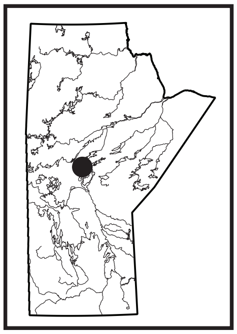
GS-4 Preliminary results of bedrock mapping in the southeastern Duck Lake–Sesep Rapids area, Pikwitonei granulite domain, central Manitoba (part of NTS 63J16)

by C.G. Couëslan



Couëslan, C.G. 2016: Preliminary results of bedrock mapping in the southeastern Duck Lake–Sesep Rapids area, Pikwitonei granulite domain, central Manitoba (part of NTS 63J16); *in* Report of Activities 2016, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 40–50.

Summary

A project to re-map portions of the Archean Pikwitonei granulite domain in central Manitoba, with emphasis on identification of volcanic and sedimentary precursors with unrecognized exploration potential, continued in 2016 with mapping in the Duck Lake–Sesep Rapids area. Rock units in the area are divided based on structural observations into 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 basalt and associated rocks, intravolcanic mafic intrusions, sedimentary rocks and various gneissic intrusive rocks ranging in composition from diorite to granite. Post-D_1 rocks consist of metamorphosed intrusive rocks that range in composition from diorite to granite. Rocks of uncertain age consist of bands of carbonate rock, and post-D_2 rocks consist of Paleoproterozoic mafic dikes. The oldest rocks in the Duck Lake–Sesep Rapids area display 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. Southwest-striking Paleoproterozoic S_3 sinistral shear zones occur along the Nelson River channel and along the southeastern shore of Duck Lake, and are accompanied by pervasive Hudsonian retrogression.

Pervasive chlorite and sericite+chlorite alteration, along with local talc alteration, suggest potential for volcanogenic massive sulphide mineralization in the Duck Lake area. Bands of carbonate rock could have a carbonatite affinity, which would suggest potential for rare-metal mineralization, possibly on a regional scale.

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 1:10 000 scale mapping in the Duck Lake–Sesep Rapids area (Figure GS-4-1) and 1:20 000 scale mapping in the Natawahunan Lake area (Couëslan, GS-3, this volume).

The Duck Lake–Sesep Rapids area was selected for mapping because of an abundance of mafic volcanic rocks recognized by Hubregtse (1978a, b). Garnet-bearing and sillimanite-bearing gneisses, as well as marble, were described as being associated with the mafic volcanic rocks. Similar aluminous and calcareous rocks associated with mafic volcanic rocks on Cauchon and Partridge Crop lakes are interpreted to be the products of hydrothermal alteration that predated regional high-grade metamorphism (Couëslan, 2014b; Couëslan and Guevara, 2015). If premetamorphic hydrothermal alteration is present, it could suggest potential for base-metal or gold mineralization in the Duck Lake 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, 2016c). 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, 1978a, 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

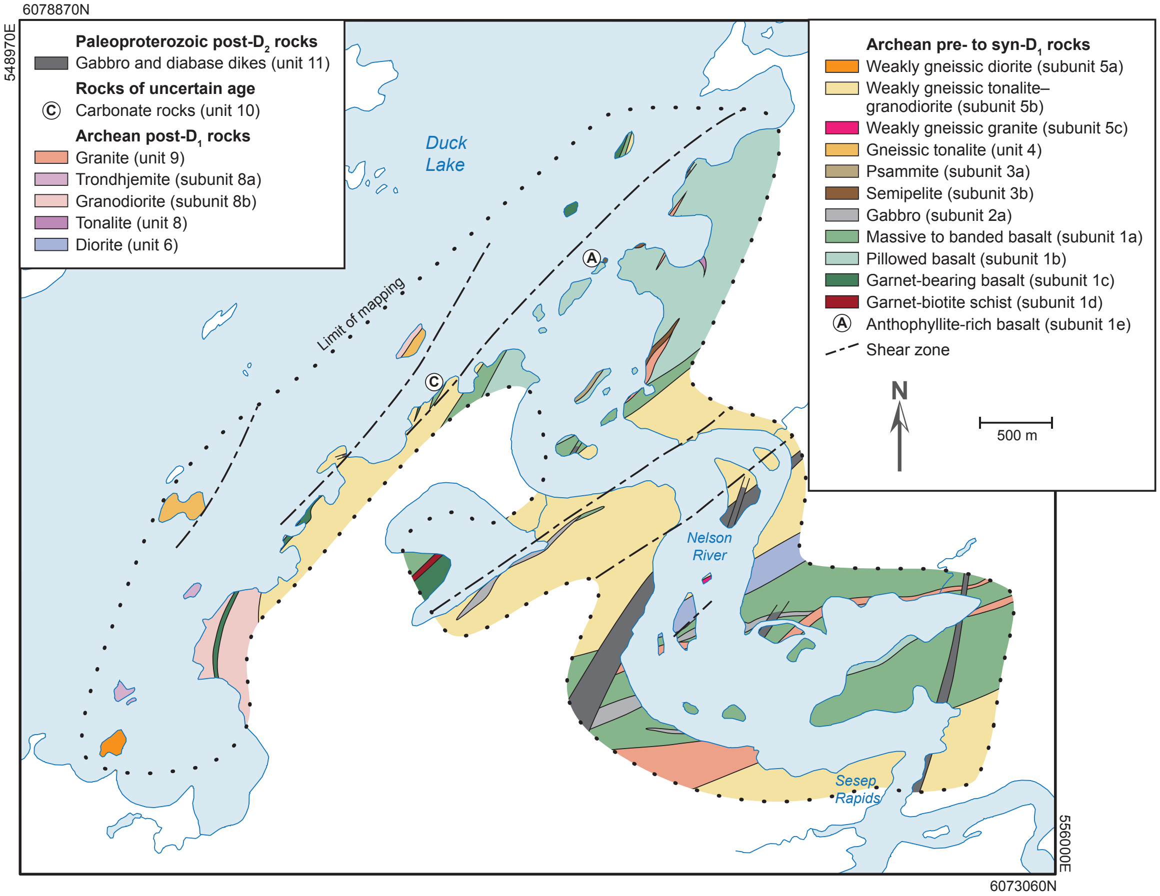


Figure GS-4-1: *Simplified geology of the Duck Lake–Sesep Rapids area, central Manitoba (modified from Couëslan, 2016a).*

(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, 1978a, 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).

Duck Lake–Sesep Rapids area

The Duck Lake–Sesep Rapids area is situated in a narrow zone of PGD rocks bounded by the Superior boundary zone to the west and the Oxford-Stull domain of the North Caribou terrane to the east (Hubregtse, 1978a; Stott et al., 2010). The area is dominated by tonalite and mafic metavolcanic rocks (Hubregtse, 1978b). The metavolcanic rocks are locally intruded by porphyritic metagabbro. Local garnet-biotite and sillimanite gneisses are interpreted as metasedimentary rocks (Hubregtse, 1978a). Paleoproterozoic mafic dikes strike north-northeast through the area and likely belong to the ca. 1880 Ma Molson dike swarm (Hubregtse, 1978a; Scoates and Macek, 1978; Heaman et al., 2009).

Lithological units

The lithological units identified in the Duck Lake–Sesep Rapids 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 appear to have reached 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 PMAP2016-3 (Couëslan, 2016a), and Figure GS-4-1 represents a simplified version of this map.

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 units within this group are listed in order of inferred age.

Basalt and associated rocks (unit 1)

Basalt is most common along the Nelson River between Duck Lake and Sesep Rapids (Figure GS-4-1). The unit consists dominantly of massive, banded and pillowed basalt, along with minor iron formation, and basalt that was subjected to various styles of hydrothermal alteration. The relative ages of the subunits are not constrained.

Massive to banded basalt (subunit 1a) occurs throughout the map area but is most common in the Sesep Rapids area (Figure GS-4-1). The rock is dark grey to black, medium grained, foliated and locally magnetic, and varies from massive to banded (Figure GS-4-2a). The unit is plagioclase rich, with mafic minerals making up 50–70% of the mineral mode, and consists of 30–70% hornblende with varying amounts of clinopyroxene and orthopyroxene. Magnetite locally constitutes up to 2% of the rock. Banding occurs on a scale of 0.5–7 cm and is typically defined by plagioclase content, which locally increases to 60% of the rock. Banded zones are commonly weakly

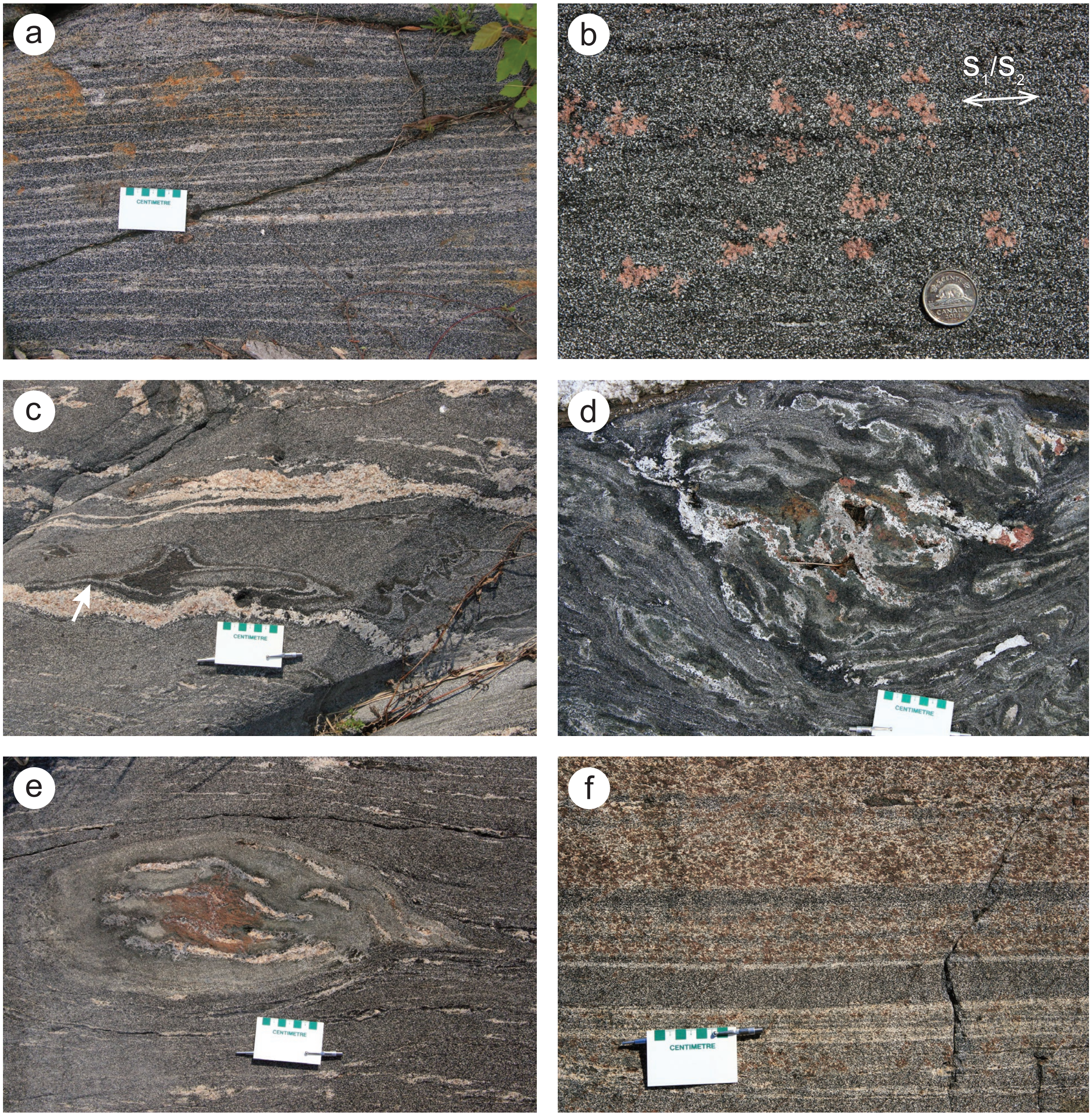


Figure GS-4-2: *Outcrop photographs of basalt from the southeastern Duck Lake–Sesep Rapids area:* ***a)*** *basalt with plagioclase-rich bands;* ***b)*** *garnet clusters overgrowing the regional* S_1*-*S_2 *fabrics;* ***c)*** *pillowed basalt (arrow) with injections of pegmatitic granite;* ***d)*** *calcsilicate pod in pillowed basalt, which could represent interpillow material, sheared zones of carbonate alteration or sheared quartz-carbonate vein material;* ***e)*** *boudin of plagioclase- and garnet-rich rock that likely represents metamorphosed epidosite;* ***f)*** *bands of garnet-bearing basalt.*

gossanous. Local boudins up to 25 cm across consist of variable amounts of medium- to coarse-grained plagioclase, clinopyroxene and garnet, and may represent pods of meta-epidosite. These rocks can contain up to 7% leucosome as orthopyroxene-bearing pods up to 15 cm thick. Garnet locally forms discrete clusters that are discordant to S_1 and S_2 fabrics within otherwise massive basalt (Figure GS-4-2b), and discordant veins of massive garnet up to 2 cm across locally crosscut the S_1 gneissosity and S_2 foliation. The reason for this relatively late garnet growth is uncertain; however, it could be related to Hudsonian-age retrogression.

Pillowed basalt (subunit 1b) appears to be most common where the Nelson River flows into Duck Lake (Figure GS-4-1). Pillows are typically flattened and deformed (Figure GS-4-2c) and are reduced to hornblende-rich pods and stringers in zones of high strain. It is likely that some of the banded basalt in subunit 1a represents sheared pillowed basalt or flow breccia. Pillowed basalt is locally associated with pods of coarse-grained calcsilicate (Figure GS-4-2d). The pods can form up to 20% of some outcrops and consist of varying amounts of garnet, scapolite, green clinoamphibole, carbonate, plagioclase and quartz. The calcsilicate likely represents interpillow material; however, it could also represent sheared zones of carbonate alteration or quartz-carbonate vein stockwork that predated the regional metamorphism. Local garnet- and plagioclase-rich boudins up to 25 cm across are commonly zoned, with garnet-rich cores and plagioclase-rich rims, and contain variable amounts of clinopyroxene, orthopyroxene and quartz (Figure GS-4-2e). The boudins likely represent epidotized pillows or fragments of epidosite.

Garnet-bearing basalt (subunit 1c) is most common in southeastern Duck Lake (Figure GS-4-1). It occurs as bands within subunit 1a or can form the dominant phase in outcrops (Figure GS-4-2f). Garnet-bearing basalt is relatively heterogeneous and plagioclase rich, with 50–70% mafic minerals that include 10–30% garnet and varying proportions of hornblende and orthopyroxene. Minor amounts of clinopyroxene and quartz are locally present. Garnet forms porphyroblasts up to 15 cm across that are locally rimmed by leucosome. The subunit is typically banded on a scale of 0.1–2.5 m. The abundance of garnet suggests enrichment in Fe and depletion in Ca relative to units 1a and b, and could be the result of pervasive Fe-chlorite alteration of the basaltic rocks.

The largest exposure of garnet-biotite schist (subunit 1d) occurs in a swampy bay of the Nelson River, south of its discharge into Duck Lake (Figure GS-4-1). Scattered occurrences of the schist also occur on islands in the nearby river channel. The main exposure of the schist is brown-grey to rusty brown, medium to coarse grained, strongly foliated and banded on a scale of 0.5–30 cm. It is quartz and plagioclase rich, with 10–20% biotite, 7–10% garnet, 5–7% anthophyllite and 3–5% sillimanite, along with minor to trace amounts of sulphides and graphite (Figure GS-4-3a). The assemblage biotite+garnet+anthophyllite+sillimanite suggests a relatively aluminous and ferromagnesian bulk composition that is also depleted in alkalis. Such bulk compositions have a fairly restricted petrogenesis and typically originate as either unusually ferromagnesian wacke/pelite or hydrothermally altered, sericite- and chlorite-rich rock. A hydrothermal origin is currently the favoured interpretation, given the close spatial association with garnet-bearing basalt. The western portions of the outcrop feature intense gossan staining, indicating the presence of higher concentrations of sulphide minerals. Bulk-rock lithogeochemical results, which are pending, will aid petrogenetic interpretation of this rock.

Nebulous zones of anthophyllite-rich basalt (subunit 1e) up to 1.5 m across occur within pillowed basalt where the Nelson River discharges into Duck Lake (Figure GS-4-1). The rock is pale green to khaki, medium grained and foliated. It consists of plagioclase with 50–60% anthophyllite and trace to minor amounts of rutile. The nebulous zones are locally discordant and contain local pods of more compositionally typical basalt (Figure GS-4-3b). The magnesian nature of these rocks could suggest an origin as talc-rich alteration of basalt with locally preserved pods of unaltered rock.

Intravolcanic mafic intrusions (unit 2)

Several bands of gabbro up to 100 m thick occur along the Nelson River channel (Figure GS-4-1). The gabbro is always found hosted in basalt and is locally associated with thin bands (1–10 m) of pyroxenite. Although all plagioclase- and hornblende-phyric rocks were mapped as gabbro, it is possible that some bands could represent porphyritic flows.

Gabbro of subunit 2a is grey to dark grey, coarse to very coarse grained and foliated. It varies from gabbro to leucogabbro and contains 20–60% hornblende and variable amounts of clinopyroxene and orthopyroxene that total <20% of the rock. The gabbro is typically plagioclase and/or hornblende phyric, with plagioclase phenocrysts up to 10 cm and hornblende phenocrysts up to 2 cm across (Figure GS-4-3c). The hornblende 'phenocrysts' are typically polycrystalline aggregates and are likely pseudomorphous after igneous pyroxene or amphibole. Gabbro exposures commonly grade from more mafic-rich hornblende-phyric layers to more leucocratic plagioclase-phyric layers, suggesting magmatic differentiation. Local orthopyroxene-bearing pods of tonalitic leucosome are up to 15 cm across (Figure GS-4-3d). Contacts between the basalt and gabbro are typically sheared but are locally chaotic, with blocks of basalt enclosed in gabbro, which supports an intrusive relationship between the two units.

Pyroxenite (subunit 2b) is dark green, coarse grained and foliated. It is hornblende rich, with 50–60% orthopyroxene and minor clinopyroxene and plagioclase. Bands

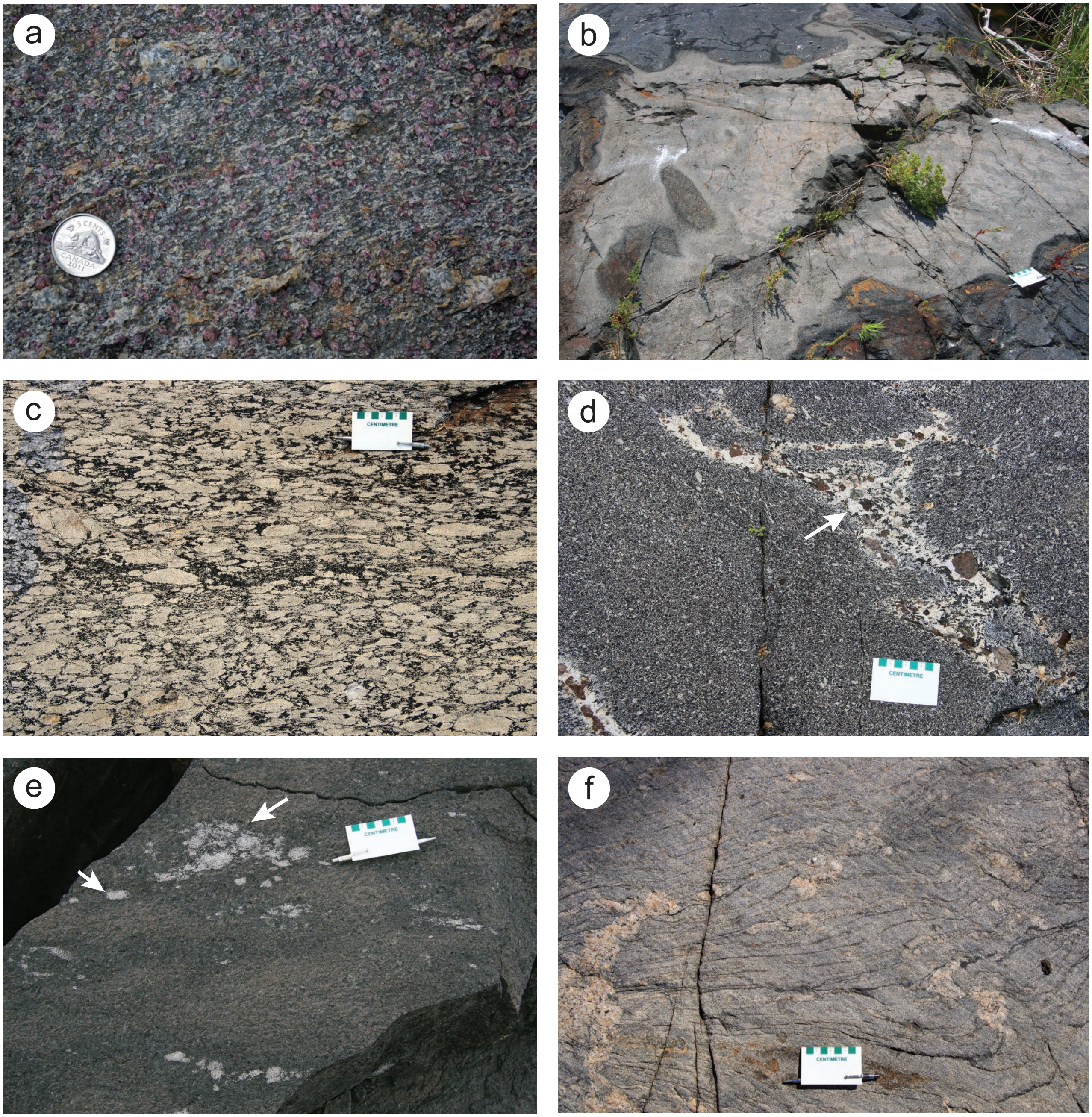


***Figure GS-4-3:** Outcrop photographs from the southeastern Duck Lake–Sesep Rapids area: **a)** sillimanite- and anthophyllite-bearing garnet-biotite schist that likely represents sericite- and chlorite-altered basalt; **b)** anthophyllite-rich basalt (light-coloured rock) that likely represents talc-altered basalt, with pods of unaltered basalt occurring toward left side of image; **c)** intravolcanic intrusion of leucogabbro with phenocrysts of plagioclase; **d)** pod of orthopyroxene-bearing tonalitic leucosome hosted in gabbro (arrow); **e)** pyroxenite with xenoliths of, and xenocrysts derived from, plagioclase-phyric gabbro (arrows); **f)** psammite, with bedding defined by biotite-rich laminations.*

of pyroxenite only occur in association with the gabbro and may be up to 10 m wide. The pyroxenite contains local xenoliths, and derived xenocrysts, of plagioclase-phyric gabbro up to 30 cm across, suggesting that it is intrusive into the gabbro rather than occurring as a basal cumulate (Figure GS-4-3e); however, the pyroxenite could be a cumulate in a composite intrusion or indicative of layering in a dynamic magma chamber.

Sedimentary rocks (unit 3)

Bands of psammitic to semipelitic sedimentary rock occur near the outflow of the Nelson River into Duck Lake (Figure GS-4-1). The bands are associated with basalt and are typically less than 100 m wide.

Psammite of subunit 3a is grey, medium grained, foliated and layered on a scale of 1–10 cm. It is quartz and feldspar rich, with 10–15% biotite. Biotite-rich laminations define the layering of the psammite (Figure GS-4-3f). Pods of granitic leucosome make up 5–15% of exposures. Local pelitic to semipelitic layers up to 15 cm thick typically contain up to 7% garnet and 15% sillimanite, along with a greater proportion of leucosome. Basalt adjacent to the contact with the psammite is garnet rich and could represent a combination of siliciclastic and volcaniclastic material.

Semipelite of subunit 3b is grey, coarse grained and moderately to strongly foliated. It is feldspar rich, with 20–40% quartz, 10–30% biotite, trace–7% sillimanite and trace amounts of garnet and sulphides. The rock forms a metatexite to diatexite, with 15–45% granitic leucosome that is locally garnet bearing (Figure GS-4-4a). Gossanous zones up to several metres thick indicate locally higher sulphide concentrations.

Gneissic tonalite (unit 4)

Gneissic tonalite occurs along the western edge of the map area (Figure GS-4-1). It is grey, coarse grained,

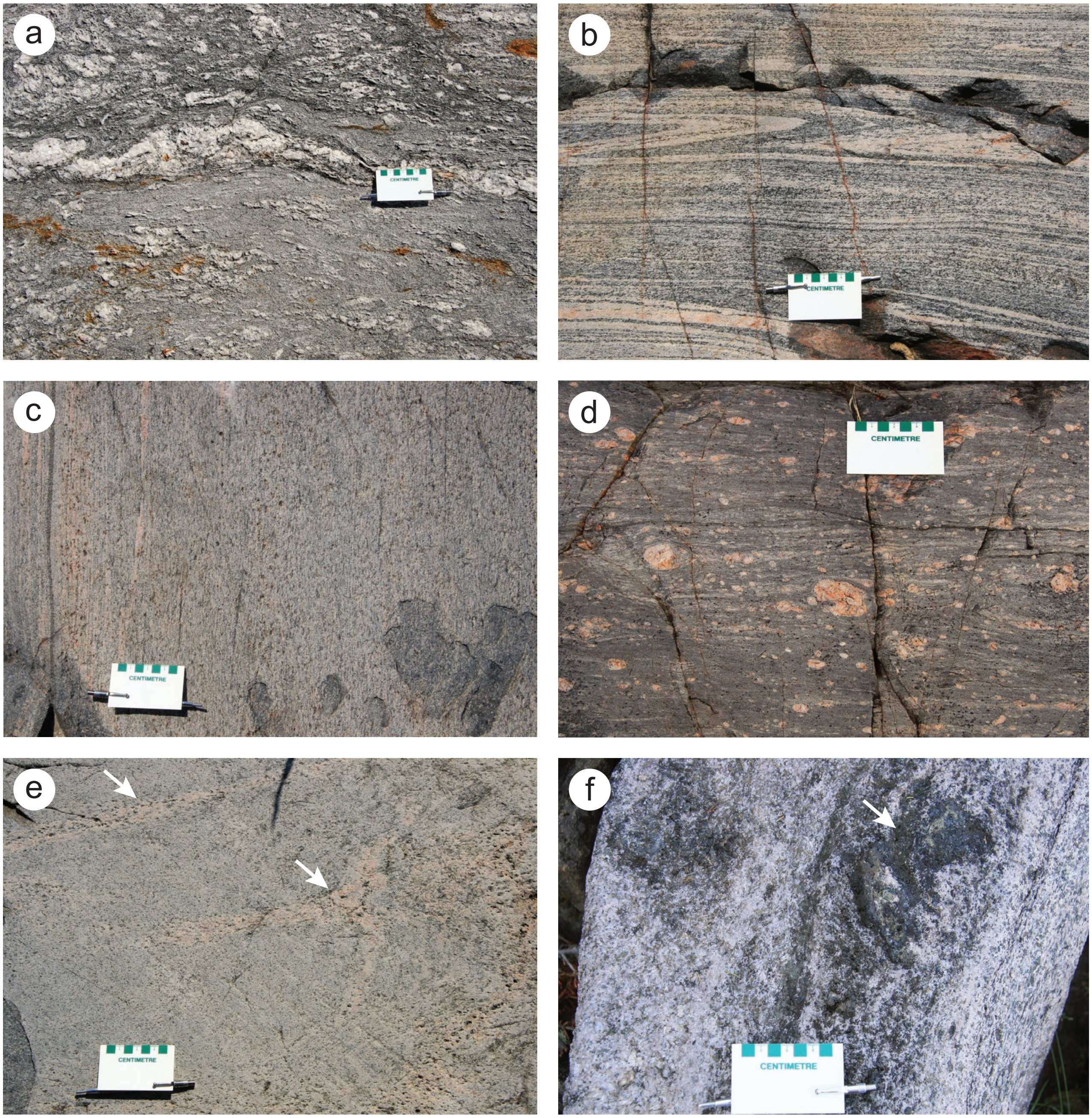


Figure GS-4-4: *Outcrop photographs from the southeastern Duck Lake–Sesep Rapids area:* ***a)*** *semipelitic diatexite;* ***b)*** *gneissic tonalite with isoclinal F_2 folds;* ***c)*** *weakly gneissic tonalite;* ***d)*** *protomylonite in weakly gneissic granodiorite with abundant K-feldspar augen that are likely derived from sheared pegmatitic material;* ***e)*** *trondhjemite with granitic leucosome (arrows);* ***f)*** *carbonate rock with a pod of carbonate-bearing amphibolite (arrow).*

foliated and banded on a scale of 0.5–10 cm (Figure GS-4-4b). The tonalite contains 10–12% mafic minerals as varying proportions of hornblende, orthopyroxene and clinopyroxene, along with trace amounts of magnetite. The unit is at least partially amphibolitized, with clinopyroxene locally rimmed by hornblende. Local xenoliths of basalt are up to 4 m across. It is possible that the gneissic tonalite is a high-strain equivalent of the weakly gneissic tonalite–granodiorite (subunit 5b).

Weakly gneissic intrusions (unit 5)

A suite of weakly gneissic intrusions underlies much of the map area and is dominated by tonalite–granodiorite, with lesser diorite and granite (Figure GS-4-1).

A single body of gneissic diorite (subunit 5a), approximately 200 m across, occurs at the south end of Duck Lake (Figure GS-4-1). It is light grey, medium grained and foliated, and contains 3–5% hornblende, 2–3% clinopyroxene and trace amounts of ilmenite. The gneissosity is defined by discontinuous laminae of mafic minerals. The exposure contains 10–20% basalt xenoliths up to 3 m across and 10–15% granodioritic to granitic leucosome as veins up to 2 cm wide.

Subunit 5b is dominantly tonalite but locally grades into granodiorite. The tonalite is grey-beige to grey, medium to coarse grained, foliated and weakly magnetic to magnetic. It contains 7–12% mafic minerals as varying proportions of orthopyroxene, clinopyroxene, hornblende and biotite. Magnetite and ilmenite locally constitute up to 2% of the rock. The rock is relatively monotonous, with a gneissosity defined by diffuse and locally discontinuous mafic laminations (Figure GS-4-4c). Granitic to granodioritic leucosome makes up 5–15% of exposures, locally forming a net-structured migmatite. The leucosome locally contains up to 5% orthopyroxene. The granodiorite is typically associated with shear zones. This could indicate that the K-feldspar is the result of weak pervasive metasomatism. Exposures of granodiorite range from foliated to protomylonitic and do not contain pyroxene or magnetite. Leucosome within the granodiorite is typically granitic and contains hornblende porphyroblasts, which could be pseudomorphous after pyroxene. High-strain outcrops commonly contain K-feldspar–rich augen that are likely derived from sheared leucosome or pegmatite injections (Figure GS-4-4d). The weakly gneissic tonalite–granodiorite locally contains xenoliths of basalt up to 4 m across and rare xenoliths of iron formation.

A single body of weakly gneissic granite (subunit 5c), approximately 50 m wide, occurs in the Nelson River channel halfway between Sesep Rapids and Duck Lake (Figure GS-4-1). The granite gneiss is pink, coarse grained and foliated. It contains 3–5% biotite, which forms discontinuous laminations.

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.

Diorite (unit 6)

Diorite is most common in the Nelson River channel approximately halfway between Duck Lake and Sesep Rapids, where it forms a body 100–150 m wide (Figure GS-4-1). The diorite is grey, medium grained and foliated, and contains 20–30% hornblende. The unit is relatively monotonous, with 3–5% granodioritic leucosome.

Tonalite (unit 7)

A single exposure of hornblende tonalite occurs on Duck Lake in the small bay immediately north of the Nelson River outlet. The tonalite is grey, coarse grained and foliated, and contains 10–15% hornblende. Granodioritic leucosome makes up 10–15% of the exposure.

Trondhjemite–granodiorite suite (unit 8)

The trondhjemite–granodiorite suite underlies much of the southeastern end of Duck Lake. Exposures contain 7–30% granitic leucosome, which forms net-structured migmatite that is locally attenuated (Figure GS-4-4e).

Trondhjemite (subunit 8a) forms an intrusion up to 400 m wide that grades into the granodiorite. It is light grey, medium grained, foliated and magnetic. Mafic minerals consist of 2–3% magnetite, 1–2% orthopyroxene and trace–1% clinopyroxene. The rock is relatively monotonous, with local xenoliths and schlieren derived from basalt.

Granodiorite (subunit 8b) forms intrusions >100 m wide that are light pinkish grey, medium to coarse grained and foliated to strongly foliated. It contains 3–5% biotite and trace amounts of magnetite.

Granite (unit 9)

Intrusions of granite up to 300 m wide occur in the Nelson River channel and bays immediately downstream of Sesep Rapids. The granite is pink, coarse grained to pegmatitic, foliated and locally magnetic. Mafic minerals consist of 2–5% biotite, trace–2% magnetite and locally up to 2% of a uralitized mafic mineral that was likely either pyroxene or hornblende. Diffuse, interconnected, quartz-rich pods are coarse grained to pegmatitic and could represent net-structured leucosome or magmatic segregations. The favoured interpretation is that the pods represent leucosome, which would indicate that unit 9 is Archean and predates M_2; however, if the pods are pegmatitic segregations, this unit could be Hudsonian.

Rocks of uncertain age

Carbonate rock (unit 10)

Bands of carbonate rock up to 1.5 m thick occur within subunit 1a along the southeastern shore of Duck Lake (Figure GS-4-1). It occurs within a relatively high-strain and heterogeneous zone, interbanded with units 1a, 5b, 8b and 9 on a metre scale. The high-strain zone is interpreted to be Hudsonian (D_3), which overprinted the Archean fabrics. The carbonate rock varies from grey to pink, from medium to coarse grained and from foliated to mylonitic, and is locally magnetic. The pink variety of the carbonate rock contains pink carbonate along with 10–20% pale green clinoamphibole and 10–20% diopside, while the grey variety contains grey carbonate along with trace–1% apatite, trace–1% tremolite, 1–2% magnetite, 10–15% phlogopite and 10–20% serpentinized olivine. The carbonate-rich bands contain local diffuse pods of carbonate-bearing amphibolite up to 15 by 30 cm (Figure GS-4-4f). The amphibolite likely represents partially altered fragments of basalt.

Although the setting of the carbonate rock could indicate a hydrothermal origin (i.e., intense carbonate alteration of basalt prior to high-grade metamorphism), the compositional variability of the bands, along with the presence of apatite and magnetite, could alternatively indicate a carbonatite affinity. A premetamorphic hydrothermal origin would imply an Archean, pre- to syn-D_1 age for the unit. If the rock is carbonatite related, its age would remain unconstrained; however, similar rocks from Paint Lake, Partridge Crop Lake and Natawahunan Lake are interpreted to be Paleoproterozoic (Chakhmouradian et al., 2009; Couëslan, 2013, 2016b; Couëslan, GS-3, this volume). Bulk-rock lithogeochemical results are pending.

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 during the Hudsonian (D_3/M_3).

Gabbro and diabase dikes (unit 11)

Gabbro and diabase dikes occur throughout the map area, but the largest gabbro dikes occur in the Nelson River and bays closer to Sesep Rapids. The dikes are green-grey to grey-brown, medium to coarse grained, massive to layered and locally magnetic. Mafic minerals make up 50–70% of the rock and occur in varying proportions; however, the proportions are typically clinopyroxene>orthopyroxene>hornblende. Local rhythmic layering can be crossbedded and is defined by variations in plagioclase content. Local pegmatitic pods are up to 5 by 30 cm and are plagioclase-rich with 20–30% hornblende. Dikes commonly have fine-grained chilled margins. Hydration is common along regularly spaced joints, and dikes become pervasively amphibolitized, and locally sheared, with increasing proximity to Duck Lake. Amphibolitized dikes are dark green and consist of plagioclase with 50–70% hornblende. The metamorphic hornblende occurs as porphyroblasts up to 0.5 cm, which are likely pseudomorphous after pyroxene. Amphibolitized dikes are locally intruded by pegmatitic granite injections along shear bands, which indicate the presence of local Hudsonian-age granitic magmatism. Paleoproterozoic mafic dikes generally trend 014–036°, which suggests they could belong to the ca. 1880 Ma Molson dike swarm (Scoates and Macek, 1978; Heaman et al., 2009); however, local dikes trending closer to 070° could be related to dikes of other ages, such as the ca. 2090 Ma Cauchon Lake dike (Halls and Heaman, 2000) or the ca. 2070 Ma Gull Rapids dike (Bowerman et al., 2004).

Structural and metamorphic geology

The earliest fabric in the Duck Lake–Sesep Rapids area consists of an S_1 gneissosity in the Archean pre- to syn-D_1 rocks. The S_1 fabric typically strikes 260–270° with a steep (~70°) dip in the Sesep Rapids area; however, along the southeastern shore of Duck Lake and near the outflow of the Nelson River, the strike of the fabric is 200–220° with a dip of 75–80°. 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 rocks along the Nelson River channel and in small bays off the channel. Mafic rocks commonly contain orthopyroxene- and clinopyroxene-bearing assemblages accompanied by pods of M_2 orthopyroxene-bearing leucosome. The M_2 leucosome occurs in all Archean rocks. It cuts across S_1 fabrics in gneissic rocks and displays an S_2 foliation.

The D_2 generation of deformation is manifested as a well-developed S_2 quartz fabric in all Archean rocks. The fabric typically strikes 240–250° with a dip of 70–80° in the Sesep Rapids area, and strikes 195–220° with a subvertical dip in the Duck Lake area. The S_2 fabric typically intersects S_1 at an angle of 20–30°; however, the S_1 gneissosity becomes 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 (F_2; Figure GS-4-4b). Fold hinges typically trend west. All 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, D_2.

Several southwest- to south-southwest-striking S_3 shear zones trend across the Nelson River channel as it approaches Duck Lake and also occur in southeastern

Duck Lake (Figure GS-4-1). Shearing is dominantly sinistral and manifested by brittle-ductile shear bands and discrete mylonite zones (Figure GS-4-4d). The west-striking Archean fabrics in the Sesep Rapids area are progressively rotated to the south-southwest fabrics observed in the Duck Lake area across each successive shear zone. The south-southwest-striking fabrics are subparallel to the fabrics of the Superior boundary zone. The shear zones locally crosscut Paleoproterozoic mafic dikes and this, combined with the rotation of the Archean fabrics, suggests that S_3 shearing is likely related to the Trans-Hudson orogeny. Sheared rocks are retrogressed and can be affected by potassic metasomatism. Small, localized, quartz-carbonate veins can be associated with the shear zones on Duck Lake.

Amphibolite-facies retrogression is pervasive in shear zones and is common in southeastern Duck Lake. Pyroxene in mafic and felsic rocks is commonly replaced by hornblende. Orthopyroxene in leucosome is locally replaced by pseudomorphous anthophyllite. The amphibolitization of Paleoproterozoic mafic dikes and association with south-southwest-striking shear zones suggests that the retrogression is likely related to the Trans-Hudson orogeny. Amphibolitized mafic rocks contain abundant hornblende with little to no epidote, suggesting that Hudsonian metamorphism reached middle to upper amphibolite-facies conditions. This is supported by the presence of biotite+sillimanite±garnet assemblages in aluminous rocks.

Economic considerations

Evidence for metamorphosed hydrothermal alteration is relatively common in basalt in the Duck Lake area and adjacent parts of the Nelson River: garnet-rich bands likely represent zones of metamorphosed chlorite alteration; anthophyllite-rich pods likely represent zones of metamorphosed talc alteration; and anthophyllite- and sillimanite-bearing garnet-biotite schist likely represents zones of metamorphosed chlorite+sericite alteration. Pods and stringers of calcsilicate±quartz±carbonate could represent metamorphosed quartz-carbonate vein stockworks or sheared carbonate alteration. In all cases, the high-grade, peak metamorphic mineral assemblages and deformation fabrics indicate that hydrothermal alteration occurred prior to high-grade metamorphism.

The presence of talc, chlorite and chlorite+sericite hydrothermal alteration in the Duck Lake area suggests potential for volcanogenic massive sulphide (VMS) mineralization. Pillows indicate a subaqueous environment for much of the basalt in the area, and local iron formation suggests the magmatism was accompanied by exhalative sedimentation. Intense chlorite±sericite alteration indicates flow of hydrothermal fluids that could have transported base metals and sulphides, as is typically documented in the footwall of VMS deposits, with the most intense alteration occurring proximal to the deposit (Franklin et al., 2005; Galley et al., 2007). Exhalative base-metal mineralization associated with hydrothermally altered rock is found at Hyers Island and Cat Eye Bay on Oxford Lake in the adjacent Oxford-Stull domain (Assessment File 93258, Manitoba Growth, Enterprise and Trade, Winnipeg; Assessment File 72236; Haskins and Stephenson, 1974; Haskins and Evans, 1977; Anderson et al., 2012). Metamorphosed, hydrothermally altered rocks associated with the Cat Eye Bay occurrence include garnet- and anthophyllite-bearing rocks (Haskins and Evans, 1977).

If the carbonate rocks on Duck Lake prove to be of carbonatite affinity, it could suggest a potential for rare-metal mineralization. Carbonatites are important sources for a variety of rare metals (e.g., rare-earth elements, Y, Nb). A carbonatite affinity for this unit could have implications for regional exploration along the eastern margin of the Superior boundary zone. Similar rocks occur on Partridge Crop and Natawahunan lakes (Couëslan, 2013; Couëslan; GS-3, this volume), and a swarm of carbonatite dikes with a strike length >23 km is known from Paint Lake (Chakhmouradian et al., 2009; Couëslan, 2016b). These occurrences suggest that mantle conditions may have been conducive to carbonatite magmatism along the entire strike-length of the Superior boundary zone from Duck Lake to Natawahunan Lake. Although no rare-metal mineralization has been found to date, the potential for discovery over such a strike-length could be significant. Alternatively, if the carbonate rocks represent intense carbonate alteration of the basalt, this could indicate a potential for orogenic gold mineralization (Robert, 1995; Dubé and Gosselin, 2007). Calcsilicate pods near the mouth of the Nelson River could also be evidence for sheared quartz-carbonate vein stockworks or carbonate alteration. Gold mineralization at Gods Lake and Little Stull Lake, in the Oxford-Stull domain, occurs in carbonatized mafic rocks (Richardson and Ostry, 1996), which could be analogous to the calcareous rocks of the Duck Lake area.

Although relatively small, the differentiated gabbro intrusions may have potential for magmatic ore deposits. Nickel-copper sulphide deposits are most commonly hosted by mafic–ultramafic intrusions. Pyroxenite with gabbro xenoliths is locally in contact with gabbro and could represent rhythmic layering in a dynamic magma chamber, which is the type of environment conducive to segregation and accumulation of nickel and copper sulphide minerals (Eckstrand, 1996; Barnes and Lightfoot, 2005). Iron-titanium-vanadium oxide deposits are associated with differentiated or massive gabbro–leucogabbro intrusions (Gross, 1996), such as the Pipestone Lake anorthosite complex in the adjacent Cross Lake belt (Cameron, 1992; Jobin-Bevans et al., 1995; Jobin-Bevans et al., 1997). The Pipestone Lake anorthosite complex comprises layered anorthosite, leucogabbro and melagabbro with minor pyroxenite, and intrudes pillowed to massive basalt flows of the Pipestone Lake group (Cameron, 1992; Jobin-Bevans et al., 1995). The complex has non-compliant NI-43-101 historical indicated resources of 156.8 million tonnes grading 5.56% TiO_2, 28.11% Fe_2O_3 and 0.22% V_2O_5 (Assessment File 73631; Gossan Resources Limited, 2016).

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