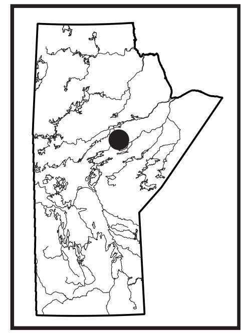
GS-2 Preliminary results from bedrock mapping in the northeastern Cauchon Lake area, eastern margin of the Pikwitonei granulite domain, central Manitoba (parts of NTS 63P9, 10)

by C.G. Couëslan



Couëslan, C.G. 2013: Preliminary results from bedrock mapping in the northeastern Cauchon Lake area, eastern margin of the Pikwitonei granulite domain, central Manitoba (parts of NTS 63P9, 10); *in* Report of Activities 2013, Manitoba Mineral Resources, Manitoba Geological Survey, p. 23–33.

Summary

A project to re-map portions of the Archean Pikwitonei granulite domain[1] in central Manitoba, with emphasis on interpretation of protoliths, continued with mapping in the northeastern Cauchon Lake area. The mapped area has been subjected to relatively uniform, high-grade Neoarchean metamorphism and deformation. Exposures in the northeastern Cauchon Lake area can be divided into three main groups based on structural observations: Archean pre-D_1 gneissic rocks, Archean post-D_1–pre-D_2 rocks and post-D_2 rocks. Pre-D_1 gneissic rocks include quartz diorite–monzodiorite gneiss, heterogeneous orthogneiss, a gneissic supracrustal sequence (including pyroxene and garnet wackes, semipelite, mafic volcanic rocks, pelite and banded iron formation), a layered anorthosite complex and opdalite (orthopyroxene granodiorite) gneiss. Post-D_1–pre-D_2 rocks include an intrusive suite, which ranges in composition from diorite to granodiorite, and discrete intrusive bodies of enderbite (orthopyroxene tonalite), granodiorite-granite, garnet monzogranite and metadiabase. Post-D_2 rocks consist mostly of Paleoproterozoic mafic dikes. The oldest group of rocks in the Cauchon Lake area displays an S_1 gneissosity. This early gneissosity was cut by leucosome that formed during a lower-granulite–facies metamorphic event, which affected all Archean rocks in the area. The rocks were then isoclinally folded and transposed during D_2 deformation, which generated S_2 fabrics in all Archean phases.

The supracrustal sequence exposed at Cauchon Lake bears many similarities to sequences observed in greenstone belts in the adjacent Superior province, where occurrences of gold and base metals are found.

Introduction

A project was initiated in 2012 to map portions of the Pikwitonei granulite domain (PGD; Couëslan et al., 2012). The objective is to re-map the mafic, intermediate and enderbitic (orthopyroxene-bearing tonalite) gneiss units, with an emphasis on protolith interpretation rather than descriptive petrography. It is also hoped that information gathered in the course of mapping will provide further insight into the tectonic significance of the PGD (e.g., Weber, 1983), and assist in assessing the mineral potential of the region. Due to the high metamorphic grade and the apparent lack of supracrustal rocks, the PGD has traditionally been considered to have insignificant or lower mineral potential compared to the adjacent, lower-grade metamorphic domains.

Mapping in 2013 focused on the Cauchon Lake area (Couëslan, 2013). Although an eight week mapping program was originally planned, rising waters on the Nelson River system during the summer necessitated a shortened mapping program of two and a half weeks that was limited to the northeastern arm of the lake (Figure GS-2-1).

Regional geology

The PGD is a Neoarchean high-grade metamorphic domain along the northwestern margin 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. 1.83–1.70 Ga) north-northeast-trending deformational fabrics, which truncate the east–west Neoarchean fabrics of the PGD (Hubregtse, 1980; Heaman et al., 2011; Kuiper et al., 2011; Couëslan et al., 2013).

The PGD is underlain by dominantly felsic to intermediate metaplutonic rocks (enderbitic, opdalitic and minor leuconoritic gneiss) 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. 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

[1] For the sake of consistency, the Manitoba Geological Survey has opted to make a universal change from capitalized to noncapitalized for the generic part of lithostructural feature names (formal stratigraphic and biostratigraphic nomenclature being the exceptions).

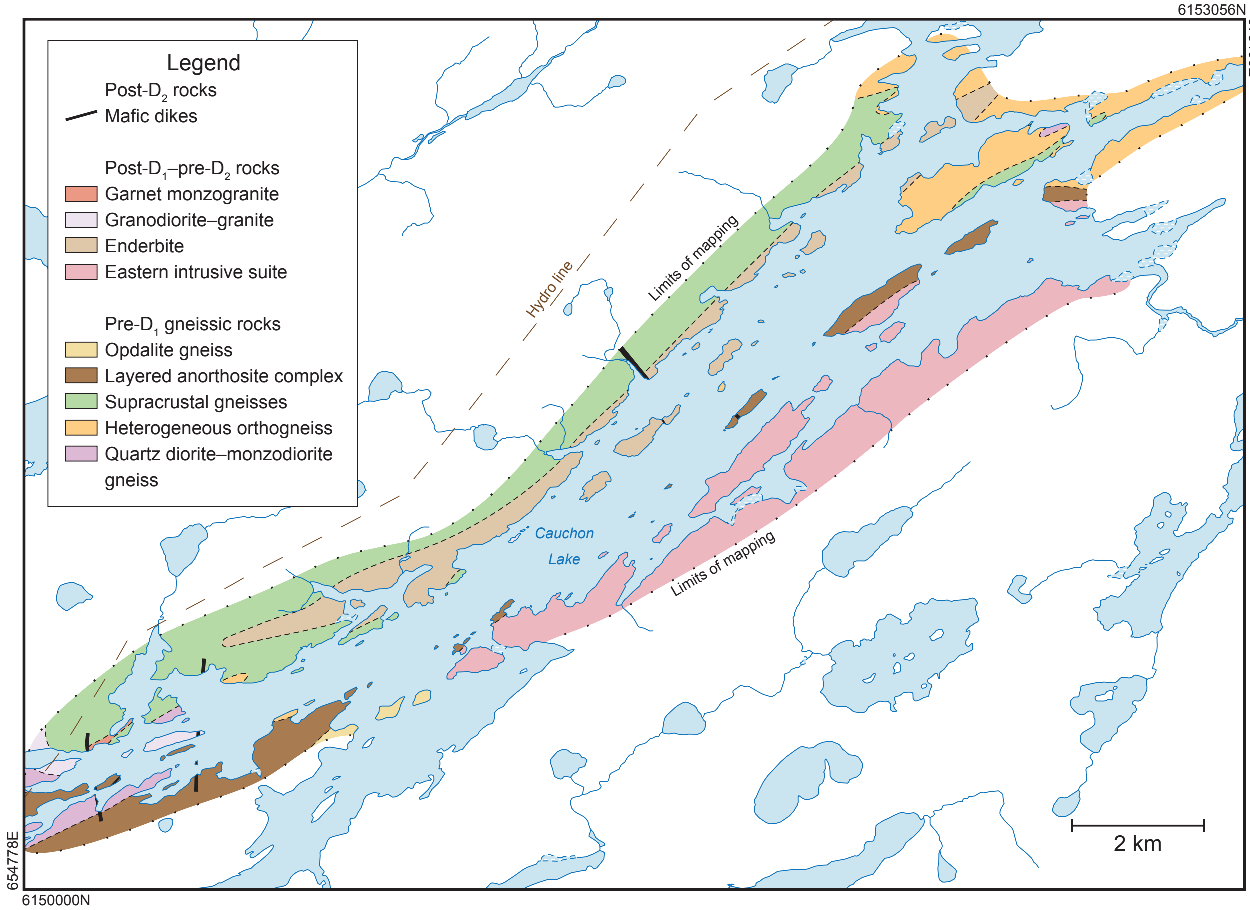


***Figure GS-2-1**: Simplified geology of the northeastern Cauchon Lake area, central Manitoba (modified after Couëslan, 2013).*

into west-southwest-trending shear folds, accompanied by granulite-facies metamorphism (Hubregtse, 1980; Heaman et al., 2011). Metamorphic conditions are estimated to have reached 750–860 °C and 6.3–7.0 kbar in the Cauchon Lake area (Mezger et al., 1990; Vry and Brown, 1992). A third generation of deformation (D_3) is recognized in the Cauchon Lake area, which produced retrogression, cataclasis and local mylonitization along southwest-trending shear zones (ca. 2640 Ma; Weber, 1977; Heaman et al., 2011). These shear zones subparallel S_2 and coincide with pronounced topographic lineaments.

Cauchon Lake area geology

The Cauchon Lake area is largely underlain by orthogneiss belonging to the informally named 'Cauchon Lake gneisses' (Weber, 1976a–d), which range from dioritic to tonalitic in composition, with mafic minerals consisting of biotite±orthopyroxene, clinopyroxene and hornblende depending on the degree of prograde and/or retrograde metamorphism. A relatively continuous belt of layered amphibolite, interpreted as metabasalt, occurs in the southern basin of the lake (Weber, 1976a–d). Rare rafts of amphibolite up to several hundred metres across occur throughout the area, hosted by the 'Cauchon Lake gneisses'. A 25 km by 0.5–1.5 km band of layered anorthosite occurs in the northern arm of the lake. Although the rocks range from anorthosite to pyroxene amphibolite, anorthositic to leucogabbroic rocks are dominant (Weber, 1976a, 1977; Peck et al., 1996). North of the layered anorthosite, and underlying much of the northern arm of the lake, is an intrusion of schollen-enderbite, which is considered to be gradational into the 'Cauchon Lake gneisses'. The enderbite is relatively homogeneous and contains ubiquitous mafic, and less abundant ultramafic, schollen (or xenoliths; Weber, 1976a). Unmetamorphosed mafic dikes related to the north-northeast-trending ca. 1.88 Ga Molson swarm and an older, east-northeast-trending ca. 2.10 Ga group (e.g., Cauchon Lake, Gull Rapids, Birthday Rapids) are reported from the Cauchon Lake area (Weber, 1976a–d, Scoates and Macek, 1978; Heaman et al., 1986; Halls and Heaman, 2000; Heaman et al., 2009).

Lithological units

The lithological units identified in the Cauchon Lake area are divided into three main groups: Archean rocks that predate the D_1 generation of deformation, Archean rocks that postdate D_1 and predate D_2, and rocks that postdate D_2. All Archean rocks in the area have been subjected to upper-amphibolite– to lower-granulite–facies metamorphic conditions; however, to improve the readability of the text the 'meta-' prefix has been omitted from rock names.

Pre-D_1 gneissic rocks

All rocks that predate D_1 are characterized by an S_1 gneissosity. The relative ages of rocks within this group are not constrained.

Quartz diorite–monzodiorite gneiss

The quartz diorite–monzodiorite gneiss is most common in the southwestern portion of the map area (Figure GS-2-1). It is creamy white to green-grey on weathered surfaces and typically honey brown on fresh surfaces. It is medium grained, foliated and crudely to well banded on a scale of 1–15 cm. The quartz diorite–monzodiorite gneiss typically contains between 15 and 30% mafic minerals as clinopyroxene, orthopyroxene and biotite, in variable proportions, up to 15% of both quartz and K-feldspar, and minor magnetite and hornblende. The quartz diorite–monzodiorite gneiss locally grades into, and is interbanded with, tonalite and granodiorite gneiss, which typically contain only 10% mafic minerals. The quartz diorite–monzodiorite gneiss typically contains 5–10% granodioritic leucosome as diffuse, coarse-grained veins and pods, which are locally orthopyroxene-bearing. Boudins up to 50 cm across, of intermediate to ultramafic composition, commonly make up 10–20% of outcrops and may represent xenoliths, disaggregated dikes, or both.

Heterogeneous orthogneiss

The heterogeneous orthogneiss is most common in the northernmost portions of the map area (Figure GS-2-1). It varies from white to grey to light orange on weathered surfaces and is typically honey brown on fresh surfaces. The orthogneiss is medium to coarse grained, moderately to strongly foliated and compositionally banded on a scale of 5 mm to 3 m. Outcrops commonly appear highly strained, with locally intense isoclinal folding. Composition of the orthogneiss varies widely and can consist of 20–60% quartz diorite–monzodiorite gneiss, 3–60% granite or granodiorite gneiss, 2–30% sheared pegmatitic granite, 2–30% mafic bands or boudins and trace to 3% ultramafic boudins (Figure GS-2-2a). Infolded bands of garnet wacke up to 3 m wide are rare and only present in the vicinity of other map-scale occurrences of metasedimentary rocks. Outcrops of orthogneiss typically contain between 5 and 30% leucosome as coarse-grained, diffuse veins and pods.

Supracrustal gneisses

Gneisses derived from supracrustal rocks occur in a previously unrecognized, relatively continuous belt at least 12 km long along the western shore of the map area (Figure GS-2-1). The belt is flanked by orthogneiss and enderbite to the southeast, and is covered by glacial deposits to the northwest of the lake. The total width of the supracrustal gneisses is not known, but in places it appears to exceed 1 km. The supracrustal rocks consist dominantly of pyroxene and garnet wackes with subordinate semipelite, mafic volcanic rocks, pelite and iron formation. Compositional banding in these rocks is interpreted as primary and subparallels the S_1 gneissosity. The supracrustal rocks are described in relative order of abundance because the depositional sequence is not known.

Pyroxene wacke

The pyroxene wacke is brown grey to rusty brown orange, medium to coarse grained, foliated and compositionally banded on a 1–30 cm scale. The pyroxene wacke typically contains 30–50% plagioclase, 20–40% quartz, 10–20% biotite and 3–10% orthopyroxene. Local clinopyroxene, K-feldspar and garnet occur in minor amounts. Local boudins and discontinuous layers of banded iron formation up to 1.5 m thick, garnetite up to 3 cm thick and more aluminous layers up to 10 cm thick are present. Local boudins and discontinuous bands of massive to laminated mafic gneiss up to 2 m thick may represent volcaniclastic deposits and/or sills (Figure GS-2-2b). The pyroxene wacke is commonly interbanded with, and locally gradational into, the garnet wacke and locally occurs interbanded with semipelite on a 10 cm to 5 m scale. Where the amount of semipelite in outcrop exceeds approximately 35%, the wacke occurs as disaggregated bands within a matrix of semipelitic diatexite (Figure GS-2-2c). The pyroxene wacke may represent metamorphosed volcaniclastic deposits.

Garnet wacke

The garnet wacke is light grey to rusty brown, medium grained, foliated and compositionally banded on a 1–20 cm scale (Figure GS-2-2d). The composition is similar to the pyroxene wacke; however, the garnet wacke typically contains 5–10% garnet and, locally, up to 30 % biotite and 50% quartz. Potassium feldspar porphyroblasts occur as rare blocky grains. Outcrops of garnet wacke are locally interbedded with up to 30% semipelite on a 2–30 cm scale. Local boudins and discontinuous bands of iron formation can reach up to 15 cm in thickness. Rare bands of mafic to ultramafic gneiss up to 3 m thick may represent volcaniclastic deposits or possibly sills.

Semipelite

The semipelite is purplish grey to rusty orange, medium to coarse grained and foliated. It commonly

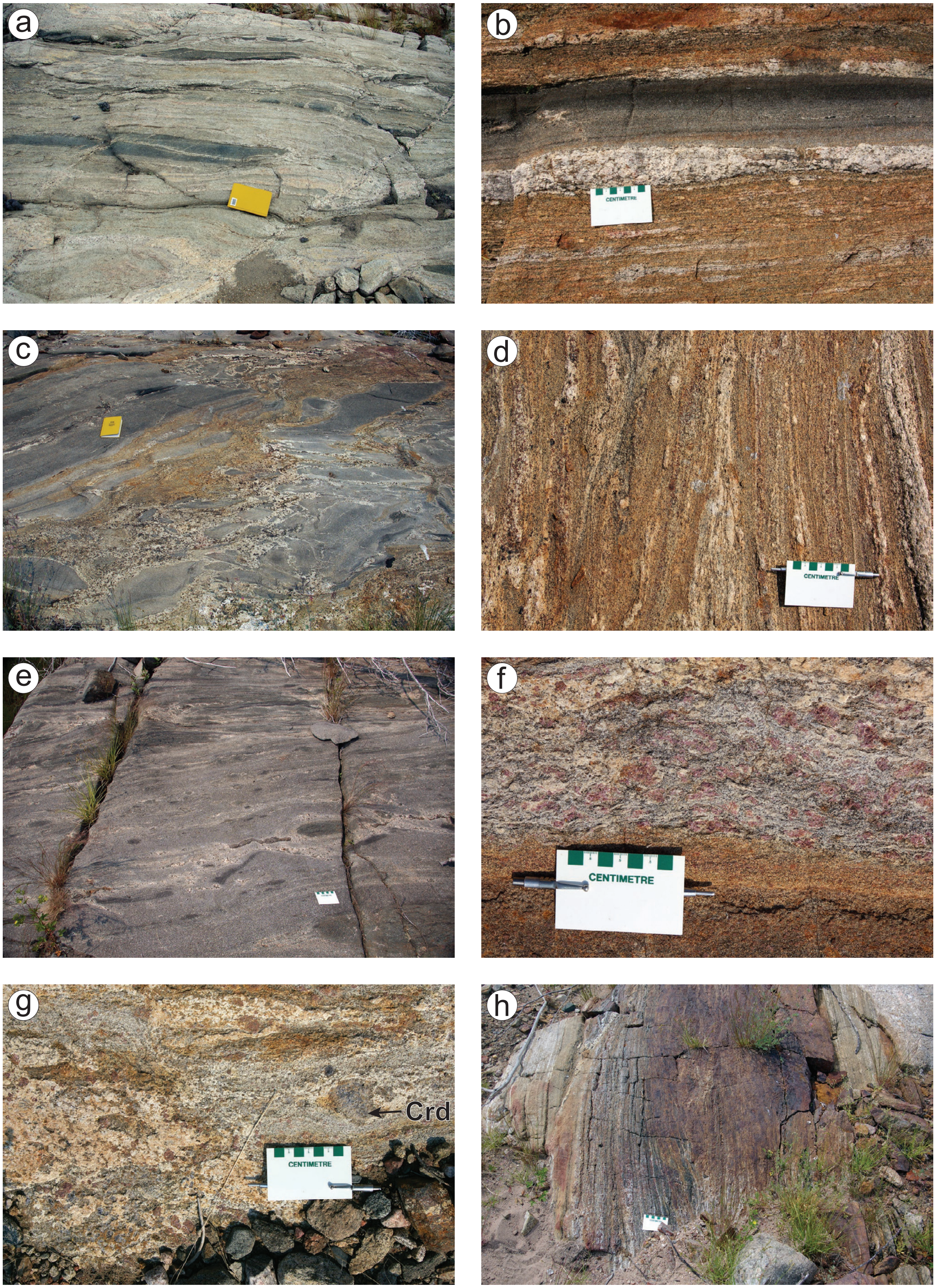


Figure GS-2-2: *Outcrop photographs from the northeastern Cauchon Lake area, central Manitoba:* ***a)*** *heterogeneous orthogneiss;* ***b)*** *band of mafic gneiss in pyroxene wacke;* ***c)*** *deformed bands of pyroxene wacke in a matrix of semipelitic diatexite;* ***d)*** *garnet wacke;* ***e)*** *mafic gneiss interpreted as volcanic rocks;* ***f)*** *garnet- and sillimanite-rich pelite;* ***g)*** *garnet- and cordierite-bearing leucosome in pelite;* ***h)*** *banded iron formation hosted in garnet wacke. Abbreviation: Crd, cordierite.*

forms a diatexite (Figure GS-2-2c); however, compositional banding is locally preserved. The semipelite typically contains 20–30% plagioclase, 15–30% quartz, 10–20% K-feldspar, 10–20% biotite and 5–10% garnet. Orthopyroxene is typically present, but occurs in variable amounts ranging from 2–20%. The semipelite, which locally grades towards a true pelitic composition, is commonly interbanded with 20–40% pyroxene wacke and contains local boudins of iron formation up to 75 cm thick.

Mafic volcanic rocks

Mafic gneiss interpreted as volcanic rocks are dark green grey, medium grained, foliated, and discontinuously and diffusely banded on a 1–10 cm scale (Figure GS-2-2e). They contain plagioclase along with 40–70% mafic minerals consisting of variable proportions of clinopyroxene, orthopyroxene and hornblende, along with minor magnetite. Local ultramafic boudins up to 1 m thick are present within the volcanic rocks. Pyroxene-rich leucosome occurs as veins and pods and locally makes up 2–3% of outcrops.

At one location in the southwestern portion of the map area, mafic volcanic rocks are in sharp contact with wacke; however, the nature of the contact is difficult to interpret due to localized shearing. Lenses of banded iron formation up to 6 m wide are locally present within the mafic volcanic rocks. Bands and lenses of layered to laminated mafic rocks up to 3 m thick are present in the pyroxene and garnet wackes (Figure GS-2-2b). Two notable outcrops with metamorphosed quartz-carbonate veining and intense carbonate alteration were identified outside of the map area, in the southern basin of Cauchon Lake. At one of these locations, a discrete stockwork of quartz-carbonate veins is concentrated along the depositional contact between ultramafic rocks, interpreted as metapicrite, and banded iron formation. At the other location, carbonate alteration occurs as a zone of intense, pervasive carbonatization of mafic volcanic rocks approximately 10 m wide.

Pelite

The pelite is purplish grey to rusty orange, coarse grained, foliated and compositionally banded on a 1–20 cm scale. It typically contains 20–30% garnet, 10–20% biotite, 3–10% sillimanite, and 2–3% graphite in a matrix of quartz and feldspar (Figure GS-2-2f). Orthopyroxene locally forms 3–5% of the rock. Local pods of leucosome can contain up to 20% cordierite as porphyroblasts, which can measure up to 4 cm across (Figure GS-2-2g). The pelite can be interlayered with up to 40% garnet wacke on a scale of 10–60 cm. Local, discontinuous orthopyroxene-, garnet- and plagioclase-rich bands up to 30 cm thick may represent layers enriched in Ca and Fe, or possibly hydrothermally-altered rock. The pelite is commonly intruded by semiconformable sheets of garnet monzogranite up to 3 m wide.

Banded iron formation

The iron formation is blue grey to rusty brown, medium grained, foliated, layered to laminated and, typically, moderately to strongly magnetic (Figure GS-2-2h). The composition is extremely variable, ranging from 10–20% Fe-orthopyroxene, 10-20% magnetite and 60–70% quartz as chert laminations; to nearly massive Fe-orthopyroxene with 10–20% garnet, 5–10% quartz, 3–5% pyrrhotite and 3–5% plagioclase. The iron formation typically occurs as discontinuous bands in the wackes, semipelite and mafic volcanic rocks, and only rarely occurs as map-scale exposures. One of these map-scale exposures in the west-central portion of the map area is characterized by a gossanous zone 6 m wide that contains disseminated and vein sulphide, and thin lenses of quartz, which could represent discontinuous chert laminations or quartz veins. This sulphidic iron formation occurs in close spatial association with mafic volcanic rocks.

Layered anorthosite complex

A single body of layered anorthositic rocks occurs across the central islands and along the southern shore of the map area (Figure GS-2-1). The anorthositic rocks are typically white to purplish grey, medium to coarse grained, foliated, and banded on a 1 cm to 3 m scale. The composition varies from almost pure plagioclase to gabbroic, with up to 90% mafic minerals as variable proportions of hornblende, clinopyroxene and orthopyroxene; however, the mafic mineral content is typically <15%. Minor biotite is locally present. Bands of megacrystic plagioclase are a characteristic feature of this unit (Figure GS-2-3a). Plagioclase megacrysts can measure up to 15 cm across and typically have a purplish core with a white, granulated rim. Quartz-epidote veins are relatively common. Plagioclase is subject to locally pervasive bleaching and replacement by disseminated quartz, epidote and, rarely, K-feldspar. Gossanous bands are rare within the anorthosite and typically narrow (2–3 cm). A more detailed description of the layered anorthosite complex can be found in Peck et al. (1996).

Opdalite gneiss

The opdalite gneiss occurs in the southern portion of the map area (Figure GS-2-1). It is light pinkish grey, medium to coarse grained and foliated. The gneiss contains 3–5% biotite, 2–5% orthopyroxene and trace to 1% magnetite. Minor hornblende is locally present. Although the opdalite is relatively homogeneous, weak compositional banding is present on a scale of 2–15 cm (Figure GS-2-3b). Outcrops typically contain 3–7% diffuse orthopyroxene-bearing leucosome and 1–5% mafic xenoliths.

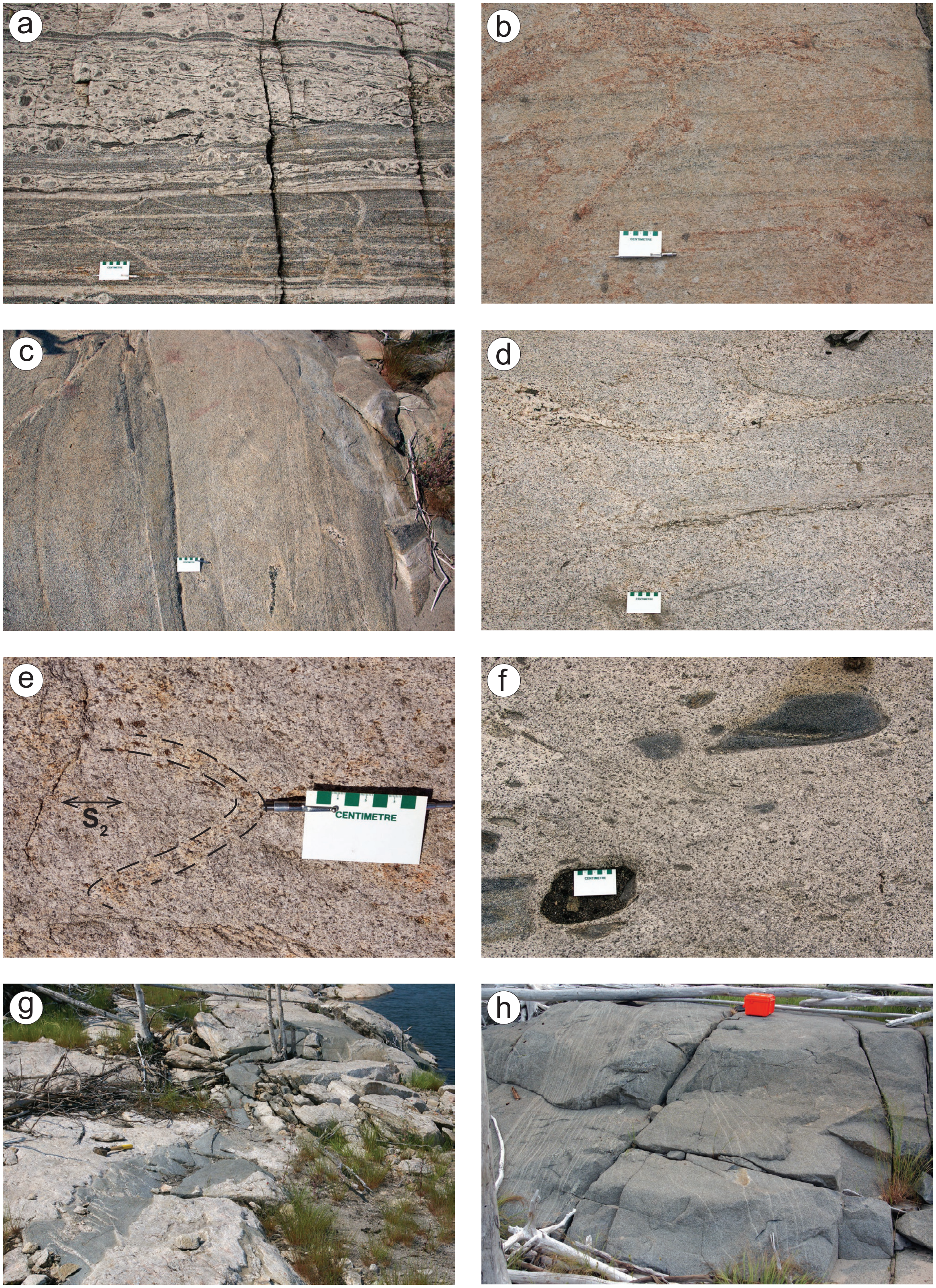


Figure GS-2-3: *Outcrop photographs from the northeastern Cauchon Lake area, central Manitoba:* ***a)*** *layered anorthosite with plagioclase megacrystic leucogabbro (top) and layered gabbro (bottom);* ***b)*** *opdalite gneiss, post-S_1 and pre-S_2 leucosome is present in the upper left-hand corner;* ***c)*** *diorite with a band of monzodiorite (centre);* ***d)*** *tonalite with coarse-grained, orthopyroxene-bearing leucosome;* ***e)*** *orthopyroxene-bearing leucosome in enderbite, folded and foliated by D_2;* ***f)*** *enderbite with xenoliths of varying composition;* ***g)*** *metamorphosed and deformed mafic dike in granodiorite;* ***h)*** *magmatic plagioclase layering defining crossbedding in a Paleoproterozoic gabbro dike.*

Post-D_1–pre-D_2 rocks

A well-defined gneissosity is absent in all post-D_1–pre-D_2 rocks; however, they do display an S_2 foliation. The order of intrusion of phases from this group is poorly constrained.

Eastern intrusive suite

The eastern intrusive suite informally refers to a group of dioritic, monzodioritic, tonalitic, and granodioritic rocks that occur along the eastern shore of the map area (Figure GS-2-1). The phases are locally interbanded/interleaved and blocks of the more mafic phases are locally found within the more felsic phases of the intrusive suite; however, the order of intrusion is not constrained. In general, mafic phases predominate in the southern and northern margins of the intrusive complex, while felsic phases are more abundant in the centre. Weber (1976a–d) grouped this suite of rocks with the quartz diorite–monzodiorite gneiss, heterogeneous orthogneiss and opdalite gneiss of the previous section under the informally termed 'Cauchon Lake gneisses'; however, an S_1 gneissosity is absent in the rocks of the eastern intrusive suite, which is therefore considered to be younger than, and unrelated to, the gneissic intrusive rocks.

Diorite–Monzodiorite

The diorite–monzodiorite is typically grey to pink, medium to coarse grained and foliated (Figure GS-2-3c). It contains 1–3% magnetite, 2–10% orthopyroxene, 5–20% hornblende and 5–15% clinopyroxene. Pyroxene is locally uralitized or partially replaced by hornblende. The unit contains up to 15% K-feldspar and is locally quartz-bearing, with coarser-grained zones containing up to 15% quartz. The diorite–monzodiorite locally grades into a hornblende-porphyritic phase, which contains up to 20% hornblende, and a more mafic phase, which contains 20–30% clinopyroxene, 20–30% orthopyroxene and 7–10% hornblende. Local compositional banding is interpreted as magmatic rather than gneissic. Outcrops typically contain 2–7% diffuse, coarse-grained, pyroxene-bearing leucosome. Two to three percent mafic rafts is relatively common, but outcrops can rarely contain up to 20% mafic and ultramafic xenoliths.

Tonalite–granodiorite

The tonalite–granodiorite is light grey to pinkish grey, medium to coarse grained and foliated (Figure GS-2-3d). It contains up to 15% K-feldspar and 3–12% biotite. Up to 7% orthopyroxene or hornblende, with minor clinopyroxene, locally occurs in place of, or along with, biotite. Mafic minerals are locally replaced by chlorite, usually in close spatial association with zones of epidote veining. Outcrops commonly contain 5–20% granitic to granodioritic leucosome, which was likely pyroxene-bearing; however, the mafic minerals were pseudomorphously replaced by uralite and/or chlorite. Local bands of medium-grained diorite up to 30 cm thick can be present.

Enderbite

The enderbite occurs as a single intrusive body along the western islands and shore of the map area (Figure GS-2-1). It is whitish to brown grey on weathered surfaces and honey brown on fresh surfaces. The enderbite is coarse grained and foliated, and contains 5–10% orthopyroxene, 2–3% biotite and trace amounts of magnetite. Minor amounts of clinopyroxene and K-feldspar are locally present. Exposures of enderbite typically contain 3–10% diffuse veins and pods of locally orthopyroxene-bearing, granodioritic to tonalitic leucosome (Figure GS-2-3e). The most distinct feature of this unit is the presence of generally rounded, intermediate to ultramafic xenoliths ranging from 2 cm to 3 m across, which typically make up 5–10% of the outcrop (Figure GS-2-3f). Granodioritic and pegmatitic granite xenoliths are locally present, and xenoliths of anorthosite, iron formation, garnet wacke and calcsilicate are rare. Xenoliths commonly display an internal S_1 gneissosity that is absent in the host enderbite. Rare exposures consist of 80–90% randomly oriented xenolithic blocks in a matrix of enderbite, and may represent a marginal phase to the intrusion. The amount of orthopyroxene and clinopyroxene within the enderbite matrix typically increases with proximity and abundance of mafic to ultramafic xenoliths.

The enderbite was previously interpreted as gradational into the 'Cauchon Lake gneisses' (Weber, 1976a). An S_1 gneissosity is absent in exposures of the enderbite, which suggests that it is younger than the quartz diorite–monzodiorite gneiss, heterogeneous orthogneiss and opdalite gneiss. Dikes of enderbite locally intrude the quartz diorite–monzodiorite gneiss and heterogeneous orthogneiss, demonstrating an intrusive relationship. However, no contact relationship was observed between the eastern intrusive suite and the texturally distinct enderbite, which are separated by the layered anorthosite complex (Figure GS-2-1). Because the 'Cauchon Lake gneisses' appear to consist of at least three temporally and spatially distinct intrusive suites, the use of this informal term should be discontinued.

Granodiorite–granite

A small intrusion varying in composition from granodioritic to granitic occurs in the southwestern portion of the map area (Figure GS-2-1). The intrusion is white to light pink, medium to coarse grained and foliated (Figure GS-2-3g). Mafic minerals consist of trace to 3% magnetite and 2–7% biotite. Outcrops are characterized by 10–20% coarse-grained granitic leucosome, which is locally magnetite-bearing.

Garnet monzogranite

A small intrusion of garnet monzogranite occurs in the southwestern portion of the map area, in close spatial association with exposures of pelite and semipelite (Figure GS-2-1). The monzogranite is white, medium to coarse grained and foliated. Mafic minerals consist of 2–5% garnet and 2–5% biotite. Xenoliths of semipelite up to 10 m across are locally present. Intrusive sheets of monzogranite up to 3 m thick are common in pelite outcrops, where the intrusion margin locally becomes cordierite-bearing.

Metadiabase

Rare dikes of metadiabase 0.5–1.5 m thick are present in quartz diorite–monzodiorite gneiss and granodiorite (Figure GS-2-3g) in the southern portion of the map area. The 'meta-' prefix is retained in this instance to differentiate these dikes from younger, unmetamorphosed mafic dikes, which occur throughout the Cauchon Lake area. The metadiabase is dark greenish grey, medium grained and foliated. The dikes are composed of minor magnetite, 10–20% orthopyroxene, 10–20% clinopyroxene, 10–20% hornblende and 50–60% plagioclase. The dikes are crosscut by leucosome derived from the surrounding country rock.

Post-D_2 rocks

Rocks that postdate the D_2 generation of deformation are relatively rare in the Cauchon Lake area. They consist dominantly of Paleoproterozoic mafic dikes, although rare, straight-walled and undeformed pegmatite dikes (typically <10 cm thick) are present.

Paleoproterozoic mafic dikes

These features consist of unmetamorphosed diabasic, gabbroic and ultramafic dikes, which occur throughout the map area (Figure GS-2-1). These dikes generally trend north-northeast (010–020°), east-northeast (045–060°), or southeast (120–140°), possibly corresponding to mafic dikes of the Molson, Cauchon and Mackenzie swarms, respectively (LeCheminant and Heaman, 1989; Halls and Heaman, 2000). The mafic dikes are locally cut by vuggy epidote veins, which locally display comb structures, and rare brittle faults and pseudotachylite.

Diabase dikes

Diabase dikes are typically <10 m wide. The diabase is green to grey green, fine to medium grained and massive. Compositions are typically clinopyroxene-rich (40–50%), with variable proportions of orthopyroxene, plagioclase and hornblende making up the remainder of the mode. Magnetite commonly accounts for 1–2% of the rock.

Gabbro dikes

Gabbro dikes typically range from 10 to 50 m in width. The dikes are dark green grey to grey brown, medium to coarse grained and massive. Dikes typically contain 40–50% plagioclase and 30–40% pyroxene, in varying proportions of clino- and orthopyroxene, and 5–10% hornblende. Up to 3% magnetite is locally present. Diabasic marginal zones are present in most dikes, and larger dikes locally display magmatic layering and, rarely, crossbedded layering 1–7 cm thick (Figure GS-2-3h). Pegmatitic pockets and veins, 10–40 cm across, locally occur near the centre of dikes, where they can crosscut magmatic layering. Granophyric zones are typically plagioclase-rich, with prismatic to acicular hornblende, and locally contain minor quartz.

Ultramafic dikes

Ultramafic dikes are typically <10 m wide and are rare compared to diabasic and gabbroic dikes. They are dark green to black, medium grained and massive. The dikes are typically composed of 30–40% prismatic clinopyroxene in a fine-grained, granular groundmass of orthopyroxene±olivine.

Structure and metamorphism

The earliest structures recognized in the Cauchon Lake area consist of an S_1 gneissosity in the orthogneisses and supracrustal rocks (pre-D_1 rocks). The metamorphic conditions that accompanied D_1 (M_1) could not be constrained from observations in the field; however, a relatively high metamorphic grade would likely be required for gneissosity development.

Veins and irregular pods of leucosome occur in all pre-D_1 and post-D_1–pre-D_2 rocks. The leucosome clearly cuts the S_1 gneissosity in older rocks and is therefore younger than D_1. The leucosome is commonly orthopyroxene-bearing and, in pelitic rocks, locally contains cordierite. The presence of these minerals suggests that the leucosome-forming metamorphic event (M_2) attained granulite-facies conditions. Assuming an average pelite bulk-composition for the pelite from Cauchon Lake, the observed mineral assemblage of garnet+sillimanite +biotite+cordierite+quartz+plagioclase+K-feldspar suggests a maximum possible pressure of 7.1 kbar and temperatures likely in the range of 730 to 810 °C (Figure GS-2-4). This is in relatively good agreement, although towards the lower temperature-end, of previous estimates (6.3–7.0 kbar and 750–860 °C, Mezger et al., 1990; Vry and Brown, 1992).

In all instances, the orthopyroxene-bearing leucosome displays a well-developed S_2 fabric and leucosome veins are locally folded by F_2. This suggests that the M_2 event predates some or all of the D_2 generation of deformation, which is manifested as a well developed S_2 quartz fabric in all Archean rocks. This fabric typically strikes 220–250° with a steep dip of 60–80° to the northwest. Typically, S_2 intersects S_1 at a small angle (<20°). The quartz fabric is axial planar to minor isoclinal folds

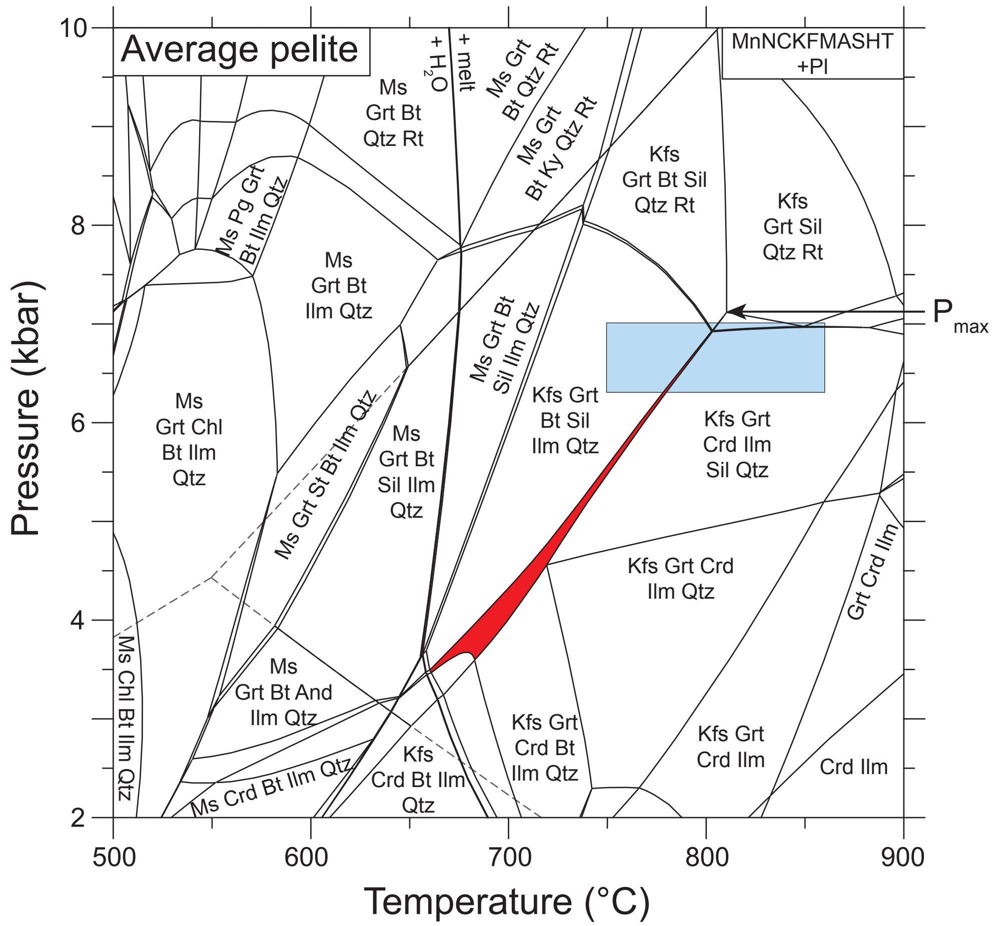


Figure GS-2-4: *Equilibrium-assemblage diagram in the MnNCKFMASHT system for average Pipe formation pelite (Couëslan and Pattison, 2012). The metamorphic assemblage observed in pelite from Cauchon Lake is indicated by the red field and the arrow marks the maximum possible pressure. The light blue field indicates the limits of previous pressure and temperature estimates (Mezger et al., 1990; Vry and Brown, 1992). The diagram was calculated using the Theriak-Domino software package (de Capitani and Petrakakis, 2010) and the updated 2003 ds5.5 thermodynamic dataset of Holland and Powell (1998) based on activity models outlined in Tinkham and Ghent (2005), Pattison and Tinkham (2009) and Couëslan et al. (2011). Abbreviations: And, andalusite; Bt, biotite; Chl, chlorite; Crd, cordierite; Grt, garnet; Ilm, ilmenite; Kfs, K-feldspar; Ky, kyanite; Ms, muscovite; Pg, paragonite; Pl, plagioclase;* P_{max}*, maximum possible pressure; Qtz, quartz; Rt, rutile; Sil, sillimanite; St, staurolite.*

(Figure GS-2-3e), which are dominantly symmetrical within the map area, although local Z-asymmetry and rare S-asymmetry folds are also present. Fold hinges typically plunge towards the northwest at a moderate to steep angle (50–80°). This orientation is also seen in L_2 fabrics in the map area, which suggests that regional fold hinges are F_2. Asymmetry of xenoliths in enderbite and fabric asymmetry around plagioclase megacrysts in anorthosite and porphyroblasts in other rocks typically indicate sinistral shear, and kinematic indicators in local protomylonitic shear zones suggest sinistral reverse motion.

Small (<3 m wide) ductile, brittle-ductile and brittle shear zones and faults with a dextral sense of movement occur throughout the map area. These faults typically strike southwest or west with a steep dip (60–80°). Rare, small (<2 cm wide) pseudotachylite veins spatially associated with brittle faults were observed. One brittle fault accompanied by pseudotachylite crosscuts an unmetamorphosed ultramafic dike, which suggests the faults may be related to Hudsonian tectonism.

Epidotization occurs as pervasive disseminated replacement in the layered anorthositic rocks, as replacement in shear zones and as local veins in most rocks in the Cauchon Lake area, including the Paleoproterozoic mafic dikes. The presence of epidote veins in the mafic dikes and the strong association between epidotization and later dextral shear zones suggests a Hudsonian age for the epidotization; however, local epidotization also occurs in association with sinistral mylonite zones in the anorthosite, so Archean epidotization cannot be discounted.

Chloritization and uralitization of mafic minerals appear to be closely associated with zones of epidotization and shearing.

Economic considerations

Iron formations are known to form chemical traps for sulphide- and Au-bearing fluids channeled along fold hinges, shear zones or faults in many Archean and Paleoproterozoic greenstone belts (Kerswill, 1995). This association is also found in greenstone belts in the northwestern Superior province (including at Bear, Utik and Oxford lakes), where gold and base metals are associated with altered volcanic rocks and exhalative deposits (Hartlaub and Böhm, 2006; Böhm et al., 2007; Anderson et al., 2012). Mafic gneiss interpreted as metavolcanic rocks in the southwestern portion of the map area hosts bands of gossanous silicate-facies iron formation up to 6 m wide, which contain disseminated and vein sulphide, and possible quartz veins, and may be prospective for Au mineralization. A sample was taken for assay and results are pending.

Pervasive carbonatization and stockworks of quartz-carbonate veins in mafic volcanic rocks are commonly associated with orogenic gold deposits (Robert, 1995; Dubé and Gosselin, 2007). Quartz-carbonate veins and pervasive carbonate alteration in mafic volcanic rocks was observed at two separate localities in the southern basin of Cauchon Lake. The presence of metamorphic mineral assemblages and deformation fabrics suggests that hydrothermal systems were active in the volcanic rocks prior to high-grade metamorphism. Pervasive carbonatization can also be associated with volcanogenic massive-sulphide (VMS) mineralization (Franklin, 1995; Anderson et al., 2012). A mapping program in the southern basin of Cauchon Lake may be warranted to further investigate the potential for gold and VMS mineralization.

Acknowledgments

The author thanks J. Combs for providing excellent field assistance, as well as N. Brandson and E. Anderson for logistical support. Thanks to J. Vry (Victoria University of Wellington, New Zealand) for enlightening outcrop and metamorphic geology discussions. Thanks to Vale Exploration–Thompson, for the use of their townhouse while transiting through Thompson.

References

Anderson, S.D., Kremer, P.D. and Martins, T. 2012: Preliminary results of bedrock mapping at Oxford Lake, northwestern Superior Province, Manitoba (parts of NTS 53L12, 13, 63I9, 16); *in* Report of Activities 2012, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 6–22.

Böhm, C.O., Heaman, L.M. and Corkery, M.T. 1999: Archean crustal evolution of the northwestern Superior Province margin: U-Pb zircon results from the Split Lake Block; Canadian Journal of Earth Sciences, v. 36, p. 1973–1987.

Böhm, C.O., Kremer, P.D. and Syme, E.C. 2007: Nature, evolution and gold potential of the Utik Lake greenstone belt, Manitoba (parts of NTS 53M4, 5, 63P1, 8); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 98–113.

Couëslan, C.G. 2013: Bedrock geology of northeastern Cauchon Lake, Manitoba (parts of NTS 63P9, 10); Manitoba Mineral Resources, Manitoba Geological Survey, Preliminary Map PMAP2013-4, scale 1:20 000.

Couëslan, C.G. and Pattison, D.R.M. 2012: Low-pressure regional amphibolite-facies to granulite-facies metamorphism of the Paleoproterozoic Thompson Nickel Belt, Manitoba; Canadian Journal of Earth Sciences, v. 49, p. 1117–1153.

Couëslan, C.G., Böhm, C.O. and Martins, T. 2012: Preliminary results from geological mapping in the central Sipiwesk Lake area, Pikwitonei Granulite Domain, central Manitoba (part of NTS 63P4); *in* Report of Activities 2012, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 79–89.

Couëslan, C.G., Pattison, D.R.M. and Dufrane, S. A. 2013: Paleoproterozoic metamorphic and deformation history of the Thompson Nickel Belt, Superior Boundary Zone, Canada, from in situ U–Pb analysis of monazite; Precambrian Research, v. 237, p. 13–35.

Couëslan, C.G., Pattison, D.R.M. and Tinkham, D.K. 2011: Regional low-pressure amphibolite-facies metamorphism at the Pipe II mine, Thompson Nickel Belt, Manitoba, and comparison of metamorphic isograds in metapelites and meta-iron formations; Canadian Mineralogist, v. 49, p. 721–747.

de Capitani, C. and Petrakakis, K. 2010: The computation of equilibrium assemblage diagrams with Theriak/Domino software; The American Mineralogist, v. 95, p. 1006–1016.

Franklin, J.M. 1995: Volcanic-associated massive sulphide base metals; *in* Chapter 6 of Geology of Canadian Ore Deposit Types, O.R. Eckstrand, W.D. Sinclair and R.I. Thorpe (ed.), Geological Survey of Canada, Geology of Canada, no. 8, p. 158–183 (*also* Geological Society of America, The Geology of North America, v. P-1).

Dubé, B. and Gosselin, P. 2007: Greenstone-hosted quartz-carbonate vein deposits; *in* Mineral Deposits of Canada: a Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods, W.D. Goodfellow (ed.), Geological Association of Canada, Mineral Deposits Division, Special Publication, no. 5, p. 49–73.

Halls, H.C. and Heaman, L.M. 2000: The paleomagnetic significance of new U–Pb age data from the Molson dyke swarm, Cauchon Lake area, Manitoba; Canadian Journal of Earth Sciences, v. 37, p. 957–966.

Hartlaub, R.P. and Böhm, C.O. 2006: Preliminary results from geological mapping of the Bear Lake greenstone belt, Manitoba (parts of NTS 53M4 and 63P1); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 65–73.

Heaman, L.M., Peck, D. and Toope, K. 2009: Timing and geochemistry of 1.88 Ga Molson Igneous Events, Manitoba: insights into the formation of a craton-scale magmatic and metallogenic province; Precambrian Research, v. 172, p. 143–162.

Heaman, L.M., Machado, N., Krogh, T.E. and Weber, W. 1986: Precise U–Pb zircon ages for the Molson dyke swarm and the Fox River sill: constraints for Early Proterozoic crustal evolution in northeastern Manitoba, Canada; Contributions to Mineralogy and Petrology, v. 94, p. 82–89.

Heaman, L.M., Böhm, Ch.O., Machado, N., Krogh, T.E., Weber, W. and Corkery, M.T. 2011: The Pikwitonei Granulite Domain, Manitoba: a giant Neoarchean high-grade terrane in the northwest Superior Province; Canadian Journal of Earth Sciences, v. 48, p. 205–245.

Holland, T.J.B. and Powell, R. 1998: An internally-consistent thermodynamic dataset for phases of petrological interest; Journal of Metamorphic Geology, v. 16, p. 309–343.

Hubregtse, J.J.M.W. 1978: Sipiwesk Lake–Landing Lake–Wintering Lake area (parts of NTS 63P3, 4, 5, 6, 63J16 and 63I13 and 14); *in* Report of Field Activities 1978, Manitoba Department of Mines, Resources and Environmental Management, Mineral Resources Division, p. 54–62.

Hubregtse, J.J.M.W. 1980: The Archean Pikwitonei Granulite Domain and its position at the margin of the northwestern Superior Province; Manitoba Energy and Mines, Mineral Resources Division, Geological Paper, GP80-3, 16 p.

Kerswill, J. A. 1995: Iron formation-hosted stratabound gold; *in* Chapter 15 of Geology of Canadian Ore Deposit Types, O.R. Eckstrand, W.D. Sinclair and R.I. Thorpe (ed.), Geological Survey of Canada, Geology of Canada, no. 8, p. 367–382 (*also* Geological Society of America, The Geology of North America, v. P-1).

Kuiper, Y.D., Lin, S. and Böhm, C.O. 2011: Himalayan-type escape tectonics along the Superior Boundary Zone in Manitoba, Canada; Precambrian Research, v. 187, p. 248–262.

LeCheminant, A.N. and Heaman, L.M. 1989: Mackenzie igneous events, Canada: Middle Proterozoic hotspot magmatism associated with ocean opening; Earth and Planetary Science Letters, v. 96, p. 38–48.

Mezger, K., Bohlen, S.R. and Hanson, G.N. 1990: Metamorphic history of the Archean Pikwitonei Granulite Domain and the Cross Lake Subprovince, Superior Province, Manitoba, Canada; Journal of Petrology, v. 31, p. 483–517.

Pattison, D.R.M. and Tinkham, D.K. 2009: Interplay between equilibrium and kinetics in prograde metamorphism of pelites: an example from the Nelson aureole, British Columbia; Journal of Metamorphic Geology, v. 27, p. 249–279.

Peck, D.C., Cameron, H.D.M., Layton-Matthews, D. and Bishop, A. 1996: Geological investigations of anorthosite, gabbro and pyroxenite occurrences in the Pikwitonei Granulite Domain and the Cross Lake region (parts of NTS 63I/6, 63J/7, 63J/8, 63P/5, 63P/6, 63P/7, 63P/8, 63P/9, 63P/11 and 63P/12); *in* Report of Activities 1996, Manitoba Energy and Mines, Geological Services, p. 85–90.

Robert, F. 1995: Quartz-carbonate vein gold; *in* Chapter 15 of Geology of Canadian Ore Deposit Types, O.R. Eckstrand, W.D. Sinclair and R.I. Thorpe (ed.), Geological Survey of Canada, Geology of Canada, no. 8, p. 350–366 (*also* Geological Society of America, The Geology of North America, v. P-1).

Scoates, R.F.J. and Macek, J.J. 1978: Molson Dyke Swarm; Manitoba Mines, Resources and Environmental Management, Mineral Resources Division, Geological Paper, GP78-1, 51 p.

Tinkham, D.K. and Ghent, E.D. 2005: Estimating P-T conditions of garnet growth with isochemical phase diagram sections and the problem of effective bulk-composition; Canadian Mineralogist, v. 43, p. 35–50.

Vry, J.K. and Brown, P.E. 1992: Evidence for early fluid channelization, Pikwitonei Granulite Domain, Manitoba, Canada; Canadian Journal of Earth Sciences, v. 29, p. 1701–1716.

Weber, W. 1976a: Cauchon, Partridge Crop and Apussigamasi lakes area (parts of 63P7, 8, 9, 10, 11, and 13); *in* Report of Field Activities 1976, Manitoba Department of Mines, Resources and Environmental Management, Mineral Resources Division, Geological Survey, p. 54–57.

Weber, W. 1976b: Prud'homme Lake, The Pas mining district (63P7); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Map 1976U-1, scale 1:50 000.

Weber, W. 1976c: Goulet Lake, The Pas mining district (part of 63P8); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Map 1976U-2, scale 1:50 000.

Weber, W. 1976d: Bear Head Lake, The Pas mining district (part of 63P9); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Map 1976U-3, scale 1:50 000.

Weber, W. 1977: Odei–Burntwood rivers region; Cauchon Lake region (parts of NTS 64A2, 3, 64P14, 53M5, 12, and 63P1, 2, 7, 8, 9, 10, and 15); *in* Report of Field Activities 1977, Manitoba Department of Mines, Resources and Environmental Management, Mineral Resources Division, p. 58–61.

Weber, W. 1983: The Pikwitonei granulite domain: A lower crustal level along the Churchill-Superior boundary in central Manitoba; *in* A Cross Section of Archean Crust, L.D. Ashwal and K.D. Card (ed.), Lunar and Planetary Institute, Houston, Texas, Technical Report 83-03, p. 95–97.