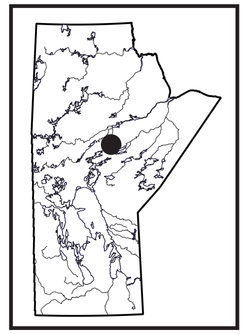
GS-2 Preliminary results from bedrock mapping in the southern and central Cauchon Lake area, eastern margin of the Pikwitonei granulite domain, central Manitoba (parts of NTS 63P7, 8)

by C.G. Couëslan and V.E. Guevara[1]



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Summary

A project to remap portions of the Archean Pikwitonei granulite domain in central Manitoba, with emphasis on interpretation of protoliths, continued in 2015 with mapping in the central and southern areas of Cauchon Lake. Exposures in the area can be divided into three main groups based on structural observations: Archean pre- to syn-D_1 rocks, Archean post-D_1 rocks and Paleoproterozoic post-D_2 rocks. Pre- to syn-D_1 rocks include metamorphosed mafic volcanic and associated rocks, psammite and semipelite, iron formation and chert, gneissic tonalite and trondhjemite, anorthosite, and monzodiorite. Post-D_1 rocks consist of metamorphosed intrusive rocks that range in composition from diorite to monzogranite. Post-D_2 rocks consist of unmetamorphosed Paleoproterozoic diabase and gabbro dikes. The oldest group of rocks in the Cauchon Lake area displays an S_1 gneissosity. This early gneissosity was cut by M_2 leucosome that formed under upper-amphibolite– to granulite–facies metamorphic conditions, 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 mafic volcanic rocks were subjected to widespread hydrothermal alteration prior to high-grade regional metamorphism. Carbonate alteration is the dominant style of alteration; however, evidence for chlorite+sericite and quartz+pyrophyllite alteration is also present. These styles of alteration suggest potential for both gold and volcanogenic massive sulphide mineralization.

Introduction

A project was initiated in 2012 to map portions of the Pikwitonei granulite domain (PGD; Couëslan et al., 2012). The objective is to remap the mafic, intermediate and enderbitic (orthopyroxene-bearing tonalite) gneiss units, with an emphasis on protolith interpretation rather than descriptive petrography, to assist in assessing the mineral potential of the region as well as provide further insight into the tectonic significance of the PGD (e.g., Weber and Mezger, 1990), the latter of which is the focus of co-author Guevara's Ph.D. dissertation. Due to the high metamorphic grade and apparent lack of supracrustal rocks, the PGD has traditionally been considered to have insignificant or low mineral potential compared to adjacent, lower-grade metamorphic domains. Preliminary mapping of the northern basin of Cauchon Lake was conducted in 2013; however, the mapping project was suspended due to high water levels on the Nelson River system (Couëslan, 2013). Water levels remained high during the 2014 field season. A return to average water levels in 2015 allowed for the completion of mapping in the central and southern areas of Cauchon Lake (Figure GS-2-1). Unfortunately, a thin coating of clay left by the high water hampered detailed observations of many exposures. The units discussed in this report correspond to those shown on Preliminary Map PMAP2015-2 (Couëslan and Guevara, 2015) and Figure GS-2-1 represents a simplified version of this map.

The Cauchon Lake area was selected for mapping for several reasons: 1) it appears to straddle the amphibolite- to granulite-facies transition that defines the eastern limit of the PGD (Weber, 1987); 2) it is situated close to a possible Archean tectonic domain boundary between the Hudson Bay and North Caribou terranes (Percival et al., 2006; Stott et al., 2010; Couëslan, 2014); and 3) evidence for hydrothermally altered mafic volcanic rocks was observed during preliminary mapping in 2013 (Couëslan, 2013). Therefore, the Cauchon Lake area is an important locality for understanding the tectonometamorphic history of the PGD (and more broadly, the Superior craton), and for assessing the mineral resource potential in Archean granulite terranes.

Regional geology

The PGD is a Neoarchean high-grade metamorphic domain along the northwestern margin of the Superior craton. 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 craton, marks the southeastern boundary of the domain (Hubregtse, 1980; Heaman et al., 2011) and appears to crosscut the boundary between the Hudson Bay and North Caribou terranes (Couëslan, 2014). The northwestern boundary of the PGD is defined by Paleoproterozoic Hudsonian (ca. 1.83–1.75

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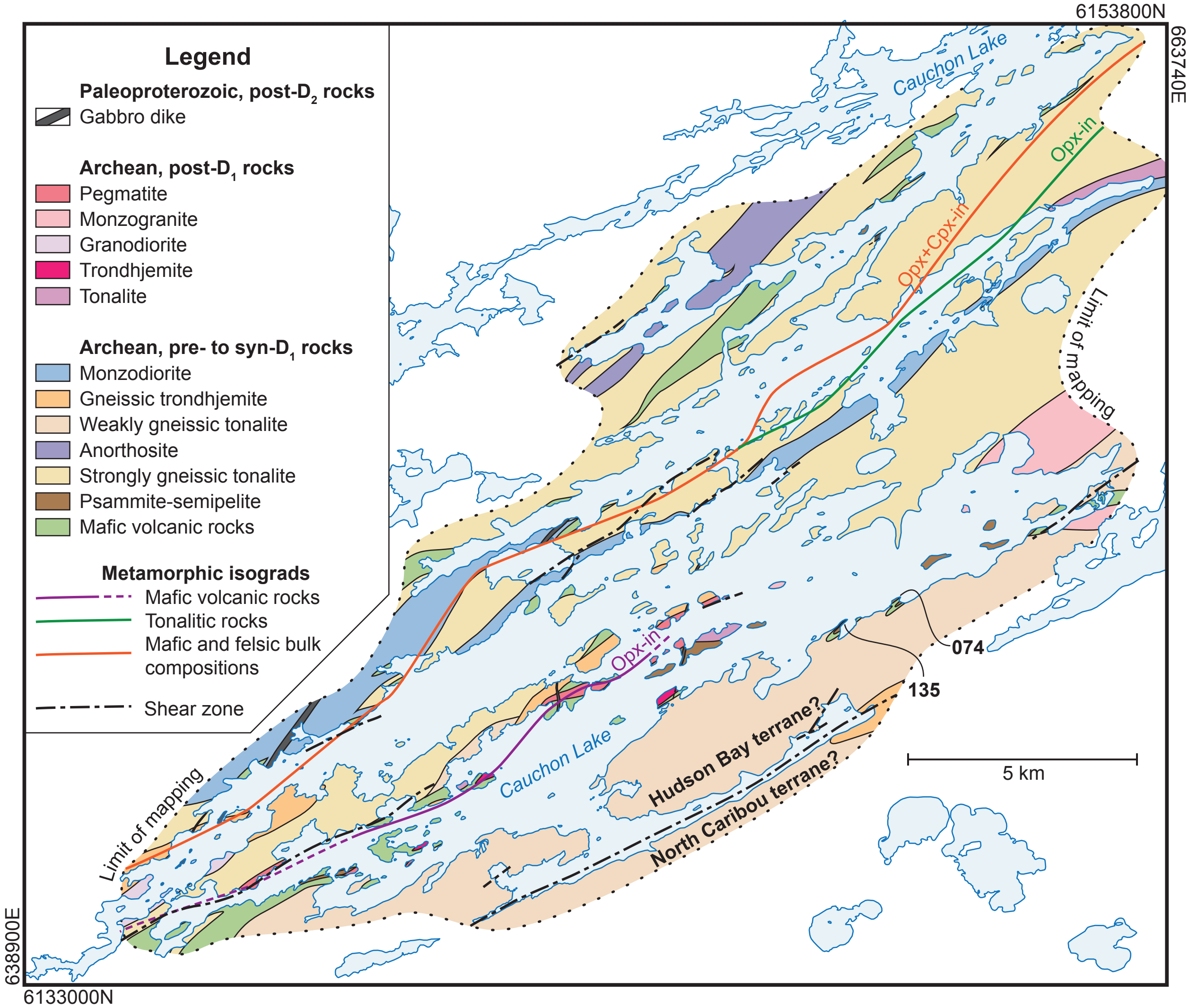

Figure GS-2-1: Simplified geology of the southern and central areas of Cauchon Lake, central Manitoba, indicating the locations of stations 074 and 135 (modified after Couëslan and Guevara, 2015). Solid coloured lines define indicated metamorphic isograds, dashed coloured lines define inferred metamorphic isograds.

Ga) north-northeast-trending deformational fabrics, which truncate the generally east–west Neoarchean fabrics of the PGD (Hubregtse, 1980; Heaman et al., 2011; Kuiper et al., 2011; Couëslan et al., 2013).

The PGD consists dominantly of felsic to intermediate metaplutonic rocks and mafic granulitic rocks (metagabbro, metapyroxenite, and metabasalt; Hubregtse, 1978, 1980; Heaman et al, 2011). Metamorphosed supracrustal rocks are considered to be 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) and isoclinal folds (Hubregtse, 1980; Heaman et al., 2011). The accompanying M_1 metamorphism is interpreted to have 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). 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; Weber, 1987; Heaman et al., 2011). These shear zones are subparallel to S_2 and coincide with pronounced topographic lineaments.

Cauchon Lake area geology

Cauchon Lake is situated along the southern margin of the Hudson Bay terrane. A shear zone that runs through the channel-like bay along the southern shore of Cauchon Lake is interpreted to roughly coincide with the boundary between the Hudson Bay and North Caribou terranes (Percival et al., 2006; Stott et al., 2010; Couëslan, 2014; Figure GS-2-1). The Cauchon Lake area is dominated by orthogneiss that ranges 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 (Weber, 1976a–d; Couëslan, 2013). Rare rafts of amphibolite up to several hundred metres across occur within the orthogneiss. A relatively continuous belt of layered amphibolite, interpreted as metabasalt, occurs in the southern basin of the lake (Weber, 1976a–d). A 25 km by 0.5–1.5 km band of layered anorthosite occurs in the northern arm of the lake. The rocks in this band vary from anorthosite to pyroxene amphibolite, but anorthositic to leucogabbroic rocks are the predominant rock type (Weber, 1976a, 1977; Peck et al., 1996). A relatively continuous belt of metasedimentary rocks occurs along the northwestern shore of the northern basin of the lake (Couëslan, 2013). Metamorphic mineral assemblages indicate upper-amphibolite–facies conditions in the southern basin to granulite-facies conditions in the northern and central basins (Weber, 1987). Peak metamorphic conditions are estimated at 730–810 °C and 6.3–7.1 kbar in the northern basin of Cauchon Lake (Mezger et al., 1990; Vry and Brown, 1992; Couëslan, 2013). Unmetamorphosed mafic dikes related to the north-northeast-trending ca. 1880 Ma Molson swarm and an older, east-northeast-trending ca. 2090 Ma group (as identified at Cauchon Lake and 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). A third set of northwest-trending mafic dikes may belong to the ca. 1270 Ma Mackenzie swarm (LeCheminant and Heaman, 1989; Couëslan, 2013).

Lithological units

The lithological units identified in the Cauchon Lake area are divided into three main groups: Archean rocks that predate or are synchronous with D_1 deformation, Archean rocks that postdate D_1, and Paleoproterozoic 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.

Archean pre-to syn-D_1 gneissic rocks

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

Mafic volcanic and associated rocks

Mafic volcanic rocks occur as a relatively continuous belt in the southern basin of Cauchon Lake and as discontinuous units in the rest of the map area (Figure GS-2-1). In the southernmost portion of the map area, these rocks are characterized by upper-amphibolite–facies mineral assemblages, which transition locally into lower-granulite facies. In the central and northern portions of the map area, the rocks are characterized by a two-pyroxene granulite-facies mineral assemblage. Evidence for hydrothermal alteration of the protolith is present in many exposures, with alteration zones characterized by upper-amphibolite– to granulite–facies metamorphic mineral assemblages, indicating that the alteration predates the regional high-grade metamorphism. Associated with the mafic volcanic rocks are local ultramafic volcanic rocks, pyroxenite sills and plagioclase amphibolite.

Mafic volcanic rocks

Mafic volcanic rocks with upper-amphibolite–facies metamorphic assemblages are typically dark grey green, medium to coarse grained, and foliated. Exposures are typically heterogeneous, varying from diffusely banded to discretely laminated, and banded on a scale of 1–50 mm (Figure GS-2-2a); however, relatively massive zones are also present and may represent massive flows or subvolcanic intrusions. Assemblages are plagioclase bearing, with mafic minerals typically making up 50–70% of the rock and consisting of varying proportions of black and green amphiboles, along with minor biotite. Hornblende locally occurs as porphyroblasts up to 7 mm and could be pseudomorphous after pyroxene phenocrysts. Rare bands with small, disseminated clots of plagioclase plus or minus garnet could represent formerly phyric or amygdaloidal flows. Deformed pillow selvages are locally present and are commonly accompanied by calcsilicate pods up to 15 cm thick, which likely represent interpillow material (Figure GS-2-2b). The calcsilicate pods typically consist of diopside-rich rinds, with plagioclase±quartz, garnet and diopside cores. Gossanous zones up to 3 m wide can be present and are locally associated with pegmatitic intrusions or shear zones; however, in other instances they appear to be caused by fine-grained disseminated sulphide within the volcanic rocks.

Calcsilicate pods are common, consisting of varying proportions of diopside, plagioclase, scapolite and garnet with minor titanite, and often associated with plagioclase-, scapolite- and diopside-rich veins, local quartz stringers, and diopside-rich bands. The pods are interpreted as a combination of the interpillow/interflow material described above and (along with the bands and veins) localized carbonate alteration of the volcanic protolith. In zones of more intense alteration the rock becomes extremely heterogeneous, with diopside-rich, hornblende-rich, garnet-rich and quartz-rich bands, and local scapolite-rich stringers (Figure GS-2-2c). Significant pitting and recessive weathering in some zones suggest the presence of carbonate. The most intense zones of carbonate alteration consist of calcsilicate, with 20–30% discontinuous bands of marble up to 40 cm thick (Figure GS-2-2d).

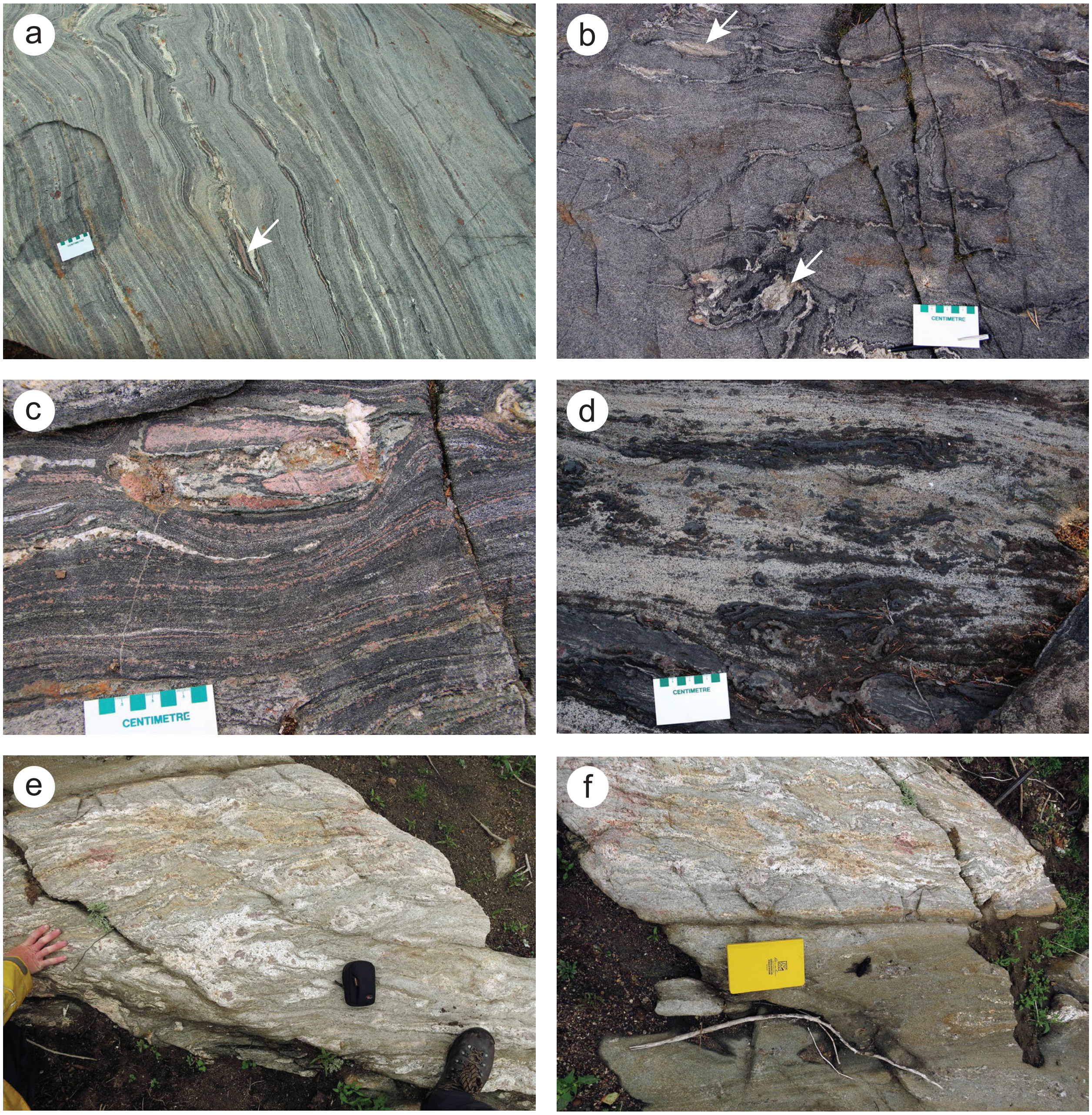

***Figure GS-2-2:** Outcrop photographs of mafic volcanic rocks from the southern basin of Cauchon Lake: **a)** diffusely banded with local pods of garnet-rich calcsilicate (arrow); **b)** deformed pillow selvages with calcsilicate pods (arrows); **c)** strongly altered mafic volcanic rocks consisting of alternating diopside-, hornblende- and garnet-rich laminations, with local garnet-, diopside- and carbonate-rich calcsilicate boudins (top of image); **d)** marble with calcsilicate lenses interpreted as an intensely carbonate-altered mafic volcanic rock; **e)** 'pelitic' schist, interpreted to represent a primary zone of chlorite and sericite alteration of a mafic volcanic protolith **f)** gradational contact between relatively unaltered mafic volcanic rocks (bottom of image) and 'pelitic' alteration (top of image).*

The calcsilicate is grey green to very dark green, medium grained, foliated, and banded on a scale of 1-100 mm. It contains variable amounts of diopside, hornblende, carbonate and plagioclase or scapolite, with minor sulphide, titanite and garnet. The marble varies from beige to green grey, fine to coarse grained, and is internally banded and locally magnetic. The marble is carbonate rich, with variable amounts of diopside and olivine, and minor garnet and magnetite. In addition to pervasive carbonate alteration, metamorphosed zones of discrete quartz-carbonate–vein stockwork are locally present. The veins typically consist of quartz, with variable amounts of garnet, diopside, plagioclase and carbonate.

Rare bands of 'pelitic' schist up to 1.5 m thick occur within the mafic volcanic rocks (Figure GS-2-2e). The schist is grey to purplish grey, medium to coarse grained, foliated to strongly foliated, and occurs as diatexite. It typically contains 5–12% garnet and 10–30% biotite, with abundant but variable amounts of sillimanite and cordierite in a groundmass of quartz and feldspar. Minor amounts of sulphide and hornblende are locally present. Garnet porphyroblasts are commonly rimmed by leucosome, which appears to be K-feldspar bearing. Contacts between the mafic volcanic rocks and the schist are diffuse, with garnet+biotite abundance and grain size decreasing within a ~40 cm zone toward the mafic rocks (Figure GS-2-2f). The abundance of sillimanite and cordierite indicates an Mg- and Al-rich bulk composition and suggests either an Mg- and Al-rich protolith or melt removal from a pelite during high-grade metamorphism, which resulted in an Mg- and Al-rich residuum. The authors believe the latter is unlikely, as such Mg- and Al-rich pelitic residua are typically only found in ultra-high temperature (>900 °C) metamorphic settings (e.g., Kelsey and Hand, 2015), where large fractions of melt were produced and extracted. The presence of abundant leucosome bands in the pelitic schist suggests that melt was retained in the rock and the abundance of biotite in the schist further suggests that the rock did not reach ultrahigh temperatures (at which nearly complete biotite breakdown through incongruent melting is expected to occur). The bands of 'pelitic' schist are thus interpreted as zones of Al- and Mg-rich alteration within the mafic volcanic rocks, analogous to chlorite+sericite alteration in a hydrothermal system. Outcrops containing bands of 'pelitic' alteration also commonly contain gossanous bands and/or iron formation.

Rare bands of fine-grained quartz+sillimanite rock up to 1 m thick are white on fresh surfaces; however, disseminated sulphide in these bands results in an intense gossan staining of the weathered rock. The quartz+sillimanite rock is interpreted to represent zones of Si- and Al-rich alteration within the mafic volcanic rocks, analogous to quartz+pyrophyllite±sulphide hydrothermal alteration.

The first sign of granulite-facies assemblages in the mafic volcanic rocks is the appearance of orthopyroxene in the groundmass and as porphyroblasts within incipient pods and stringers of plagioclase-rich leucosome (Figure GS-2-3a). Polycrystalline aggregates of orthopyroxene and plagioclase can occur locally, and could be pseudomorphous after hornblende porphyroblasts. These rocks are texturally similar to the mafic volcanic rocks characterized by upper-amphibolite–facies assemblages and also record hydrothermal alteration.

As the metamorphic grade increases toward the northwest, the rocks typically become more homogeneous and are characterized by two-pyroxene assemblages, containing both orthopyroxene and clinopyroxene (Figure GS-2-3b). Both hornblende-bearing and hornblende-free assemblages are present, and may constitute entire outcrops or occur interbanded on a scale of 20–100 cm. Assemblages consist of plagioclase, along with 40–60% mafic minerals as varying proportions of hornblende, clinopyroxene and orthopyroxene. Hornblende-free assemblages typically contain 30–40% mafic minerals as a combination of orthopyroxene, clinopyroxene and minor magnetite. This apparent decrease in mafic mineral content may reflect an increase in the modal content of anorthite-rich plagioclase as hornblende is consumed during high-grade metamorphism, as opposed to indicating a variation in bulk composition.

Although generally more homogeneous in appearance than mafic volcanic rocks with upper-amphibolite–facies assemblages, the granulite-facies rocks are locally discontinuously laminated but more typically diffusely banded on a scale of 1–10 cm. Exposures typically contain up to 7% diffuse pods and stringers of plagioclase-rich, two-pyroxene leucosome. Dioritic injections or mobilizate typically contain both clinopyroxene and orthopyroxene and can locally constitute up to 30% of granulite-facies outcrops. Evidence for carbonate or hydrothermal alteration is typically less abundant than that observed at lower grades. Rare clinopyroxene-rich pods can reach up to 10 cm across. Calcsilicate pods up to 15 cm across and containing garnet or scapolite cores could represent inter-pillow or interflow material, or carbonate alteration. Discontinuous carbonate-rich lenses up to 3 cm thick were observed in one exposure in the northern basin of the lake. Rare gossanous zones up to 70 cm thick are also present.

Ultramafic volcanic rocks

Exposures of ultramafic volcanic rocks occur at station 074 and at the eastern end of the southern basin of Cauchon Lake. These rocks are dark green, fine to medium grained, foliated and locally magnetic. They are composed of roughly equal proportions of anthophyllite and green amphibole, with <10% serpentine and variable, but minor, amounts of magnetite and phlogopite. Needles of anthophyllite are locally up to 3 cm long. The serpentine is pseudomorphous after aggregates of olivine, which likely represented glomerocrysts (Figure GS-2-3c). Surficial weathering of the olivine pseudomorphs resulted in pits or pockmarks 2–15 mm across. Metamorphosed zones of quartz-carbonate–vein stockwork are present within the ultramafic volcanic rocks at station 074 (Figure GS-2-3d).

Outcrops of granulite-facies mafic volcanic rocks locally contain discontinuous bands and isolated boudins of ultramafic rocks up to 7 m thick. These rocks contain roughly equal proportions of orthopyroxene and clinopyroxene, with lesser clinoamphibole and locally minor plagioclase. The bands and boudins vary from relatively massive to layered or laminated, and could represent either ultramafic volcanic rocks or minor intrusions.

Pyroxenite sills

Bands of pyroxenite up to 15 m thick occurring in mafic volcanic rocks were observed at three locations.

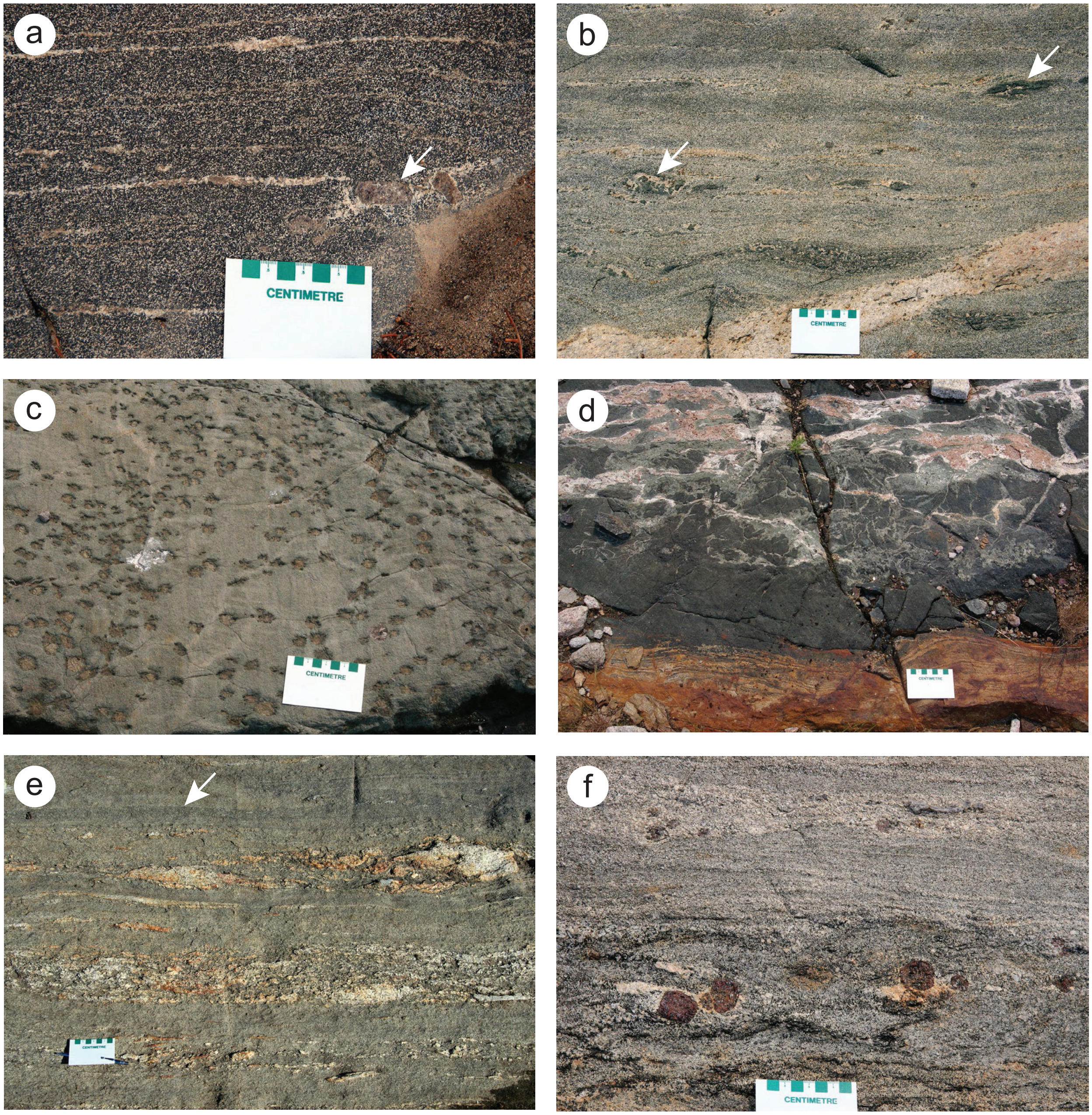

Figure GS-2-3: *Outcrop photographs of supracrustal rocks from the Cauchon Lake area:* ***a)*** *mafic volcanic rocks with incipient veins of orthopyroxene-bearing leucosome (arrow);* ***b)*** *mafic volcanic rocks with orthopyroxene- and clinopyroxene-bearing granulite-facies assemblages and local relict pods of calcsilicate (arrows);* ***c)*** *ultramafic volcanic rock with recessively weathered aggregates of serpentinized olivine (station 074);* ***d)*** *stockwork consisting of quartz-carbonate veins hosted in ultramafic volcanic rock (station 074), which is overlain by iron formation (bottom of photo);* ***e)*** *psammite interbedded with semipelitic diatexite, some compositional banding of the psammite is visible at the top of the photo (arrow);* ***f)*** *garnet-bearing semipelite.*

The bands are subparallel to compositional banding in the volcanic rocks and could represent sills or semiconcordant dikes. The rock is dark green to green brown, coarse grained, foliated, and composed of roughly equal proportions of anthophyllite and clinoamphibole, with minor serpentine and phlogopite. The anthophyllite occurs as porphyroblasts up to 3 cm across, which are likely pseudomorphous after orthopyroxene phenocrysts.

Plagioclase amphibolite

Zones of plagioclase amphibolite up to 50 m wide occur throughout the map area and are commonly associated with occurrences of mafic volcanic rocks. Exposures are typically dark green grey, medium to coarse grained, foliated and relatively homogeneous. The rock is plagioclase-rich, with 40–60% mafic minerals dominated by hornblende. At higher metamorphic grades, the amphibolite may also contain up to 20% orthopyroxene and 5% clinopyroxene. Local occurrences of the amphibolite contain porphyroblasts of hornblende up to 5 mm across. The amphibolite could represent subvolcanic intrusions or relatively massive mafic volcanic flows; however, younger unrelated mafic intrusions could also be present.

Psammite and semipelite

The psammite and semipelite form a relatively continuous belt, up to 800 m wide and 10 km long, through the islands along the southeastern shore of the southern basin of the lake (Figure GS-2-1). The psammite is grey, fine to medium grained, foliated and commonly forms a metatexite. It is plagioclase-rich, with 10–30% biotite and 20–30% quartz. Garnet is typically absent in the eastern extent of the belt, but can constitute up to 5% of the rock in western occurrences. Where present, garnet occurs as porphyroblasts up to 2 cm in diameter, typically mantled by leucosome. The psammite is typically massive, although local diffuse banding occurs on a scale of 1–30 cm (Figure GS-2-3e). Discontinuous amphibole-rich bands occur locally within the psammite. The bands are dark grey green and contain 10–20% biotite, 30–40% clinoamphibole and little to no quartz. It is uncertain whether these amphibole-rich horizons represent disaggregated mafic dikes or sills, volcaniclastic material or calcareous lenses.

The semipelite varies from brown to rusty orange, is medium to coarse grained, and foliated to strongly foliated. The semipelite varies from metatexite to diatexite, with diatexite being most common. Leucosome typically makes up 40–50% of diatexite exposures. The semipelite is quartzofeldspathic, with 10–30% biotite, and locally minor graphite and sillimanite. In the easternmost exposures, the semipelite typically contains no garnet, but may contain up to 7% garnet in the western extent of the belt. Garnet occurs as polycrystalline aggregates and discrete porphyroblasts up to 6 cm, typically in pods or bands of leucosome (Figure GS-2-3f). Rounded knots of muscovite are present in a single boudinaged horizon of semipelite at station 074. The knots appear to be pseudomorphous after a porphyroblastic phase with a form reminiscent of andalusite (Figure GS-2-4a). Local zones of semipelite up to 2 m wide are characterized by intense gossan staining, which suggests local accumulations of sedimentary sulphide. Local mafic boudins up to 7 cm thick appear to be subconcordant and could represent disaggregated volcanic flows, sills or dikes.

Although the psammite and semipelite are gradationally interlayered on a scale of 0.1–7 m, the psammite appears to be dominant in exposures toward the east, whereas the exposures in the western extent of the belt appear to predominantly consist of semipelite. This gradational relationship appears to indicate a general decrease in depositional grain size (fining) toward the west. The psammite–semipelite sequence is observed to be in direct (apparently depositional) contact with the mafic volcanic rocks at two locations along the southeastern shore of the southern basin of Cauchon Lake (Figure GS-2-1). The best example occurs at station 074, where the top 0.5–1.5 m of an ultramafic volcanic flow contains a stockwork of quartz-carbonate veins. The volcanic rock is in diffuse contact with a layered to laminated plagioclase-rich horizon 5–10 cm thick, with 10–20% green amphibole and minor sulphide (Figure GS-2-3d). This plagioclase-rich rock becomes increasingly sulphidic and grades over several centimetres into a package of gossanous, silicate-facies iron formation 5–8 m thick. The iron formation is then overlain by psammite interbedded with semipelite. This contact is locally marked by a layer of massive anthophyllite 4 cm thick, with discrete knots of plagioclase. The stratigraphic relationship of ultramafic volcanic rock underlying iron formation, which in turn is overlain by psammite and semipelite is consistent over a strike length of roughly 50 m and wraps around an F_2 fold nose. A similar relationship with psammite and semipelite overlying mafic volcanic rock is observed at station 135. Although at higher strain and locally infolded, the contact is relatively sharp and continuous over a strike length of >70 m. Where the contact is gradational, it is marked by a layer of biotite- and plagioclase-rich garnet-bearing rock 5–10 cm thick.

Iron formation and chert

Discontinuous bands and lenses of iron formation up to 2 m thick occur within the mafic volcanic rocks, psammite and semipelite. The bands vary from green grey to intensely gossan stained and are typically strongly magnetic. Exposures of iron formation are internally laminated to layered, with nearly pure chert layers separating Fe-rich layers. The Fe-rich layers locally consist of massive magnetite, massive orthopyroxene or massive garnet; however, they more typically contain varying proportions of all three mineral constituents. Pyrrhotite is typically present, and minor biotite, clinopyroxene and clinoamphibole are common. Orthopyroxene may be pseudomorphously replaced by retrograde grunerite. Rare bands of garnetite up to 50 cm thick can occur within the mafic volcanic rocks and are mantled by iron formation.

Bands of chert up to 7 m thick, closely associated with mafic volcanic rocks and semipelite, occur at two locations in the southern basin of Cauchon Lake. The chert is typically interlaminated to layered with semipelite to pelite, and is locally gossanous. Both exposures are located on reefs and are disrupted by pegmatite injections, thus making field relationships difficult to ascertain; however, the chert appears to be infolded with semipelite and in close association with mafic volcanic rocks. Recrystallized xenoliths of massive to laminate quartzite up to 10 m thick occur within a large pegmatite body in the central portions of the southern basin of the lake. It is uncertain

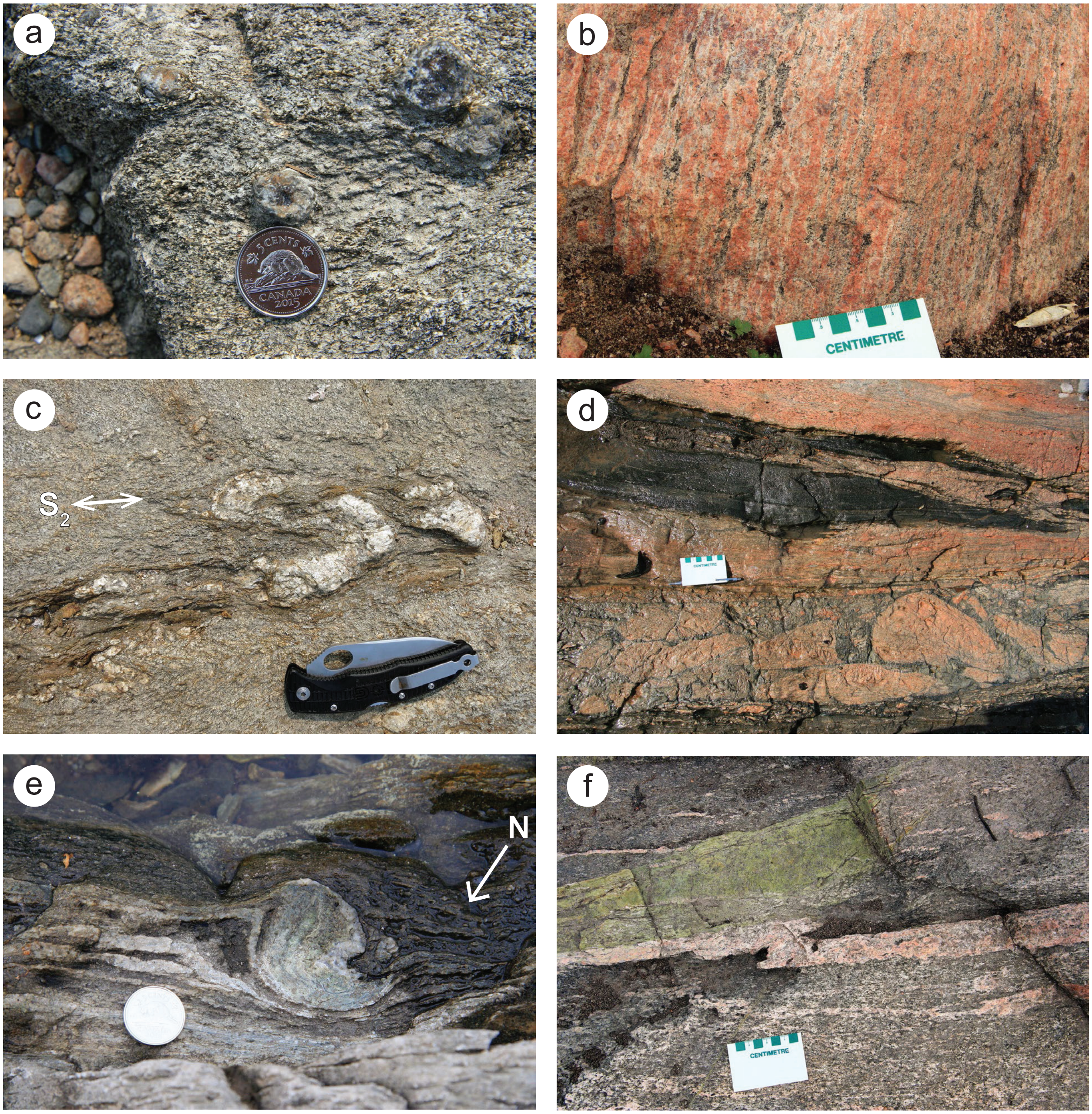

***Figure GS-2-4:** Outcrop photographs from the Cauchon Lake area: **a)** possible andalusite pseudomorph in semipelite (above coin, station 074); **b)** monzonite-syenite with fine-grained mosaic of white plagioclase rimming K-feldspar; **c)** M_2 leucosome folded by F_2, the retrograde biotite selvage to the leucosome is foliated axial planar to the fold hinge (S_2); **d)** protomylonitic shear zone cut by brittle, pseudotachylite-lined fault (below scale card); **e)** asymmetric porphyroclast with delta-type tails indicating dextral shear in a north-northeast trending shear zone (N); **f)** sheared and retrogressed monzodiorite with band of massive epidote.*

whether these xenoliths are derived from similar occurrences of chert or from siliciclastic deposits.

Polymictic conglomerate

A single exposure of polymictic conglomerate occurs roughly 500 m west of the channel leading from the central basin to the northern basin of the map area. The conglomerate occurs as a 5 m wide xenolith in tonalite gneiss. The matrix is arkosic, with 10–30% amphibole. The rock is matrix supported and consists mostly of mafic to ultramafic clasts, with felsic clasts making up 2–5% of the exposure; however, due to the extent of recrystallization, intermediate clasts roughly approximating the composition of the matrix would not be discernible. Clasts range from 1 cm to10 cm in width, typically with aspect ratios of 4:1, but ranging from 1:1 to 8:1 depending on bulk composition and the degree of strain localization.

Strongly gneissic tonalite

Strongly gneissic tonalite is the dominant rock type in the Cauchon Lake area (Figure GS-2-1). Amphibolite-facies metamorphic assemblages are predominant in the southern basin of the lake, and transition to granulite-facies assemblages in the central basin. Variable degrees of heterogeneity (variety of xenoliths and intruding phases) suggest that this unit is likely a composite intrusion. This observation is supported by the presence of boudinaged anorthosite dikes in strongly gneissic tonalite at the eastern end of the central basin and small bodies of the gneissic tonalite intrusive into, and containing xenoliths of, the anorthosite in the northwestern portion of the map area. Discontinuous mafic bands and boudins up to several metres across are common and can constitute up to 30% of outcrops. The mafic boudins range from homogeneous plagioclase amphibolite, possibly derived from mafic dikes, to layered and more heterogeneous rocks likely derived from xenoliths of mafic volcanic rock. Dikes of later intrusive phases are common and range in size from one centimetre to several metres in width. Local ultramafic boudins and xenoliths derived from sedimentary rocks are also observed.

The strongly gneissic tonalite with amphibolite-facies metamorphic assemblages is light grey to pale pinkish grey, medium to coarse grained, foliated to strongly foliated, and banded on a scale of 0.3–40 cm. Although dominantly tonalitic, the gneiss locally grades into more granodioritic compositions. It typically contains 5–20% biotite as the predominant mafic mineral; however, hornblende is locally present and can at times be the dominant mafic mineral. Trace amounts of magnetite and sulphide may also be present. Diffuse pods of granodioritic leucosome up to 10 cm across can form up to 10% of exposures.

At higher metamorphic grade, the strongly gneissic tonalite typically weathers honey brown with a grey-green fresh interior. Banding appears more diffuse but remains distinct. Mafic minerals typically range from 7 to 12% and consist of varying proportions of orthopyroxene, clinopyroxene and biotite. Magnetite is typically present in minor amounts. Diffuse pods and veins of granodioritic to tonalitic leucosome contain coarse-grained peritectic orthopyroxene and locally clinopyroxene. Leucosome can form up to 30% of exposures. The mafic boudins commonly contain veins of pyroxene-bearing tonalitic leucosome. Orthopyroxene-bearing gneissic tonalite has historically been referred to as enderbite or enderbitic gneiss (Hubregtse, 1980; Weber and Mezger, 1990).

Anorthosite

Anorthosite occurs in the northwestern portion of the map area (Figure GS-2-1); however, much of the complex occurs in the northern basin and was previously described by Couëslan (2013) and in greater detail by Peck et al. (1996). The anorthositic rocks are typically white to purplish grey, medium to coarse grained, foliated, and banded on a scale of 1 cm to 3 m. Bands are typically disaggregated, boudinaged and rotated. The composition varies from almost pure plagioclase to gabbroic, with up to 90% mafic minerals dominated by hornblende; however, the mafic mineral content is typically <15%. Bands of megacrystic plagioclase are a characteristic feature of this unit.

Weakly gneissic tonalite

A large body of weakly gneissic tonalite, >21 km along strike, occurs along the southern margin of the map area (Figure GS-2-1). The tonalite is white to light grey, medium to coarse grained, and foliated to strongly foliated. A weak gneissosity is defined by discontinuous biotite laminations. Biotite typically forms 5–10% of the rock, and rare hornblende and garnet may occur in minor amounts. Minor disseminated epidote becomes common in the narrow channel at the southern end of the lake and is likely related to a major shear zone (the possible terrane boundary labeled in Figure GS-2-1). The weakly gneissic tonalite is typically more homogeneous in appearance than the strongly gneissic tonalite. Diffuse veins and pods of granitic to granodioritic leucosome form 5–10% of most exposures and local xenoliths of plagioclase amphibolite rarely exceed 5 cm in width.

Gneissic trondhjemite

Bodies of gneissic trondhjemite are most common in the southern basin of the map area, where they form elongate intrusions up to 6 km long and 1 km wide (Figure GS-2-1). The trondhjemite varies from white to light pink and is medium to coarse grained, and foliated. The gneissosity varies from diffuse bands 1–10 mm thick to discontinuous biotite laminations. Mafic minerals make up <5% of the rock and consist mostly of biotite, with local magnetite and hornblende in trace to minor amounts. Minor K-feldspar can also be present. Exposures typically contain 5–20% granodioritic to granitic leucosome that occurs as veins and diffuse attenuated pods. Local boudins of banded amphibolite up to 60 cm thick may be derived from mafic volcanic rocks.

Monzodiorite-syenite suite

A continuous band of monzodiorite, >26 km long, strikes across the map area between the southern and central basins (Figure GS-2-1). A small body of monzonite-syenite (~1 km long) occurs in the southwestern corner of the central basin. It is spatially associated with the monzodiorite and is likely cogenetic. Although rare exposures of the monzodiorite (generally along the northeastern extent) display both an S_1 and S_2 foliation, most exposures display only an S_2 foliation. Therefore, the monzodiorite is tentatively interpreted to be syn-D_1;

however, it is possible that more than one period of monzodioritic magmatism occurred.

The monzodiorite is pinkish grey to brown green, medium to coarse grained, foliated and moderately magnetic. Mafic minerals typically make up 20–30% of the rock and consist of varying proportions of biotite and green amphibole or clinopyroxene, along with minor magnetite. Black amphibole locally occurs in place of other mafic minerals. Quartz is rarely observed and, where present, makes up less than 5% of the rock. The composition of the rock may locally grade toward dioritic or monzonitic compositions. K-feldspar locally occurs as phenocrysts up to 7 mm. Exposures are characterized by an anastomosing network of pink, monzonitic, syenitic or granitic veins, which form 3–30% of the outcrop. Some veins are characterized by diffuse contacts and may represent attenuated leucosome; however, some or much of the veining could also represent a stockwork of cogenetic melts. Local mafic and rare ultramafic xenoliths or autoliths can reach up to 20 cm across, and consist mostly of green and black amphibole, along with variable amounts of biotite.

The monzonite-syenite is pink, fine to coarse grained, foliated to strongly foliated, and moderately magnetic. The plagioclase content varies from 10–40% and typically occurs as a fine-grained mosaic of grains peripheral to larger K-feldspar phenocrysts/porphyroblasts up to 2 cm (Figure GS-2-4b), which could indicate a metamorphic/metasomatic origin for the plagioclase. Mafic minerals make up <10% of the rock and consist of variable amounts of biotite and green amphibole, with trace to minor amounts of magnetite. The amphibole is locally seriate and forms phenocrysts/porphyroblasts up to 2 cm.

Archean post-D_1 rocks

All Archean post-D_1 rocks display an S_2 foliation. The relative ages of rocks within this group are not constrained.

Diorite

The diorite occurs as relatively small intrusions, typically tens of metres wide, in the southwestern portion of the map area. The diorite is grey, coarse grained and foliated. Mafic minerals make up 20–40% of the rock and consist dominantly of hornblende, with lesser biotite. Quartz locally forms up to 5% of the mode. The diorite is relatively homogeneous, but locally contains xenoliths of weakly gneissic tonalite and mafic enclaves.

Tonalite

Several small intrusions of tonalite occur in the southern basin and the northeastern corner of the map area, typically forming bodies <2 km long (Figure GS-2-1). The intrusions are light grey to white, medium to coarse grained, and foliated. Mafic minerals make up anywhere from 10–30% of the rock and consist of varying proportions of hornblende and biotite. Diffuse pods and veins of granodioritic leucosome make up 10–30% of exposures. Mafic xenoliths as well as xenoliths of tonalite gneiss are locally present. One body contains plagioclase aggregates up to 1 cm across, which could be pseudomorphous after phenocrysts. The tonalite locally grades into trondhjemite.

Trondhjemite

Trondhjemite forms relatively small intrusions, typically <1 km long and 200 m wide. The largest of these bodies are found in the southern basin (Figure GS-2-1), but small dikes occur throughout the map area. Exposures are typically white, medium grained and foliated, with 3–5% biotite as the sole mafic mineral. Small dikes in the northern portions of the map area are honey yellow in colour and contain 1–2% orthopyroxene, in addition to 2–3% biotite. Exposures typically contain 10–20% granodioritic leucosome as diffuse veins and pods.

Granodiorite

The granodiorite most commonly occurs as small dikes <4 m wide intruding into other plutonic phases; however, an intrusive body in the southwestern portion of the map area appears to be at least 6 km long and up to 800 m wide (Figure GS-2-1). Mafic minerals make up <7% of the rock and mostly consist of biotite. Hornblende locally forms up to 2% of the rock. Exposures contain 10–20% granitic leucosome as diffuse, and often attenuated, pods and veins up to 5 cm thick. Relatively continuous mafic bands up to 20 cm thick are locally present, and could represent disrupted and metamorphosed diabase dikes.

Monzogranite

Two bodies of monzogranite occur toward the eastern end of the southern basin of the lake, the largest of which is at least 6 km long by 1.4 km wide (Figure GS-2-1). The monzogranite is pink, coarse grained and foliated. Biotite makes up 2–7% of this unit, which locally grades into granodiorite. Although coarse grained in general, exposures locally grade into more pegmatitic zones. Outcrops in the eastern end of the southern basin are characterized by xenoliths and schlieren of tonalite gneiss and amphibolite up to 4 m across. The amphibolite xenoliths are locally banded and could be derived from mafic volcanic rocks.

Pegmatite

Pegmatite dikes up to 10 m wide are ubiquitous throughout the map area and typically make up 3–30% of a given exposure. Most intrusions appear to predate, or to be synchronous with, D_2; however they typically subparallel the gneissosity in pre- to syn-D_1 rocks, consequently the presence of pre- to syn-D_1 intrusions cannot be ruled out. Mafic minerals make up <7% of most dikes and may consist mostly of biotite, magnetite or orthopyroxene, with orthopyroxene being most common in pegmatite dikes that intrude mafic volcanic rocks in northern portions of the map area. Several larger pegmatite bodies are present in the southern basin of Cauchon Lake, the largest of which is approximately 3.5 km long and up to 700 m thick (Figure GS-2-1). Local, highly discordant pegmatite dikes, with relatively straight and sharp contacts, crosscut pods of M_2 leucosome and show no evidence for partial melting or high-grade metamorphism. The straight-walled, discordant dikes are interpreted to have formed relatively late and likely postdate peak metamorphism. One of these late dikes yielded a $^{207}Pb/^{206}Pb$ zircon age of 2629 ±1 Ma (Mezger et al., 1989) and was interpreted as postkinematic (Mezger et al., 1990). However, this particular dike displays an S_2 foliation (as do the other straight-walled pegmatite dikes) and may be defining a relatively open F_2 fold, which suggests late-D_2 emplacement.

Paleoproterozoic, post-D_2 rocks

The only post-D_2 rocks recognized in the Cauchon Lake area are unmetamorphosed diabase and gabbro dikes interpreted as Paleoproterozoic. The majority of dikes trend 000–042° and are assumed to be related to the ca. 1880 Ma Molson dike swarm (Scoates and Macek, 1978; Heaman et al., 2009).

Diabase and gabbro dikes

Diabase and gabbro dikes occur throughout the map area and range from 2 cm up to approximately 80 m in width. Diabase dikes are typically <10 m wide, dark grey green and very fine to fine grained. Gabbro dikes are typically >10 m wide, dark grey green to brown green and medium to coarse grained. Although diabase dikes are typically too fine grained for mineral identification, the gabbro dikes typically consist of variable amounts of clinopyroxene, orthopyroxene, plagioclase and hornblende. The dikes locally grade into pyroxenite, with only 5% plagioclase. Most dikes display a diabasic texture, although the coarsest dikes may locally display subophitic textures. Diffuse laminations or layering are locally apparent on weathered surfaces. Larger dikes commonly contain pegmatitic pods up to 20 cm across. The pegmatitic pods are plagioclase-rich, with 10–30% euhedral hornblende.

Structure and metamorphism

The earliest fabric recognized in the Cauchon Lake area consists of an S_1 gneissosity in the Archean pre- to syn-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. Orthopyroxene present in the strongly gneissic tonalite is commonly observed in the field to parallel S_1, suggesting that D_1 may have been accompanied by granulite-facies metamorphic conditions. It is also possible that the orthopyroxene grew during a later metamorphic event (M_2), and replaced lower grade, S_1-parallel mafic minerals, thus inheriting the S_1 fabric.

Three metamorphic isograds are identified in the map area: they are defined by the first appearance of orthopyroxene in mafic volcanic rocks, the first appearance of orthopyroxene in tonalitic rocks, and the first appearance of co-existing orthopyroxene and clinopyroxene in both felsic and mafic bulk compositions (Figure GS-2-1). The isograds strike northeast and indicate a prograde metamorphic field gradient increasing toward the northwest. This gradient is interpreted as an expression of the M_2 event, which also resulted in the development of diffuse veins and irregular pods of leucosome in most Archean rocks, with the exception of the later pegmatite intrusions and lowest grade exposures of the mafic volcanic rocks. The leucosome clearly cuts the S_1 gneissosity in older rocks, suggesting that the leucosome-forming metamorphic event (M_2) postdated D_1. Orthopyroxene and clinopyroxene hosted in the leucosome of the higher grade rocks are commonly equant and likely peritectic. Exposures of the lowest grade mafic volcanic rocks do not contain leucosome, which does not appear until the orthopyroxene-in isograd for the mafic volcanic rocks, where it occurs as incipient pods and veins (e.g., Figure GS-2-3a). The abundance of leucosome within the mafic volcanic rocks increases to the northwest (e.g., Figure GS-2-3b), effectively demonstrating the prograde nature of the metamorphic-field gradient. This contradicts Heaman et al. (2011), who suggested that the disappearance of granulite-facies assemblages in the southern Cauchon Lake area was related to a zone of amphibolite-facies retrogression. In addition, the metamorphic-field gradient (as well as textures observed in the field) indicates that orthopyroxene present in the granitoid rocks is metamorphic, and that most of the orthopyroxene-bearing granitoid rocks should more properly be referred to as metatonalite and metagranodiorite, rather than enderbite and opdalite, which are derived from anhydrous felsic magmas.

All observed M_2 leucosome displays a well-developed S_2 fabric and is commonly attenuated and folded by F_2. This suggests that the M_2 event predated, or was synchronous with, the D_2 generation of deformation. In the semipelite, folded M_2 leucosome is surrounded by a retrograde biotite selvage foliated axial planar to the F_2 fold hinge (S_2), which suggests that D_2 outlasted heating (i.e., some D_2 deformation occurred after peak M_2 metamorphism and melt crystallization; Figure GS-2-4c). The D_2 generation of deformation is most commonly manifested as a well-developed S_2 quartz fabric in all Archean rocks. This fabric typically strikes 220–250° with a steep 60–80° dip to the northwest. The S_2 foliation typically intersects S_1 at a small angle (<20°). The S_1 gneissosity is locally attenuated parallel to S_2 in high-strain zones and in less competent rocks, such as the semipelite. The quartz fabric is axial planar to minor isoclinal folds. Fold hinges typically plunge toward the west or northeast at a moderate to steep angle (50–80°).

Protomylonitic to mylonitic shear zones are prevalent in the southern basin of the lake (Figure GS-2-4d). Discrete zones of mylonite can be >5 m wide, and both sinistral and dextral shear-sense indicators were observed (Figure GS-2-4e). Diffuse zones and bands of disseminated to massive epidote±chlorite, along with discrete veins of epidote, are commonly associated with the shear zones (Figure GS-2-4f). These shear zones, typically subparallel to the S_2 fabrics, could represent a later manifestation of D_2, or they could represent the D_3 structures of Weber (1977, 1987). The shear zone in the southeastern-most bay of the map area is interpreted to roughly coincide with the boundary between the North Caribou and Hudson Bay terranes (Figure GS-2-1).

Subparallel veins of pseudotachylite locally overprint the mylonite zones, suggesting either that deformation continued into the brittle regime or that the shear zones were later reactivated by brittle faults (Figure GS-2-4d). Pseudotachylite was previously reported cutting a Paleoproterozoic dike in the northern basin of Cauchon Lake (north of the 2015 map area; Couëslan, 2013), which led to the interpretation of a Hudsonian age. However, a Paleoproterozoic dike crosscuts a pseudotachylite vein in the southwestern corner of the 2015 map area, suggesting either mafic dikes of various ages, faulting of various ages or roughly contemporaneous faulting and dike emplacement. Regardless of the scenario, crosscutting relationships between pseudotachylite and Paleoproterozoic dikes clearly indicate that at least some of the brittle faulting in the Cauchon Lake area predates the Trans-Hudson orogeny. Mutual crosscutting relationships between pseudotachylite veins and Paleoproterozoic mafic dikes were also noted at Sipiwesk Lake (Couëslan et al., 2012).

Economic considerations

Evidence for metamorphosed hydrothermal alteration zones is relatively common in the mafic volcanic rocks of the southern basin of Cauchon Lake. Zones of pervasive carbonate alteration are manifested by discontinuous bands of marble and heterogeneous diopside-rich, hornblende-rich and garnet-rich bands within the mafic volcanic rocks. Pods, stringers and local vein networks of calcsilicate±quartz±carbonate could represent metamorphosed quartz-carbonate veins. Local bands of 'pelitic' schist likely represent metamorphosed zones of chlorite+sericite alteration, whereas bands of quartz+sillimanite likely represent metamorphosed quartz+pyrophyllite alteration. Local quartz-rich bands could represent zones of metamorphosed silicification. In all cases, the presence of high-grade, peak-metamorphic mineral assemblages and deformation fabrics suggests that hydrothermal systems were active in the volcanic rocks prior to high-grade metamorphism.

Pervasive carbonate alteration occurs in several outcrops of the mafic volcanic rocks and there is local evidence for attenuated stockworks consisting of quartz-carbonate veins. This style of alteration is commonly associated with orogenic gold mineralization (Robert, 1995; Dubé and Gosselin, 2007). The close proximity of the mafic volcanic rocks to the southern margin of the Hudson Bay terrane and a potential terrane-bounding fault could therefore make this area favourable for orogenic gold mineralization. Crustal-scale fault zones act as major pathways for hydrothermal fluids and gold deposits are often associated with second- and third-order, oblique-shear and high-strain zones located within 5 km of the main fault (Dubé and Gosselin, 2007).

The mafic volcanic rocks locally host, and are locally overlain by, iron formation and sulphidic chert. Iron formations are known to form chemical traps for sulphide- and gold-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 craton (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).

There is also some potential for volcanogenic massive sulphide (VMS) mineralization in the Cauchon Lake area. Pillows in mafic volcanic rocks point to formation in a subaqueous environment for at least some of the flows, and a limited dataset of bulk-rock geochemical analyses suggests a volcanic-arc setting (Couëslan, 2014). The presence of iron formation and sulphidic chert also suggests that magmatism was accompanied by exhalative sedimentation. Bands of intense chlorite +sericite alteration indicate flow of hydrothermal fluids, which could have transported base metals and sulphides. Quartz+pyrophyllite±sulphide alteration indicates focused flow of hot, acidic fluid. These types of alteration are typically found in the footwall of VMS deposits, with the most intense quartz+aluminosilicate alteration occurring proximal to the deposit (e.g., Galley et al., 2007; Hudak, 2015).

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