GS2022-3

Bedrock mapping in the Halfway Lake area, Thompson nickel belt, central Manitoba (parts of NTS 63O1, 2)

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In Brief:

- A new bedrock mapping project was initiated at Halfway Lake, in the southern Thompson nickel belt
- Two sedimentary associations were identified: a calcsilicate-semipelite assemblage, and a quartzite-pelite assemblage
- A mineralized ultramafic body is known to be associated with the calcsilicate-semipelite assemblage, and sulphidic pelite layers in the quartzite-pelite assemblage could be viable sources of sulphur for intruding ultramafic magmas and the generation of Ni-Cu sulphide deposits

Citation:

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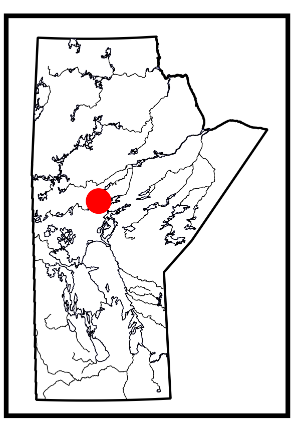
Summary

A new bedrock mapping project was initiated by the Manitoba Geological Survey at Halfway Lake, 80 km south-southwest of Thompson, in the Thompson nickel belt (TNB). Several mineralized ultramafic bodies are known to underlie the lake. The aim of the project is to update mapping with respect to Ospwagan group stratigraphy and to search for possible Paint sequence rocks. Much of the lake is underlain by Archean orthogneiss with rare metre-scale screens of Archean metasedimentary rocks. A large granite–tonalite intrusion of uncertain age occurs along roughly 12 km of the western shoreline. The intrusion is characterized by the presence of disseminated, pinhead-sized garnet. A calcsilicate-semipelite assemblage occurs at the north end of a bay in east-central Halfway Lake. This assemblage is tentatively correlated with the Thompson formation of the Ospwagan group. Outcrops of quartzite-pelite assemblage rocks occur throughout the Halfway Lake area and could be correlative with the upper stratigraphy of the Ospwagan group, or possibly the Garand quartzite of the Paint sequence. Mafic volcanic rocks occur along a 12 km strike length in south-central Halfway Lake and are tentatively correlated with the Bah Lake assemblage of the Ospwagan group. The volcanic rocks are intruded by an irregular body, or several bodies, of foliated granite. A quartz monzonite intrusion with a strike length of approximately 14 km occurs along the southeastern shoreline of the lake.

The majority of rocks in the Halfway Lake area are characterized by a northeast-trending, subvertical S_2 gneissosity, with the exception of later granitoid intrusions. The gneissosity is folded by upright, northeast- and southwest-plunging isoclinal F_3 folds. The isoclinal folds are accompanied by an axial-planar S_3 foliation. Sinistral, mylonitic shear zones commonly occur along the limbs of major fold structures and are subparallel to S_3. Upper-amphibolite–facies mineral assemblages in pelitic rocks suggest that peak metamorphism outlasted D_2 and continued until at least early D_3.

Current models for the generation of Ni-Cu deposits in the TNB call for the intrusion of ultramafic magmas into sulphidic Ospwagan group rocks, leading to sulphur saturation of the magma and the precipitation and concentration of Ni-Cu sulphides. Ultramafic bodies at Halfway Lake are associated with both the calcsilicate-semipelite and quartzite-pelite assemblages. The presence of sedimentary sulphide within the quartzite-pelite assemblage, including metre-scale beds of sulphidic pelite, indicate that it could be a viable source of sulphur for an intruding ultramafic magma and the generation of Ni-Cu sulphides. A mineralized ultramafic body associated with the calcsilicate-semipelite assemblage was the focus of exploration between 1992 and 2008. Similar metamorphic grade, and structural and mineralization styles as found at the Thompson mine, suggest that exploration targeting F_3 fold structures for thickened zones of sulphide in hinge zones, and mineralization hosted by metasedimentary rocks rather than by intrusions, could be viable strategies in the Halfway Lake area.



Introduction

Halfway Lake is located 80 km south-southwest of Thompson in the southern Thompson nickel belt (TNB; Figure GS2022-3-1). It is situated between Provincial Highway 6 and the Hudson Bay Railway line. The Halfway Lake area has been the focus of airborne and ground geophysical surveys, diamond drilling and outcrop mapping by various companies from 1958 to present, and several ultramafic bodies have been delineated underlying the lake (Macek et al., 2006; Griffin et al., 2012). Current mineral dispositions in the Halfway Lake area are held by Anglo American plc, CanAlaska Uranium Ltd., CaNickel Mining Ltd. and Vale Canada Ltd. (Manitoba Mineral Resources, 2013). Shoreline mapping by the MGS was last conducted on Halfway Lake in 1980 (Macek, 1980; Macek and Scoates, 1980), prior to the formal definition of the Ospwagan group stratigraphy and Paint sequence rocks (Bleeker and Macek, 1988; Bleeker, 1990; Zwanzig et al., 2007; Couëslan, 2016, 2022b). The geology of the area was updated in 2006 by correlating the shoreline mapping with the Ospwagan group stratigraphy and incorporating drillcore and geophysical data (Macek et al., 2006).

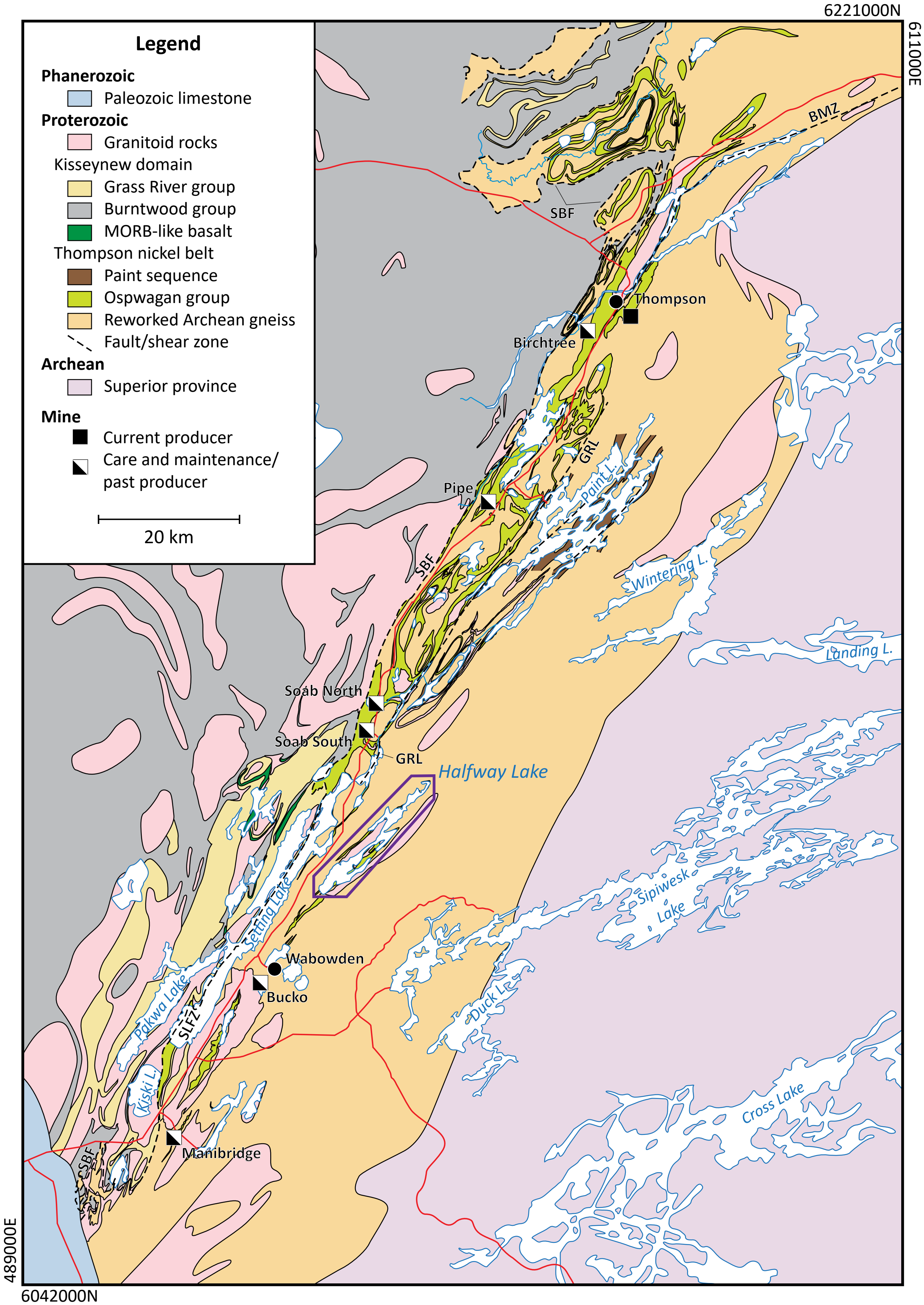


Figure GS2022-3-1: *Simplified geological map of the Thompson nickel belt, central Manitoba (modified from Macek et al., 2006; Couëslan, 2016). Purple outline indicates the location of the study area. Abbreviations: BMZ, Burntwood mylonite zone; GRL, Grass River lineament; SBF, Superior boundary fault; SLFZ, Setting Lake fault zone.*

A new bedrock-mapping project was initiated at Halfway Lake in July of 2022. Mapping was conducted at a scale of 1:20 000 utilizing the stratigraphic framework for the Thompson nickel belt. The goal of the project is to update mapping with respect to the Ospwagan group stratigraphy, and to characterize the mafic rocks of southeastern Halfway Lake, which are believed to be correlative with the Bah Lake assemblage. In addition, a search was made for possible Paint sequence rocks misidentified as Archean basement gneiss or as 'ghost successions' of the Ospwagan group (Zwanzig et al., 2007).

Regional geology

The TNB forms a segment of the Superior boundary zone, flanked to the northwest by the Kisseynew domain of the Trans-Hudson orogen and to the southeast by the Pikwitonei granulite domain (PGD) of the Superior craton. The TNB is underlain largely by reworked Archean gneiss of the Superior craton, which is typically quartzofeldspathic with enclaves of mafic to ultramafic rock; clearly recognizable paragneiss is rare. It is commonly migmatitic and characterized by complex internal structures that are the result of multiple generations of Archean and Paleoproterozoic deformation and metamorphism. The gneiss is interpreted to be derived from the adjacent PGD, which was subjected to amphibolite- to granulite-facies metamorphic conditions from ca. 2720 to 2640 Ma (Hubregtse, 1980; Mezger et al., 1990; Heaman et al., 2011; Guevara et al., 2020; Couëslan, 2021). The granulites of the PGD were exhumed and unconformably overlain by the Paleoproterozoic supracrustal rocks of the Ospwagan group and Paint sequence prior to intrusion of the Molson dike swarm and associated ultramafic intrusions at ca. 1880 Ma (Bleeker, 1990; Zwanzig et al., 2007; Heaman et al., 2009; Scoates et al., 2017). The Archean basement gneiss and Proterozoic supracrustal rocks were subjected to multiple generations of deformation, and metamorphic conditions ranging from middle-amphibolite facies to lower-granulite facies, during the Trans-Hudson orogeny (Bleeker, 1990; Burnham et al., 2009; Couëslan and Pattison, 2012).

The dominant phase of penetrative deformation is D_2, which affected the Ospwagan group, Paint sequence and ca. 1880 Ma magmatic rocks. This deformation phase resulted in the formation of F_2 nappe structures, which incorporated the underlying Archean gneiss. The nappe structures have been interpreted as either east verging (Bleeker, 1990; White et al., 2002) or southwest verging (Zwanzig et al., 2007; Burnham et al., 2009). The recumbent folds are associated with regionally penetrative S_2 fabrics. The D_2 phase of deformation is interpreted to be the result of convergence between the Superior craton margin and the Reindeer zone of the Trans-Hudson orogen from ca. 1830 to 1800 Ma. The D_3 phase of deformation resulted in isoclinal folds with vertical to steeply southeast-dipping axial planes (Bleeker, 1990; Burnham et al., 2009). Mylonite zones with subvertical stretching lineations parallel many of the regional F_3 folds. Tightening of D_3 structures continued during D_4, marked by localized retrograde greenschist-facies metamorphism along northeast-striking, mylonitic and cataclastic shear zones that commonly record southeast-side-up sinistral movement (Bleeker, 1990; Burnham et al., 2009). The geometry of metamorphic-field gradients in the belt are primarily controlled by regional D_3–D_4 structures (Couëslan and Pattison, 2012).

Ospwagan group stratigraphy

The following summary of the Ospwagan group is sourced largely from Bleeker (1990) and Zwanzig et al. (2007). The Paleoproterozoic Ospwagan group unconformably overlies Archean basement gneiss in the TNB (Figure GS2022-3-2). The lowermost unit of the Ospwagan group is the Manasan formation, which is made up of two members: the lower M1 member, consisting of layered to laminated sandstone with local conglomerate layers near the base; and the overlying M2 member, consisting of semipelitic rock. The Manasan formation is interpreted as a transgressive, fining-upward sequence deposited along a passive margin. This siliciclastic system grades into the overlying calcareous sedimentary rocks of the Thompson formation.

The Thompson formation consists of three members: the T1 member comprises a variety of calcareous–siliceous rocks, including chert, calcsilicate and impure marble; the T2 member is a semipelitic calcareous gneiss that is rarely present; and the T3 member consists of impure dolomitic marble with local horizons of calcsilicate. The Thompson formation represents a transition from a siliciclastic-dominated to a carbonate-dominated system.

The Pipe formation is subdivided into three members. The P1 member consists of a graphite-rich, sulphide-facies iron formation at the base (the locus of the Pipe II and Birchtree orebodies), overlain by a silicate-facies iron formation. The top of the P1 member consists of a reddish, laminated, siliceous rock. The P1 member grades into the overlying pelitic rocks of the P2 member, the top of which is marked by a sulphide-facies iron formation (the locus of the Thompson orebody). The overlying P3 member consists of a wide variety of rock types, including laminated, siliceous sedimentary rocks; silicate-, carbonate- and local oxide-facies iron formations; and semipelitic rocks, calcsilicate and a local horizon of relatively pure dolomitic marble. The Pipe formation represents a mix of chemical sediments and fine to very fine siliciclastics that were deposited in either an open-marine environment (Zwanzig et al., 2007) or during the development of a foredeep basin (Bleeker, 1990).

The Setting formation is divided into two members and is defined to include all siliciclastic rocks above the uppermost iron formation of the P3 member. The S1 member consists of rhythmically interbedded quartzite and pelitic schist with local garnet-rich pods, which are interpreted as calcareous concretions and are characteristic of the S1 member. The S2 member consists of thickly layered greywacke, with local horizons grading from conglomeratic at the base to pelitic at the top. No contact has been observed between the S1 and S2 members. It is

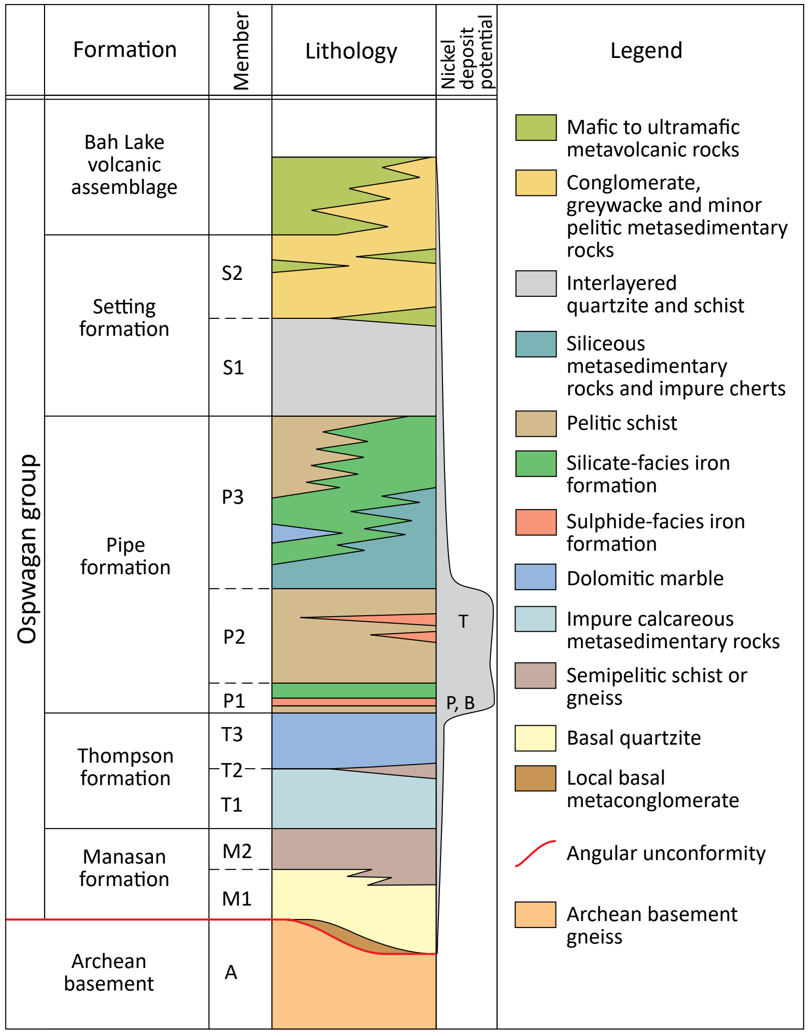


Figure GS2022-3-2: *Schematic lithostratigraphic section of the Ospwagan group (modified from Bleeker, 1990). Abbreviations: B, stratigraphic location of the Birchtree orebody; P, stratigraphic location of the Pipe II orebody; T, stratigraphic location of the Thompson orebody.*

possible that they represent a lateral facies change as opposed to a vertical succession. The Setting formation is interpreted as turbidite deposits in a relatively deep-marine environment, possibly a foredeep basin (Bleeker, 1990). The coarse clastic material and thick turbidite bedding of the S2 member may record the shallowing of the basin, the onset of active tectonism or a lateral sedimentary facies change to a submarine-channel or upper-fan environment (Zwanzig et al., 2007).

At the top of the Ospwagan group is the Bah Lake assemblage, which consists of mafic to ultramafic volcanic rocks dominated by massive to pillowed basalt flows with local picrite and minor synvolcanic intrusions. The Bah Lake assemblage is dominated by a high-Mg suite, similar to normal mid-ocean–ridge basalt (N-MORB), which occurs throughout much of the main TNB; and an incompatible-element–enriched suite, similar to enriched mid-ocean–ridge basalt (E-MORB), that occurs in the northwestern Setting Lake area and along the margin of the Kisseynew domain (Zwanzig, 2005). The enriched suite is interpreted to overlie the high-Mg suite; however, it is uncertain if this represents a stratigraphic or tectonic relationship. The Bah Lake assemblage may suggest the onset of active rifting in the TNB (Zwanzig, 2005; Zwanzig et al., 2007), or that the foredeep was magmatically active (Bleeker, 1990).

A maximum age for the Ospwagan group is provided by a ca. 1974 Ma zircon recovered from Setting formation greywacke (Bleeker and Hamilton, 2001); however, inherited zircons younger than ca. 2600 Ma are rare. A minimum age is provided by crosscutting amphibolitized dikes interpreted to be part of the Molson dike swarm, and the possibly comagmatic Ni-ore–bearing ultramafic sills, that intruded the Ospwagan group at all stratigraphic levels at ca. 1880 Ma (Bleeker, 1990; Heaman et al., 2009; Scoates et al., 2017). Ospwagan group rocks yield crustal-residence Nd-model ages of ca. 3.22–2.82 Ga, which is typically younger than model ages obtained from the Archean basement (ca. 3.70–3.14 Ga; Böhm et al., 2007).

Granulite-facies assemblages in semipelitic and pelitic rocks of the Ospwagan group can become almost indistinguishable from the Archean basement gneiss; however, petrological end members such as marble, quartzite and iron formation remain recognizable at the highest metamorphic grades and can be used as marker horizons. Basement-like gneiss or migmatite successions between isolated but still recognizable marker horizons may represent 'ghost successions' of the Ospwagan group (Zwanzig et al., 2007). Distinguishing Archean from Ospwagan group rocks at high metamorphic grade may require the use of lithogeochemistry or Sm-Nd isotope geochemistry (Böhm et al., 2007; Zwanzig et al., 2007).

Paint sequence rocks

The Paint sequence occurs as three northeast-striking belts of metasedimentary rocks in the Paint Lake area (Figure GS-2022-3-1) and continues southwest along strike to the Phillips Lake area (Couëslan, 2016, 2022b). To date, the sequence has only been recognized east of the Grass River lineament in areas of granulite-facies metamorphism where primary textures and structures are all but obliterated save for centimetre-scale compositional layering. The Paint sequence is subdivided into two lithological packages. The Klippen wacke is the most widespread member of the sequence and is characterized by centimetre- to metre-thick layering of more mud-rich and more sand-rich beds. Pods of in-situ and in-source leucosome are abundant. Outcrops of wacke are characterized by rusty weathered surfaces because of the presence of minor but ubiquitous pyrrhotite. Rare flakes of molybdenite can be present. The wacke contains subordinate interbeds of iron formation as discontinuous layers and lenses <3 m thick. Iron formations are typically of the silicate facies; however, significant pyrrhotite and magnetite can be present. The Garand quartzite is not as widely distributed and is only exposed at Paint Lake. It consists of interbedded quartzite and pelite with rare garnet-rich pods, which are interpreted as concretions. The pelite contains abundant graphite and pyrrhotite, and is characterized by rusty weathered surfaces. The stratigraphic relationships between the Klippen wacke and Garand quartzite, and the Paint sequence and Ospwagan group, are unknown.

A maximum age for the Klippen wacke is provided by five ca. 1970 Ma detrital zircon grains (Couëslan, 2022b) present in samples from both Paint and Phillips lakes. The Paint sequence rocks are intruded by relatively straight-walled mafic dikes, which are tentatively interpreted to be part of the Molson dike swarm, suggesting a minimum age of ca. 1880 Ma for the sequence. The Paint sequence rocks differ from the Ospwagan group rocks in having a significant detrital zircon component younger than ca. 2600 Ma, a wider range of crustal-residence Nd-model ages (ca. 3.57–2.92 Ga), and unique trace-element compositions (Couëslan, 2016, 2022b). Paint sequence rocks have been misidentified as part of the Archean basement and as ghost successions of Ospwagan group rocks.

Geology of the Halfway Lake area

Bedrock exposures in the Halfway Lake area are limited by extensive Quaternary deposits. The majority of outcrop occurs along the lakeshore and varies from poor to excellent in quality (Macek and Scoates, 1980). The Halfway Lake area is interpreted to be underlain by several highly attenuated dome-and-basin–like structures of Ospwagan group rocks (Macek et al., 2006; Burnham et al., 2009). The structures are enclosed by Archean basement gneiss and interpreted to have Manasan formation at the margins and Pipe formation or Bah Lake assemblage in the cores. Ultramafic rocks are present within all of these structures and are hosted predominantly at the top of the Manasan formation, or within the Pipe formation (Macek et al., 2006). A mineralized ultramafic body in the east-central part of the lake has been the focus of the majority of exploration in the Halfway Lake area (cf. 'Economic considerations'; Griffin et al., 2012; Assessment Files 72495 and 74607, Manitoba Natural Resources and Northern Development, Winnipeg).

Most of the Ospwagan group rocks underlie the lakebed, but the compilation mapping of Macek et al. (2006) indicates shoreline exposures throughout the area, including a 7 km long zone of Bah Lake assemblage rocks in the south-central part of the lake. A large garnet-bearing granite intrusion outcrops along the west shore of the lake (Assessment File 99528; Macek et al., 2006), and hornblende monzonite outcrops along much of the southeast shore in the Clarence Evans Bay area (Macek et al., 2006). The majority of shoreline outcrops consist of Archean basement gneiss. The Archean basement gneiss consist of grey hornblende-biotite gneiss, and migmatitic multicomponent gneiss (Macek and Scoates, 1980). The Halfway Lake area is believed to have attained upper-amphibolite–facies conditions during the Trans-Hudson orogeny (Couëslan and Pattison, 2012). The compilation work of Macek et al. (2006) suggests the presence of ghost succession Ospwagan Group rocks in the southern Halfway Lake area.

Results of 2022 mapping

Mapping during the 2022 field season was restricted to the lakeshore. Inland and underwater geology in Figure GS2022-3-3 is largely interpreted and modified from Macek et al. (2006). In several parts of the lake, shoreline observations were difficult to reconcile with previous mapping. In general, the extent of Ospwagan group exposures on Halfway Lake appears to be less than that indicated by previous compilation work. It is hoped that future study of archived drillcore will help to resolve some of these issues. All rock units described below, with the possible exception of the latest intrusive rocks, were metamorphosed to at least amphibolite-facies conditions. To improve the readability of the text, the 'meta-' prefix has been omitted from rock names.

Archean rocks

Archean orthogneiss, undivided

Much of the Halfway Lake area is underlain by tonalitic to granodioritic rocks with a well-developed gneissosity (Figure GS2022-3-4a). The gneissic rocks are typically grey to pinkish grey, medium to coarse grained, foliated to strongly foliated,

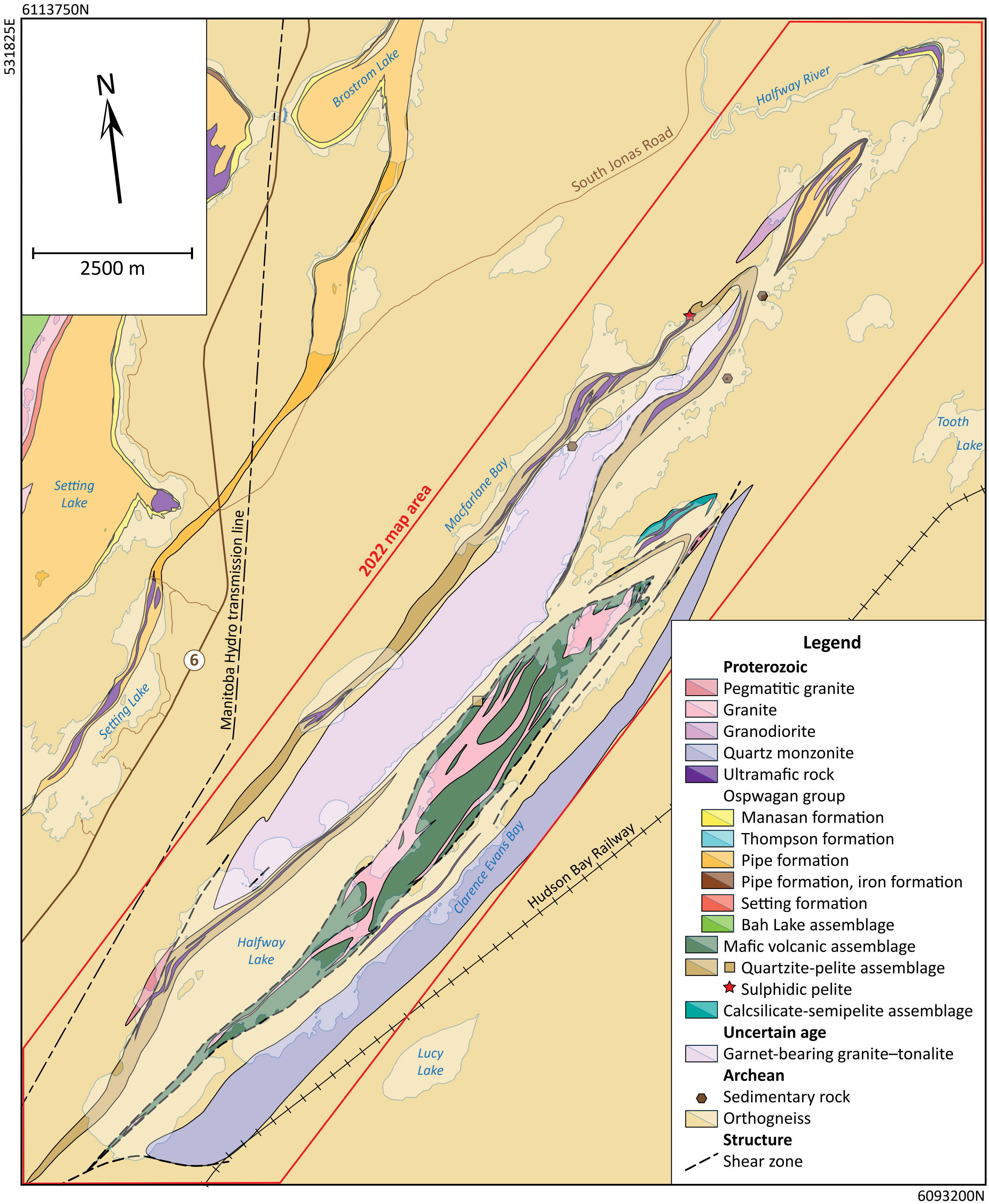


Figure GS2022-3-3: *Bedrock geology map of the Halfway Lake area, central Manitoba (simplified from Couëslan, 2022a). Lighter shade of a colour indicates a body of water. Geology outside of the 2022 map area is from Macek et al. (2006).*

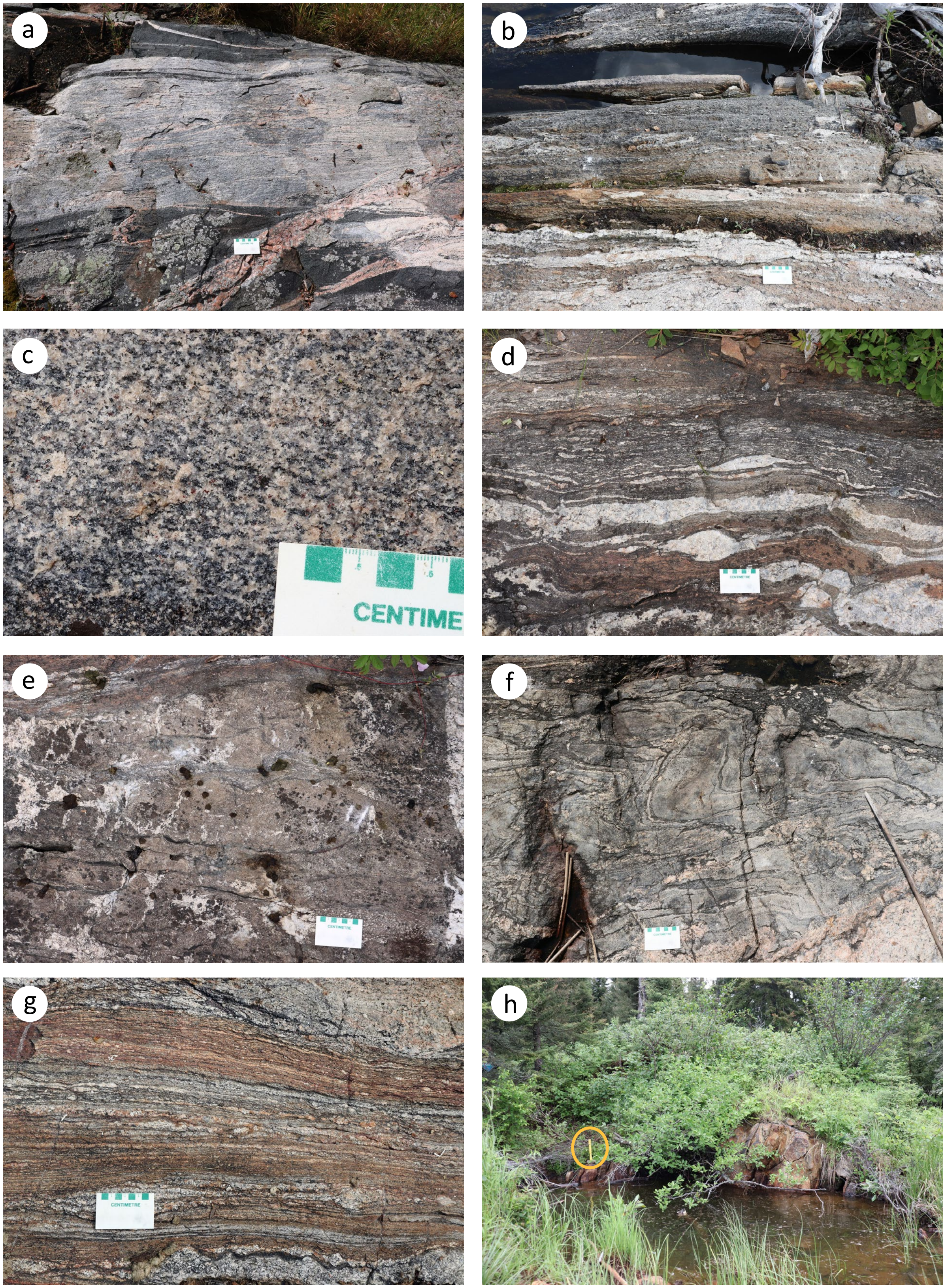


Figure GS2022-3-4: *Outcrop images from Halfway Lake:* ***a)*** *Archean biotite orthogneiss with discontinuous layers of plagioclase amphibolite (interpreted as diabase dikes) and crosscut by pegmatitic granite dikes;* ***b)*** *Archean sedimentary rock, likely derived from wacke;* ***c)*** *garnet-hornblende granodiorite–tonalite of uncertain age with garnet occurring as pinhead-sized grains in the groundmass;* ***d)*** *tremolite-bearing semipelite and* ***e)*** *calcsilicate from the calcsilicate-semipelite assemblage;* ***f)*** *quartzite with pelite laminations from the quartzite-pelite assemblage, the rocks are folded by F_3 minor folds and an intrusion of pegmatitic granite is present in the lower right corner;* ***g)*** *high-strain wacke interlayered with quartzite from the quartzite-pelite assemblage;* ***h)*** *graphitic and sulphidic pelite from the quartzite-pelite assemblage in an outcrop that is approximately 5 m wide (circled hammer for scale).*

and locally magnetic. They are most commonly biotite bearing, but can contain hornblende in place of, or in addition to, biotite. Biotite and hornblende typically form discontinuous, mafic-rich laminations separated by quartzofeldspathic layers; however, alternating mafic and felsic layers <4 cm thick can also occur. Garnet is relatively common, but generally makes up <3% of the rock and occurs as dark red grains randomly distributed throughout the groundmass. Magnetite locally occurs in trace amounts. Local, diffuse, hornblende-rich bands <20 cm thick could represent Archean mafic dikes. Local granitic to granodioritic pods and discontinuous layers <20 cm thick could represent attenuated leucosome.

Archean sedimentary rocks

Several outcrops in northern Halfway Lake consist of discrete, metre-scale screens of sedimentary rock surrounded by Archean orthogneiss (Figures GS2022-3-3 and GS2022-3-4b). The screens are quartzofeldspathic, with 10–30% biotite and either minor garnet or cummingtonite with trace amounts of garnet, and were likely derived from wacke. They are characterized by compositional layering on a scale of <20 cm. Local rusty layers <10 cm thick contain up to 5% pyrrhotite. These sedimentary rocks are interpreted as Archean because they are of limited extent and enclosed by Archean orthogneiss.

Rocks of uncertain age

Garnet-bearing intrusion

A garnet-bearing intrusion approximately 12 km long occurs along much of the western shoreline of Halfway Lake (Figure GS2022-3-3). The intrusion consists largely of garnet-biotite granite–granodiorite but grades into garnet-hornblende granodiorite–tonalite toward the northeast. The granite–granodiorite is pink to pinkish grey, whereas the granodiorite–tonalite is pinkish grey to grey weathering and beige on fresh surfaces (Figure GS2022-3-4c). Both phases are coarse grained, foliated, locally magnetic and locally gneissic, with either diffuse biotite laminations or flattened clots of hornblende that give the rock a spotted appearance. Red garnet typically occurs in trace amounts as fine, pinhead-sized grains. Trace amounts of magnetite occur in the groundmass; however, local pods of leucosome <15 cm thick can contain 3–5% magnetite. The leucosome is commonly attenuated and forms discontinuous bands in the rock. The granodiorite–tonalite is locally intruded by pegmatite dikes that contain prismatic hornblende up to 3 cm long. The garnet-bearing intrusion is tentatively interpreted as Archean because of the weakly developed gneissosity and presence of leucosome; however, it could be a pre-D_2 intrusion similar to the ca. 1885 Ma Clarke Lake pluton east of the former Manibridge mine (Percival et al., 2005).

Paleoproterozoic rocks

Calcsilicate-semipelite assemblage

The calcsilicate-semipelite assemblage outcrops at the northern end of a bay in east-central Halfway Lake (Figure GS2022-3-3). This sedimentary rock assemblage consists of semipelite and calcsilicate intercalated on a metre to sub-metre scale. The semipelite forms a coarse-grained, foliated to strongly foliated diatexite that is grey to rusty brown weathering and purplish brown to brown-grey on fresh surfaces (Figure GS2022-3-4d). It is relatively calcareous, with 10–20% diopside or tremolite and 10–20% biotite in a quartzofeldspathic groundmass. Minor pyrrhotite is locally present. The calcsilicate is brown weathering and grey-green on fresh surfaces. It varies from medium to coarse grained and from massive to foliated, and is locally magnetic. It is diopside and quartz rich, with minor biotite and carbonate and trace to minor amounts of pyrrhotite. The calcsilicate is internally layered with alternating biotite-rich and diopside-rich strata <15 cm thick (Figure GS2022-3-4e), and it can contain discontinuous layers of marble <5 cm thick. The marble is white, medium to coarse grained and foliated. It is diopside rich with minor serpentinized olivine and phlogopite, and trace amounts of pyrrhotite and a mineral tentatively identified as titanite or possibly a member of the humite group. The semipelite-calcsilicate assemblage is tentatively correlated with the Thompson formation of the Ospwagan group.

Quartzite-pelite assemblage

Outcrops of the quartzite-pelite assemblage occur scattered throughout the Halfway Lake area (Figure GS2022-3-3). The assemblage consists of quartzite with subordinate wacke and sulphidic pelite. The majority of outcrops are dominated by quartzite; however, the wacke and sulphidic pelite can be dominant. The quartzite is light grey weathering and beige on fresh surfaces. It is medium to coarse grained and foliated, and contains 10–20% plagioclase with minor biotite and pink–violet garnet, and trace amounts of pyrrhotite. The quartzite occurs as layers <1 m thick separated by pelitic laminations <1 cm thick (Figure GS2022-3-4f), which contain garnet, sillimanite, biotite, graphite and sulphide. The pelitic laminations are commonly associated with a rusty orange staining of the outcrop. The quartzite contains local layers of wacke <1 m thick and rare, fine-grained, garnet-rich pods or 'concretions' <3 cm thick.

The wacke, or quartz-rich pelite, is grey-brown to rusty orange, medium to coarse grained and foliated to protomylonitic. It typically consists of interlayered quartz-rich and biotite-rich laminations and contains minor pink–violet garnet and local sillimanite and graphite. The prevalence of orange weathering suggests the ubiquitous presence of disseminated pyrrhotite (Figure GS2022-3-4g). In the rare instances where the wacke is the dominant rock in outcrop, it contains beds of internally layered to laminated quartzite <30 cm thick. The wacke commonly contains discontinuous layers of leucosome <10 cm thick and boudinaged layers of plagioclase amphibolite <50 cm thick, which are locally garnet bearing.

The sulphidic and graphitic pelite is rusty weathering and brown-grey on fresh surfaces. It is coarse grained, strongly foliated and magnetic. The rock forms a quartzofeldspathic diatexite with 10–20% biotite, 10–12% sillimanite, 3–5% pyrrhotite, 3–5% graphite and trace amounts of pink–violet garnet. In northern Halfway Lake, the pelite forms a gossanous outcrop approximately 5 m wide that disappears beneath overburden in both directions across strike (Figure GS2022-3-4h).

The affinity of the quartzite-pelite assemblage is uncertain. The presence of minor iron formation in the assemblage was interpreted from geophysics and drillcore by Macek et al. (2006), which led them to correlate these rocks with the Pipe formation of the Ospwagan group. However, no chemical sedimentary rocks were observed during the course of mapping, which would argue against correlation with the Pipe formation. The quartzite-pelite assemblage is lithologically most similar to the Setting formation rocks of the Ospwagan group, with the sulphidic pelite possibly representing a sliver of the P2 member pelite of the Pipe formation. Alternatively, it could be correlative with the Garand quartzite of the Paint sequence. It is hoped that lithogeochemical and isotopic analyses will provide additional insight.

Mafic volcanic assemblage

Outcrops of plagioclase amphibolite, which are interpreted to be of mafic volcanic origin, occur along a strike length of approximately 12 km and underlie much of a long peninsula in south-central Halfway Lake (Figure GS2022-3-3). The mafic volcanic rocks are dark grey-green, medium to coarse grained and foliated. The rocks are hornblende and plagioclase rich, with <20% clinopyroxene, local biotite and trace amounts of titanite. The unit varies from relatively homogeneous to diffusely and discontinuously layered on a scale <40 cm (Figure GS2022-3-5a). Local layers have a spotted appearance caused by plagioclase clots <1 cm across. Garnet was observed in one of these layers with plagioclase coronas of varying thickness (Figure GS2022-3-5b). This suggests that the plagioclase clots are pseudomorphous after garnet; however, it is possible that, in other instances, they represent recrystallized phenocrysts or amygdules. Local layers <3 m thick contain small (<2 cm) nebulitic pods of equal proportions of quartz, plagioclase and green amphibole ± garnet. These layers could represent basaltic breccia. Other outcrops are characterized by irregular, plagioclase-rich, vein-like networks, which could represent deformed pillow selvages (Figure GS2022-3-5c). Possible interpillow material in these outcrops forms plagioclase-rich lenses with hornblende, quartz and minor garnet. Rare pods of quartz-carbonate contain minor clinopyroxene, suggesting that they predate or are synchronous with relatively high-grade metamorphism.

A relatively small band of quartzite-pelite assemblage was found along the narrow channel in central Halfway Lake, in close spatial association with the mafic volcanic rocks; however, no direct contact relationship could be determined. The mafic volcanic rocks are interpreted to be Paleoproterozoic in age because there is no evidence for partial melting, which would be expected if these rocks were derived from Archean mafic rocks of the adjacent PGD. These rocks are tentatively correlated with the Bah Lake assemblage of the Ospwagan group.

Diabase

Relatively homogeneous layers of plagioclase amphibolite occur in all of the previously described units throughout the Halfway Lake area. These layers are sharp sided and vary from discontinuous and boudinaged (Figure GS2022-3-4a) to relatively continuous at the outcrop scale. They are typically <1.5 m wide and conformable with the gneissosity, but rarely form layers or zones close to 20 m. The amphibolite is dark grey, medium to coarse grained and foliated, and consists of hornblende with 30–50% plagioclase. The amphibolite is locally garnet bearing, and this variety may be more commonly associated with rocks of the quartzite-pelite assemblage. The relatively homogeneous plagioclase amphibolite is interpreted as metamorphosed and attenuated gabbro and diabase dikes, likely correlative with the Molson dikes; however, homogeneous amphibolite associated with the mafic volcanic rocks could represent massive flows or related subvolcanic intrusions.

Quartz monzonite

The quartz monzonite forms much of the southeastern shoreline of the lake and is believed to extend over approximately 14 km (Figure GS2022-3-3). It is dark green-pink to green-grey weathering and dark pink on fresh surfaces, coarse grained and foliated. It is relatively homogeneous, with attenuated dikes of granite and pegmatite that locally contain hornblende <2 cm across. The monzonite contains 20–30% mafic minerals, usually dominated by hornblende with subordinate biotite; however, local zones contain approximately equal proportions of hornblende and biotite. These zones are reddish in colour, suggesting a higher potassium feldspar content, and could be the result of localized metasomatism. Local amphibole-rich lenses and pods <15 cm across could represent cognate xenoliths (Figure GS2022-3-5d). The amphibole-rich pods also contain abundant clinopyroxene and biotite, and minor feldspar.

The compilation map of Macek et al. (2006) indicates that rare map-scale lenses of ultramafic rock occur within the monzonite. Assuming the ultramafic rock is intrusive into the monzonite, it would imply the monzonite is older than ca. 1880 Ma and could suggest an affinity with the 1883 Ma Paint Lake syenite (Couëslan, 2016). Alternatively, if the ultramafic rock represents a large-scale xenolith, the monzonite could be related to the ca. 1835 Ma Bucko quartz monzonite intrusion south of Wabowden (Bleeker et al., 1995).

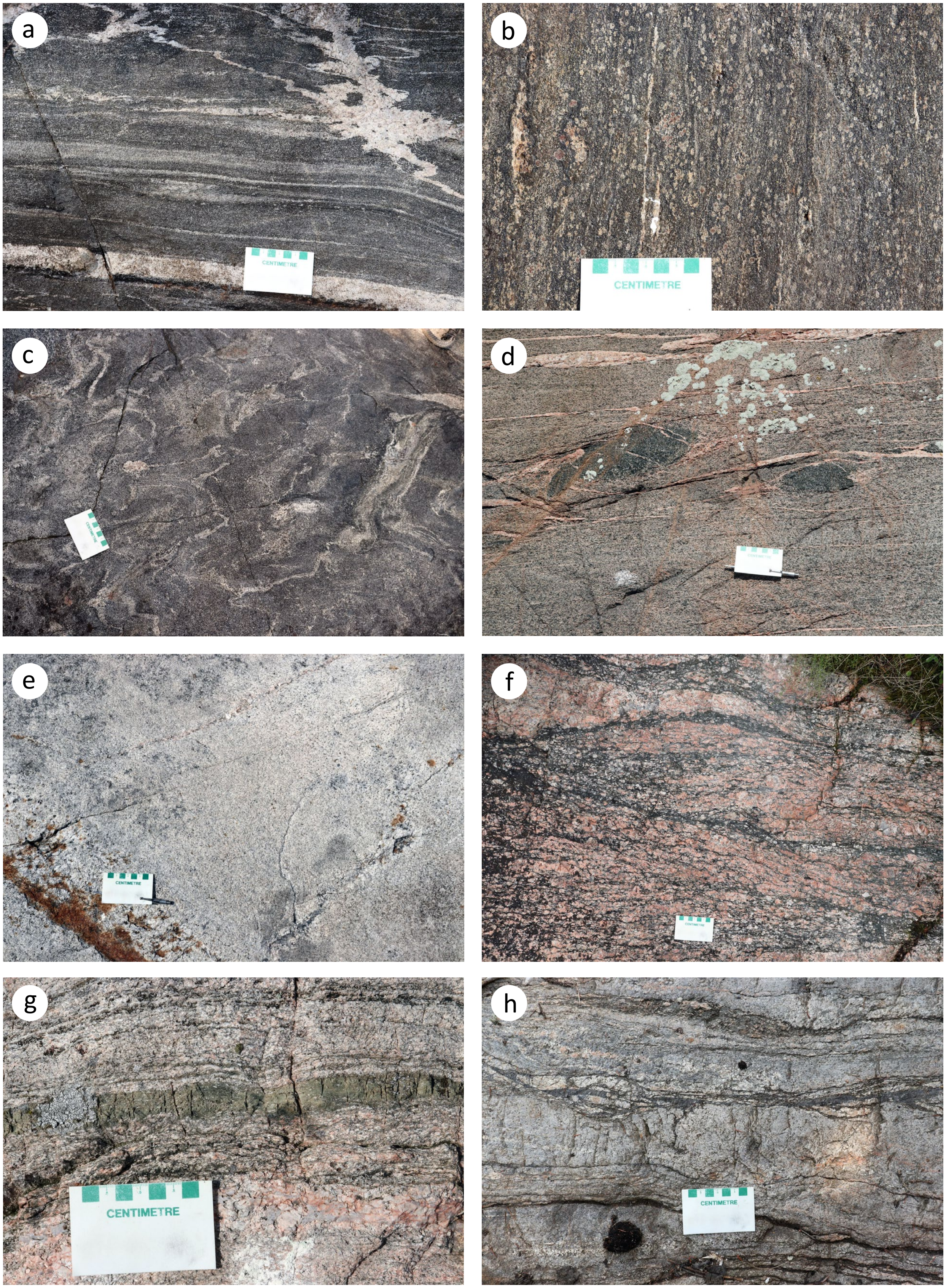


***Figure GS2022-3-5:** Outcrop images from the Halfway Lake area: **a)** diffusely and discontinuously layered plagioclase amphibolite interpreted as mafic volcanic rocks; **b)** plagioclase clots and garnet with plagioclase corona in mafic volcanic rocks; **c)** irregular, plagioclase-rich veins in the mafic volcanic rocks likely represent deformed pillow selvages; **d)** mafic pods within quartz monzonite could represent cognate xenoliths; **e)** granodiorite from the north basin of Halfway Lake; **f)** shear zone of mylonitized pegmatite; **g)** ultramylonite seam in high-strain outcrop of garnet-hornblende granodiorite–tonalite; **h)** pseudotachylite vein in quartzite.*

Other granitoid rocks

Several isolated reefs and rocky points of granodiorite occur in the northern basin of the lake (Figure GS2022-3-3). The granodiorite is light grey to pinkish white, coarse grained, foliated and homogeneous (Figure GS2022-3-5e). Mafic minerals typically consist of minor biotite; however, trace amounts of sulphide and hornblende can be present. Outcrops locally contain schlieren of biotite gneiss.

An irregular body, or several bodies, of pink granite intrude the mafic volcanic rocks in southern Halfway Lake (Figure GS2022-3-3). The granite is coarse grained and foliated, and contains minor biotite. Hornblende was noted in place of biotite at one location. It is relatively homogeneous, with diffuse patches of leucosome or pegmatite and sparse schlieren.

Dikes of pegmatitic granite occur in all outcrops of the Halfway Lake area and are generally <5 m wide (Figure GS2022-3-4a, f); however, local map-scale (>20 m wide) intrusions of pegmatite are present. They are typically pink and granitic with minor biotite, and can locally contain trace amounts of garnet. There is evidence for multiple generations of pegmatite. The dikes can be strongly foliated and conformable, or attenuated parallel to the regional gneissosity; or foliated and crosscutting the gneissosity; or massive and crosscutting all fabrics. In addition, foliated pegmatite dikes are observed crosscutting other foliated pegmatite dikes. The massive dikes locally display comb-textured biotite or quartz. Rare white pegmatite is typically associated with the mafic volcanic rocks (Figure GS2022-3-5a).

Structural and metamorphic geology

All rocks in the Halfway Lake area, with the exception of Paleoproterozoic intrusive rocks, display a northeast-trending, subvertical S_2 gneissosity. The gneissosity in supracrustal rocks is defined by the attenuation of primary compositional layering (S_0). The gneissosity is folded by upright, northeast- and southwest-plunging, isoclinal F_3 folds. The isoclinal folds are accompanied by an axial-planar S_3 foliation that affected all rocks except the massive pegmatite dikes. The foliation is commonly defined by a quartz fabric in outcrops. The S_2 gneissosity is commonly attenuated parallel to the S_3 foliation, but local outcrops display a divergence of up to 45°. Protomylonitic to mylonitic shear zones are relatively common and subparallel to S_3 (Figure GS2022-3-5f). The shear zones are dominantly sinistral and are locally accompanied by discrete seams of ultramylonite <3 cm thick (Figure GS2022-3-5g). The shear zones typically occur along the limbs of major fold structures and, most notably, appear to enclose the mafic volcanic assemblage. Rare pseudotachylite veins (D_4?) are typically found overprinting ductile shear zones (Figure GS2022-3-5h).

Pelitic rocks from the Halfway Lake area are migmatitic and appear from hand sample to contain a peak metamorphic assemblage of quartz–plagioclase–K-feldspar–biotite–sillimanite–garnet. This mineral assemblage is typical for upper-amphibolite–facies pelitic rocks. Although this mineral assemblage is typically found within the S_2 gneissosity, it was locally observed within S_3 mylonitic shear zones. This suggests that peak metamorphic conditions outlasted D_2 and continued until at least early D_3. Clinopyroxene is relatively common in the rocks of the mafic volcanic assemblage; however, no orthopyroxene was observed. This suggests that granulite-facies metamorphic conditions were not attained during the Paleoproterozoic.

Economic considerations

The most widely accepted model for generating Ni-Cu deposits in the TNB invokes the intrusion of ultramafic magmas into sulphide-rich horizons of the Pipe formation of the Ospwagan group (Figure GS2022-3-2). There the magmas scavenged sulphide from the host sedimentary rocks, leading to sulphur saturation of the melt and the precipitation and concentration of sulphides enriched in Ni and Cu. As a result, ultramafic bodies hosted by Pipe formation rocks are considered the most likely to host mineralization and are prime exploration targets in the TNB (Bleeker, 1990; Layton-Matthews et al., 2007; Zwanzig et al., 2007).

The recently recognized Paint sequence consists of sulphide-bearing wacke with minor iron formation and quartz arenite interbedded with sulphidic and graphitic pelite (Couëslan, 2016). These sedimentary rocks were deposited sometime after ca. 1970 Ma but likely prior to the intrusion of the Molson swarm and Thompson-type ultramafic bodies at ca. 1880 Ma (Couëslan, 2022b). Therefore, there is also potential for the sulphide-bearing Paint sequence rocks to host mineralized ultramafic intrusions.

Although the affinity of the quartzite-pelite assemblage is not constrained, the presence of ubiquitous rusty orange weathering suggests the existence of disseminated sulphide, and local metre-scale layers of sulphidic pelite indicate greater concentrations of sulphide. A number of ultramafic bodies were interpreted by Macek et al. (2006) to be present within this sedimentary assemblage, which would have been a potential source of sulphide for intruding magmas.

The calcsilicate-semipelite assemblage of east-central Halfway Lake is tentatively correlated with the Thompson formation of the Ospwagan group. The presence of pyrrhotite (locally up to 5%) within this assemblage could indicate proximity to the overlying sulphide-facies iron formation of the P1 member (Pipe formation). The contact between the Thompson and Pipe formations correlates with the same stratigraphic level as the ore horizons at the Pipe II and Birchtree mines of Vale Ltd. (Bleeker, 1990). A mineralized ultramafic body in this vicinity was the focus of exploration for Falconbridge Ltd. (now Glencore plc) and Crowflight Minerals Inc. (now Canickel Mining Ltd.) between 1992 and 2008. The best mineralized intersections to date include 1.38% Ni over 17.55 m (drillcore HW95-05; Assessment File 72905) and 1.58% Ni over 13.03 m (drillcore HW08-02; Assessment File 74607).

Intersections of Ni mineralization at Halfway Lake include ultramafic-hosted disseminated and net-textured sulphide, similar to mineralization in much of the Thompson belt, as well as metasedimentary-hosted semisolid to solid sulphide, similar to mineralization at the Thompson mine (Assessment Files 74504, 74607). The metamorphic grade at Halfway Lake is comparable to that of the Thompson mine area, which implies a similar ductile structural regime, with sulphides deforming in a plastic or viscous manner. A considerable portion of the Thompson orebody is contained within an F_3 hinge zone, with mineralization also associated with parasitic F_3 fold structures along one of the limbs (Lightfoot et al., 2017). Although it occurs at the same stratigraphic level as a train of ultramafic bodies, most of the Ni ore at the Thompson mine is hosted by Pipe formation rocks (Bleeker, 1990; Lightfoot et al., 2017).

Future exploration at Halfway Lake might consider targeting F_3 fold structures to look for thickened zones of sulphide plunging along fold hinges. The mineralized ultramafic body mentioned in the previous paragraph occurs along the west limb of an F_3 fold, not far from the hinge zone. Additional fold hinges and zones of thickening occur in the northern part of Halfway Lake, in the vicinity of the sulphidic pelite exposure. It should also be remembered that sulphide could have remobilized under high-grade metamorphic conditions and need not be directly associated with ultramafic bodies. Exploration at the same stratigraphic level as ultramafic bodies could reveal the presence of mineralization that is hosted by sedimentary rocks rather than by the intrusion.

The relatively common occurrence of garnet in Archean orthogneiss and garnet-bearing intrusions at Halfway Lake, combined with sparse screens of Archean sedimentary rocks, could be potential sources of confusion while logging drillcore in the Halfway Lake area. The presence of garnet alone cannot be used as an indicator for sedimentary protolith, and small isolated intersections of metasedimentary rock may not be good indicators for the existence of Ospwagan group or other assemblages with the potential to host Ni-mineralized ultramafic bodies. An observation that may be useful in separating low-potential Archean rocks from higher potential Paleoproterozoic sedimentary rocks is the colour and distribution of garnet. It was observed that garnet within the Archean orthogneiss (and garnet-bearing intrusion) is generally dark red and randomly disseminated throughout the rock. Garnet within the quartzite-pelite assemblage rocks is typically pink to violet and is more abundant along pelitic (aluminous/mafic-rich) layers.

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