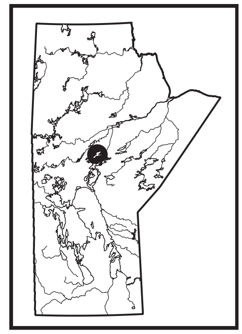
GS-7 Preliminary results from geological mapping in the central Sipiwesk Lake area, Pikwitonei Granulite Domain, central Manitoba (part of NTS 63P4)

by C.G. Couëslan, C.O. Böhm and T. Martins



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Summary

A project has been initiated to re-map portions of the Archean Pikwitonei Granulite Domain in central Manitoba, with emphasis on interpretation of pre-granulite protoliths; this report summarizes the findings from the first summer of field mapping at central Sipiwesk Lake. The mapped area has been subjected to relatively uniform, high-grade Neoarchean metamorphism accompanied by intense deformation. Exposures in the central Sipiwesk Lake area include: 1) mafic and intermediate granulite, which likely represent a variety of protoliths, including intrusive and volcanic rocks; 2) newly recognized suites of supracrustal rocks, including metapelite to semipelite, metapsammite, metawacke, meta-iron formation, layers of Mg-Al rock interpreted as the products of seafloor alteration, and layers of Ca-Al rock of uncertain origin; 3) vast amounts of metaplutonic rocks, including mesocratic and leucocratic enderbite to opdalite, and minor mesocratic to leucocratic monzodiorite; 4) a suite of later granitoid intrusions, including granitic pegmatite and aplite dikes, and sheets of granite and tonalite/granodiorite; and 5) unmetamorphosed mafic dikes ranging from diabasic to gabbroic to ultramafic, some of which are more than 50 m wide. Exposures are typically high strain and characterized by an early gneissosity, which is locally folded and pervasively transposed by later ductile deformation. Late, likely Paleoproterozoic, brittle structures are common and include zones of pervasive fracturing and hematitization, discrete faults with fault gouge, and zones of intense pseudotachylite veining. The metamorphic grade appears to be relatively constant across the map area. Mafic, intermediate and enderbitic gneiss units are characterized by orthopyroxene+clinopyroxene metamorphic assemblages; metapelite contains orthopyroxene+garnet+sillimanite+rutile±cordierite assemblages; and quartz-free Mg-Al rocks are characterized by sapphirine+orthopyroxene+cordierite assemblages. Peak metamorphic conditions are estimated to have been 6.9–8.3 kbar and 810–930 °C, based on preliminary phase-equilibria modelling.

Introduction

A project was initiated in 2012 to map portions of the Pikwitonei Granulite Domain (PGD). The objective is to re-map the mafic, intermediate and enderbitic gneiss units, with an emphasis on protolith interpretation rather than descriptive petrography. It is also hoped that information gathered through the course of mapping will provide further insight into the tectonic significance of the PGD (e.g., Weber, 1983).

Regional geology

The PGD is a Neoarchean high-grade metamorphic domain along the northwestern edge of the Superior Province. It is exposed over a length of approximately 200 km, with a maximum width of 75 km in the Split Lake area (Hubregtse, 1980; Böhm et al., 1999). A regional orthopyroxene-in isograd, which is oblique to the generally east–west fabrics of the Superior Province, marks the southeastern boundary of the domain (Hubregtse, 1980; Heaman et al., 2011). The northwestern boundary is defined by Paleoproterozoic Hudsonian (ca. 1.80 Ga) north-northeast-trending deformational fabrics, which truncate the Neoarchean fabrics of the PGD (Hubregtse, 1980; Heaman et al., 2011; Kuiper et al., 2011).

The PGD is underlain by dominantly felsic to intermediate metaplutonic rocks (enderbite, opdalite and minor leuconorite) and mafic granulite (metagabbro, metapyroxenite and metabasalt; Hubregtse, 1978, 1980; Heaman et al., 2011). Supracrustal rocks are considered to be relatively rare in the PGD and, in the Sipiwesk Lake area, have only been recorded toward the southern end of Bear Island (Hubregtse, 1980). The PGD has experienced two main generations of tectonometamorphism. The D_1-M_1 generation (ca. 2695 Ma) resulted in well-defined, northwest-trending metamorphic layering (S_1) accompanied by isoclinal folding (Hubregtse, 1980; Heaman et al., 2011). The accompanying M_1 metamorphism is interpreted as having attained amphibolite to locally hornblende-granulite–facies conditions (Hubregtse, 1978, 1980). The D_2-M_2 generation (ca. 2680 Ma) resulted in the development of D_2 fabrics and transposition of S_1 into west-southwest-trending shear folds, accompanied by granulite-facies metamorphism (Hubregtse, 1980; Heaman et al., 2011). Metamorphic conditions were interpreted as having reached a culmination at what is presently central Sipiwesk Lake, where the presence of sapphirine-bearing rocks has led to pressure and temperature (P-T) estimates of 9 ±1 kbar and 780–880°C (Arima and Barnett, 1984).

The northwestern Superior Province is intruded by locally abundant mafic to ultramafic dikes, which vary from diabasic to gabbroic to peridotitic (Scoates and Macek, 1978). The main concentration of dikes occurs between the Nelson River and the Superior craton margin, and they likely continue southward under Lake Winnipeg and rocks of the Phanerozoic (Scoates and Macek, 1978; Heaman et al., 2009). The intrusion of the dikes occurred over at least two different periods at ca. 2.10 Ga (dominantly east-trending dikes; e.g., Cauchon Lake, Gull Rapids, Birthday Rapids) and ca. 1.88 Ga (Molson dikes; Heaman et al., 1986; Halls and Heaman, 2000; Heaman et al., 2009). The younger, dominantly north-northeast-trending Molson dikes are interpreted as being the more common in the PGD. Approaching the Superior Boundary Zone, the dikes become metamorphosed and rotated subparallel to the Paleoproterozoic foliation trending northeast (Scoates and Macek, 1978).

Lithological units

Exposures throughout central Sipiwesk Lake are characterized by high-strain fabrics and migmatitic textures. Parasitic folds, veins and pools of leucosome, and S_1 metamorphic banding are moderately to pervasively transposed by D_2 deformation; rootless minor folds are locally observed. The intense deformation is accompanied by uniformly high metamorphic grade across the map area, making the identification of original lithological units challenging. Figure GS-7-1 presents a simplified distribution of lithological units in the central Sipiwesk Lake area, modified after Coueslan et al. (2012).

Mafic and intermediate granulite

Exposures of the mafic and intermediate granulite are generally internally banded, but are locally relatively homogeneous. Interbanding between the two units is common and occurs on the scale of centimetres to tens of metres. The proportion of interbanding varies from outcrop to outcrop and can range from an entire end member to roughly equal proportions. Discontinuous bands, xenolithic rafts and schlieren of mafic and intermediate granulite are common occurrences in the metaplutonic rocks, which are interpreted as being younger.

Mafic granulite

The mafic granulite is dark green to black, medium- to coarse-grained, and locally strongly magnetic. It consists dominantly of plagioclase, orthopyroxene and clinopyroxene, with subordinate magnetite and hornblende, and rare garnet and biotite. Mafic minerals typically make up more than 50% of the rock (Figure GS-7-2a). Patches of plagioclase-rich leucosome are common and form up to 20% of a given outcrop. Mafic granulite likely represents a mixture of metagabbroic rocks and mafic metavolcanic rocks, as suggested by the local association of units interpreted as supracrustal rocks (see below).

Intermediate granulite

The intermediate granulite is light grey-green on weathered surfaces and dark grey to brown-grey on fresh surfaces (Figure GS-7-2b); it is medium- to coarse-grained and varies from nonmagnetic to magnetic. The intermediate granulite is plagioclase-rich and contains variable amounts of orthopyroxene and clinopyroxene, with subordinate magnetite, local hornblende and biotite. Quartz is rare and only occurs in trace amounts. Mafic minerals typically make up less than 30% of the rock. Patches of coarse-grained leucosome are common and may form up to 30% of the outcrop; leucosome is typically quartz-bearing and plagioclase-rich, with minor orthopyroxene and clinopyroxene. Coarse-grained clinopyroxene-rich clots are also common.

A garnet-bearing variety of intermediate granulite, which is interpreted as being iron-enriched, typically occurs adjacent to layers of banded iron formation; however, it also occurs in rare isolated exposures, and is associated with rocks interpreted as metapsammite (see below). This Fe-enriched variety is typically banded on a scale of 1–40 cm, with mafic minerals consisting of varying proportions of garnet, clinopyroxene and orthopyroxene, along with magnetite as well as local pyrrhotite and biotite. Minor quartz is relatively common. This Fe-enriched variety usually grades into more typical intermediate granulite, as described above. The compositional and textural variability of the intermediate granulite suggests it is likely derived from a variety of protoliths, including plutonic as well as possibly volcanic and sedimentary rocks.

Ultramafic granulite

Bands and boudins of ultramafic granulite up to 3 m thick occur within the intermediate and mafic granulite, and rarely in enderbite. The ultramafic granulite is dark brown to black, medium- to very coarse-grained and magnetic. It is composed of clinopyroxene and orthopyroxene, with subordinate hornblende, minor plagioclase and magnetite, and rare biotite. The ultramafic granulite is likely derived from pyroxenitic layers in gabbroic intrusions and pyroxenite dikes.

Supracrustal rocks

Exposures of supracrustal rocks are most common in the central and north-central portions of the map area (Figure GS-7-1). These rocks were typically recognized based on the presence of aluminous minerals such as garnet, cordierite, sillimanite and sapphirine, and the presence of very quartz-rich layers. The supracrustal rocks are typically gneissic, and interlayering between the metapelite, metapsammite and metawacke is common. Local bands of mafic granulite are present in exposures of the supracrustal rocks and may be common in the metawacke.

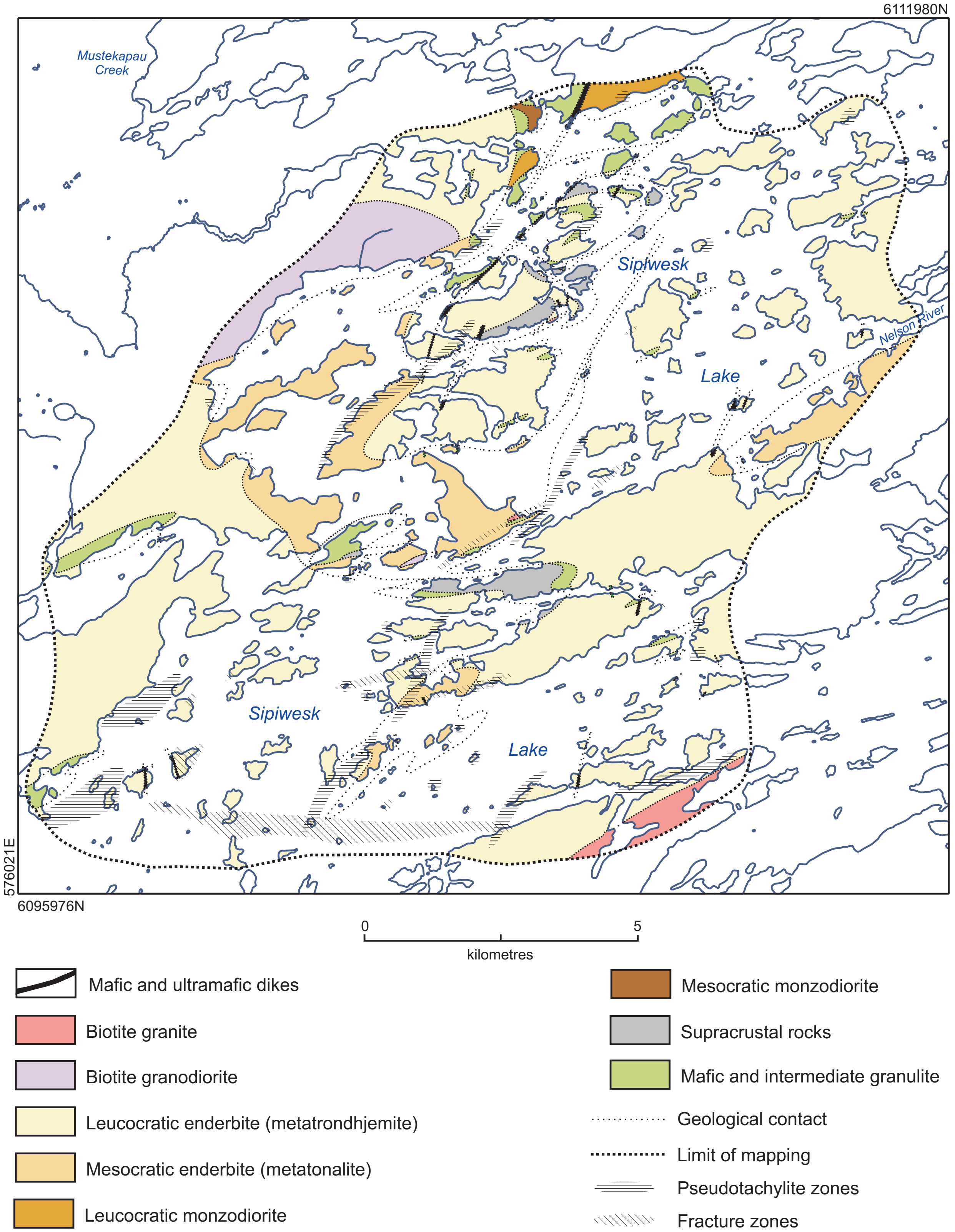

Figure GS-7-1: *Simplified geology of the central Sipiwesk Lake area (modified after Couëslan et al., 2012).*

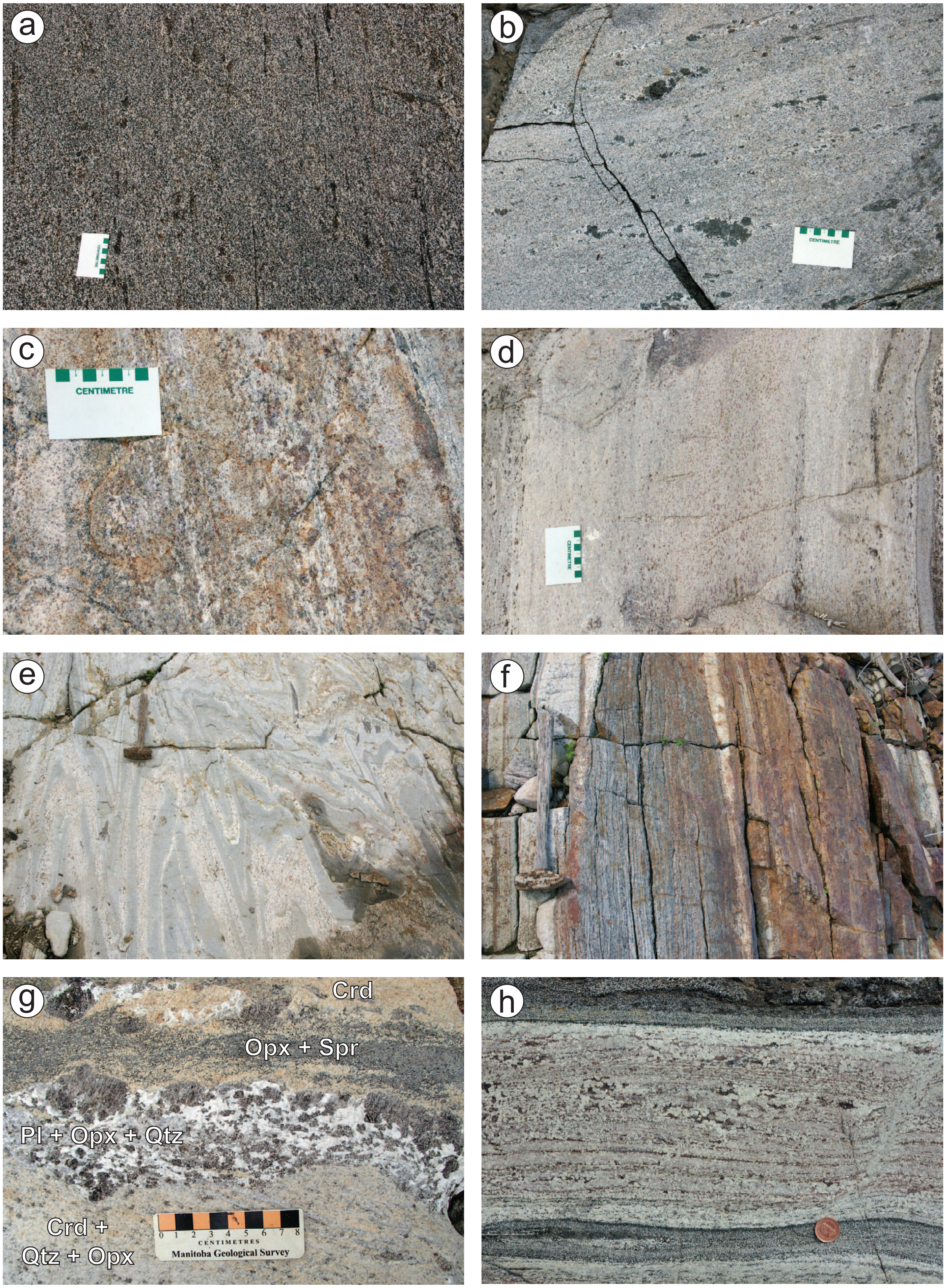

Figure GS-7-2: *Outcrop photographs from the central Sipiwesk Lake area, central Manitoba:* ***a)*** *rather homogeneous exposure of mafic granulite;* ***b)*** *intermediate granulite with clots of clinopyroxene;* ***c)*** *metapelite with porphyroblasts of garnet and orthopyroxene;* ***d)*** *metapsammite with a garnet-rich layer;* ***e)*** *intensely folded metawacke with abundant concordant leucosome;* ***f)*** *layer of banded iron formation hosted in intermediate granulite;* ***g)*** *heterogeneous banding of the Mg-Al rock labelled with the dominant minerals in each band, the central plagioclase+orthopyroxene+quartz band is interpreted as leucosome;* ***h)*** *mottled Ca-Al rock consisting dominantly of greenish-yellow plagioclase and reddish-brown garnet. Abbreviations: Crd, cordierite; Opx, orthopyroxene; Pl, plagioclase; Qtz, quartz; Spr, sapphirine.*

Metapelite and semipelite

Pelitic and semipelitic rocks vary from pinkish-orange to light grey and locally have a gossanous brown weathered surface. They are typically medium- to coarse-grained and nonmagnetic. The composition of these rocks is somewhat variable, but they typically contain quartz, plagioclase and K-feldspar, with varying proportions of pink garnet, biotite, orthopyroxene, sillimanite and rutile, with or without cordierite (Figure GS-7-2c). Garnet±cordierite-bearing leucosome is ubiquitous. Layering in these rocks is typically gradational and partially obscured by the results of high strain and intense partial melting. Pelitic layers may be over 20 m thick and are commonly interlayered with, and compositionally gradational into, metapsammite and metawacke.

Metapsammite

The metapsammite is white to light pink on weathered surfaces and dark grey on fresh surfaces. It varies from fine- to coarse-grained and nonmagnetic to magnetic. Exposures of metapsammite are characteristically quartz- and plagioclase-rich, with variable proportions of pink garnet, biotite, orthopyroxene and magnetite (Figure GS-7-2d). Mafic minerals make up less than 15% of the rock. Centimetre-scale gradational layering is common, and the unit is locally interlayered with metawacke and more pelitic compositions. The metapsammite locally forms a diatexite with discontinuous, quartz-rich bands of paleosome/melanosome in a matrix of leucosome.

Metawacke

The metawacke is light grey, fine- to coarse-grained, banded on a centimetre scale and locally magnetic. Layers are typically plagioclase-rich, with variable proportions of quartz, orthopyroxene, clinopyroxene, garnet, biotite and magnetite. Mafic minerals typically make up 20–40% of the rock. Orthopyroxene-bearing leucosome, with or without garnet, is common and can form up to 40% of exposures (Figure GS-7-2e). The metawacke is commonly interbanded with metapsammite and pelitic layers.

Banded iron formation

Banded iron formation typically occurs as gossan-stained layers up to 1.5 m thick commonly associated with intermediate and mafic granulite (Figure GS-7-2f). The iron formations are typically medium-grained, strongly magnetic and characterized by laminations of metachert. They are rich in quartz, green orthopyroxene and magnetite, with variable proportions of pyrrhotite and garnet.

Mg-Al rocks

Exposures of Mg-Al rocks are yellow-grey to brown-grey, medium- to very coarse-grained, and nonmagnetic. This unit is typically cordierite-rich, with variable proportions of orthopyroxene, sapphirine and quartz, with local spinel and rutile, as well as minor phlogopite, K-feldspar and plagioclase (Figure GS-7-2g). Sapphirine and free quartz do not occur in the same layer, and are only found together where quartz appears to be the product of melt crystallization, such as along the margins of injected leucosome, where reaction textures suggest the two minerals may not be in equilibrium. The Mg-Al rock typically occurs as layers less than 2.5 m thick, which are gradationally banded and spatially associated with metapsammite, and bands of mafic granulite. The close association of Mg-Al rock with supracrustal rocks suggests a supracrustal origin. The extreme MgO and Al_2O_3 enrichment of this unit (22.00 and 20.62 wt. % respectively) limits the possible origins for this rock. One possibility is that the rock represents the residuum of intense partial melting of a pelitic rock; however, the character and composition of other metapelitic and semipelitic rocks in the area are distinctly different. If the Mg-Al rocks are the residuum of partial melting, it would require invoking a unique process such as filter pressing of partial melts, which did not affect the other pelitic layers. The favoured interpretation is that the Mg-Al rocks represent a unit that was subjected to the effects of seafloor alteration. This hypothesis is supported by the extreme MgO and Al_2O_3 enrichment, as well as the depletion in SiO_2 (46.69 wt. %), Fe_2O_3 (0.93 wt. %) and alkalis (CaO, 0.06 wt. %; Na_2O, 0.07 wt. %; and K_2O, 0.16 wt. %).

A sample of granulite containing sapphirine was collected by Heaman et al. (2011) for zircon U-Pb age determination. The sapphirine-bearing rock was found to contain two populations of zircon, interpreted as metamorphic, which yielded isotope-dilution thermal-ionization mass spectrometry U-Pb ages of ca. 2680 and 2716 Ma. Dating of 38 zircon grains by laser-ablation multiple-collector inductively coupled plasma–mass spectrometry revealed the presence of Mesoarchean zircons, with several age population nodes ranging between ca. 2.80 and 3.0 Ga, in addition to a major ca. 2.70 Ga metamorphic population.

Ca-Al rocks

The Ca-Al rocks occur as bands 40–100 cm thick spatially associated with mafic granulite and typically hosted in enderbite. The bands are typically pale greenish-yellow, fine- to medium- grained and nonmagnetic. This unit is plagioclase- and garnet-rich, with subordinate deep green clinopyroxene. Scapolite is locally present and quartz can be present in major or minor amounts. The texture of the Ca-Al–rich rock varies according to quartz content. Quartz-poor layers are characterized by interstitial garnet, which gives the rock a mottled appearance (Figure GS-7-2h). The mottled layers are locally boudinaged, suggesting they behaved competently during deformation, whereas the quartz-rich layers are typically strongly sheared, suggesting a plastic behaviour. The chemistry of a quartz-poor layer was found to be enriched in CaO (19.83 wt. %), Al_2O_3 (21.69 wt. %) and Fe_2O_3 (4.15 wt. %) versus FeO (3.00 wt. %). The rock is also depleted in SiO_2 (49.01 wt. %), MgO (0.27 wt. %), Na_2O (0.68 wt. %) and K_2O (0.07 wt. %). The nature of this rock's protolith is uncertain; however, because of its high Al content, it is included with the supracrustal rocks, and may represent the remnants of a decarbonated limey mud.

Metaplutonic rocks

Two varieties of enderbite, leucocratic and mesocratic, were recognized and are the volumetrically dominant rock type in the map area (Figure GS-7-1). The two varieties of enderbite are locally interbanded and intercalations of enderbite are commonly present in exposures of other lithological units. Exposures of enderbite commonly contain pink feldspar, suggesting compositions trending toward opdalite or charnockite. Some opdalite is present; however, initial results from whole-rock geochemistry and thin-section petrography suggest the pink colouration is most commonly related to antiperthitic intergrowths in the plagioclase (Figure GS-7-3a). Although they can make up the dominant phase in outcrops, the two varieties of monzodiorite are rather minor phases and occur only in the northern portion of the map area. Xenolithic rafts, discontinuous bands and schlieren of the mafic and intermediate granulite are common in the metaplutonic rocks.

Mesocratic and leucocratic enderbite (metatonalite and metatrondhjemite)

The enderbite varies from light grey to pink to white on weathered surfaces and honey-brown to dark grey-blue on fresh surfaces (Figure GS-7-3b). It varies from medium- to coarse-grained and nonmagnetic to magnetic. The mesocratic enderbite contains >10% mafic minerals, whereas the leucocratic enderbite contains <10%. Mafic minerals consist of varying proportions of clinopyroxene and orthopyroxene, with subordinate magnetite and, locally, trace biotite. Rare exposures may be orthopyroxene-free. Exposures may contain up to 30% leucosome, which is typically transposed, but locally forms irregular pools and discordant veins. The mesocratic enderbite is locally gneissic.

Mesocratic monzodiorite

The mesocratic monzodiorite is grey-brown, medium- to coarse-grained and strongly magnetic. It is typically biotite-rich, with subordinate clinopyroxene and magnetite; however, the proportions of biotite to clinopyroxene are locally variable. The relatively high biotite content results in a strongly foliated rock, which is characterized by ubiquitous transposed leucosome (Figure GS-7-3c). The leucosome is typically clinopyroxene-bearing and coarse- to very coarse-grained K-feldspar augen commonly form its core.

Leucocratic monzodiorite

The leucocratic monzodiorite is light pink to pinkish-grey on weathered surfaces and dark grey on fresh surfaces. The unit is diffusely banded to rather homogeneous (Figure GS-7-3d); it is medium- to coarse-grained and magnetic. Mafic minerals typically make up ≤20% of the rock and consist of varying proportions of clinopyroxene, orthopyroxene and hornblende, with subordinate magnetite. Exposures locally contain up to 5% quartz. There is typically an antithetic relationship between the amount of hornblende and the amount of ortho- and clinopyroxene present, which may vary across a single outcrop. Greater proportions of pyroxenes are locally correlated to more leucocratic bands.

Late granitoid rocks

Intrusions of moderately to strongly foliated, pyroxene-free granitoid rocks flank the northwestern and southeastern margins of the map area (Figure GS-7-1). Rare exposures of these potentially larger intrusive bodies are relatively homogeneous and lack metamorphic banding and mobilizate, suggesting that these intrusions formed after granulite-grade metamorphism or outside the orthopyroxene-in isograd. Along the northwestern margin of the map area, adjacent to predominantly enderbitic rocks, strongly foliated biotite±hornblende granodiorite locally displays a K-feldspar–augen texture. In comparison, the intrusion along the southeastern margin of the map area appears to be dominantly foliated biotite granite.

Small granitic pegmatite and aplite dikes (typically <3 m) are locally present throughout the map area, but are volumetrically minor. These mineralogically simple dikes are typically massive, although a weak foliation is locally present. They commonly contain minor magnetite and allanite. Rare garnet-bearing dikes appear to be spatially related to exposures of supracrustal rocks. No systematic orientation of granitic dikes was noted. Rare intrusions of medium- to coarse-grained pink granite were observed in the central portion of the map area; this granite contains biotite and forms bodies 8–50 m wide.

Mafic dikes

Unmetamorphosed mafic dikes are relatively common in the map area and range in width from <1 cm to >50 m. They vary in texture and composition from diabasic to gabbroic to ultramafic. Chilled margins are relatively common for smaller diabasic dikes and rare examples of rhythmic banding may point to the formation of composite dikes. Dendritic plagioclase is locally present along

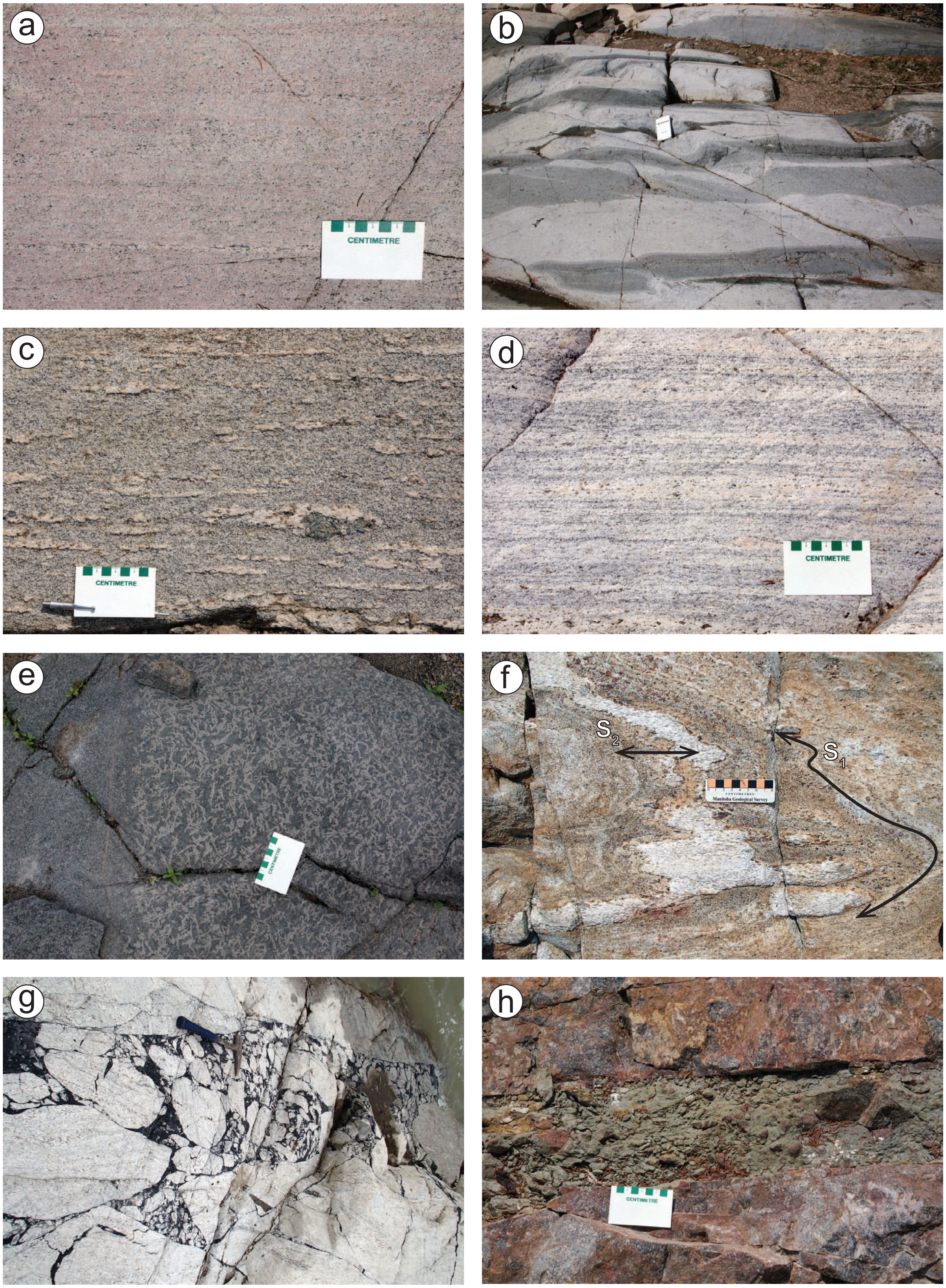

Figure GS-7-3: *Outcrop photographs from the central Sipiwesk Lake area, central Manitoba:* ***a)*** *pink, antiperthite-rich leucocratic enderbite;* ***b)*** *mesocratic enderbite, with discontinuous bands of mafic and intermediate granulite;* ***c)*** *mesocratic monzodiorite, with biotite-rich matrix;* ***d)*** *leucocratic monzodiorite, with diffuse amphibole-rich bands alternating with feldspar- and pyroxene-rich bands;* ***e)*** *dendritic plagioclase near the margin of an unmetamorphosed mafic dike;* ***f)*** *S_1 gneissosity in metapelite folded by F_2, the S_2 foliation is developed parallel to the axial plane;* ***g)*** *zone of brecciation and pseudotachylite veining;* ***h)*** *brittle fault with fault gouge, the enderbitic country rock is characterized by pervasive hematite staining.*

the margins of larger dikes (Figure GS-7-3e). Igneous layering is common in larger gabbroic and ultramafic dikes. Gabbroic pegmatite segregations are also relatively common in larger dikes. The segregations are typically amphibole-bearing and locally contain biotite and minor quartz. Although smaller dikes may be rather random in orientation, larger dikes are consistently oriented in a north-northeasterly direction with subvertical dips, the prevalent orientation of the ca. 1880 Ma Molson dike swarm (Scoates and Macek, 1978; Heaman et al., 2009).

Structural geology

Exposures throughout the map area are characterized by relatively high-strain features. The S_1 gneissosity is transposed by the later S_2 fabrics. The S_2 foliation most commonly strikes 240–260° and dips steeply toward the north (typically >70°). Minor folds in outcrop are interpreted as being parasitic to regional similar folds (Figure GS-7-3f); the regional fold pattern suggests multiple generations of folding. Rootless parasitic folds are locally observed. Lineations typically parallel minor fold axes and trend 050–080°, with a relatively moderate plunge of 30–60°.

Late brittle structures are locally abundant in the map area. Zones of pseudotachylite veining up to 5 m wide are present in localized zones throughout the map area (Figure GS-7-3g). The intervening blocks enclosed by veins of pseudotachylite locally form a chaotic juxtaposition of various (usually local) rock types. Some exposures reveal the presence of multiple crosscutting generations of pseudotachylite. Typically north-northeast-trending pseudotachylite veins cut, and are cut by, the unmetamorphosed mafic dikes

Brittle shear zones occur as zones of pervasive fracturing and hematitization up to 10 m wide. The shear zones are commonly lined by chlorite and are locally filled with vuggy carbonate. Discrete faults lined with chloritic/clay-rich fault gouge (Figure GS-7-3h) locally form the core of the fracture zones. Fault grooves and slicken lines indicate both sinistral and dextral senses of displacement. Brittle shears were observed cutting both pseudotachylite veins and mafic dikes, and are typically northeasterly trending with relatively steep dips. The brittle shear zones are most common in the southern portion of the map area, and tend to coincide with prevalent pseudotachylite zones.

Metamorphism

There appears to be little variation in the metamorphic grade across the map area. Mafic, intermediate and enderbitic gneiss units typically contain orthopyroxene- and clinopyroxene-bearing assemblages, and metapelitic rocks typically contain assemblages of orthopyroxene, sillimanite, garnet and rutile, with or without cordierite, these assemblages suggest peak metamorphism attained granulite-facies conditions. Preliminary phase-equilibria diagrams have been constructed from sample bulk compositions using the Theriak-Domino modelling software (de Capitani and Brown, 1987; de Capitani and Petrakakis, 2010) and the thermodynamic dataset (version 5.5 updated in 2003) of Holland and Powell (1998, 2003), based on activity models modified by Tinkham and Ghent (2005) and Pattison and Tinkham (2009). Samples of metapelite and Mg-Al rock were modelled in the NCKFMASHT (Na_2O-CaO-K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O-TiO_2) system and projected from pyrrhotite. Although these models are preliminary and require further refinement, they likely represent a good approximation of the peak P-T conditions attained by the rocks in the central Sipiwesk Lake area.

A sample of Mg-Al rock (108-12-1080A) contains the assemblage cordierite+orthopyroxene+orthoamphibole+sapphirine+spinel+rutile+biotite. The orthoamphibole is assumed to be a retrograde phase, which has pseudomorphously replaced grains of orthopyroxene. Spinel occurs only as grains enclosed by sapphirine and locally appears to be partially reacted to sapphirine, as noted by Arima and Barnett (1984), and Macek (1989); this seems to suggest that spinel is a metastable (likely relict) part of the assemblage. The assemblage cordierite+orthopyroxene+sapphirine+rutile+biotite occurs over a relatively restricted field in Figure GS-7-4a, defining P-T conditions of approximately 5.8–8.3 kbar and 920–950°C. In the adjacent, lower temperature fields, where plagioclase and clinoamphibole are predicted to be part of the assemblage, the two minerals are predicted to make up <1% of the rock. Because they make up such a small proportion of the rock, plagioclase and clinoamphibole may be present in the bulk rock sample, but not necessarily in the studied thin section; alternatively, they may be artefacts stemming from the rather extreme bulk-rock composition and the activity models used for the calculation. If these fields containing minute amounts of plagioclase and clinoamphibole are considered, the possible temperature range for this rock is increased to approximately 800–950°C.

A sample of metapelite (108-12-1084B) contains the assemblage quartz+plagioclase+cordierite+biotite+sillimanite+orthopyroxene+garnet+K-feldspar+rutile. This assemblage is restricted to a very small field in Figure GS-7-4b, represented by the black dot, and defines P-T conditions of approximately 8.8 kbar and 865°C. However, it is possible that biotite and sillimanite may have been retained as metastable phases to temperatures beyond their predicted stability range; alternatively, local skeletal quartz-biotite and quartz-sillimanite intergrowths suggest that at least some of the biotite and sillimanite grew as the sample cooled to near solidus conditions (Sawyer, 1999; Waters, 2000). A more realistic range for peak P-T conditions would therefore include fields where garnet, orthopyroxene, cordierite and rutile are predicted to form part of the stable assemblage. This suggests peak

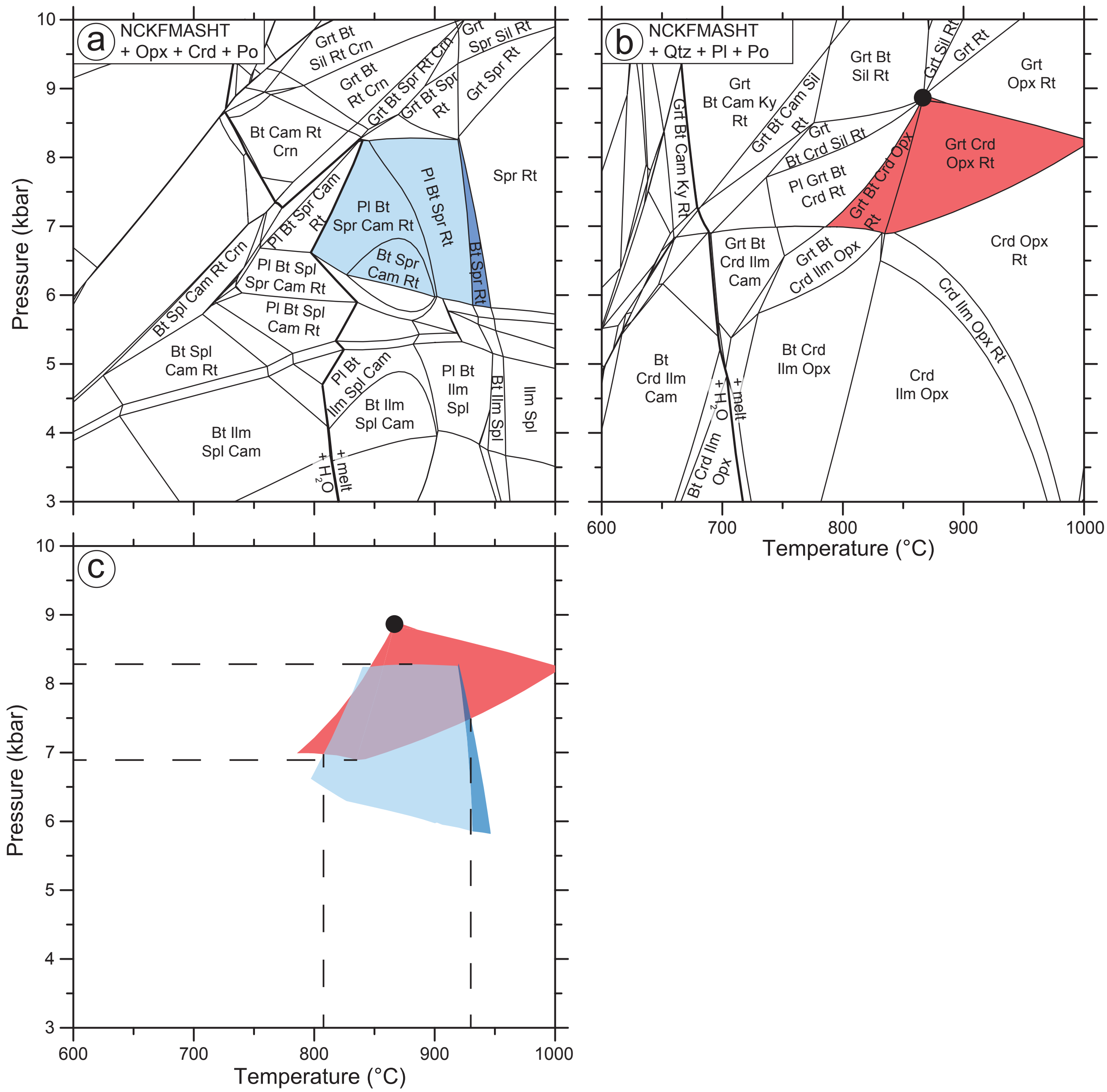

Figure GS-7-4: *Equilibrium-assemblage diagrams in the NCKFMASHT system of samples from the central Sipiwesk Lake area, central Manitoba:* ***a)*** *Mg-Al rock (sample 108-12-1080A), where the observed assemblage is marked by the dark blue field; however, the adjacent light blue fields are predicted to contain only minute amounts of plagioclase and clinoamphibole, which may not be represented in the thin section or may be artefacts of the bulk-rock composition and activity models used;* ***b)*** *metapelite (sample 108-12-1084B), where the observed mineral assemblage is marked by the dot; however, the possibility that sillimanite and biotite may be relict and/or retrograde suggests that the broader field of coexisting garnet+orthopyroxene+cordierite+rutile, marked in red, could be a more realistic estimate of the P-T conditions;* ***c)*** *the overlapping fields of a) and b) yield a best estimate for the peak metamorphic conditions in the central Sipiwesk Lake area of 6.9–8.3 kbar and 810–930°C. Abbreviations: Bt, biotite; Cam, Ca-clinoamphibole; Crd, cordierite; Crn, corundum; Grt, garnet; Ilm, ilmenite; Ky, kyanite; Opx, orthopyroxene; Pl, plagioclase; Po, pyrrhotite; Qtz, quartz; Rt, rutile; Sil, sillimanite; Spl, spinel; Spr, sapphirine.*

P-T conditions of 6.9–8.9 kbar and 780–1000°C. By overlapping the metamorphic conditions estimated from Figures GS-7-4a and b, the peak P-T conditions can be further constrained to approximately 6.9–8.3 kbar and 810–930°C (Figure GS-7-4c). This is similar to the 780–880°C temperature estimate of Arima and Barnett (1984), but suggests a lower pressure.

Hydration of the mafic dikes locally occurred along joints and fractures and resulted in the growth of chlorite- and actinolite-rich assemblages. Assuming an age of ca. 1.88 Ga for the dikes, this would suggest greenschist-facies metamorphic conditions during the Trans-Hudson orogeny.

Economic considerations

The presence of supracrustal rocks at central Sipiwesk Lake suggests the distribution of Archean greenstone-belt–type rocks in the PGD may be more widespread than previously recognized. Greenstone belts in the Superior Province are known to host a wide variety of mineral-deposit types, including lode gold (Rice Lake, Monument Bay), volcanogenic massive sulphide (Oxford Lake, Sturgeon Lake, Ring of Fire) and magmatic nickel (Ring of Fire) deposits; therefore, the potential exists for similar mineral-deposit types to exist in the PGD. The presence of possible seafloor-altered rocks, in the form of sapphirine-bearing gneiss, suggests that seafloor hydrothermal systems may have been active in the region prior to the high-grade metamorphic events and accompanying deformation. Seafloor hydrothermal systems are locally associated with exhalative massive sulphide deposits, as well as auriferous chert and banded iron formation, as observed on Utik Lake (Bernier and MacLean, 1989).

Although mineral exploration in high-grade metamorphic terranes can be a daunting task, a number of world-class mineral deposits are hosted in granulite-facies rocks, most notably in Australia with the Broken Hill Pb-Zn and Challenger Au deposits (Tomkins and Mavrogenes, 2002; Frost et al., 2005, 2011; McFarlane et al., 2007). In Canada, the Werner Lake Co-Cu-Au deposit from the English River Subprovince is believed to be an exhalative-related deposit, which was subjected to granulite-facies metamorphic conditions (Pan and Therens, 2000). Studies have also suggested that high-grade metamorphism may be responsible for the localized concentration of metals in these and other deposits (Pan and Therens, 2000; Tomkins and Mavrogenes, 2002; Tomkins et al., 2007; Frost et al., 2011).

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