GS-6 Cat Lake–Euclid Lake area in the Neoarchean Bird River greenstone belt, southeastern Manitoba (parts of NTS 52L11, 12): preliminary results of bedrock geological mapping and their implications for geodynamic evolution and metallogeny

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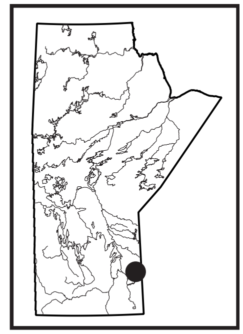

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Summary

This report presents the preliminary results of bedrock geological mapping conducted at a scale of 1:10 000 in the Cat Lake–Euclid Lake area by the Manitoba Geological Survey in the summer of 2013. The map area is located in the northern arm of the Bird River greenstone belt[2], southeastern Manitoba, about 145 km northeast of Winnipeg. The main part of this area is underlain by a Neoarchean supracrustal assemblage comprising volcano-sedimentary and intrusive rocks, which is bounded to the south by the Mesoarchean Maskwa Lake batholith and to the north by sedimentary[3] rocks and derived gneissic, weakly foliated to massive granitoid rocks. The supracrustal assemblage consists of 1) mafic volcanic and synvolcanic intrusive rocks, 2) epiclastic and minor volcaniclastic rocks, and 3) mafic–ultramafic intrusions. Both the Mesoarchean granitoid batholith and supracrustal rocks are intruded and disrupted by a Neoarchean tonalite-trondhjemite-granodiorite (TTG) suite and late peraluminous granitoid rocks and associated pegmatites. The mafic–ultramafic intrusions are emplaced within a mid-ocean-ridge basalt (MORB)–type sequence that is extensive in the northwestern part of the map area, and are in fault contact with granitoid and sedimentary rocks in the southeastern part. Some of the mafic–ultramafic intrusions are associated with platinum-group element (PGE)–Ni–Cu–Cr mineralization, and thus have become targets for mineral exploration. Rare-metal (Li, Cs, Nb, Ta) mineralization is confined to pegmatite intrusions associated with peraluminous granitoid rocks that are relatively younger than the TTG suite, in which pegmatite and aplite intrusions are, in contrast, compositionally simple and devoid of metasomatic textures. There exists, however, a potential for porphyry Cu-(Au) mineralization associated with some granitoid phases in the Neoarchean TTG suite.

The results of new and previous mapping suggest that the MORB-type basalts and related synvolcanic intrusive rocks, as well as the mafic–ultramafic intrusions, may have been emplaced in an extensional setting at a continental margin, possibly represented by older granitoid rocks in the Maskwa Lake batholith (i.e., Maskwa Lake batholith I, ca. 2853–2782 Ma; Gilbert et al., 2008). The Neoarchean mafic–ultramafic intrusions, including the Cat Lake, New Manitoba Mine and Euclid Lake (U-Pb zircon age of 2743 Ma) intrusions, consist of a diversity of rock types, including gabbro, leucogabbro to anorthositic gabbro, melagabbro, amphibolite and/or pyroxenite, and peridotite. Whereas all three of the these intrusions may be coeval and thus the products of the 'Bird River magmatic event' (Houlé et al., 2013), the precise age and affinity of the Cat Lake and New Manitoba Mine intrusions are yet to be determined.

The TTG suite, which includes Neoarchean phases of the Maskwa Lake batholith (Maskwa Lake batholith II, 2725 ±6 Ma; Wang, 1993), as well as the Inconnu pluton I (Černý et al., 1981), may have been formed in a magmatic-arc setting; subsequent emplacement of peraluminous granitoid rocks and associated rare-metal-bearing pegmatites may have occurred during continental collision subsequent to plate subduction. The north-northwest-trending Cat Lake–Euclid Lake dextral shear zone is confined to gneissic, peraluminous granitoid rocks, as well as strongly foliated and mylonitic granitoid rocks that may mark the southern boundary of the English River subprovince.

Introduction

Geological mapping in 2013 was a continuation of a mapping program initiated in 2011 by the Manitoba Geological Survey (MGS) in the northern arm of the Bird River greenstone belt (BRGB) of the western Superior province (Figures GS-6-1, -2; Yang et al., 2011, 2012). This project is collaborative with the Geological Survey of Canada (GSC) through the Targeted Geoscience Initiative Phase IV (TGI-4) program. The reader is referred to Yang et al. (2012) and Gilbert et al. (2013) for a brief history of mineral exploration, geological mapping and investigative studies in the BRGB. The objectives of this project are to

1) update the available regional geological maps at a more detailed scale (1:10 000),

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

[3] All Neoarchean supracrustal rocks have been metamorphosed; however, for brevity, the prefix 'meta' has been omitted in rock terminology.

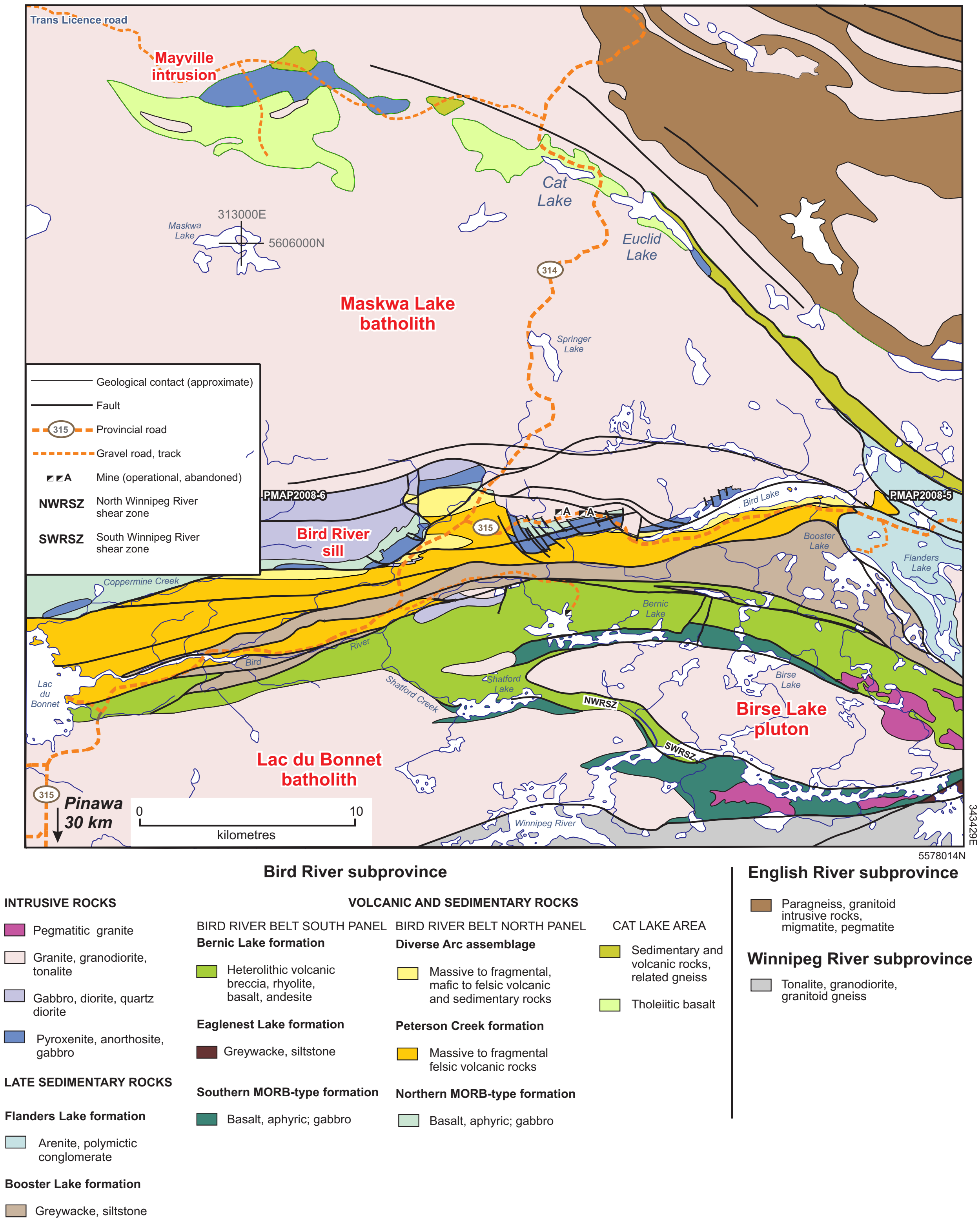

Figure GS-6-1: *Regional geology between Cat Lake–Euclid Lake and the Winnipeg River, southeastern Manitoba, showing the main part of the Bird River greenstone belt (BRGB) between Lac du Bonnet and Flanders Lake, and the northern arm extending as far as the Mayville intrusion.*

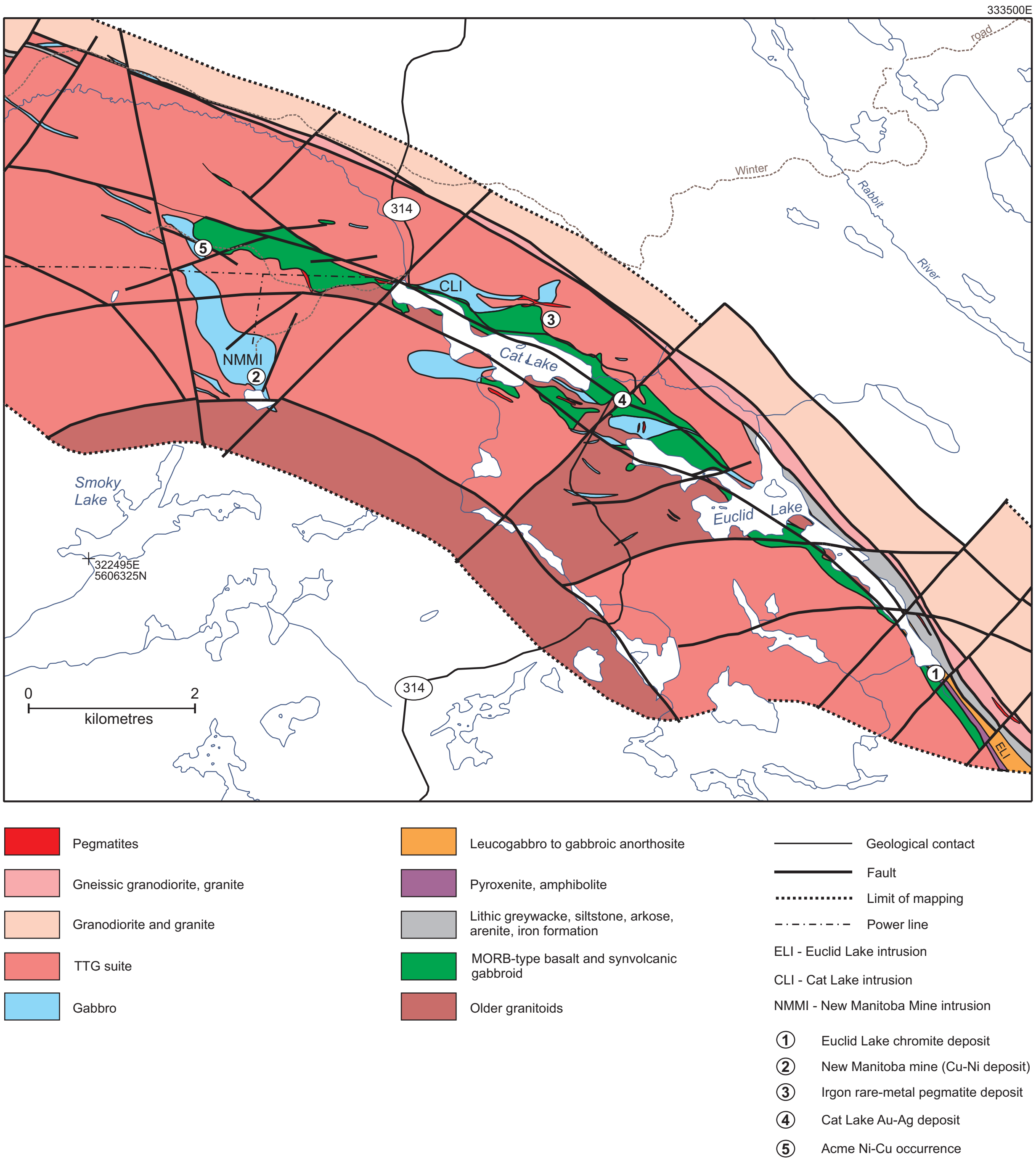

Figure GS-6-2: *Simplified geology of the Cat Lake–Euclid Lake area, southeastern Manitoba.*

2) address the geodynamic evolution of the region, and
3) evaluate the metallogeny of diverse mineral resources in the BRGB.

This report presents the results of geological mapping at a scale of 1:10 000 conducted in 2013 and includes new findings, such as 1) occurrences of amphibolite and/or pyroxenite at Euclid Lake, and 2) the location and nature of the possible contact between the BRGB and the southern boundary of English River subprovince. The report also discusses the significance of new lithogeochemical and geochronological data acquired during the previous year. The associated preliminary map of the Cat Lake–Euclid Lake area (Yang, 2013) provides new data and updates the geology of the previously mapped area.

Regional geology

The Neoarchean BRGB is situated between the English River and Winnipeg River subprovinces of the western Superior province (Peck et al., 2002; Gilbert, 2007; Gilbert et al., 2008). It is part of an approximately 150 km long, east-trending supracrustal belt that extends from Lac du Bonnet (Manitoba) in the west to Separation Lake (Ontario) in the east, where it is termed the 'Separation Lake greenstone belt' (Percival et al., 2006a, b). Regional aeromagnetic data and Nd-isotope evidence suggest that the BRGB may also extend westward beneath Paleozoic sedimentary cover (McGregor, 1986; Stevenson et al., 2000; Percival et al., 2006b).

Investigations of the complex history of deformation, tectonism, metamorphism, magmatism and associated mineralization in the southern part of the BRGB (Percival, 2007; Duguet et al., 2009; Yang et al., 2012) have shown it to be in a key position for studies of crustal tectonic processes and the geodynamics of the western Superior province. These studies have also indicated that the greenstone belt is a prospective area for base metals (Ni, Cu, Cr), precious metals (PGEs, Au), rare metals (Li, Cs, Nb, Ta), and rare-earth elements (REE).

The emplacement of the Bird River Sill (BRS; Trueman 1980), Mayville intrusion (MI; Peck et al., 2002; Yang et al., 2012) and Euclid Lake mafic–ultramafic intrusion (ELI) all occurred at 2743 Ma (high-precision U-Pb zircon dates of BRS [Scoates and Scoates, 2013], MI and 'Bird River magmatic event' and ELI [Houlé et al., 2013; Bécu et al., GS-7, this volume]). These intrusions—all of which host magmatic Ni-Cu-PGE-Cr mineralization—were apparently emplaced at a relatively early stage of continental-arc magmatism that is assumed to span more than 30 m.y., from ca. 2.75 to 2.72 Ga (Percival et al., 2006a, b; Gilbert et al., 2008, 2013).

Geology of the northern arm of the BRGB

The oldest rocks in the Cat Lake–Euclid Lake area—referred to as Maskwa Lake batholith I in Gilbert et al. (2008) and corresponding to unit 1 in Yang (2013)—consist of various granitoid intrusions (2852.8 ±1.1 Ma to 2832.3 ±0.9 Ma [Gilbert et al., 2008], 2844 ±12 Ma [Wang, 1993]) that represent a basement for the BRGB. The supracrustal rocks of the BRGB extend along the north and south margins of the older Maskwa Lake batholith cratonic block (Figure GS-6-1), suggesting that they may have been deposited in a continental-margin setting.

The northern arm of the BRGB consists of mafic volcanic and synvolcanic intrusive rocks, epiclastic and minor volcaniclastic rocks, and mafic–ultramafic layered intrusions. These mafic–ultramafic intrusions within the greenstone assemblage include the Cat Lake, New Manitoba Mine and Euclid Lake intrusions, as well as other relatively smaller intrusions. The setting and composition of these various intrusions are comparable to those of the MI and BRS. In emplacement age, they are interpreted as coeval with the MI and BRS; they are emplaced within a mid-ocean-ridge basalt (MORB) sequence (unit 2) to the northwest, and are in fault contact with granitoid and sedimentary rocks in the southeastern part of the map area.

Relatively younger granitoid rocks (Maskwa Lake batholith II, unit 7 of this study; 2725 ±6 Ma [Wang, 1993]) belong to a tonalite-trondhjemite-granodiorite (TTG) suite that was emplaced in both the granitoid basement and supracrustal rocks of the BRGB; the TTG suite was, in turn, intruded by late, gneissic, peraluminous granitoid rocks; strongly foliated to massive granitoid rocks; and related pegmatites (units 8–10, respectively).

Geology of the Cat Lake–Euclid Lake area

During the course of the mapping, ten map units were defined in the Cat Lake-Euclid Lake area These are, from the oldest to youngest (Table GS-6-1, Figure GS-6-2; Yang, 2013): 1) Maskwa Lake batholith I, 2) MORB-type formation, 3) Euclid Lake formation, 4-5) Euclid Lake intrusion, 6) gabbroic intrusions, 7) TTG suite, 8) Inconnu pluton I, 9) Inconnu pluton II, and 10) late intrusive rocks. These units are described in the following sections.

Maskwa Lake batholith I (unit 1)

The Maskwa Lake batholith is a multiphase pluton. The older granitoid phases, which constitute the Maskwa Lake batholith I (2852.8 ±1.1 Ma, 2832.3 ±0.9 Ma; Gilbert et al., 2008), are mainly granodiorite, tonalite and diorite (Figure GS-6-3a), and related gneiss. The older phases span at least 50 m.y. Coarse-grained, locally porphyritic pink granodiorite of the Maskwa Lake batholith is in contact with massive and pillowed MORB-type basalt (unit 2; Mayville assemblage of Bailes et al., 2003), which is comparable to the northern MORB-type formation in the main part of the BRGB (Gilbert et al., 2008). The granitoid rocks (Maskwa Lake batholith I) are intruded, brecciated and fragmented at the contact zone by diabase that is thought to be compositionally similar and genetically related to the MORB-type basalt (Figure GS-6-3b); the granitoid rocks, furthermore, are intruded by sporadic gabbro dikes (up to 5 m wide) that may be synvolcanic. Based on these intrusive relationships, unit 1 granitoid rocks (>2832 Ma; Gilbert et al., 2008) are thus thought to be older than the MORB-type basalt (unit 2).

Relatively younger granitoid phases—termed here the 'Maskwa Lake batholith II—include quartz diorite, tonalite and granodiorite to granite, and are interpreted to be part of the TTG suite (unit 7; see below). These rocks (2725 ±6 Ma; Wang, 1993) are ca. 20 m.y. younger than the BRS and MI of the 2743 Ma 'Bird River magmatic event' (Houlé et al., 2013), as well as the northern MORB-type formation in which the BRS is emplaced (Gilbert et al., 2008).

Table GS-6-1: Principal lithological units, affiliations and their contact relationships in the Cat Lake–Euclid Lake area, southeastern Manitoba.

Map unit[1]	Affiliation	Rock type
10	Late intrusive rocks	Pegmatite (simple/rare-element-bearing)
	Intrusive contact	
9	Inconnu pluton II	Gneissic granodiorite, granite
	Intrusive contact	
8	Inconnu pluton I	Granodiorite and granite
	Intrusive contact	
7	TTG suite (includes Maskwa Lake batholith II; 2725 ±6 Ma[2])	Tonalite, trondhjemite, granodiorite (TTG)
	Intrusive contact	
6	Cat Lake (CLI), New Manitoba Mine (NMMI) and Euclid Lake (ELI) intrusions	Gabbro
	Intrusive contact	
5	Euclid Lake intrusion (ELI; 2743 ±1 Ma[3])	Leucogabbro to gabbroic anorthosite
4		Pyroxenite, amphibolite
	Intrusive contact	
3	Euclid Lake sedimentary formation	Sedimentary, volcaniclastic and intercalated mafic rocks
	Inferred faulted contact	
2	MORB-type formation (Mayville assemblage of Bailes et al., 2003)	MORB-type basalt, synvolcanic gabbro
	Inferred unconformity	
1	Maskwa Lake batholith I (2832.3 ±0.9 Ma[4], 2844 ±12 Ma[2], 2852.8 ±1.1 Ma[4])	Older granitoid rocks, comprising tonalite, granodiorite, related gneiss

[1] on Preliminary Map PMAP2013-7
[2] Wang (1993)
[3] Houle et al. (2013)
[4] Gilbert et al. (2008)

MORB-type formation (unit 2)

Mid-ocean-ridge–type basalt (MORB) and synvolcanic gabbro are intermittently exposed in the northwestern and northern parts of the Cat Lake area, in the area between Cat and Euclid lakes and in the southeastern part of Euclid Lake (Bécu et al., GS-7, this volume). The massive to pillowed basalt is very fine grained to aphanitic and typically aphyric; plagioclase-phyric or megaphyric flows are subordinate (Figure GS-6-3c). Unit 2 basalt is strongly foliated and metamorphosed to greenschist or lower amphibolite facies. Microscopically, the rocks consist largely of elongated amphibole and plagioclase laths, typically parallel to the foliation, and accessory chlorite, epidote and albite. Disseminated magnetite is common, and pyrrhotite (±pyrite±chalcopyrite) occurs locally. In addition, angular to irregularly shaped fragments of this basalt are common in contact zones of the TTG suite.

Synvolcanic gabbro, present as sills up to 30 m in thickness, is fine to medium grained and consists dominantly of plagioclase and amphibole. Locally, disseminated sulphide minerals (pyrrhotite±chalcopyrite pyrite) are present.

Euclid Lake sedimentary formation (unit 3)

The Euclid sedimentary formation (unit 3) is composed mainly of sedimentary rocks, intercalated thin mafic volcaniclastic sandstone beds and mafic rocks, and is located mainly in the northeastern part of Euclid Lake (Yang, 2013). Other minor occurrences were also mapped southeast of the Cat Lake–Euclid Lake area. The main rock types are well layered (1–10 cm) feldspathic greywacke, arkose, siltstone and oxide-facies iron formation. The fine- to medium-grained sedimentary rocks display alternating feldspathic and mafic laminae, and are intercalated with thin beds of volcaniclastic sandstone (Figure GS-6-4a). Where the sedimentary rocks are folded and relatively more metamorphosed, they contain leucosome veins parallel—and locally oblique—to the foliation (Figure GS-6-4b).

Gabbroic sills and/or dikes (up to 1 m thick) within the sedimentary sequence at Euclid Lake are thought to be penecontemporaneous with deposition of their hostrocks, based on consistently concordant contact relationships; they are strongly deformed and foliated, together with the sedimentary rocks (Figure GS-6-4c). Late pegmatitic

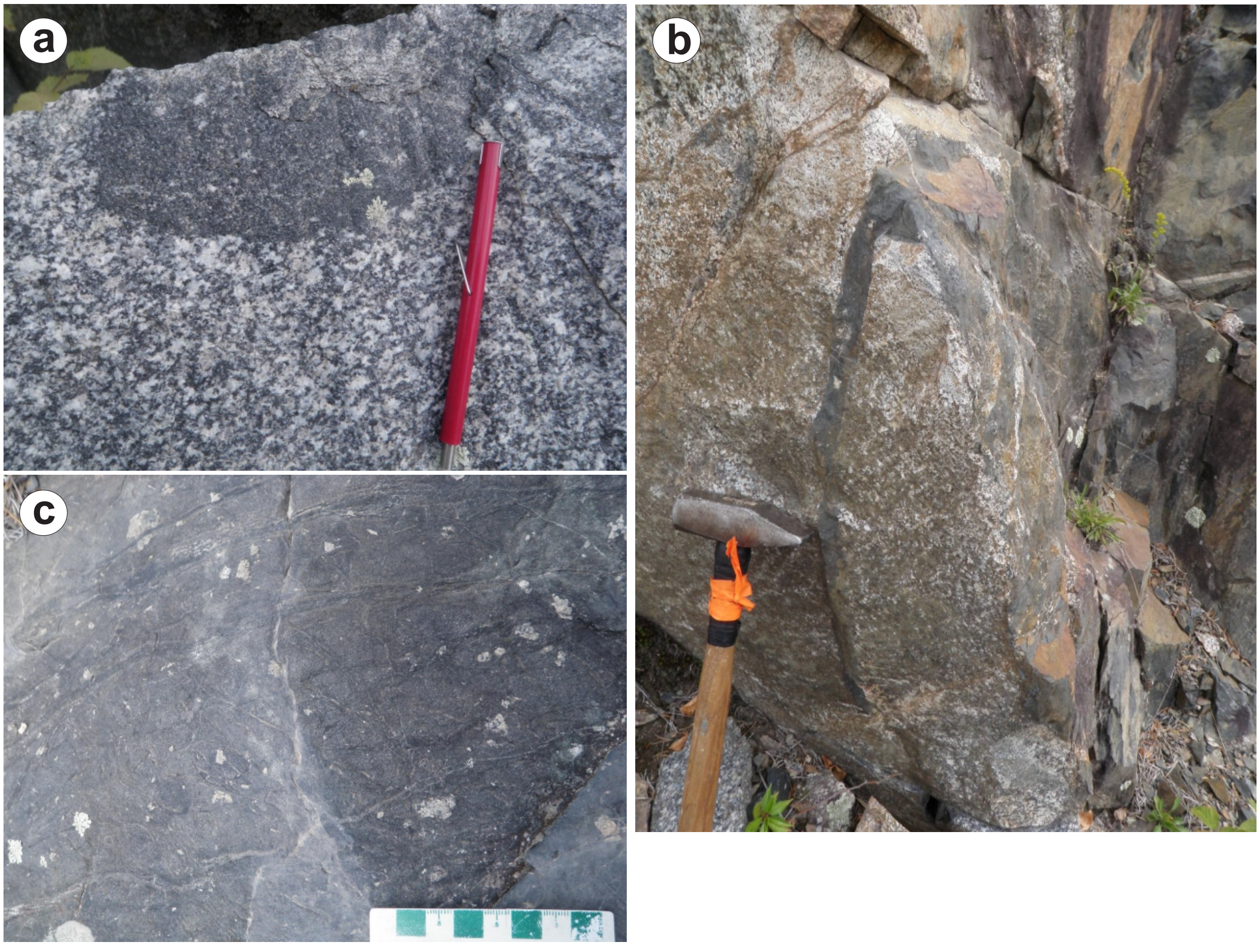

***Figure GS-6-3:** Field photographs of typical granitoid rocks of the Maskwa Lake batholith I (map unit 1), showing their relationship with mafic volcanic rocks and (inferred) synvolcanic gabbro (unit 2), Cat Lake–Euclid Lake area, southeastern Manitoba: **a)** medium- to coarse-grained tonalite with subrounded to elongated mafic xenoliths (UTM Zone 15U, 328799E, 5606450N [NAD 83]); **b)** tonalite intruded by a diabase dike at the contact zone (UTM 328700E, 5606539N); **c)** very fine grained to aphanitic basalt containing plagioclase glomerocrysts; stretched pillow selvages are discernible (UTM 328700E, 5606539N); pillows are north facing, as in the majority of MORB-type basalt localities.*

granite dikes are emplaced within unit 3 rocks; some of these dikes are boudinaged (Figure GS-6-4d).

Comparison of supracrustal rock formations in the northern arm with those in the main part of the BRGB suggests possible correlations. Based on field observation, Yang et al. (2012) interpreted a volcaniclastic rock (Table GS-6-1, unit 3) in the Cat Creek area of the northern arm to predate the 2742.8 ±0.8 Ma MI (Houlé et al., 2013). However, new detrital zircon age data provide a mean of 2735.7 ±3.8 Ma for the dominant detrital zircon population in a rock sample from this unit close to the northern margin of the MI, suggesting it probably postdated the 'Bird River magmatic event' and may correlate with rocks of the Peterson Creek formation in the main part of BRGB (Gilbert et al., 2008; Figure GS-6-1). In the Euclid Lake area, however, sedimentary rocks contain layers of mafic volcanic rocks and/or are intruded by thin gabbro sills that could be related to the 2743 Ma 'Bird River magmatic event' (Houlé et al., 2013) or to synvolcanic gabbro within the mafic volcanic rocks; thus, a pre-ELI age cannot be ruled out for this portion of the sedimentary package.

Northwest-trending, 1–3 m thick oxide-facies iron formation is intercalated with fine-grained quartz-biotite schist and gneiss northwest of Euclid Lake (Theyer, 1994; Assessment File 92607, Manitoba Mineral Resources, Winnipeg). The iron formation is locally folded and disrupted, and extends discontinuously along strike for more than 350 m; it is locally mineralized with minor pyrrhotite (Theyer, 1994).

Euclid Lake intrusion (units 4 and 5)

Pyroxenite and amphibolite (unit 4)

Pyroxenite and amphibolite (unit 4) underlie a small islet (measuring <10 m by 2 m) close to the south shore

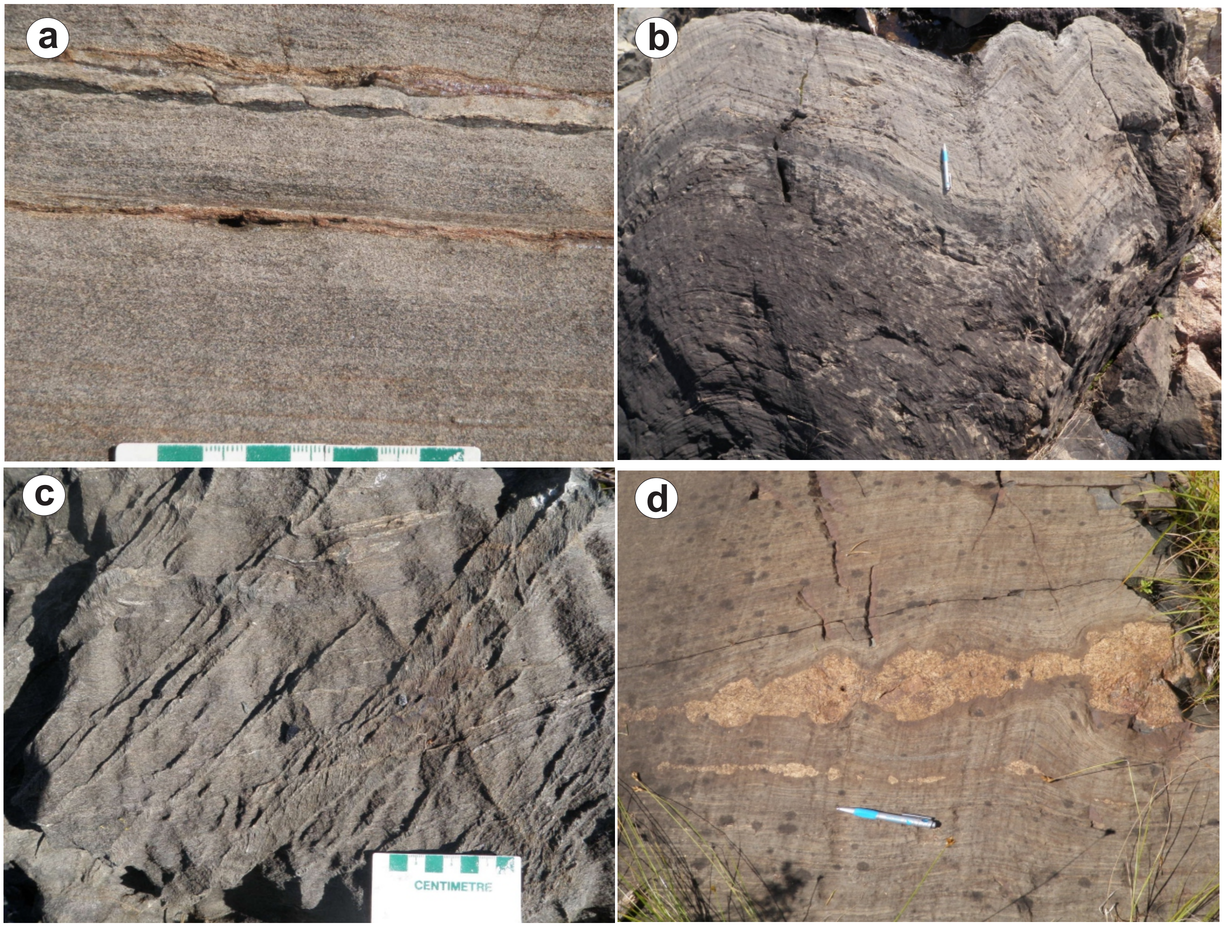

Figure GS-6-4: *Field photographs of sedimentary and volcaniclastic rocks, showing their relationships with (inferred) syndepositional mafic rocks (map unit 3) and younger pegmatite dikes, Cat Lake–Euclid Lake area, southeastern Manitoba:* ***a)*** *lithic greywacke and arkose, with thin, mafic volcaniclastic sandstone and quartzite (iron formation) beds; bedding is reinforced by penetrative foliation (UTM Zone 15U, 332040E, 5605616N [NAD 83]);* ***b)*** *greywacke, arkose and mafic volcaniclastic sandstone, with leucosome veinlets both parallel and oblique to foliation planes; this sedimentary package is cut by coarse-grained to pegmatitic granite (visible at right margin; UTM 332040E, 5605616N);* ***c)*** *medium-grained amphibolite interpreted as intrusive, penecontemporaneous with deposition of sedimentary host; also showing brittle deformation of early penetrative fabric (UTM 332040E, 5605616N);* ***d)*** *greywacke intruded by boudinaged granite dike and veinlets (UTM 332040E, 5605616N).*

of the northwestern part of Euclid Lake. These rocks are medium to coarse grained, brown-grey to dark green-grey weathering, and variously foliated (Figure GS-6-5a). Pyroxene is altered to a secondary amphibole-chlorite assemblage; the rock contains disseminated pyrrhotite and is strongly magnetic. Very coarse grained to mega-crystic amphibolite occurs within a strongly foliated and folded mafic–ultramafic rock unit at the lakeshore, southeast of the pyroxenite occurrence. The amphibolite is weakly magnetic and consists entirely of clusters of radiating tremolite-actinolite prisms up to 5 cm long (Figure GS-6-5b). A north-northwest-trending, elongated positive magnetic anomaly at this locality (Galeschuk, pers. comm., 2012) is coincident with the exposures of pyroxenite and amphibolite.

Olivine-bearing pyroxenite and serpentinized peridotite—reported in diamond-drill logs in the southeastern part of Euclid Lake (Bannatyne and Trueman, 1982)—are interpreted as part of unit 4. The drill logs show that the ultramafic rocks contain several chromitite horizons and are overlain by a thick gabbro–leucogabbro sequence (unit 5, see below; Bécu et al., GS-7, this volume) that underlies an island at the southeastern end of Euclid Lake. Springer (1950) located an ultramafic rock exposure and observed that “disseminated and dense chromite may be seen in the few feet of peridotite exposed”; however, no peridotite outcrop was encountered during the current mapping.

Leucogabbro to gabbroic anorthosite (unit 5)

Leucogabbro to anorthositic gabbro (unit 5; Figure GS-6-5c) is the dominant rock type among the limited number of rock exposures of the ELI in the southeastern

Figure GS-6-5: *Field photographs of representative mafic–ultramafic intrusive rocks (map units 4 to 6), Cat Lake–Euclid Lake area, southeastern Manitoba:* ***a)*** *medium- to coarse-grained pyroxenite, strongly magnetic, with scattered disseminated pyrrhotite (unit 4; UTM Zone 15U, 329664E, 5607287N [NAD 83]);* ***b)*** *very coarse grained amphibolite, consisting of radiating amphibole crystals up to 5 cm in length (unit 4; 329700E, 5607237N);* ***c)*** *very coarse grained to megacrystic leucogabbro to anorthositic gabbro, with euhedral to subhedral plagioclase crystals and interstitial amphibole (unit 5; UTM 332407E, 5605007N);* ***d)*** *medium- to coarse-grained gabbro with disseminated chalcopyrite and pyrrhotite (New Manitoba Mine intrusion, unit 6; UTM 324533E, 5608618N);* ***e)*** *fine-grained gabbro, marginal phase of New Manitoba Mine intrusion, displaying ophitic texture (UTM 324035E, 5609005N);* ***f)*** *fine- to medium-grained gabbro (Cat Lake intrusion, unit 6; UTM 327649E, 5609300N), intruded first by trondhjemite and then by pegmatite (locally contains gabbro xenoliths);* ***g)*** *medium-grained gabbro (unit 6; UTM 330094E, 5606632N) intruded by a granodiorite dike derived from the Maskwa Lake batholith II (unit 8);* ***h)*** *medium-grained gabbro dike (unit 6) emplaced in tonalite of the Maskwa Lake batholith I; both rock types are strongly foliated (unit 1; UTM 330493E, 5607254N).*

part of Euclid Lake (Yang, 2013). The mineral composition and texture of this unit are comparable with those of leucogabbro in the Mayville intrusion (Yang et al., 2012). Igneous layering, defined by variations in grain size and/or mineralogical composition, was observed at several localities. Leucogabbro is typically coarse to very coarse grained and locally megacrystic, and contains 65–80% calcic plagioclase, 15–25% hornblende (after pyroxene) and accessory Fe-Ti oxide, zircon and apatite. Plagioclase occurs as equant, subhedral to euhedral crystals that lack optical zoning. Subordinate gabbroic anorthosite contains >85% plagioclase (Ashwal, 1993).

A bulk sample of unit 5 leucogabbro collected at the southeastern end of Euclid Lake yielded a U-Pb zircon age of 2743 Ma, interpreted to represent the crystallization age of the ELI (Houlé et al., 2013).

Gabbroic intrusions (unit 6)

Unit 6 gabbro (Figure GS-6-5d, e) is the main rock type observed in the New Manitoba Mine intrusion (NMMI) and Cat Lake intrusion (CLI), as well as other smaller unnamed gabbroic intrusions in the map area. Marginal phases of the NMMI and some other intrusions are characterized locally by fine-grained ophitic gabbro (Figure GS-6-5e). The gabbro is leucocratic to melanocratic and typically massive, equigranular and medium to coarse grained (2–5 mm crystals); locally it is strongly magnetic. It consists essentially of plagioclase (50–60%), hornblende after pyroxene (30–40%) and accessory magnetite and ilmenite. Secondary sericite, chlorite, epidote and biotite are common, especially within fault zones. Sporadic mineralized localities contain up to 15% disseminated chalcopyrite and pyrrhotite (±pyrite).

Unit 6 gabbroic intrusions are intruded by various granitoid rocks (units 7–10), such as north of Cat Lake, where the CLI is intruded by trondhjemite and younger pegmatite (Figure GS-6-5f). Elsewhere, unit 6 gabbro dikes intrude older granitoid rocks of unit 1 (Figure GS-6-5h).

TTG suite (includes Maskwa Lake batholith II; unit 7)

The TTG suite (unit 7) is well developed south of the Cat Lake–Euclid Lake area, where it represents part of the ca. 2725 Ma Maskwa Lake batholith II (Table GS-6-1; Yang, 2013). Intrusions of the TTG suite also occur within the eastern part of the MI (Yang, 2012), where granitoid rocks intrude unit 2 basalt and medium-grained gabbro of the MI. Similar relationships are observed on the northwestern shore of Sausage Lake, where medium- to coarse-grained granodiorite (unit 7) intrudes and brecciates medium-grained gabbro (unit 6; Figure GS-6-6a). In the northwestern corner of the map area, unit 7 granodiorite intrudes basalt (unit 2).

In addition to tonalite, trondhjemite and granodiorite, subordinate phases of the TTG suite include quartz diorite and diorite, as well as late quartz-feldspar porphyry dikes that postdate the other phases. Granitoid rocks of the TTG suite are generally medium to coarse grained, weakly foliated to massive and locally porphyritic. Feldspar and quartz are the predominant minerals; K-feldspar locally accounts for more than one-third of the total feldspar content (commonly as phenocrysts), whereas mafic minerals (biotite±amphibole) are subordinate (10–20% of the rock).

Granodiorite north of Sausage Lake contains chalcopyrite-bearing quartz veins and is characterized by K-metasomatism (K-feldspar+biotite), suggesting a potential for porphyry Cu-(Au)–type mineralization within the Neoarchean TTG suite. The depth of emplacement and erosion level of the granitoid intrusion may be estimated by Al-in-hornblende geobarometry (Hammarstrom and Zen, 1986).

Inconnu pluton I (unit 8)

Granodiorite and granite (unit 8) occur in the area directly north of unit 9 gneissic granodiorite and granite (see below), as well as in the area north of the north-northwest-trending Cat Lake–Euclid Lake fault zone. Unit 8 granitoid rocks are interpreted as early phases of the Inconnu pluton I of Černý et al. (1981), which consists mainly of coarse-grained, locally porphyritic, pinkish-grey granodiorite, granite and minor monzogranite. Some of these granitoid rocks show heterogeneous texture (Figure GS-6-6b); very coarse grained to pegmatitic granite with heterogeneous texture is locally transitional to homogeneous, massive or porphyritic varieties. The massive to weakly foliated granitoid rocks are characterized by a mineral assemblage of quartz-feldspar(s)-amphibole-biotite±muscovite. Late (quartz-feldspar±muscovite) pegmatite dikes are common within unit 8 granitoid rocks.

Inconnu pluton II (unit 9)

Unit 9 granitoid rocks are confined to a narrow zone that extends from the area north of Euclid Lake northwestward to the area north of the Trans License road (Figure GS-6-1). Unit 9 is variously transitional with, or intrusive into, granitoid rocks of unit 8 that occur immediately north of Euclid Lake. This unit was interpreted as part of the young phases of the Inconnu pluton II of Černý et al. (1981). Contacts between unit 9 and unit 3 sedimentary rocks were not observed, but unit 9 is assumed to be younger. Unit 9 granitoid rocks are gneissic, light grey to grey and medium grained; the mineral assemblage includes dark brown (Fe-rich) biotite±greenish amphibole±muscovite±garnet (Figure GS-6-6c). Micaceous, dark brown biotite stringers (1–3 mm wide) parallel to the foliation locally wrap around feldspar porphyroclasts.

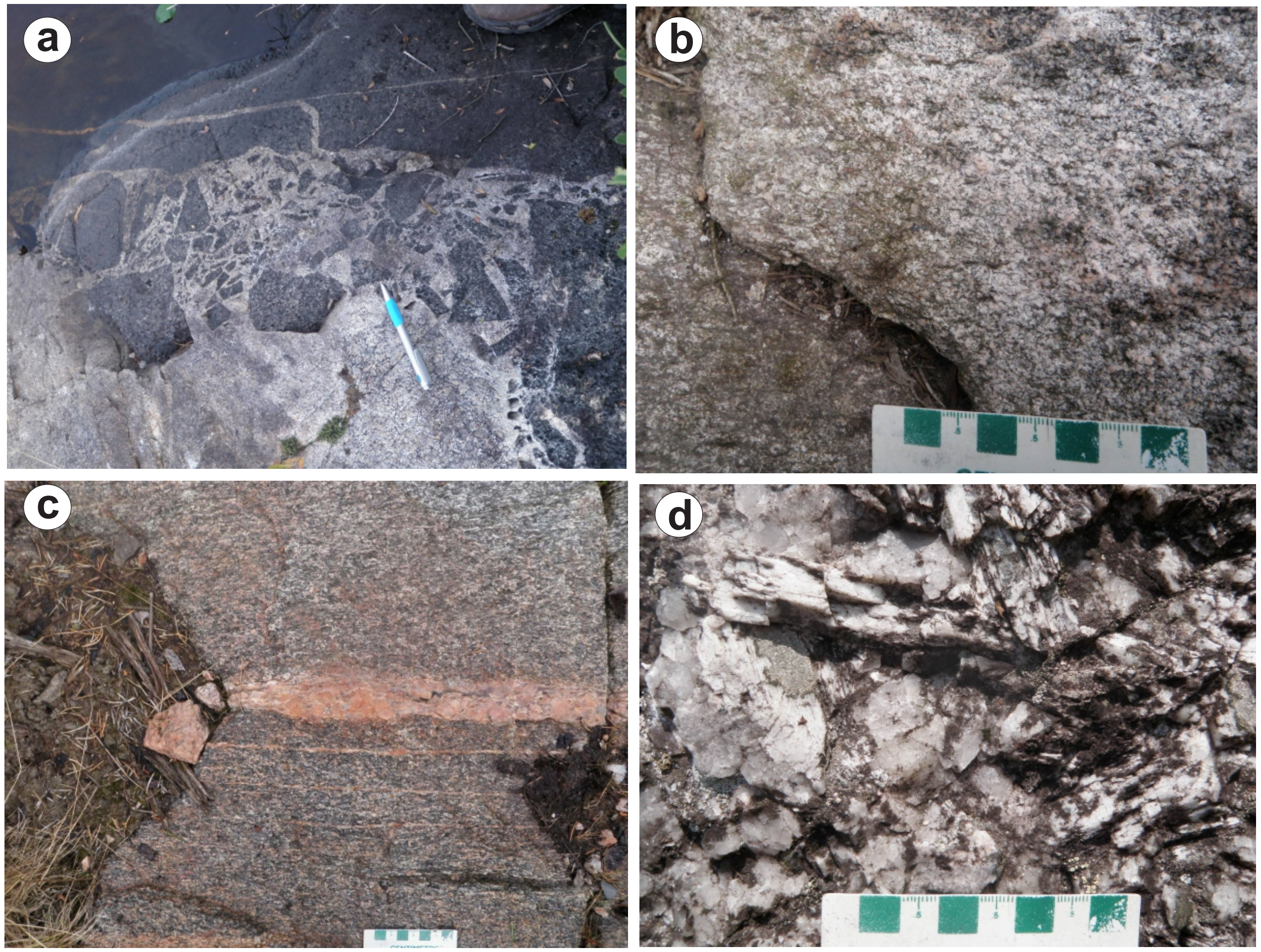

***Figure GS-6-6:** Field photographs of various phases of granitoid rocks and pegmatites, showing some of the key field relationships (map units 7 to 10), Cat Lake–Euclid Lake area, southeastern Manitoba: **a)** medium- to coarse-grained granodiorite, Maskwa Lake batholith II (unit 7), which intrudes and brecciates medium-grained gabbro (unit 6; UTM Zone 15U, 328104E, 5605981N [NAD 83]); **b)** coarse-grained granite with heterogeneous texture (unit 8; UTM 333044E, 5605525N); **c)** gneissic granodiorite (unit 9) and associated simple pegmatite vein (UTM 332922E, 5605199N); **d)** spodumene-muscovite pegmatite (UTM 324702E, 5609789N) from a 60 cm wide dike, trending 325°.*

Late intrusive rocks (unit 10)

Pegmatite intrusions (unit 10), typically 0.5–30 m thick, are the youngest known rocks in the map area. Both simple and complex pegmatites occur in the Cat Lake–Euclid Lake area. Simple pegmatite is composed mainly of K-feldspar, plagioclase and quartz (±muscovite), without notable replacement textures, whereas complex pegmatite exhibits metasomatic texture and contains more diverse mineral assemblages (K-feldspar–quartz–albite±muscovite±garnet±tourmaline±spodumene±beryl; Figure GS-6-6d); graphic texture is locally evident in both simple and complex pegmatites. The simple type is commonly hosted by all phases of granitoid intrusions (units 1, 7 to 9), whereas the complex type appears to be associated only with unit 9; in some cases, however, it is not possible to identify the affiliation of a complex pegmatite intrusion.

For a comprehensive review of pegmatites in the BRGB, the reader is referred to the very detailed descriptions in Černý et al. (1981).

Structural geology

The southern boundary of English River subprovince appears to be a gradational tectonic zone in contact with the BRGB to the southwest. The north-northwest-trending Cat Lake–Euclid Lake fault zone—thought to be coincident with this tectonic zone—is located within gneissic, peraluminous granitoid rocks as well as strongly foliated and mylonitic granitoid rocks (unit 8, 9; Yang, 2013). The northwest-trending penetrative foliation in this area dips steeply south. Deformation fabrics suggest a north-side-up sense of dextral-normal, oblique-slip shear, consistent with the observations of Gilbert et al. (2008) and Duguet et al. (2009).

Geochemistry and economic implications of supracrustal and intrusive map units

Mid-ocean-ridge–type basalt and related gabbroic rocks (unit 2), as well as mafic–ultramafic intrusive rocks (units 4–6), are collectively tholeiitic, with evidence of minor crustal contamination (Figure GS-6-7a, b). Their geochemical signatures are consistent with those of modern back-arc basin basaltic rocks (Yang et al., 2011, 2012).

The TTG suite typically displays calcalkaline, metaluminous to slightly peraluminous characteristics. These rocks plot in the volcanic-arc field (Figure GS-6-7c, d) in the tectonomagmatic discrimination diagrams of Pearce et al. (1984), consistent with a possible suprasubduction setting. Such an environment for the TTG suite (unit 7) is considered favourable for porphyry Cu-(Au) and skarn-type Cu-Au-Ag mineralization. Calcalkaline and peraluminous granitoid rocks of unit 9, on the other hand, plot in the field of syncollisional granitoid rocks in the discrimination diagrams of Pearce et al. (1984). Pegmatite intrusions (unit 10) associated with units 8 and 9 may thus have been emplaced in a 'continental-collision' setting, consistent with the presence of rare metals (e.g., Li, Cs, Nb, Ta) that occur within some of these intrusions. The pegmatites are thought to be coeval with the world-class Ta-Cs-Li TANCO ore deposit (2640 ±7 Ma; Baadsgaard and Černý, 1993), located within the main part of the BRGB approximately 15 km south of the map area (Černý et al., 1981). Additional geochemical analyses of samples taken in 2013 are planned.

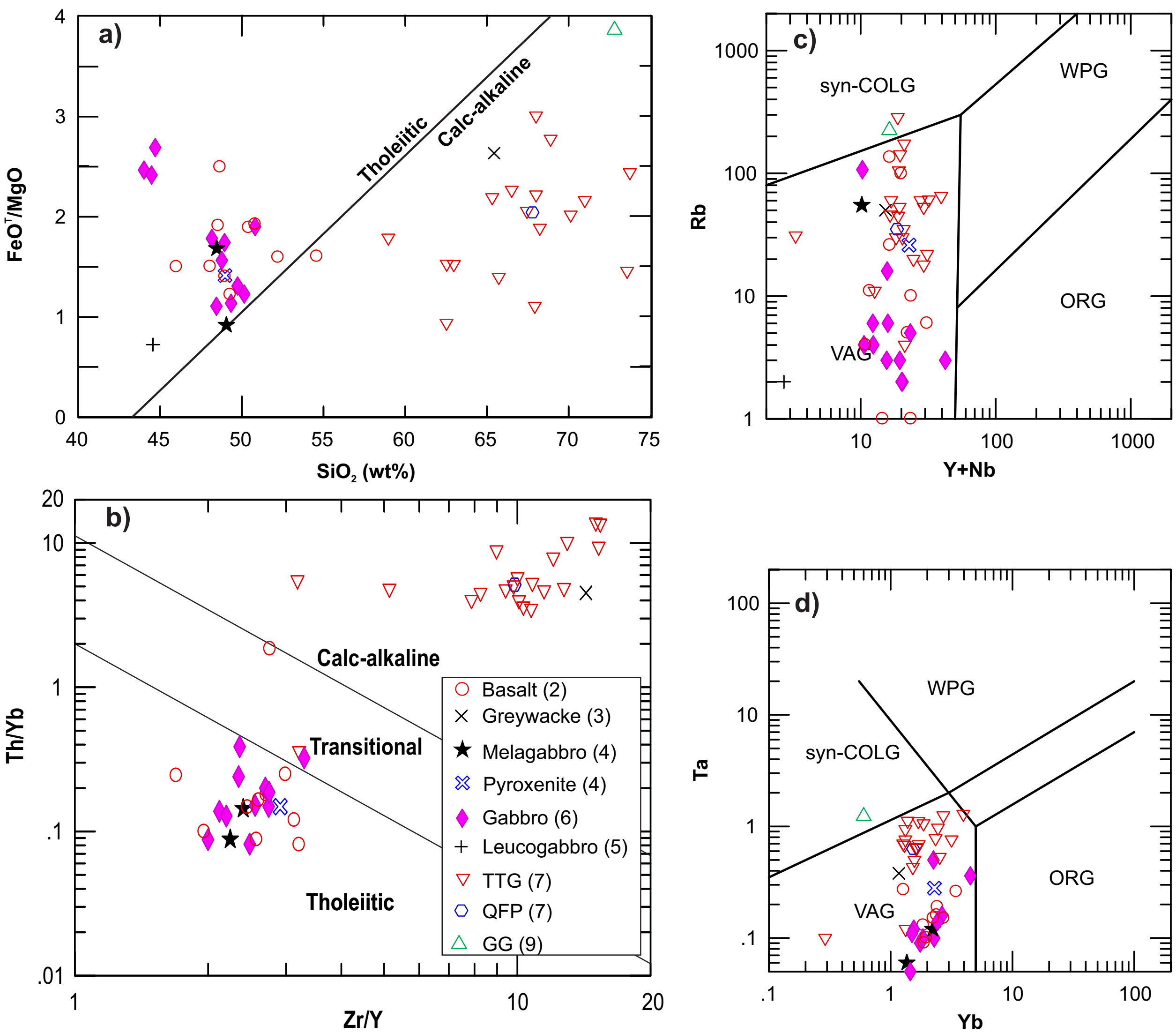

*Figure GS-6-7: Discrimination diagrams for rocks of various map units (shown in brackets) in the Cat Lake–Euclid Lake area, southeastern Manitoba: **a**) FeO^T/MgO vs. SiO_2 (Miyashiro, 1974); **b**) Th/Yb versus Zr/Y (Ross and Bédard, 2009); **c**) Rb vs. (Y+Nb); and **d**) Ta vs. Yb (fields of tectonomagmatic discrimination from Pearce et al., 1984). Abbreviations: GG, gneissic granodiorite; QFP, quartz-feldspar porphyry; TTG, tonalite-trondhjemite-granodiorite; ORG, ocean-ridge granitoid rocks; Syn-COLG, syncollisional granitoid rocks; VAG, volcanic-arc granitoid rocks; WPG, within-plate granitoid rocks.*

Mineral occurrences and deposits

Previous mineral exploration in the Cat Lake–Euclid Lake area located several base-metal, as well as precious- and rare-metal, occurrences and deposits, indicating a favourable exploration potential. The principal mineral-occurrence types identified by current and previous MGS mapping, together with private-sector mineral-exploration programs, are as follows:

- Magmatic Ni-Cu-PGE-Cr mineralization (e.g., Euclid Lake chromite deposit, New Manitoba mine), probably formed in an extensional, continental-margin setting
- Porphyry Cu (Au) and skarn Cu-Au-Ag mineralization (e.g., Cat Lake Au-Ag mine; Figure GS-6-8), related to arc magmatism and the TTG suite in an environment akin to a modern suprasubduction setting
- Rare metal–bearing pegmatites (e.g., Irgon mine at Cat Lake), related to younger peraluminous granitoid rocks (units 8, 9) emplaced in a continental-collision setting

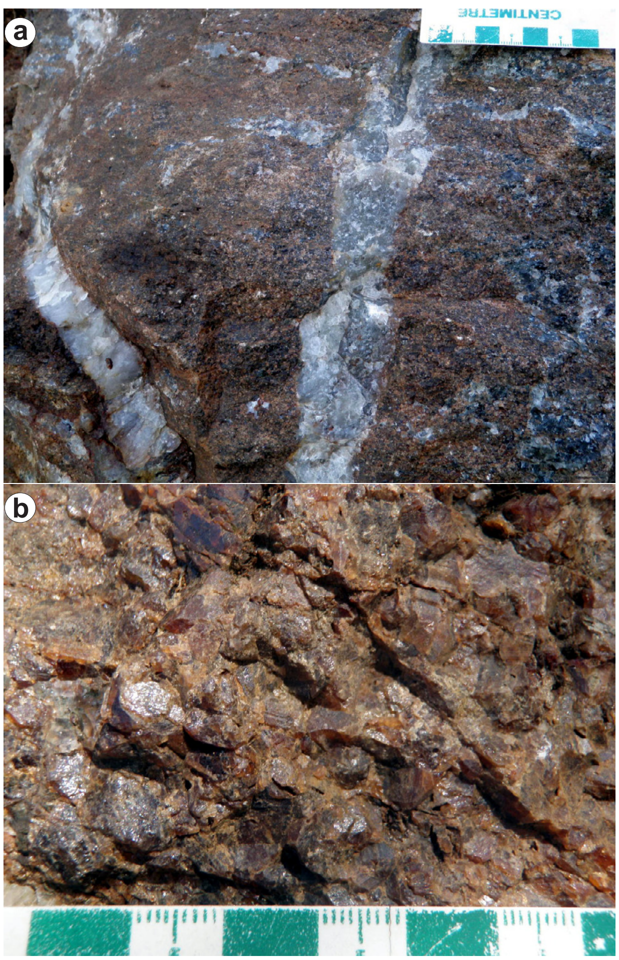

*Figure GS-6-8: Field photographs showing skarn Cu-Au-Ag mineralization in a boulder extracted from the Cat Lake Au-Ag mine (UTM Zone 15U, 328671E, 5608315N [NAD 83]), Cat Lake–Euclid Lake area, southeastern Manitoba: **a**) massive scapolite-garnet skarn cut by chalcopyrite-pyrite–bearing quartz veins; **b**) enlarged view of euhedral to subhedral garnet crystals in (a).*

Euclid Lake chromite deposit

The Euclid Lake chromite deposit contains an estimated resource of approximately 9 million tonnes grading 4.6% Cr_2O_3 in a 373 m long 'main mineralized zone' (Bannatyne and Trueman, 1982; Assessment Files 73385, 73690). The main zone occurs within the ELI, which trends southeast and dips steeply southwest. The northwestern portion of the intrusion, exposed on a small island in the southeastern part of Euclid Lake, consists of coarse-grained to megacrystic leucogabbro (unit 5); most of the ELI is not exposed.

Chromite mineralization occurs as layers, lenses and disseminations within serpentinized peridotite (unit 4) near the contact with overlying gabbro–leucogabbro (unit 5) to the northeast (Watson, 1985; Theyer, 1994). Theyer (1994) reported that some chromite crystals contain subrounded to rounded, small (<0.8 mm) silicate inclusions and minor sulphide inclusions, suggesting that sulphide saturation occurred prior to chromite crystallization. The gabbro-peridotite contact is not exposed but is projected to surface from historical drill data (Bannatyne and Trueman, 1982; Assessment File 74747). The ELI is in fault contact with unit 3 sedimentary and volcaniclastic rocks and oxide-facies iron formation to the northeast, whereas, to the southwest, the base of the intrusion is intruded by granitoid rocks of the Maskwa Lake batholith II (unit 7; Springer, 1950). The ELI has been correlated stratigraphically with the BRS farther southwest, in the main part of the BRGB (Figure GS-6-1), the two intrusions representing opposite limbs of an inferred regional anticlinal structure (Bateman, 1942; Springer, 1950; Trueman and Macek, 1971). However, new geological observations on recent drillholes indicate that the ELI consists of an ultramafic zone sandwiched between two mafic zones, identified as the lower and upper gabbroic zones (Bécu et al., GS-7, this volume). This stratigraphic succession is distinctively different from typical layered intrusions (e.g., the Bird River Sill) and requires further investigation.

New Manitoba mine

The New Manitoba mine—a Cu-Ni-PGE deposit—is hosted by the NMMI, which is emplaced in unit 2 MORB-type basalt. The deposit contains an estimated resource of 2 million tonnes grading 0.75% Cu and 0.33% Ni (Davies et al., 1962). Disseminated pyrrhotite, chalcopyrite and pyrite (1–30%) are present in mineralized zones that range from 8 to 18 m wide and up to 50 m long within the gabbroic intrusion (Theyer, 1994); for details of the NMMI exploration history, see Theyer (1994) and

Assessment File 74825. Analyses of channel samples across the mineralized zones range from <10 to 40 ppb Pt and <2 to 68 ppb Pd (Theyer, 1986).

In 2009, diamond-drilling by Clifton Star Resources Inc. within gabbro in the basal part of the NMMI located an east-trending zone of disseminated to net-textured Cu-Ni sulphide mineralization (pyrrhotite-chalcopyrite-pentlandite) up to 42.5 m in width, dipping 60–65° to the south (Assessment File 74825). This mineralized zone also contains minor Co, PGE and Au.

Cat Lake rare-metal (Li-Cs-Be-Nb-Ta) deposits

The Cat Lake rare-metal (Li-Cs-Nb-Ta) deposit within the Irgon pegmatite is located immediately north of Cat Lake (Springer, 1950; Černý et al., 1981; Theyer, 1994; Assessment File 94932). The deposit contains an estimated resource of more than 1 million tonnes of spodumene-bearing pegmatite grading 1.5% Li_2O; a detailed description and geochemical data for the pegmatite are given in Černý et al. (1981). Rare metal–bearing intrusions such as the Irgon pegmatite typically contain Fe-rich biotite, muscovite and/or garnet, and show metasomatic textures and mineral zonation. They appear to be genetically related to peraluminous granitoid rocks (units 8, 9) and may have been emplaced in a continental-collision setting (see above).

Economic considerations

The Bird River greenstone belt (BRGB) has a long history of mineral exploration, early landmarks being the discovery of the TANCO pegmatite in the 1920s, and Ni-Cu sulphide and Cr mineralization within the mafic–ultramafic Bird River sill (BRS) in 1920 and the early 1940s, respectively. These two intrusions continue to represent viable economic resources and have, in addition, provided targets for numerous studies and the incentive for on-going exploration in the BRGB. Current MGS mapping in the Cat Creek–Cat Lake–Euclid Lake area (2011–2013) has reassessed known magmatic base-metal mineralization in several mafic–ultramafic intrusions and, in addition, identified a potential for porphyry Cu and skarn-type mineralization hitherto not considered for the BRGB.

It is emphasized that mineralization and the formation of various mineral deposits and/or occurrences resulted from distinct stages (events) of protracted geological and geodynamic evolution. In the northern arm of the Neoarchean BRGB, magmatic Ni-Cu-PGE-Cr mineralization (e.g., Euclid Lake chromite deposit, New Manitoba mine) probably formed in an extensional, continental-margin setting; porphyry Cu (Au) and skarn Cu-Au-Ag mineralization (e.g., Cat Lake Au-Ag mine) associated with some granitoid rocks in the TTG suite are likely related to arc magmatism due to plate subduction; and rare metal–bearing pegmatite (e.g., Irgon mine at Cat Lake) related to younger peraluminous granitoid rocks may have been emplaced in a continental-collision environment. Establishing the spatial and temporal relationships between the host geological units through detailed bedrock mapping and geological analysis is thus a key approach to resolve the fundamental problems of geological and geodynamic evolution of the area, and metallogeny of the associated mineral deposits.

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