both igneous and sedimentary origin. Ortho- and paragneiss occupy northern and western extents of the map area (Kremer, 2008), and are generally poorly exposed in outcrop.

Paragneiss generally retains strong compositional banding, reflective of primary layering. Variations in

Table GS-8-1: Lithostratigraphy of the Pukatawakan Bay area.

Late intrusive rocks
Diabase
Pegmatitic alaskite
Granitic pegmatite
~~ *Deformation* D_3 ~~~~~~~~~~~~~~~~~~~~~~~~
~~ *Deformation* D_2 ~~~~~~~~~~~~~~~~~~~~~~~~
Syn- to post-tectonic (D_2) ***intrusive rocks***
Pyroxene-hornblende gabbronorite to leucogabbro
K-feldspar porphyritic monzogranite to monzonite
Gabbro, diorite, quartz diorite
K-feldspar megacrystic granite
K-feldspar megacrystic magnetite granodiorite
Porphyritic biotite granodiorite
Feldpsar porphyry
Quartz-phyric magnetite-bearing granodiorite
Fine-grained leucogranite
~~ ***Intrusive contact*** ~~~~~~~~~~~~~~~~~~~~~
~~ *Deformation* D_1 ~~~~~~~~~~~~~~~~~~~~~~~~
Later clastic sedimentary rocks
Polymictic conglomerate, bedded feldspathic arenite, minor quartzite
~~ **Unconformity** ~~~~~~~~~~~~~~~~~~~~~~
Whyme Bay assemblage
Massive to pillowed basalt, synvolcanic diabase, magentite-bearing greywacke-mudstone turbiditic sedimentary rocks
~~ **Relationship unknown** ~~~~~~~~~~~~~~~~~~
Pukatawakan Bay assemblage
Massive to pillowed basalt, synvolcanic gabbro, psammitic to psammopelitic sedimentary rocks
~~ **Unconformity** ~~~~~~~~~~~~~~~~~~~~~~
~~ *Deformation* D_0 ~~~~~~~~~~~~~~~~~~~~~~~~
Gneissic suite
Tonalitic to granodioritic orthogneiss
Variably migmatized paragneiss

texture, grain size and mineralogy within the paragneiss include fine- to medium-grained, quartzofeldspathic garnet-biotite gneiss (south of Long Point); fine-grained, locally sillimanite-bearing banded gneiss (western shore of Pine Lake); and medium-grained, crudely layered quartz arenite gneiss (northeastern shore of Pine Lake). Owing to the minimal exposure of paragneiss in the map area, stratigraphic correlations between interpreted facies are not possible. Migmatitic mobilizate in paragneiss forms <10% to >50% narrow granitic to granodioritic layers and *in situ* neosome parallel to the compositional banding. Subsequent injection dikes and veins (compositionally similar to layer-parallel earlier injection) crosscut the gneissosity and are oriented along the axial planes of an early generation of folds (Figure GS-8-3a). Bands of highly altered and attenuated volcanic rocks were observed in paragneiss at two locations (Figure GS-8-3b).

Orthogneiss, locally containing xenoliths of paragneiss, is fine to coarse grained and ranges from tonalitic to granodioritic in composition, with heterogeneous textures that vary from medium grained, massive and weakly deformed to strongly banded over short distances across and/or along strike. In some instances, when flooded by younger intrusive phases, gneissic foliation is overgrown by randomly oriented, euhedral, metasomatic K-feldspar crystals up to 4 cm in size (Figure GS-8-3c). Both ortho- and paragneiss, particularly at Pine Lake, are intruded by abundant granodioritic to tonalitic material, part of which may represent *in situ* mobilizate.

On the shore south of Long Point, gneiss is crosscut by diabase and gabbroic dikes that are petrographically indistinguishable in the field from, and therefore possibly represent feeders to, the volcanic rocks of the Pukatawakan Bay assemblage (*see* below), suggesting that the gneiss represents the basement rocks onto which the volcanic rocks were extruded (Figure GS-8-3d). Mafic dikes of this type were not observed in similar gneissic rocks exposed on the northern shoreline of Pine Lake. Similar relationships have been suggested by Frohlinger (1972) on the basis of rare xenoliths of folded paragneiss (not seen during this study) in volcanic rocks around Pukatawakan Bay. At Pine Lake, the contact zone between

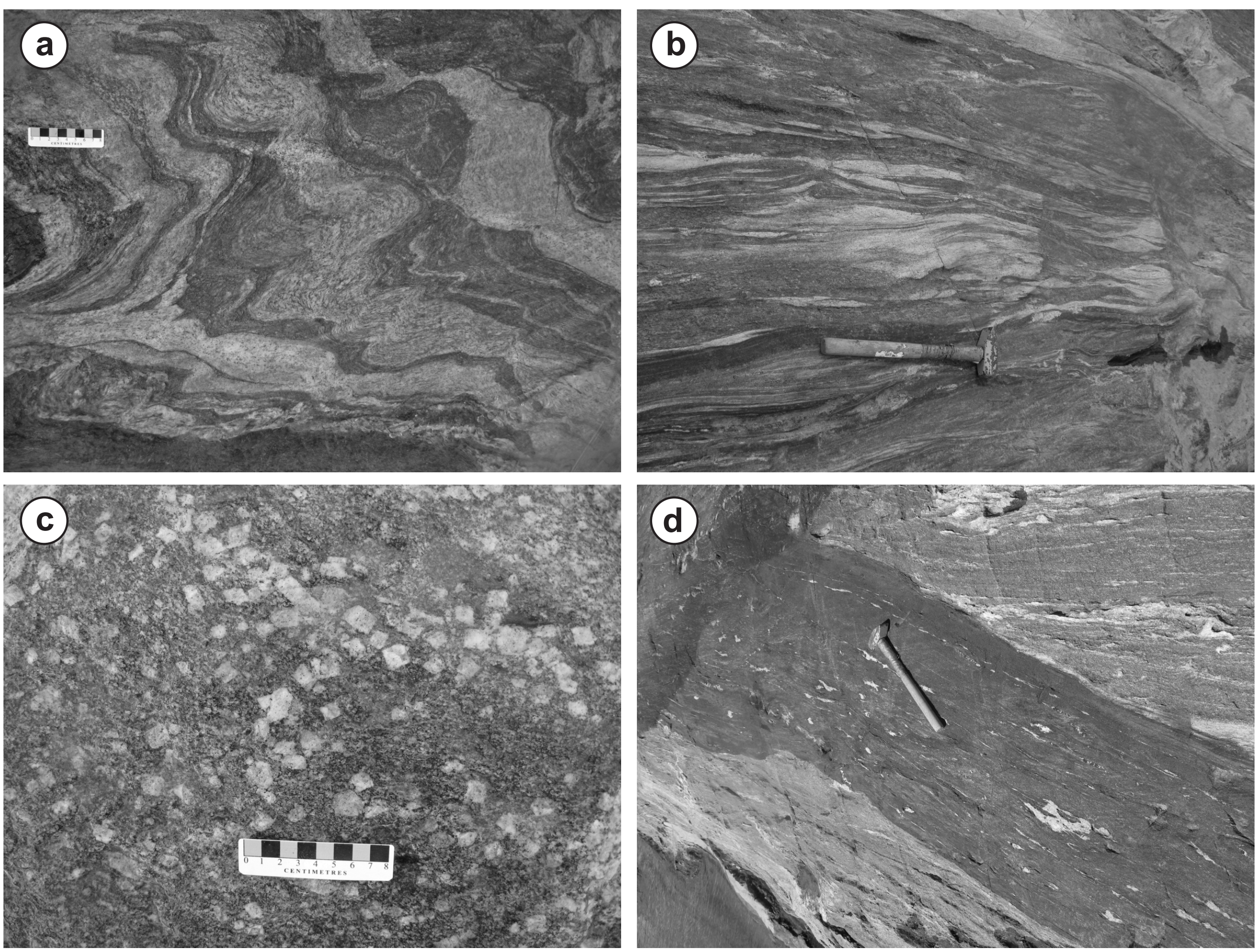

Figure GS-8-3*: Outcrop photos of ortho- and paragneiss from Pukatawakan Bay, Southern Indian Lake:* ***a)*** *folded and migmatized paragneiss, east of Pukatawakan Bay;* ***b)*** *attenuated and silicified pillow basalt in paragneiss, south of Long Point;* ***c)*** *metasomatic K-feldspar overgrowing gneissosity in tonalitic orthogneiss, north of Whyme Bay;* ***d)*** *basalt dike crosscutting gneissosity, south of Long Point.*

tonalitic orthogneiss and the overlying volcanic rocks was strongly reworked, sheared and intruded by abundant pegmatitic dikes, making correlation of the two rock types based on field relationships at this location impossible. A sample of orthogneiss was collected on a small island east of Pukatawakan Bay for U-Pb geochronology to further assess the relationship between the gneissic and volcanic rocks.

Pukatawakan Bay assemblage

A continuous sequence of mafic volcanic rocks occurs at Pukatawakan Bay and extends northeast through Pine Lake and south of Long Point. Major-element chemical analyses correspond to basaltic compositions, with the majority of samples plotting in the tholeiitic field (Frohlinger, 1972). Major- and trace-element geochemical results from samples taken during the current study are pending. The basalt weathers dark grey and is aphyric and nonamygdaloidal. Both pillowed and massive flows occur, with locally recognizable flow-top facies including amoeboid pillow breccia and pillow-fragment breccia (Figure GS-8-4a, -4b). On a large outcrop north of Whyme Bay, successive pillowed flows less than 5 m thick are separated by layers of pillow-fragment breccia in a ferruginous matrix. Pillows are typically densely packed with <10% interpillow hyaloclastite, are irregularly shaped, have thick selvages and rarely exceed 1 m in length. This degree of preservation of primary structures in basalt, however, is rare. Characteristic exposures consist of highly flattened and strained, pillowed and massive flows that are often completely recrystallized to homogeneous, fine- to medium-grained orthoamphibolite in which any primary features are difficult or impossible to discern. Mineralogically, the basalt contains hornblende, plagioclase, biotite (after hornblende) and local minor quartz. Light grey-green zones of calcsilicate alteration occur in all exposures of basalt and amphibolite. Alteration zones impart a mottled texture to the rock in low-strain domains but are completely transposed into the dominant fabric in areas of high strain (Figure GS-8-4c).

Fine- to medium-grained, equigranular to subophitic, synvolcanic gabbro dikes and sills occur throughout the

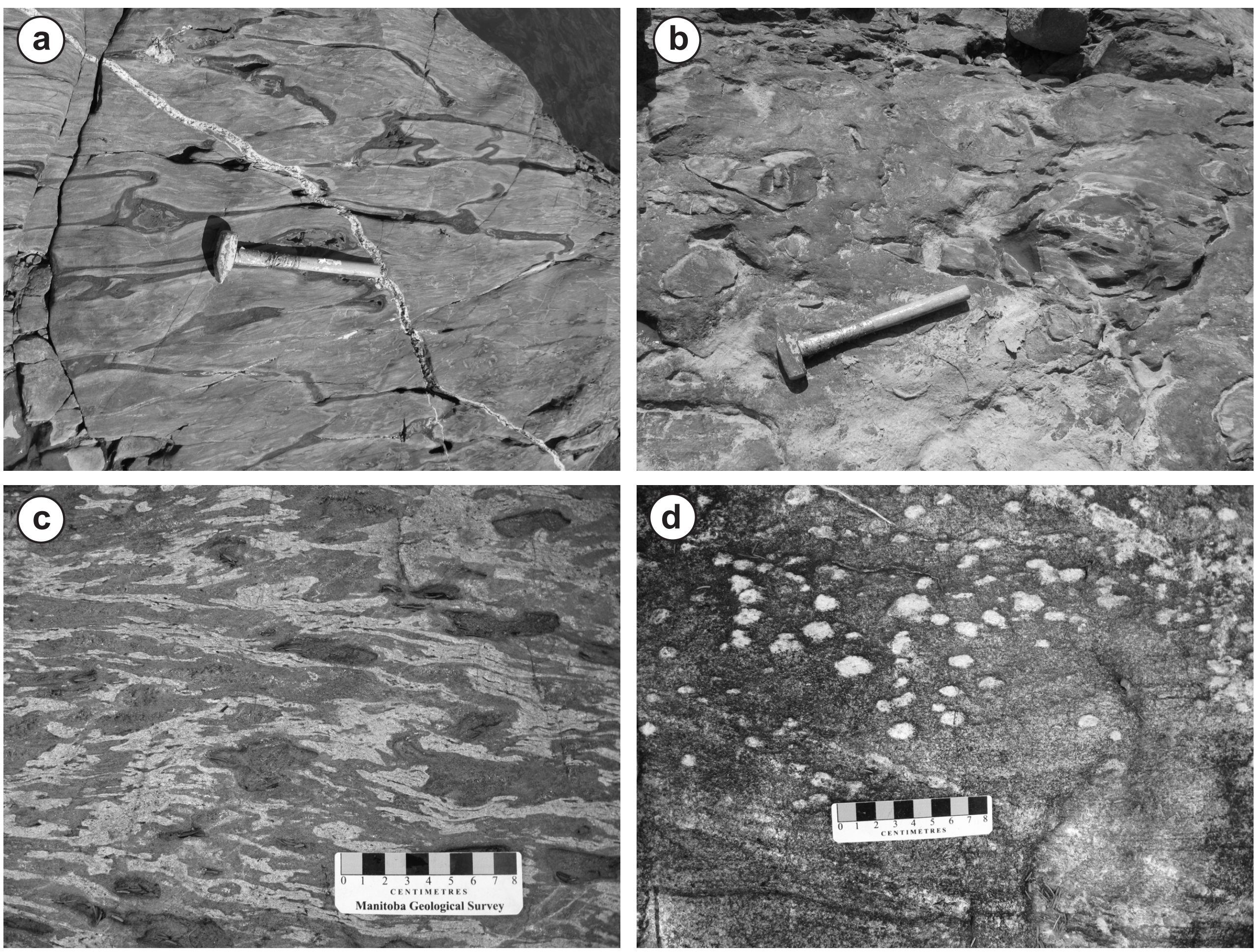

***Figure GS-8-4**: Outcrop photos of the Pukatawakan Bay assemblage, Southern Indian Lake: **a)** well-preserved pillow basalt with thick selvages and minor interpillow material, north of Whyme Bay; **b)** matrix-supported pillow-fragment breccia, same outcrop as Figure 4a; **c)** mottled calcsilicate hydrothermal alteration in basalt, central Pukatawakan Bay; **d)** faserkiesel (quartz-sillimanite intergrowths) in psammopelite, northwestern Pukatawakan Bay.*

mafic volcanic sequence. The mafic intrusions range from several decimetres to a few metres in thickness. Where basalt is strongly recrystallized, distinguishing between massive basaltic flows and fine-grained gabbroic sills can be difficult. Rare serpentinized peridotite dikes were observed in the Pukatawakan Bay volcanic rocks and also crosscut the gneissic suite. Contact relationships between ultramafic dikes and volcanic rocks are not exposed in the map area.

Basalt is interbedded with attenuated, discontinuous beds of fine-grained sedimentary rock. In a few locations in the northwestern portion of Pukatawakan Bay, continuous, mappable sedimentary sequences consist of thinly bedded (generally <30 cm) greywacke, psammopelite and pelite, with occasional narrow calcsilicate beds. Garnet and sillimanite in rare sedimentary outcrops at Pukatawakan Bay represent the peak, upper-amphibolite–grade metamorphic assemblage (Figure GS-8-4d).

Whyme Bay assemblage

A second sequence of mafic volcanic and associated sedimentary rocks, historically assigned to the Sickle Group (Cranstone, 1972; Frohlinger, 1972), occurs southeast of Pukatawakan Bay along the length of Whyme Bay. Completely enclosed by quartz diorite, K-feldspar porphyritic monzogranite and monzonite, these rocks (the Whyme Bay assemblage) display a screen-like geometry on the map (Figure GS-8-2; Kremer, 2008) and thus reveal no direct relationship to the Pukatawakan Bay assemblage rocks. Mafic volcanic rocks at Whyme Bay weather dark grey to black, are aphyric and strongly magnetic, and contain abundant quartz-, feldspar- and local chlorite-filled amygdules (Figure GS-8-5a). Both pillowed and massive flows occur at Whyme Bay, but tuff and tuff breccia are predominant between flows (Figure GS-8-5b), which is different from the mafic flows at Pukatawakan Bay. Well- and thin-bedded, magnetite-bearing greywacke-mudstone

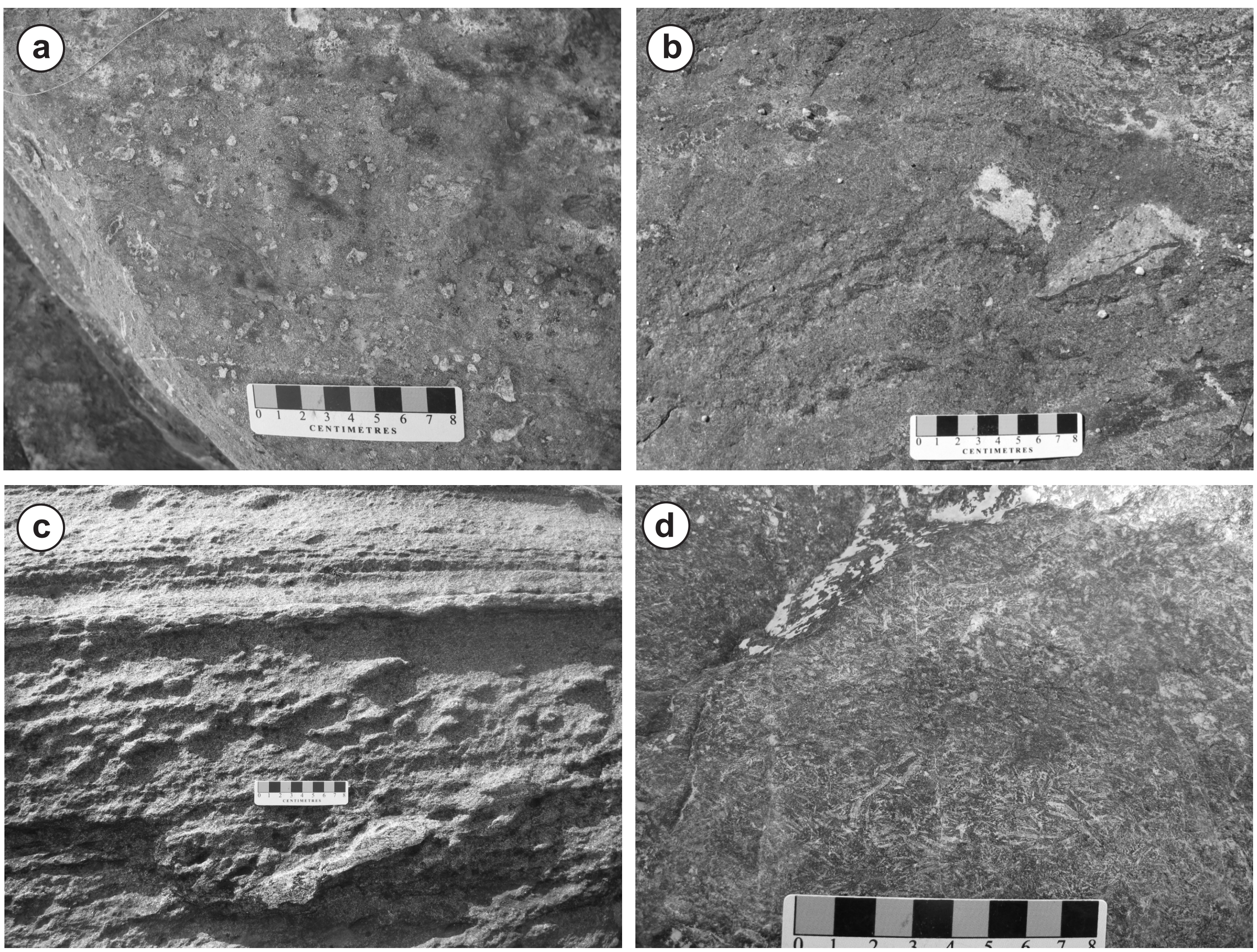

***Figure GS-8-5**: Outcrop photos of the Whyme Bay assemblage, Southern Indian Lake: **a)** quartz-feldspar-chlorite–filled amygdules in massive basalt, east shore of Whyme Bay; **b)** heterolithic scoriaceous tuff breccia, west shore of Whyme Bay; note the angular clasts of felsic volcanic rocks; **c)** pinitized cordierite porphyroblasts in metaturbidite, west shore of Whyme Bay; cordierite is oriented along S_2 oblique to bedding; **d)** coarse-grained, magnetite-bearing diabase, east shore of Whyme Bay.*

turbidite sequences with garnet-cordierite-anthophyllite metamorphic assemblages are dispersed throughout the Whyme Bay volcanic rocks. The strongly pinitized cordierite porphyroblasts are oriented oblique to bedding, overgrow the layer-parallel (S_1) foliation and show dextral asymmetry (Figure GS-8-5c). Fine- to medium-grained, magnetite-bearing synvolcanic gabbro and diabase dikes and sills occur throughout the succession (Figure GS-8-5d).

Younger clastic sedimentary rocks

Spatially associated with the Whyme Bay assemblage, a sequence of magnetite-bearing fluvial-alluvial clastic sedimentary rocks occurs as >1 km long screens in K-feldspar monzogranite (Figure GS-8-2; Kremer, 2008). The dominant sedimentary facies is well-bedded to massive, fine- to medium-grained arenitic sandstone (Figure GS-8-6a) with well-preserved primary features such as normal graded bedding and crossbedding (Figure GS-8-6b). Lesser amounts of crudely bedded quartzite are found in some outcrops. A large exposure of polymictic, clast-supported conglomerate, located on a ridge between Whyme Bay and Pukatawakan Bay, may represent the basal unit of the clastic sedimentary sequence. The conglomerate contains clasts of fine- to coarse-grained granite, mafic volcanic and intrusive rocks, and sedimentary rocks similar to those in the Whyme Bay assemblage, as well as rare cobbles of felsic volcanic rocks and massive quartz (Figure GS-8-6c). Although the contact is not exposed in the map area, the presence of possible clasts of the Whyme Bay assemblage in the conglomerate suggests that the clastic sedimentary sequence is younger and may unconformably overlie the Whyme Bay assemblage. Despite the abundance of younging criteria in the clastic sedimentary rocks, the presence of ubiquitous isoclinal F_1 folds rules out a homoclinal sequence (Figure GS-8-6d).

The presumably younger sequence of clastic sedimentary rocks displays a prominent high magnetic signature on the aeromagnetic survey, but its extent in outcrop is rather limited. At one location in the Whyme Bay area, the contact between the sedimentary rocks and surrounding granite is exposed on a steep cliff face. Here, the contact is

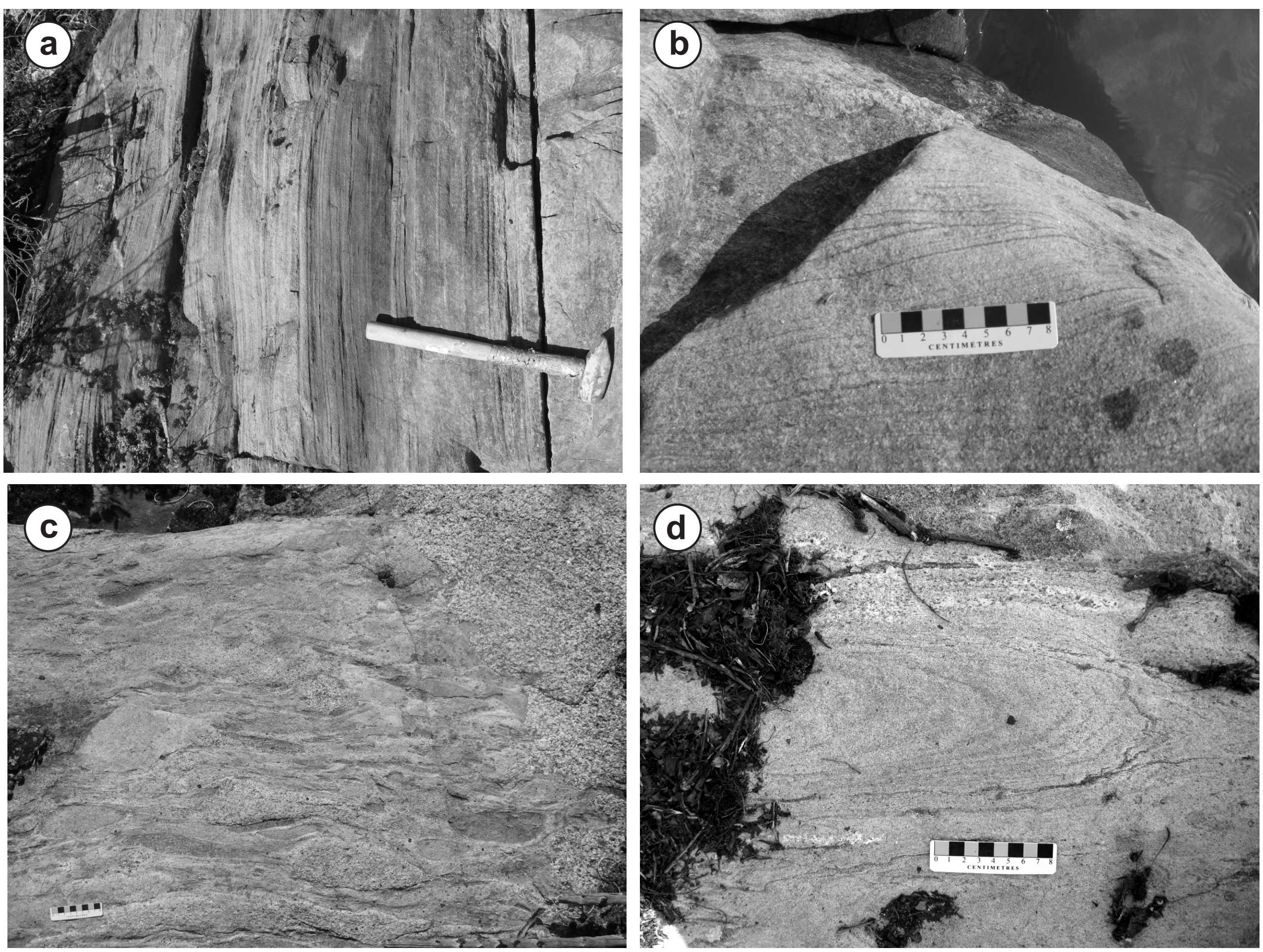

Figure GS-8-6**: Outcrop photos of clastic sedimentary rocks, Whyme Bay area, Southern Indian Lake:* ***a) *well- and thin-bedded arenite, east shore of Whyme Bay;* ***b)*** *crossbedded arenite, west shore of Whyme Bay;* ***c)*** *clast-supported, polymictic conglomerate cut by K-feldspar porphyritic monzogranite, 3 km west of Whyme Bay;* ***d)*** *isoclinal F_1 folds in bedded arenite, west shore of Whyme Bay.*

subhorizontal and folded by upright F_2 folds (*see* 'Structural geology' section), suggesting that, even though not exposed, sedimentary rocks and underlying supracrustal rocks of the Whyme Bay assemblage may be continuous at shallow depth beneath the granite.

Felsic intrusive rocks

The gneissic and supracrustal rocks in the Pukatawakan and Whyme bays areas are intruded by felsic intrusive batholiths, stocks and dikes, the majority of which are interpreted from field relationships to have been emplaced during the dominant D_2 deformation.

Swarms of synkinematic feldspar porphyry dikes were intruded along S_2 foliation planes throughout most of Pukatawakan Bay. The dikes have large textural variability, even within a single dike, ranging from fine grained and homogeneous with 30% euhedral feldspar phenocrysts to pegmatitic. Trace to 5% garnet occurs in pegmatitic zones of the dikes. Along some shorelines, porphyry dikes form nearly 50% of the exposed outcrops. The dikes are commonly boudinaged along S_2 foliation and locally folded by F_2 folding, suggesting syn-D_2 emplacement. Blebs and stringers of sulphide mineralization are common along dike margins and also occur within the dikes and within silicified zones in the proximal basaltic wallrocks along dike margins (*see* 'Economic considerations' section). Based on the above field relationships, a sample of a boudinaged porphyry dike was collected for U-Pb geochronology to constrain the absolute timing of D_2 deformation and synchronous sulphide mineralization. A larger, stock-sized body of felsic porphyry, possibly representing a source for the dike swarm, is located in the southwestern corner of Pukatawakan Bay towards the Muskego River. Samples were collected from both the stock and the dikes for whole-rock geochemical analysis to test this hypothesis. In the same area, porphyry dikes intrude older, fine-grained leucogranite. The leucogranite contains a foliation that predates and is crosscut by porphyry dikes. No contact relationships between fine-grained leucogranite and other rock types were observed in this single exposure of leucogranite. It is therefore unclear whether leucogranite is younger than the Pukatawakan Bay supracrustal sequence or forms part of the older orthogneiss suite.

The central part of the Pukatawakan Bay assemblage is dominated by polyphase, variably K-feldspar–megacrystic granite and granodiorite. The western and southwestern extremities of the pluton consist of coarse-grained, K-feldspar–porphyritic, magnetite-bearing, biotite±hornblende granodiorite, with lesser amounts of fine- to medium-grained porphyritic biotite granodiorite. In a series of outcrops along the east shore of Pukatawakan Bay, potassic alteration is common in magnetite-bearing granodiorite. The alteration is limited to narrow (<5 cm) anastomosing zones that crosscut the S_2 foliation at a shallow angle. The majority of the intrusion is composed of K-feldspar–megacrystic hornblende granite. Foliations in the intrusive rocks are defined by parallel alignment of K-feldspar phenocrysts, the dominant ferromagnesian minerals (biotite and/or hornblende) and partially resorbed, flattened xenoliths (20 cm to much greater than 1 m in size). The foliation in the felsic intrusive rocks is subparallel to S_2 in the host supracrustal rocks (*see* 'Structural geology' section). Potassium-feldspar–megacrystic granite is bounded to the north by fine- to medium-grained, massive tonalite and granodiorite (Figure GS-8-2).

Along the southern margin of the map area (Kremer, 2008), the predominant intrusive rocks are massive to weakly foliated, polyphase, K-feldspar–porphyritic monzogranite and monzonite. Associated with and likely related to the monzogranite are smaller bodies of gabbro and quartz diorite. Metasomatic K-feldspar occurs in gabbro and quartz diorite near the contacts with monzogranite. Similar rock types and relationships have been described for the ca. 1.86–1.85 Ga Chipewyan Batholith (Corrigan et al., 2000). Recent U-Pb geochronology by Rayner and Corrigan (2004), however, yielded younger ages of 1829 Ma for monzogranite and quartz diorite from Pukatawakan Bay. Rare outcrops and xenoliths of medium-grained, magnetite-bearing, variably hematized granodiorite to granite occur within monzogranite at Whyme Bay.

Late pink pegmatite dikes transect the entire map area. The pegmatite dikes, which trend between 340º and 010º, range in thickness from less than 2 m to greater than 10 m. Pegmatitic alaskite occurs as an isolated body in the northwestern corner of Pukatawakan Bay (Kremer, 2008).

Mafic intrusive rocks

Medium- to coarse-grained gabbro forms circular intrusive plugs, 100–500 m in diameter, north of Pukatawakan Bay and on the east shore of Pine Lake (Kremer, 2008). Gabbro is typically subophitic to equigranular, massive and homogeneous at outcrop scale. The intrusion at Pine Lake, however, shows evidence of igneous or metamorphic layering or multiple injections. Texture and mineralogy vary across the intrusion, although contacts between the various phases are not exposed. The rim of the intrusion consists of fine- to medium-grained, strongly magnetic, pyroxene-hornblende gabbronorite. The core of the intrusion is composed of pyroxene-bearing leucogabbro with 2–5% phenocrysts of anorthositic feldspar up to 2 cm in length. Rare, narrow (<5 m), northwest-trending diabase dikes crosscut all other rock types and structures, and may be related to the regionally straight, northwest-trending Mackenzie dike swarm.

Structural geology

On the basis of outcrop and overprinting relationships, four discrete generations of ductile deformation have been identified in rocks in the Pukatawakan Bay area. The earliest deformation (D_0) is restricted to the mixed gneiss sequence and is not manifested in any of the younger rocks. A well-developed gneissic foliation is crosscut by basaltic dikes interpreted to represent feeders to the Pukatawakan Bay assemblage (Figure GS-8-3d). Furthermore, at one location in Pukatawakan Bay, an early fold generation in paragneiss (F_0) is refolded by F_1 in the volcanic rocks of the Pukatawakan assemblage.

Supracrustal rocks of the Pukatawakan and Whyme Bay assemblages invariably contain a strongly developed, layer-parallel, S_1 transposition fabric. The S_1 foliation at Pukatawakan Bay generally trends northeast, dips steeply and is defined by flattening of primary structures (e.g., pillows), and parallel alignment of fine-grained hornblende and biotite. It is axial planar to rare, metre-scale F_1 isoclinal folds. These early structures in the Pukatawakan Bay supracrustal rocks are strongly reworked into a northeasterly orientation by subsequent deformation, attributed to D_2 (Figure GS-8-7a, -7b). The S_1 foliation is folded by tight to isoclinal F_2 folds with a variably developed S_2 axial-planar foliation that strikes northeast. The paucity of preserved younging indicators in the supracrustal rocks at Pukatawakan Bay makes it difficult to confidently identify larger fold structures. Macroscopic F_2 folds, however, can be traced on the basis of reversals in the vergence between the S_1 and S_2 foliations near F_2 fold hinges (along F_2 fold limbs, the foliations are subparallel, forming a composite S_1-S_2 fabric) and outcrop-scale parasitic F_2 fold asymmetry (s-, z- and m-folds are all present in the area, although z-asymmetric folds predominate). All linear structures associated with D_2 deformation (minor F_2 fold axes, hornblende mineral lineation, S_0–S_2 intersection lineation) plunge moderately to steeply northeast. Numerous outcrop-scale chloritic shear zones with dextral kinematic indicators provide evidence for a strong dextral shear component associated with D_2. Garnet, cordierite and sillimanite porphyroblasts (the latter occurring as large knots of faserkiesel; Figure GS-8-4d) in metasedimentary rocks overgrew the layer-parallel (S_1) foliation and developed asymmetric pressure shadows consistent with dextral kinematics, suggesting that peak metamorphic conditions were reached during D_2 (Figure GS-8-5c).

Deformation structures in the Whyme Bay area are

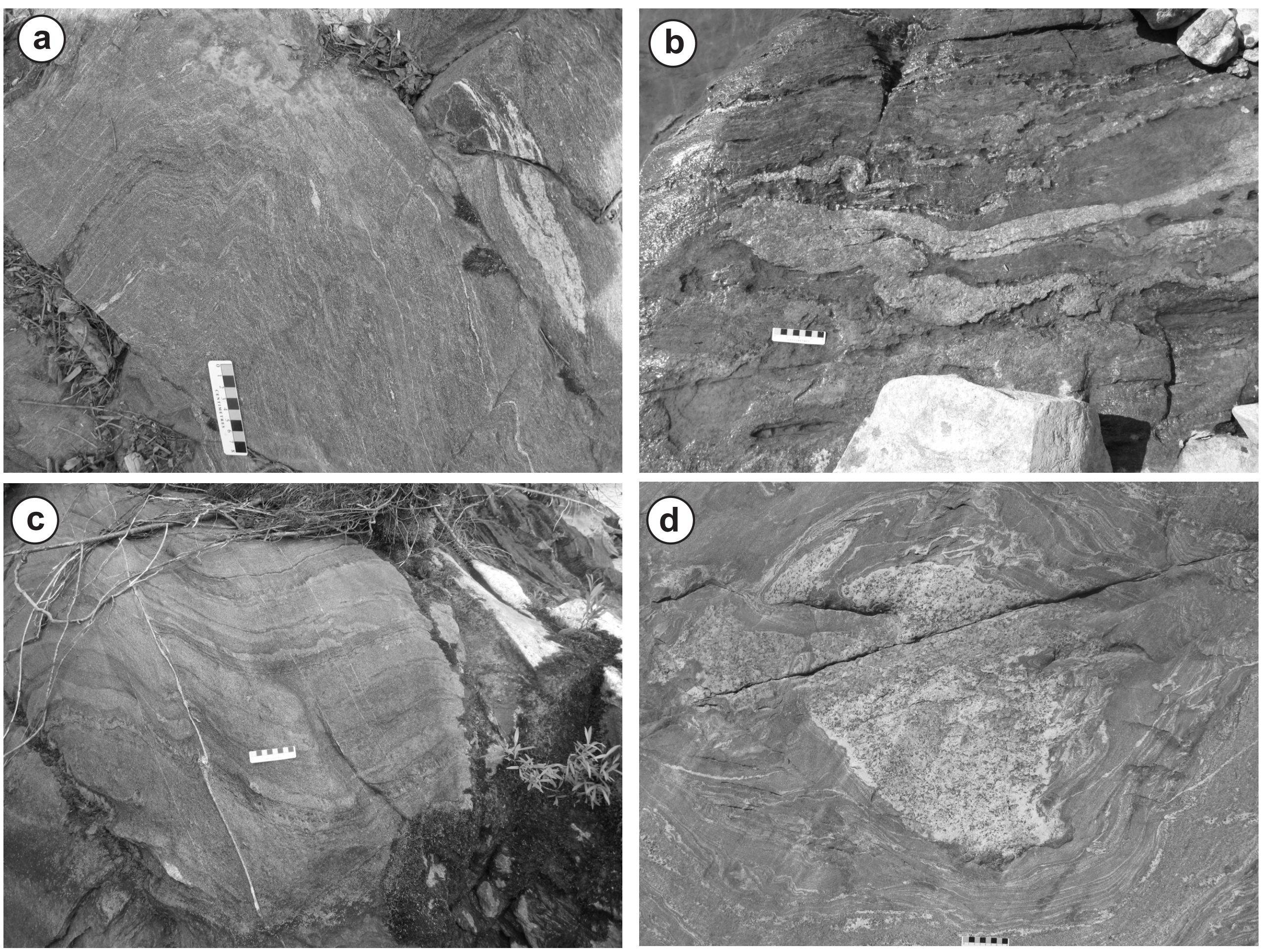

***Figure GS-8-7**: Outcrop photos of structures in Pukatawakan and Whyme Bay assemblage rocks, Southern Indian Lake: **a)** isoclinal F_1 fold refolded by northeast-trending F_2 fold, northern Pukatawakan Bay; **b)** isoclinal F_1 fold refolded by northeast-trending F_2 fold, north of Whyme Bay; **c)** upright F_2 fold with moderately developed axial-planar foliation, Whyme Bay; **d)** dome-and-basin interference patterns between monzogranite and sedimentary rocks, east of Whyme Bay.*

similar to those described at Pukatawakan Bay. Volcanic and sedimentary rocks of the Whyme Bay assemblage all bear a penetrative, layer-parallel S_1 foliation that is axial planar to isoclinal F_1 folds. At Whyme Bay, S_1 fabrics trend east and are only mildly reworked by macroscopic, z-asymmetric F_2 folds (Kremer, 2008). The northeast-trending S_2 foliation is only weakly to moderately developed and is axial planar to outcrop-scale, upright F_2 folds (Figure GS-8-7c).

Broad, northwest-trending, gentle to open, F_3 crossfolds that increase in frequency and spacing eastward are responsible for local reorientation of D_2 structures throughout the map area. Macroscopically, this is most readily apparent where the S_1-S_2 composite foliation is rotated from its typical northeasterly orientation into a northerly direction through the narrows in Pine Lake. This axis can be traced to the southeast, where S_1-S_2 follows the shoreline east of Pukatawakan Bay and sweeps northward towards Long Point (Kremer, 2008). Two alternative explanations exist for these crossfolds, depending on the timing of emplacement and crystallization of the K-feldspar–megacrystic granite in the core of the Pukatawakan Bay assemblage. If the granite largely crystallized prior to deformation, it would have acted as a rigid body and foliation development in the basalt would have wrapped around it. Conversely, if the granite intruded late during D_2 deformation, it could have displaced the pre-existing foliation during emplacement.

In a single outcrop east of Whyme Bay, outcrop-scale dome-and-basin F_2-F_3 fold interference patterns were observed between sedimentary rocks and monzogranite (Figure GS-8-7d). Though generally not represented on a large scale at Pukatawakan Bay, these interference patterns may have partly caused the current geometric distribution of rock types in areas where the intensity of F_3 folds increases.

Economic considerations

Sulphide occurrences are found throughout the Pukatawakan Bay area associated with the Pukatawakan Bay assemblage, in which sulphide mineralization appears to be controlled in two ways by D_2 deformation:

- along syn-D_2 feldspar porphyry dikes throughout the Pukatawakan Bay assemblage
- along a major structure and its subsidiary splays that mark the tectonized unconformity between the volcanic rocks and their basement (ortho- and paragneiss sequence) to the northwest (Figure GS-8-2; Kremer, 2008)

In the former case, pyrite±chalcopyrite±pyrrhotite occurs disseminated and as stringers concentrated towards the margins of the porphyry dikes and in the adjacent altered zones in the mafic volcanic wallrocks. Two contiguous zones of mineralization of this type can be found in the Pukatawakan Bay area, in low-strain domains northeast and southwest of syn- to late-D_2, K-feldspar–megacrystic granite. Mineralization in the shear zones is associated with siliceous, carbonate, chloritic and/or sericitic alteration, which can be favourable for orogenic lode gold.

Frohlinger (1972) reported assay results up to 2.2% Cu from a narrow, 1.2 m (4 foot) long malachite-rich fracture in volcanic rocks of the Whyme Bay assemblage. Fracture veins of this type were not observed, however, during the present study. The layered mafic intrusion at Pine Lake locally contains 1–2% disseminations and blebs (up to 0.6 cm) of chalcopyrite and pyrite. The intrusion is poorly exposed and more detailed study is required to more fully assess its mineral potential. Results are pending from assay samples collected from 21 locations throughout the map area that contain trace to 10% sulphides.

Voluminous K-feldspar–porphyritic monzogranite surrounding the Whyme Bay supracrustal series is largely homogeneous, contains very little fracturing and would slab nicely. If access to Southern Indian Lake is improved, significant amounts of high-quality granitic rock could be easily quarried.

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