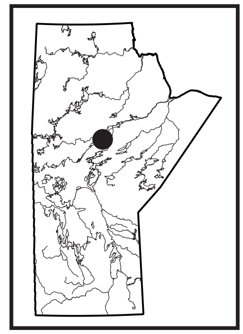
GS-3 Preliminary results of bedrock mapping in the Natawahunan Lake area, western margin of the Pikwitonei granulite domain, central Manitoba (parts of NTS 63P11, 14)

by C.G. Couëslan



Couëslan, C.G. 2016: Preliminary results of bedrock mapping in the Natawahunan Lake area, western margin of the Pikwitonei granulite domain, central Manitoba (parts of NTS 63P11, 14); *in* Report of Activities 2016, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 28–39.

Summary

A project to re-map portions of the Archean Pikwitonei granulite domain in central Manitoba, with emphasis on interpretation of protoliths, continued in 2016 with mapping in the Natawahunan Lake area. Exposures in the area can be divided into four main groups based on structural observations: Archean pre- to syn-D_1 rocks, Archean post-D_1 rocks, rocks of uncertain age and Paleoproterozoic post-D_2 rocks. Pre- to syn-D_1 rocks include metamorphosed mafic volcanic and associated rocks, sedimentary rocks and gneissic tonalite–granodiorite. Post-D_1 rocks consist of metamorphosed intrusive rocks that range in composition from pyroxenite to monzogranite. Rocks of uncertain age consist of two varieties of strongly foliated granite. Post-D_2 rocks consist of Paleoproterozoic mafic–ultramafic dikes and a suite of carbonate rocks. The oldest group of rocks in the Natawahunan Lake area displays an S_1 gneissosity. This early gneissosity is cut by M_2 leucosome that formed at 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. A Paleoproterozoic S_3 sinistral shear zone runs along the Grass River channel, down the length of Natawahunan Lake, and is accompanied by pervasive Hudsonian retrogression.

Quartz-carbonate veins and intense carbonate alteration are locally associated with Paleoproterozoic shear zones and could have potential for gold mineralization. Evidence for local chlorite-sericite alteration of the basaltic rocks prior to metamorphism could indicate a potential for volcanogenic massive-sulphide mineralization. Bands of carbonate rock may have an affinity to carbonatite magmatism, which could indicate a potential for rare-metal 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 re-map the mafic, intermediate and enderbitic (orthopyroxene-bearing tonalite) gneiss units, with emphasis on protolith interpretation rather than descriptive petrography, to assist in assessing the mineral potential of the region and provide further insight into the tectonic significance of the PGD (e.g., Weber and Mezger, 1990). 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. Field investigation of the PGD continued in 2016 with 1:20 000 scale mapping in the Natawahunan Lake area (Figure GS-3-1) and 1:10 000 scale mapping in the Duck Lake–Sesep Rapids area (Couëslan, GS-4, this volume).

The Natawahunan Lake area was selected for mapping because of an abundance of garnet-bearing rocks and mafic rocks, which could represent metamorphosed supracrustal rocks (Dawson, 1952; Weber, 1978; Böhm, 1998). Petrography, geochemistry and isotopic methods will be used to further constrain the nature of the supracrustal rocks. In addition, zones of hydrothermal alteration were identified in the mafic volcanic rocks of adjacent Partridge Crop Lake (Couëslan, 2014c), suggesting potential for base-metal mineralization in the area.

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 (Stott et al., 2010; Couëslan, 2014a, 2016b). The northwestern boundary of the PGD is defined by Paleoproterozoic, Hudsonian (ca. 1.83–1.75 Ga), north-northeast-trending deformational fabrics that 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 (enderbitic, opdalitic and minor leuconoritic gneisses) and mafic granulites (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. 2700–2692 Ma) resulted in well-defined, northwest-trending metamorphic gneissosity (S_1) and isoclinal folds (Hubregtse, 1980; Heaman et

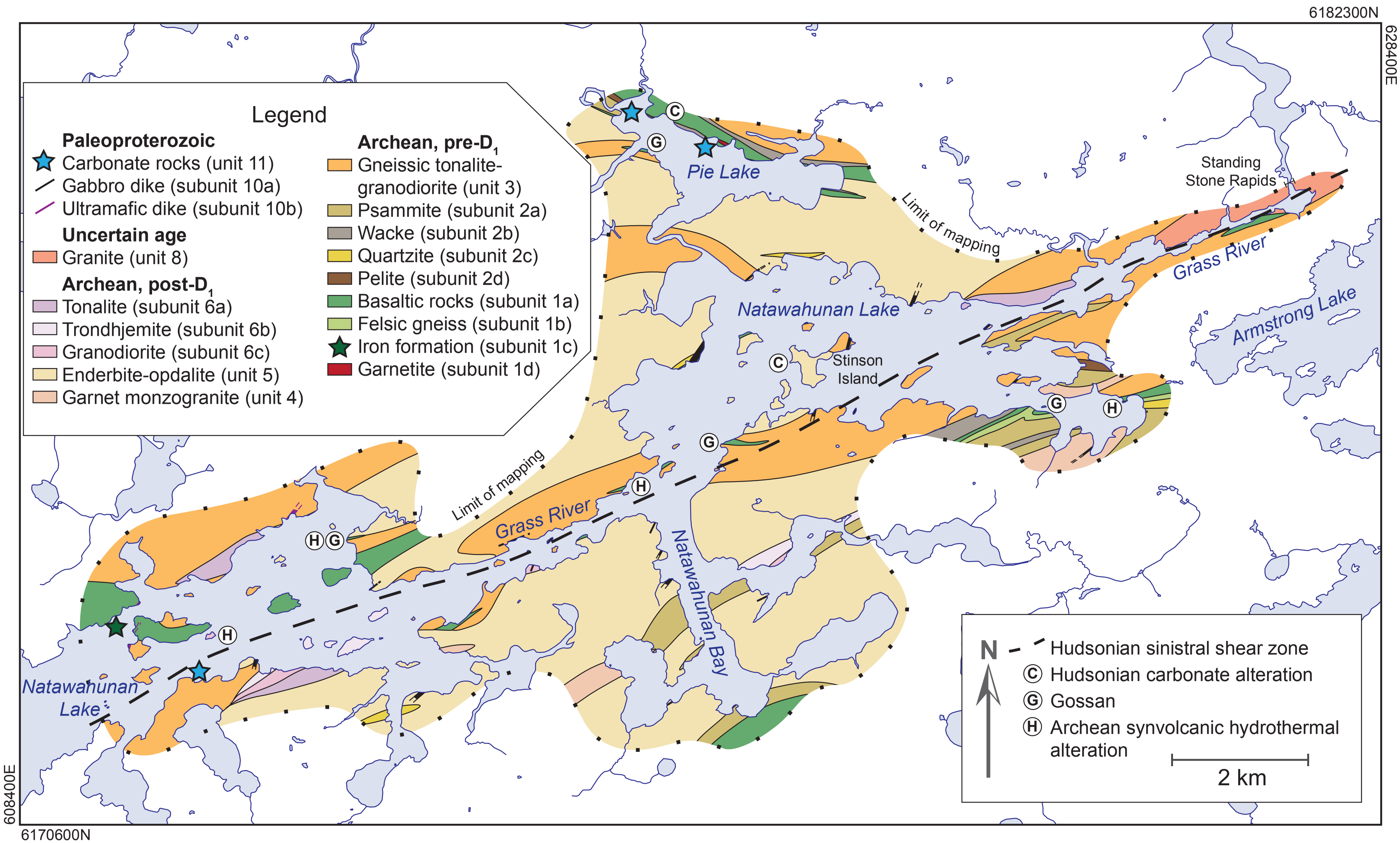


Figure GS-3-1: *Simplified geology of the Natawahunan Lake area, central Manitoba (modified after Couëslan, 2016a).*

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. 2683–2657 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).

Natawahunan Lake area geology

The Natawahunan Lake area is situated along the western margin of the PGD near the boundary with the Superior boundary zone (Weber, 1978). The area is dominated by tonalite and tonalite gneiss (Weber, 1978; Böhm, 1998). Local mafic gneiss (interpreted as metabasalt and metagabbro) and garnet-bearing gneiss (interpreted as either sedimentary or hydrothermal/'fumarolic' in origin) form discontinuous east-striking belts through the area (Weber, 1978). Peak Archean metamorphic conditions are estimated to have attained 830°C and 7.5–8 kbar in the Natawahunan Lake area (Mezger et al., 1990). Paleoproterozoic mafic and ultramafic dikes strike north-northeast through the area and may belong to either the ca. 1880 Ma Molson dike swarm (Scoates and Macek, 1978; Böhm, 1998; Heaman et al., 2009) or an earlier swarm of ca. 2090 Ma mafic dikes (Böhm, 1998; Halls and Heaman, 2000; Bowerman et al., 2004).

Lithological units

The lithological units identified in the Natawahunan Lake area are divided into four main groups: Archean rocks that predate or are synchronous with D_1 deformation, Archean rocks that postdate D_1, rocks of uncertain age and Paleoproterozoic rocks that postdate D_2. All Archean rocks in the area were subjected to granulite-facies metamorphic conditions during the Archean and were variably retrogressed during the Trans-Hudson orogeny; however, to improve the readability of the text, the 'meta-' prefix has been omitted from rock names. The units and subunits discussed in this report correspond to those shown on Preliminary Map PMAP2016-2 (Couëslan, 2016a). Figure GS-3-1 represents a simplified version of this map and some units are too small to be resolved at the scale of the figure.

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 (unit 1)

Mafic volcanic rocks occur as a continuous belt in the western portion of the map area and along the northern shore of Pie Lake, and as discontinuous units throughout the remainder of the area (Figure GS-3-1). The unit consists dominantly of basaltic rocks and likely includes synvolcanic gabbro intrusions, along with minor iron formation, garnetite and felsic gneiss that could represent felsic volcanic rocks. Local evidence for hydrothermal alteration is present within the basaltic rocks.

Basaltic rocks (subunit 1a) are brown-grey to green-grey, medium to locally coarse grained and foliated. Exposures are typically heterogeneous, with banding on a scale of 0.01–3 m defined by variations in mafic mineral content (Figure GS-3-2a). Plagioclase constitutes 20–60% of the rock, with the remainder consisting of varying amounts of hornblende, orthopyroxene and clinopyroxene, along with minor amounts of garnet, magnetite and quartz. Banding varies from diffuse to discrete and is commonly discontinuous. Local homogeneous exposures could represent either massive flows or synvolcanic intrusions. Plagioclase-rich leucosome with 3–5% quartz, 5–7% clinopyroxene and 10–12% orthopyroxene can constitute up to 15% of exposures. Local gossanous zones up to 3 m wide can occur in association with iron formation. Local bands of iron formation can be up to 20 m thick but typically form bands or lenses <1.5 m. Adjacent to iron formation, the basaltic rocks can contain up to 10% disseminated magnetite. The basaltic rocks are locally retrogressed to plagioclase amphibolite.

Aluminous and/or magnesian bands up to 2.5 m thick are locally present within the basaltic rocks. The bands are typically coarse grained, foliated and heterogeneous, and vary in composition from phlogopite-anthophyllite schist to aluminous bands with varying proportions of garnet, orthopyroxene, biotite and sapphirine, with ≤30% quartzofeldspathic matrix (Figure GS-3-2b). The bands are often associated with iron formations or gossans, and are interpreted to represent zones of chlorite-rich, possibly synvolcanic hydrothermal alteration that were metamorphosed during regional high-grade metamorphism.

Finely laminated felsic gneiss (subunit 1b) is locally associated with basaltic rocks in eastern Natawahunan Lake (Figure GS-3-1). The gneiss is pale pink-grey, medium to coarse grained, foliated and locally strongly magnetic. It is feldspathic, with 10–30% quartz and 7–10% mafic minerals as varying amounts of orthopyroxene, clinopyroxene, garnet, magnetite and, locally, biotite. The mafic minerals form discrete laminations (Figure GS-3-2c). Garnet is largely restricted to discontinuous coarse-grained layers of the gneiss that are up to 3 cm thick. These coarse-grained lenses are diffuse and tentatively interpreted as pods of leucosome. Discontinuous bands and boudins of basaltic rock up to 1 m thick are common. This subunit is tentatively interpreted as a felsic volcanic rock; however, it could also represent an arkosic sedimentary rock, or gneissic tonalite–granodiorite.

Iron formation (subunit 1c) is gossanous to dark grey, fine to coarse grained, discontinuously laminated

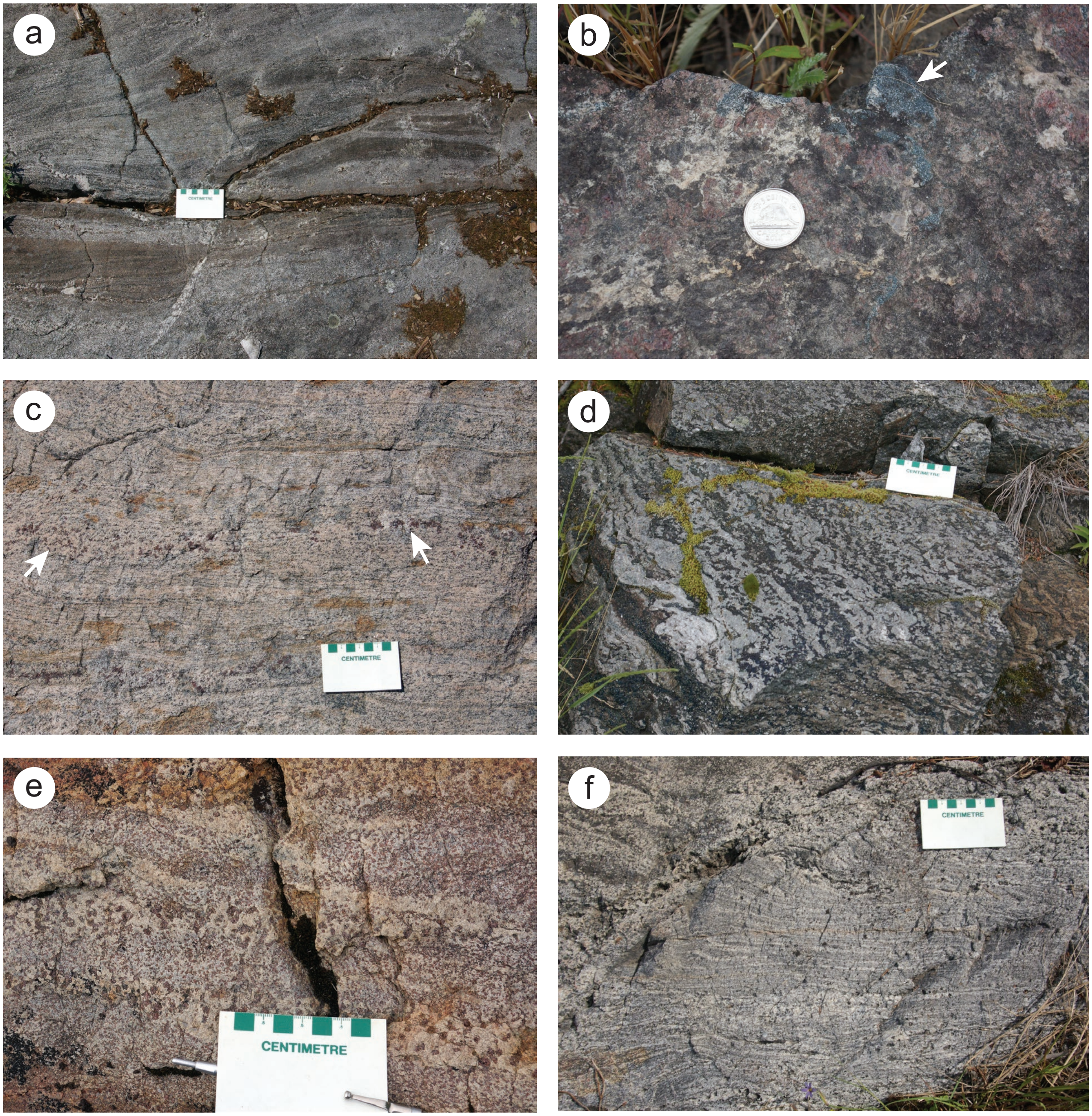


__Figure GS-3-2:__ Outcrop photographs of supracrustal rocks from Natawahunan Lake: __a)__ discontinuously banded basaltic rocks; __b)__ garnet- and sapphirine-rich rock that likely represents intense chlorite alteration of a basaltic precursor; sapphirine indicated by arrow; __c)__ felsic gneiss that is locally associated with basaltic rocks and is tentatively interpreted as rhyolite; coarse-grained garnet-bearing band indicated by arrows; __d)__ oxide-facies iron formation with discontinuous chert-rich and magnetite-rich layers; __e)__ garnetite with banding defined by abundance and grain size of garnet; __f)__ psammite with alternating quartz-rich and plagioclase-rich layers. Scale card is in centimetres, coin has a diameter of 2.1 cm.

to banded and strongly magnetic. Oxide-facies iron formation with stringers of 20–30% magnetite and minor orthopyroxene and/or garnet in a quartz-rich matrix is most common (Figure GS-3-2d); however, gossanous silicate-facies iron formation with orthopyroxene>magnetite and minor pyrrhotite occurs as local bands up to 1.5 m thick. The thickest exposure of iron formation occurs at the western end of the map area, where a 20 m wide band of oxide-facies iron formation is hosted by basaltic rocks. Local lenses of silicate-facies iron formation up to 1 m thick are present within the psammite (subunit 2a).

Garnetite (subunit 1d) is locally associated with basaltic rocks along the northern shore of Pie Lake (Figure GS-3-1). It is red-orange, medium to coarse grained and banded on a scale of 5–10 cm. The rock is quartz-rich, with 20–30% plagioclase and 20–40% garnet (Figure GS-3-2e). Banding is defined by variations in garnet content and grain size. Garnetite is generally considered to represent metamorphosed exhalite (impure chert) or the product of intense metasomatism; however, metamorphosed clastic sediments of unusual bulk composition and peritectic garnet-rich restite have also been proposed for the formation of garnetite (Spry et al., 2007; Dorais et al., 2009).

Sedimentary rocks (unit 2)

Sedimentary rocks are most common in eastern Natawahunan Lake, in Natawahunan Bay and along the northern shore of Pie Lake (Figure GS-3-1). They are similar to those described on adjacent Armstrong Lake (Couëslan, 2014b) and are likely a continuation of the same sedimentary belt. Isotope geochemistry on the Armstrong Lake rocks has yielded old Sm-Nd model ages of ca. 3.93–3.51 Ga and complex detrital zircon populations with age modes ranging from ca. 3870 to 2750 Ma (Couëslan, unpublished data, 2015). The depositional sequence of the sedimentary rocks is not known, so the subunits are listed in order of relative abundance. Exposures are commonly intruded by varying amounts of garnet-bearing monzogranite (unit 4).

Psammite (subunit 2a) is white to grey, medium to coarse grained, foliated and laminated to layered. It is quartz and plagioclase rich, with 7–10% mafic minerals as varying proportions of garnet, biotite and orthopyroxene. Layering is defined by alternating and discontinuous plagioclase-rich and quartz-rich layers (Figure GS-3-2f). The psammite typically forms a metatexite with 10–20% leucosome; however, it can form a diatexite with 50–60% locally derived garnet monzogranite leucosome. Wacke layers up to 2 cm thick and quartzite layers up to 5 cm thick are common. Layers of pelitic diatexite up to 10 cm thick occur as bands of granitic leucosome with 20–40% pelitic restite. The psammite can be retrogressed, with the majority of mafic minerals being replaced by chlorite±biotite and locally preserved relict garnet. The psammite can locally grade into quartzite or wacke.

Wacke (subunit 2b) is grey to grey-brown, medium to coarse grained, foliated and laminated to layered. The rock is plagioclase rich, with 30–50% quartz and 15–25% mafic minerals as varying proportions of biotite, garnet and orthopyroxene. Biotite typically makes up 10–20% of the rock; however, it is locally subordinate to anhydrous phases. Layering consists of quartz-rich laminations separated by mafic-rich layers and conformable bands of leucosome (Figure GS-3-3a). Mafic mineral–poor zones in the wacke are gradational into psammite, while local, more aluminous zones can contain up to 10% cordierite and are gradational into pelite.

Quartzite (subunit 2c) occurs as isolated exposures along the north shore of the eastern basin of Natawahunan Lake, where it is associated with calcsilicate (subunit 2e), and in a small bay along the south shore of the western basin of Natawahunan Lake (Figure GS-3-1). It is typically coarsely recrystallized, foliated and diffusely banded; however, discrete layering on a 5–50 mm scale is locally observed (Figure GS-3-3b). The quartzite contains <10% feldspar and trace to minor amounts of orthopyroxene and biotite. Rare discontinuous seams or bands of fuchsite are conformable to the layering (Figure GS-3-3c). Layers of wacke up to 2 cm thick are locally observed. The exposure in the western basin of Natawahunan Lake contains a 1 m wide lens of calcarenite that contains 20–30% diopside.

Pelite (subunit 2d) is typically interlayered with, and subordinate to, subunits 2a and 2b; however, it can be the predominant subunit in outcrop. It forms a purple-grey, coarse-grained and foliated diatexite consisting of discontinuous lenses and stringers of biotite-, cordierite-, garnet- and sillimanite-rich melanosome in a granitic leucosome groundmass (Figure GS-3-3d).

Calcsilicate (subunit 2e) is associated with quartzite in the eastern basin of Natawahunan Lake. It is pale green, coarse grained, weakly foliated and diffusely banded on a scale of 1 cm to metres. The rock varies from almost 100% diopside to discontinuous bands of diopside with 20–40% clinoamphibole and 10–15% dark green spinel (Figure GS-3-3e). Local plagioclase-rich segregations up to 15 cm across contain 10–20% clinoamphibole, 10–20% biotite and 5–7% spinel; these segregations could represent pods of leucosome. Adjacent outcrops of the quartzite contain boudin trains of calcsilicate that could represent a gradational change in the depositional system from siliciclastic dominated to carbonate dominated; however, the contact between the quartzite and the calcsilicate is obscured by a 2 m wide band consisting of units 3 and 4.

Gneissic tonalite–granodiorite (unit 3)

Gneissic tonalite is one of the dominant rock types in the area and forms a relatively continuous east-striking unit through the central portion of Natawahunan Lake (Figure GS-3-1). Although granulite-facies metamorphic assemblages are locally preserved, the unit is commonly affected by variable degrees of retrogression related to the Trans-Hudson orogeny. A large variety of discontinuous bands and boudins up to several metres wide are present in the tonalite; they most commonly include mafic volcanic rocks and clinopyroxenite, with local examples of wacke, quartzite and anorthosite. Quartz-rich bands of granodiorite and tonalite likely represent dikes of later intrusive phases.

The gneissic tonalite is medium to coarse grained and foliated to strongly foliated, with discontinuous 1–20 cm banding. The banding is defined by discontinuous laminations of mafic minerals. Where granulite-facies

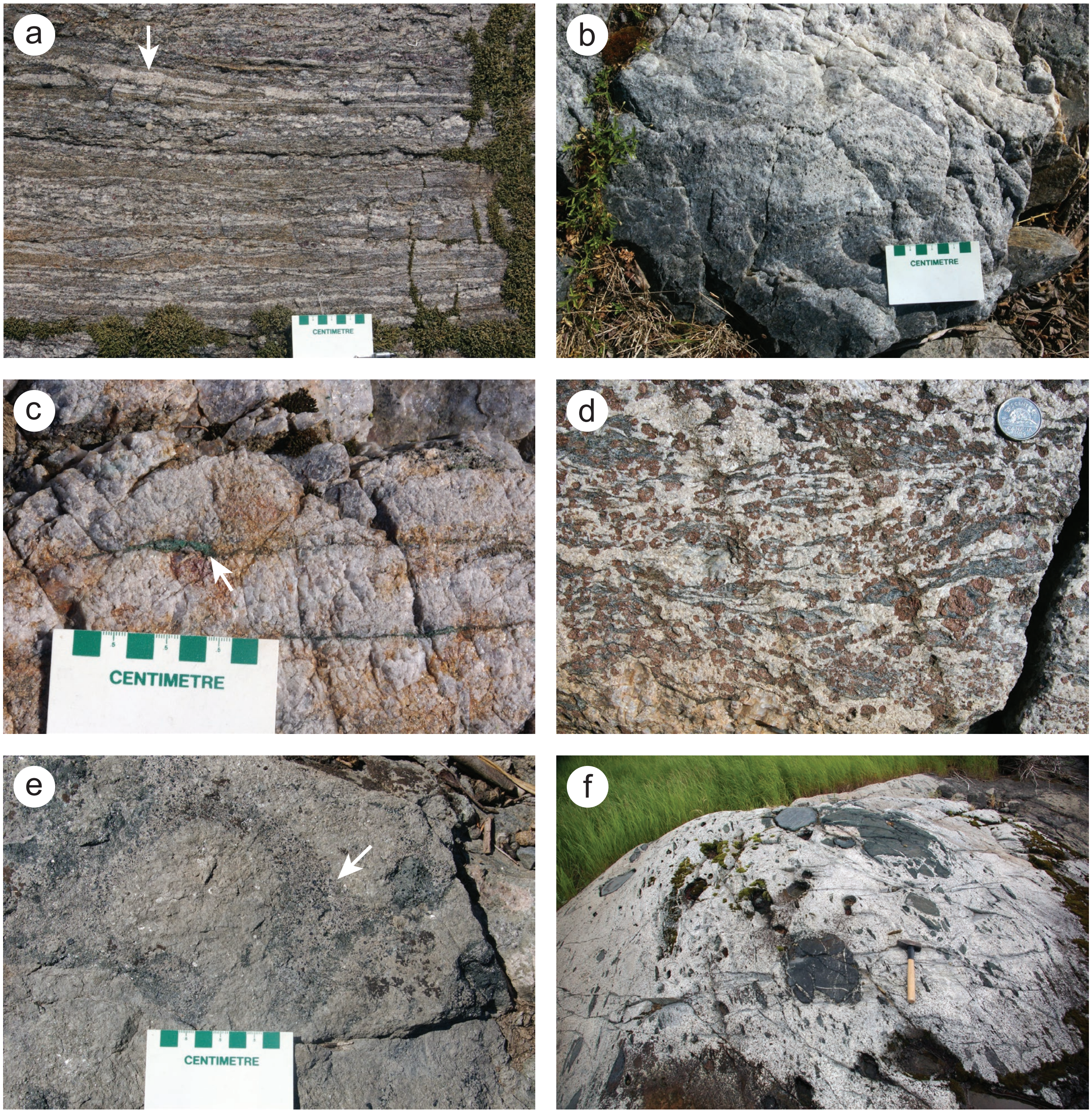


Figure GS-3-3: *Outcrop photographs from Natawahunan Lake:* ***a)*** *wacke with interlayered quartzofeldspathic and mafic-rich bands, and conformable bands of leucosome (arrow);* ***b)*** *coarsely recrystallized quartzite with diffuse layering (above scale card);* ***c)*** *conformable seam of fuchsite in quartzite (arrow);* ***d)*** *pelitic diatexite with garnet-, cordierite- and sillimanite-rich stringers of melanosome hosted in granitic leucosome;* ***e)*** *calcsilicate with diffuse spinel- and clinoamphibole-bearing layers (arrow);* ***f)*** *enderbite with xenoliths of basalt.*

assemblages predominate, the rock is typically beige and contains 3–5% orthopyroxene with local accessory amounts of magnetite, ilmenite and clinopyroxene; however, mafic minerals can locally constitute up to 15% of the rock. The gneissic tonalite is commonly retrogressed and appears white to pinkish grey, with mafic minerals replaced by pseudomorphous aggregates of biotite and/or actinolite±chlorite. Retrogression is commonly accompanied by varying degrees of potassic metasomatism, and the rocks may grade into granodiorite. Toward the western end of the lake, high-strain zones 10–20 m wide in the retrogressed gneissic tonalite result in an augen-textured straight gneiss. Heaman et al. (2011) estimated this unit to be older than ca. 2.97 Ga, based on a U-Pb zircon analysis.

Archean post-D_1 rocks

All Archean post-D_1 rocks display an S_2 foliation and contain M_2 leucosome. Units in this group are placed in approximate order of intrusion.

Garnet-bearing monzogranite (unit 4)

Most intrusions of garnet-bearing monzogranite are associated with occurrences of sedimentary rocks in Natawahunan Bay and eastern Natawahunan Lake (Figure GS-3-1). The monzogranite varies from white to pink and is medium to coarse grained, foliated and locally porphyritic. It contains 3–5% garnet and trace amounts of magnetite and sillimanite. Local K-feldspar phenocrysts are up to 1 by 2 cm. The garnet occurs as disseminated grains up to 5 mm across and in schlieric bands up to 15 cm thick that contain as much as 30% garnet. Exposures contain 10–30% coarse-grained leucosome as net-structured migmatite. Xenoliths of quartzite and schlieric wisps of biotite±garnet and orthopyroxene are locally abundant. The unit is commonly retrogressed, with sericitized sillimanite, and garnet pseudomorphously replaced by chlorite±biotite.

Enderbite–opdalite (unit 5)

Enderbite (orthopyroxene-bearing tonalite) is the dominant rock type underlying the Natawahunan Lake area (Figure GS-3-1). It is beige, coarse grained and foliated, and contains 5–10% orthopyroxene and trace to minor amounts of magnetite. Trace sulphide and minor amounts of biotite, clinopyroxene and K-feldspar are locally present. The orthopyroxene occurs as ubiquitous equant grains. The unit is characterized by the presence of xenoliths, which vary from relatively equant and subrounded to attenuated and flattened, depending on xenolith composition and local strain intensity (Figure GS-3-3f). Xenoliths can range from a few centimetres to at least 4 m across and typically make up 1–5% of exposures, but they can locally constitute up to 60% of the outcrop. Xenoliths of basaltic rocks and gneissic tonalite are most common, but anorthosite, quartzite and garnet monzogranite also occur. Rounded xenocrysts of K-feldspar up to 5 cm across are likely derived from pegmatitic material. Exposures typically contain 10–15% tonalitic to granodioritic leucosome as net-structured migmatite. The enderbite is commonly retrogressed, with orthopyroxene replaced by uralite and beige plagioclase replaced by light grey to pink feldspar. The pink feldspar could be K-feldspar, suggesting potassic metasomatism and gradation of the rock to granodiorite. Heaman et al. (2011) provided minimum age estimates for this unit of ca. 2812 Ma and ca. 2708 Ma (samples MAN85-8 and CB97-179a, respectively), which would suggest a pre-D_1 age of intrusion; however, a similar enderbite unit from Cauchon Lake (Couëslan, 2013) yielded a mean $^{207}Pb/^{206}Pb$ zircon age of 2689 ±3 Ma (Couëslan, unpublished data, 2014). A ca. 2689 Ma age is in agreement with textural and field relationships that suggest the enderbite–opdalite intruded after D_1–M_1 (ca. 2700–2692 Ma) but prior to D_2–M_2 (ca. 2683–2657 Ma; Heaman et al., 2011).

Tonalite-trondhjemite-granodiorite suite (unit 6)

Rocks of the tonalite-trondhjemite-granodiorite (TTG) suite are grouped together because of their textural similarities and frequently close spatial association. Rocks of this suite are relatively homogeneous and even grained, except for the presence of 10–20% coarse-grained granodioritic to granitic leucosome that forms a net-structured migmatite (Figure GS-3-4a). These rocks occur as relatively small intrusive bodies (<0.5 by 3 km) throughout the map area.

Tonalite (subunit 6a) is white to beige, medium grained, foliated and magnetic, and contains 10–20% quartz, 7–10% orthopyroxene and 1–2% magnetite. Local pink feldspar grains could indicate that as much as 12% K-feldspar is present and would imply the unit is gradational into granodiorite; however, the pink feldspar grains could be antiperthite. Minor clinopyroxene is locally present. Basaltic rocks occur as local boudins and discontinuous bands up to 6 m across.

Trondhjemite (subunit 6b) is white to beige, medium grained and foliated. It contains <5% mafic minerals as varying proportions of biotite and orthopyroxene. Magnetite, clinopyroxene and K-feldspar are locally present in trace to minor amounts. Xenoliths of basaltic rocks and gneissic tonalite up to 2 m across typically make up <5% of the outcrop.

Granodiorite (subunit 6c) is light pink to pinkish grey, medium grained and foliated. It typically contains <5% mafic minerals as varying proportions of biotite and orthopyroxene. The mafic minerals are locally retrogressed to aggregates of biotite and actinolite±chlorite. Zones of retrogression are locally more mesocratic, with 15–20% mafic minerals. Some occurrences could represent retrogressed tonalitic rocks that were subjected to potassic metasomatism. Local xenoliths of basaltic rock up to 5 m in size can be accompanied by xenoliths of quartzite, iron formation and hydrothermally altered rock. Bands of granodiorite up to 5 m wide occur within the enderbite (unit 5) and are interpreted as dikes.

Pyroxenite (unit 7)

The pyroxenite occurs throughout the map area as dikes up to 20 m wide intruding basaltic rocks, gneissic tonalite and tonalite. The rock is green to brown, medium to coarse grained, foliated and magnetic. It contains approximately equal proportions of clinopyroxene and orthopyroxene, along with 10–20% hornblende and trace to minor amounts of magnetite. Trace to minor amounts of plagioclase and biotite, as well as trace amounts of sulphide, are locally present. Local discontinuous bands up to 3 cm thick are defined by variations in grain size. Plagioclase-bearing pyroxenite is characterized by local pods of plagioclase-rich leucosome with zoned selvages. One dike contains xenoliths or autoliths of clinopyroxenite.

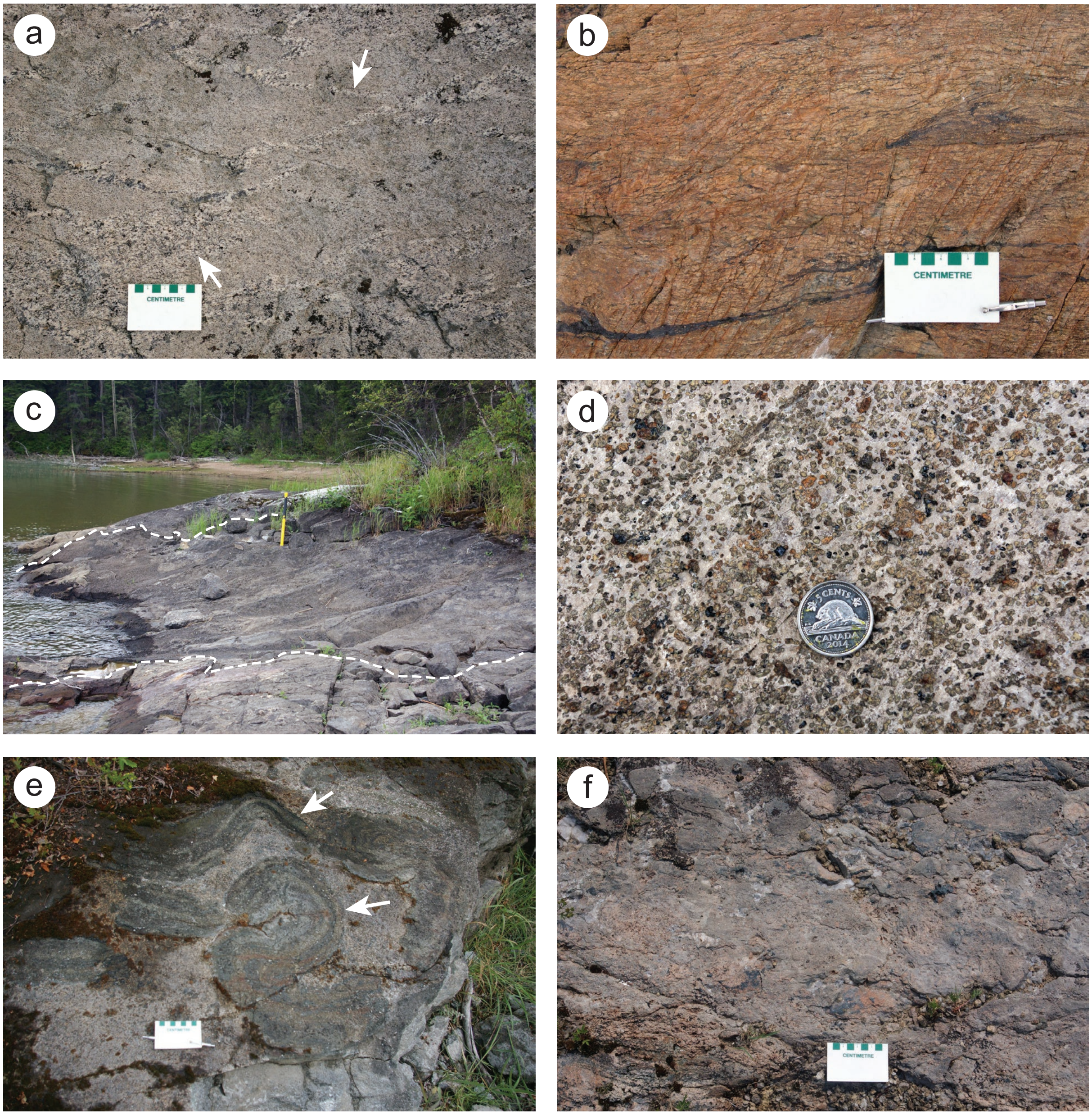


Figure GS-3-4: *Outcrop photographs from the Natawahunan Lake area:* ***a)*** *granodiorite with granitic leucosome (arrows) forming a net-structured migmatite;* ***b)*** *strongly sheared to mylonitized granite near Standing Stone Rapids;* ***c)*** *zone of carbonate rocks outlined by dashed line; sledge hammer at centre for scale;* ***d)*** *carbonate rock containing serpentinized olivine and phlogopite;* ***e)*** *contorted bands of apatite-phlogopite rock (arrows) hosted in carbonate rock;* ***f)*** *wacke that was intensely altered to carbonate-chlorite-sericite rock, Pie Lake.*

Rocks of uncertain age

Rocks of uncertain age were observed in a Hudsonian (D_3) high-strain zone. It is not known if Archean fabrics existed in these rocks because of the strong S_3 fabric; however, no M_2 leucosome was identified. The rocks could be either syn- to post-M_2 Archean or Paleoproterozoic.

Granite (unit 8)

The granite occurs in the Grass River channel between Natawahunan Lake and Standing Stone Rapids. It is light pink to pinkish red, coarse grained and strongly foliated, and contains 5–7% chloritized biotite. The rock is homogeneous but strongly sheared (Figure GS-3-4b). Local, lower strain exposures can grade into granodiorite. This could suggest that the intrusion was originally granodiorite and that shearing was accompanied by potassic metasomatism.

Pegmatitic granite (unit 9)

The pegmatitic granite occurs in a shear zone at the confluence of the Grass River channel and Natawahunan Bay. It is grey to pink and strongly foliated to mylonitic, and contains local xenoliths of sheared and retrogressed gneissic tonalite and basaltic rock.

Paleoproterozoic, post-D_2 rocks

Paleoproterozoic, post-D_2 rocks postdate the Archean granulite-facies metamorphism (M_2); however, they were locally deformed and amphibolitized/chloritized during the Hudsonian (D_3/M_3).

Mafic–ultramafic dikes (unit 10)

The majority of mafic and ultramafic dikes are north-northeast trending and assumed to be part of the ca. 1880 Ma Molson swarm (Scoates and Macek, 1978; Heaman et al., 2009); however, dikes with more easterly trends could be related to dike swarms of different ages (cf. Zhai et al., 1994; Halls and Heaman, 2000; Bowerman et al., 2004).

Diabase dikes (subunit 10a) are typically <15 m wide, dark grey-green, fine grained, massive and moderately to strongly magnetic. They contain 40–60% plagioclase and variable amounts of clinopyroxene and orthopyroxene, and minor amounts of hornblende and magnetite. Gabbro dikes are up to 70 m wide and commonly have diabasic margins. The gabbro is grey-green to grey-brown, medium to coarse grained, massive and magnetic. Compositions can be quite variable, with anywhere from 10% to 60% plagioclase and variable amounts of orthopyroxene, clinopyroxene and hornblende. Hornblende typically makes up <20% of the rock and magnetite occurs in trace to minor amounts. Local pegmatitic pods can be up to 0.3 by 1 m and are plagioclase-rich, with 10–20% each of quartz, hornblende and clinopyroxene. Local hydration of the mafic dikes is relatively common. Hydrated dikes are dark grey-green and contain 40–60% plagioclase and 40–60% amphibole. Amphibole appears to be dominated by actinolite, but hornblende is locally present.

Pyroxenite dikes (subunit 10b) are most common in the western basin of Natawahunan Lake (Figure GS-3-1). They are dark grey-green to green-brown, medium to coarse grained and massive. Composition varies from orthopyroxenite to clinopyroxenite, with varying but minor amounts of plagioclase, olivine and hornblende. Dikes are locally zoned, with diabase margins and pyroxenite cores.

Carbonate rocks (unit 11)

Carbonate rocks are found along the south shore of the western basin of Natawahunan Lake, hosted in gneissic tonalite with local blocks of calcsilicate and pegmatitic granite dikes, and in northwestern Pie Lake, hosted by sedimentary rocks and locally cut by quartz-carbonate veins (Figure GS-3-1). At Natawahunan Lake, they occur within a 20 m wide zone as conformable, discontinuous, irregular bands and nebulous pods that range from 3 cm to 5 m across (Figure GS-3-4c). The rocks are grey, medium grained and massive to locally sheared. Composition varies between bands but is carbonate rich, with 20–40% mafic minerals as varying proportions of serpentinized olivine, phlogopite, diopside and apatite (Figure GS-3-4d). Magnetite and titanite are locally present in minor to trace amounts. Phlogopite grains are locally zoned. The rock locally contains boudinaged and contorted bands of apatite-phlogopite rock 10–15 cm thick (Figure GS-3-4e). The apatite-phlogopite rock consists of alternating 0.5–3 cm thick phlogopite-rich and apatite-rich bands with interstitial carbonate. The largest bands of carbonate rock contain rounded fragments of locally derived granitoid country rock. The fragments are rimmed by phlogopite-rich selvages and appear to be partially altered. The presence of the carbonate rocks as bands within tonalitic rocks suggests they were emplaced as either magmatic dikes or hydrothermal veins/alteration. The presence of magnetite, apatite and titanite could indicate an affinity to carbonatite magmatism.

Quartz-carbonate veins and intense carbonate alteration

Quartz-carbonate veins up to 35 cm wide are locally associated with Hudsonian brittle-ductile shear zones throughout the Natawahunan Lake area. They consist of coarse-grained quartz with generally subordinate, brown-weathering carbonate. Veins are typically lined with fine-grained chlorite. At the east end of Stinson Island and along the north shore of Pie Lake, quartz-carbonate veins are associated with intense carbonate-chlorite-sericite alteration along zones up to 2.5 m wide (Figure GS-3-4f).

Structure and metamorphism

The earliest fabric in the Natawahunan Lake area consists of an S_1 gneissosity in the Archean pre- to syn-D_1 rocks that typically strikes 260–280° with a subvertical dip. 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.

Archean granulite-facies metamorphic assemblages are best preserved in the mafic volcanic and associated rocks, which commonly retain orthopyroxene- and clinopyroxene-bearing assemblages, and in the sedimentary rocks. Sapphirine-quartz assemblages were recognized in both the eastern and western basins of Natawahunan Lake (Figure GS-3-2b), suggesting ultra-high–temperature metamorphic conditions (>900°C; Harely, 1998; Kelsey, 2008). Leucosome developed during M_2 metamorphism is commonly orthopyroxene bearing and occurs in all Archean rocks. The leucosome cuts across S_1 fabrics in gneissic rocks but displays an S_2 foliation in all Archean rocks.

The D_2 generation of deformation is manifested as a well-developed S_2 quartz fabric in all Archean rocks. The fabric typically strikes 240–255° with a dip greater than 75°. The S_2 fabric typically intersects S_1 at a small to moderate angle (20–40°); however, the S_1 gneissosity is locally attenuated parallel to S_2 in zones of higher strain and in less competent rocks, such as the sedimentary rocks. The S_2 fabric is axial planar to isoclinal minor folds. Fold hinges typically plunge to the west at a moderate to steep angle (60–70°). All observed M_2 leucosome displays a well-developed S_2 fabric and is commonly attenuated. The leucosome is locally folded by F_2. This suggests that the M_2 peak metamorphism predated, or was synchronous with and outlasted by, the D_2 generation of deformation.

A Paleoproterozoic S_3 shear zone runs the length of the Grass River channel between the western and eastern basins of Natawahunan Lake and continues along the out-flowing channel toward Standing Stone Rapids (Figure GS-3-1). Minor shear zones are also present on Pie Lake and peripheral to the Grass River channel. Shearing is dominantly sinistral and manifested as brittle-ductile shear bands and discrete mylonite zones (Figure GS-3-4b). The shear zones crosscut mafic dikes and are likely related to the Trans-Hudson orogeny. Sheared rocks are retrogressed and can be affected by potassic metasomatism. Quartz-carbonate veins are locally associated with the shear zones, as are rare zones of intense carbonate-chlorite-sericite alteration.

Retrogression is pervasive throughout the map area. The granitoid rocks that underlie much of the area appear to be more susceptible to retrogression, with Archean pyroxene-bearing assemblages commonly replaced by biotite, actinolite and/or chlorite. Retrogression is likely related to the Trans-Hudson orogeny. The presence of local hornblende in hydrated Paleoproterozoic dikes suggests Hudsonian metamorphism may have reached amphibolite-facies conditions.

Economic considerations

Intense carbonate-chlorite-sericite alteration and discrete quartz-carbonate veins are locally associated with shear zones in the Natawahunan Lake area. This style of alteration is commonly associated with orogenic gold mineralization (Robert, 1995; Dubé and Gosselin, 2007). The proximity of the veins and alteration to the major shear zone along the Grass River channel could 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).

There is some potential for volcanogenic massive-sulphide (VMS) mineralization in the Natawahunan Lake area. The association of iron formation with the basaltic rocks suggests a subaqueous environment for at least some of the mafic volcanism, and that magmatism was accompanied by exhalative sedimentation. Evidence for metamorphosed hydrothermal alteration zones is locally present in the basaltic rocks. Magnesian and aluminous bands up to 2.5 m thick likely represent zones of chlorite and chlorite-sericite alteration. These mineral assemblages were replaced during high-grade metamorphism by orthopyroxene-, garnet- and sapphirine-bearing assemblages. Bands of intense chlorite-sericite alteration indicate flow of hydrothermal fluids that could have transported base metals and sulphides. This type of alteration is typically found in the footwall of VMS deposits (Galley et al., 2007).

Carbonatites are important sources for a variety of rare metals (rare-earth elements, Y, Nb) and, if the carbonate rocks in the Natawahunan Lake area are found to be of carbonatite affinity, this could indicate a potential for rare-metal mineralization in the area. Samples of the carbonate rocks were collected by J. Macdonald and A. Chakhmouradian, and will be the subject of additional study and a B.Sc. thesis at the University of Manitoba.

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