GS2020-5

Preliminary results from bedrock mapping in the northern arm of Russell Lake, northwestern Manitoba (parts of NTS 64C5, 6)

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In Brief:

- Field work in the northern arm of Russell Lake is a continuous effort in updating bedrock geology and regional framework and interpretation of this part of the Kisseynew domain of the Trans-Hudson Orogen
- Bedrock outcrops of the area are dominated by the coeval sedimentary rocks of the Burntwood and Sickle groups, and mafic volcanic rocks
- Assay results from the 2019 field season reveal up to 3.31 wt. % total carbon in Burntwood group rocks, suggesting widespread economical potential for graphite in the Kisseynew domain

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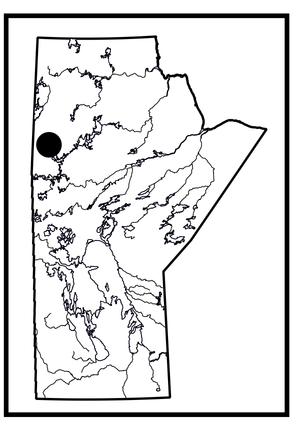

Summary

A multidisciplinary mapping project at Russell Lake was initiated by the Manitoba Geological Survey in the summer of 2019. Geological bedrock mapping at 1:20 000 scale continued in the 2020 field season, focusing on the northern arm of Russell Lake. Outcrops in the northern arm of Russell Lake are dominated by the coeval sedimentary rocks of the Burntwood and Sickle groups, as well as volcanic rocks and granodiorite intrusive bodies. Overall, these rock types are a continuation of the stratigraphy defined in the south basin of Russell Lake; however, there are distinct differences amongst the units. The mapped rock units were sampled for lithogeochemical, petrographic, metamorphic, isotopic and geochronological studies, and for comparison with the results from the previous field season. Graphite contents of Burntwood sedimentary rocks suggest widespread economic potential for this commodity in the study area and the Kisseynew domain at large. Furthermore, observations from this year's field season suggest that graphite is also present within a quartzite unit spatially associated with volcanic rocks.

Introduction

Bedrock mapping was undertaken by the Manitoba Geological Survey (MGS) in the northern arm of Russell Lake during June and July of 2020 as a follow-up to work by Martins and Couëslan (2019a, b). Preliminary results from bedrock mapping of the 2020 field season are presented here and on the accompanying map PMAP2020-1 (Martins and Couëslan, 2020a).

Outcrops are less abundant in the northern arm of Russell Lake than in the south; this is especially true for the north shoreline, where esker deposits and boulders dominate. Steep rock faces, high water levels and often heavy and dark lichen cover hindered outcrop observations during the 2020 fieldwork. A magnetic anomaly map of Canada (Miles and Oneschuk, 2016) was used to help trace rock units. The preliminary maps of Baldwin (1974) and Zwanzig and Wielezynski (1975b) were used to trace units in areas that were inaccessible.

The main objectives of bedrock mapping for the 2020 field season were to

1) continue to update the bedrock geology to produce a seamless geological map of the Russell Lake area;
2) continue with lithogeochemical, isotopic, metamorphic and geochronology studies;
3) contribute to updating the regional framework and tectonic interpretation by taking into account recent work in the Trans-Hudson orogen (THO), particularly in the Granville Lake area (e.g., Zwanzig, 2019) of the Kisseynew domain (KD) north flank; and
4) assess the economic potential of the KD, especially graphite occurrences reported by previous authors (e.g., Lenton, 1981), in light of the current market trends and growing interest in this commodity.

Rock descriptions and mineral estimates in this report are based on outcrop observations. Further studies focusing on metamorphic, tectonic and stratigraphic interpretations of the Russell–McCallum lakes area are ongoing. All rocks in the study area were metamorphosed to at least upper-amphibolite–facies conditions (Lenton, 1981; Martins and Couëslan, 2019b); however, for the sake of brevity, the 'meta' prefix has been omitted from rock names. Where possible, protolith interpretation was used in the naming of rock units.

Previous work

The Russell–McCallum lakes area was previously mapped by Downie (1936) of the Geological Survey of Canada (GSC) at a scale of 1:253 440. Later, geological mapping by Hunter (1953) extended the regional coverage into McKnight Lake at a scale of 1:126 720. The MGS mapped the area in the 1970s, Russell Lake by McRitchie (1975a, b) at a scale of 1:126 720 and the adjoining areas by

Baldwin (1974) and Zwanzig and Wielezynski (1975a, b) at a scale of 1:126 720 and Pollock (1966) at a scale of 1:63 360. The area to the west of Russell–McCallum lakes was mapped by Gilboy (1976) at a scale of 1:100 000. Lenton (1981) mapped the area extending from the Russell–McCallum lakes area to McKnight Lake at a scale of 1:50 000. In 2019, the MGS initiated a multidisciplinary geological mapping project in the Russell–McCallum lakes area. Preliminary results of bedrock mapping can be found in Martins and Couëslan (2019a, b, 2020a, b), and results from surficial mapping in Hodder (2019, 2020).

The Russell Lake area was a target for economic studies focused on base-metal mineralization along the contact zone between rocks of the Burntwood and Sickle groups, the two major stratigraphic units of the area (Baldwin, 1976, 1980). There are records of base-metal exploration work in the area from 1954 until 1983 (e.g., Assessment Files 91616, 93803, Manitoba Agriculture and Resource Development, Winnipeg). Airborne electromagnetic surveys located a number of conductors that were commonly followed up by diamond-drilling. Unfortunately, base- and precious-metal assay results (e.g., Ni, Au, Ag, Cu) were not promising and led to abandonment of the claims. However, significant graphite mineralization was reported in the majority of drillholes (e.g., Assessment Files 92387, 93001, 93804), including Assessment File 90985, submitted by Hudson Bay Exploration and Development Company Limited. The company drilled six holes in 1962 and reported up to 2.2 m (7.3 feet) of near-solid to solid graphite, pyrite and pyrrhotite, 1.9 m (6.2 feet) of well-mineralized graphite and 1.2 m (4.1 feet) of mineralized graphite.

Regional geology

The KD forms the large central part of the predominantly juvenile Paleoproterozoic internides, which make up the Reindeer zone of the Trans-Hudson orogen (THO) in Manitoba (Figure GS2020-5-1; Stauffer, 1984; Lewry and Collerson, 1990). The KD is dominated by metamorphosed greywacke and mudstone of the Burntwood group and arkose of the Sickle group. The provenance of the Burntwood group is interpreted to be

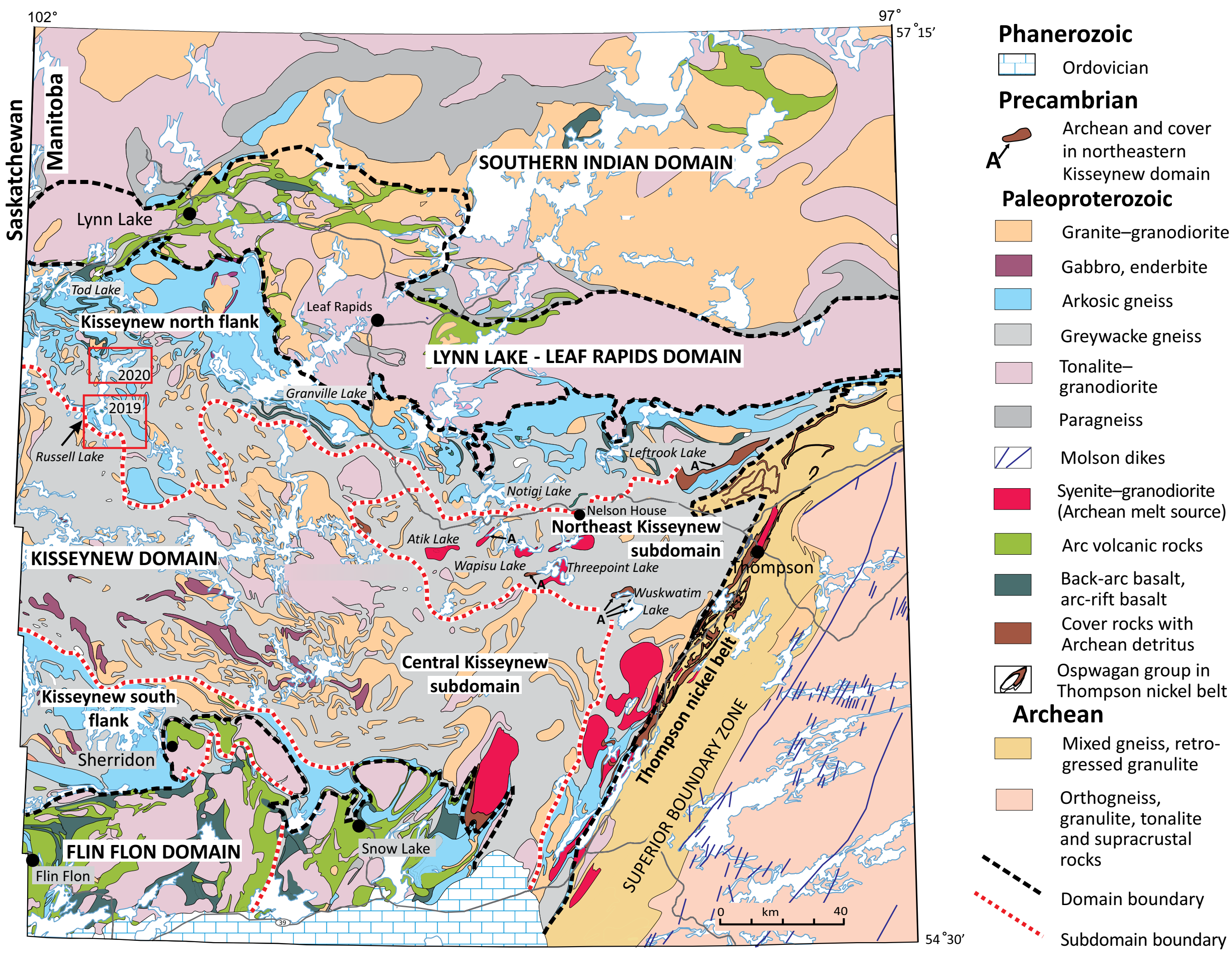

Figure GS2020-5-1: *Regional geology of the Trans-Hudson orogen in Manitoba, indicating the subdivision of the Kisseynew domain proposed by Zwanzig and Bailes (2010). Red rectangles outline the 2020 and 2019 study areas.*

the adjacent magmatic-arc terranes, with detritus from the arcs being deposited in coalescing turbidite fans (Bailes, 1980; Zwanzig, 1999). The turbidites were deformed and metamorphosed to amphibolite- and transitional granulite–facies, resulting in migmatization. Rocks from the Sickle group are typically metamorphosed arkosic units that are interpreted to have been deposited unconformably on the Lynn Lake arc massif (Zwanzig, 2008) and prograded over the Burntwood group during the onset of terminal continental collision. Both Burntwood and Sickle groups are intruded by granitoid rocks, including foliated granitoid bodies ranging from granite to tonalite and later pegmatite (e.g., Lenton, 1981; Zwanzig and Bailes, 2010; Zwanzig, 2019).

The geological setting of the KD is a matter of debate. Some authors (Ansdell, 2005; Corrigan et al., 2005, 2009) favour the interpretation of the KD as a back-arc basin to the Flin Flon volcanic arc that was filled during its opening. However, other authors (e.g., Zwanzig, 1999; Zwanzig and Bailes, 2010) favour an interpretation of a longer lived and dynamic evolution in which the present geographic distribution of rocks resulted from crustal-scale overturning and oroclinal bending during continental collision.

The Russell Lake area is located within the Kisseynew north flank, a subdivision of the KD introduced by Zwanzig and Bailes (2010; Figure GS2020-5-1). The Kisseynew north flank is dominated by Paleoproterozoic metasedimentary rocks of the Burntwood and Sickle groups, typically separated by the volcanosedimentary Granville complex, a composite, predominantly mafic assemblage that includes remnants of ocean floor. The Kisseynew north flank is bounded to the north by the Lynn Lake belt, to the east by the northeast Kisseynew subdomain and to the south by the central Kisseynew subdomain.

Bedrock geology of Russell Lake, northern arm

The majority of outcrops in the northern arm of the Russell lake area are dominated by sedimentary rocks of the Burntwood and Sickle groups, volcanic rocks and minor granodiorite bodies (Figure GS2020-5-2). Figure GS2020-5-3 represents an idealized stratigraphic column for the Russell Lake area presented by Martins and Couëslan (2019b). The Burntwood and Sickle groups are interpreted to be coeval (e.g., Zwanzig and Bailes, 2010); therefore, the succession of units is not to be viewed as a true chronostratigraphic sequence.

Mafic volcanic rocks and associated sediments (unit 1a–d)

Massive basalt (unit 1a)

Massive basalt (unit 1a) is dark green-grey, medium to coarse grained and foliated, with massive layering <2 m thick. Local, discontinuous and heterogeneous bands (<10 cm wide) may represent flow breccia. Local, discontinuous green layers could be the result of calcsilicate alteration (Figure GS2020-5-4a) or represent strongly attenuated pillowed basalt. The composition of the massive basalt is variable but is typically 60–70% amphibole, 20–30% plagioclase and 5–10% biotite, with trace amounts of pyrite and chalcopyrite, and rare magnetite. Local layers contain up to 10% garnet, which can be partially or completely pseudomorphously replaced by plagioclase. Local gossanous zones or layers up to 2 m wide occur within the basalt. The gossanous layers can be associated with zones of carbonate alteration containing variable amounts of carbonate, quartz, very dark titanite or spinel, diopside and plagioclase, or be spatially associated with quartzite (unit 1c) or diopside gneiss (unit 1d).

Pillowed basalt (unit 1b)

Pillowed basalt (unit 1b) was identified with confidence in a single outcrop in the northern arm of Russell Lake; however, it is more common in the southern basin. This unit is foliated, nonmagnetic and medium to coarse grained, with light grey-green weathered and dark green fresh surfaces. The groundmass is plagioclase rich, with 50–60% hornblende, up to 5% garnet and trace to 1% pyrite and chalcopyrite. Fine- to medium-grained plagioclase aggregates could be pseudomorphous after garnet, or amygdules (Figure GS2020-5-4b). Pillows are densely packed, flattened and vary in size. They are up to 30 cm in the longest direction. Pillow selvages are about 5 cm thick and very dark grey-green. Top indicators for the pillowed basalt were obscured by deformation.

Quartzite with minor schistose layers (unit 1c)

Quartzite is spatially associated with massive basalt (unit 1a) on the south shoreline of the northern arm of Russell Lake (Figure GS2020-5-2; Martins and Couëslan, 2020a). This unit is light rusty grey on weathered surfaces and dark grey where fresh, fine grained, nonmagnetic and compositionally layered with minor intervals of schist (variable but typically 5–10 cm wide). This quartzite is nearly 98% quartz, with 1–2% graphite and trace to 1% sulphide. Local, strongly gossanous beds contain 80–90% quartz, 1–3% sulphides and up to 15% graphite.

Diopside gneiss and associated marble (unit 1d)

Diopside gneiss is found associated with marble, and both are spatially associated with massive basalt (unit 1a). The diopside gneiss is well layered, foliated to strongly foliated, nonmagnetic, coarse grained, and very dark grey when weathered and dark green-grey when fresh. The mineralogy of this unit is highly variable: 30–60% quartz, 15–20% diopside, 2–3% titanite, and plagioclase. The marble component is commonly recessively weathered (Figure GS2020-5-4c) and composed mainly of carbonate (60–70%), diopside (10–15%) and scapolite (10–20%). Marble appears to be conformable with

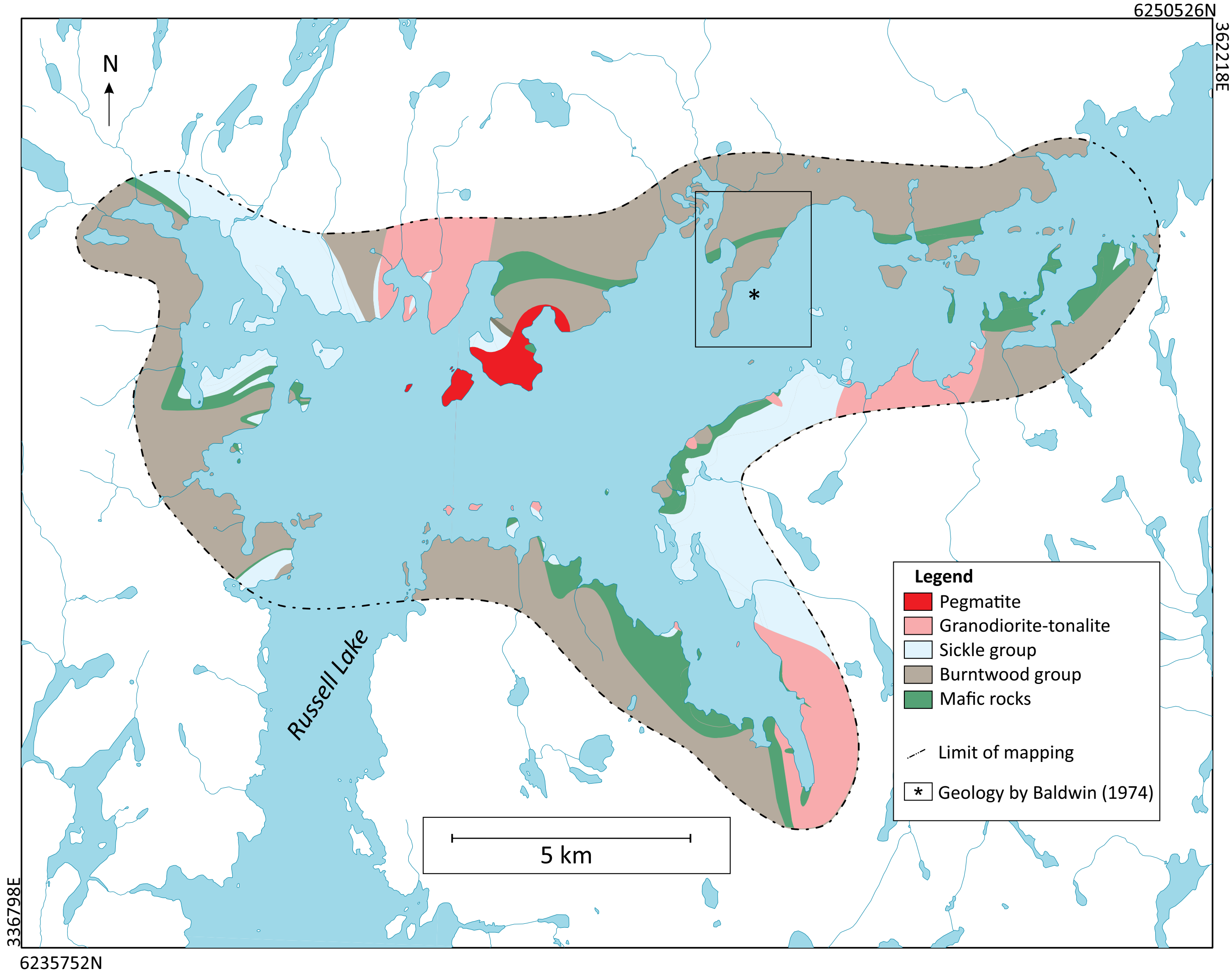

Figure GS2020-5-2: *Simplified geology of the northern arm of Russell Lake (after Martins and Couëslan, 2020a).*

the gneissosity and occurs in pods or lenses. At one locality, marble outcrops for more than 10 m across strike and is nonmagnetic, medium grained, black where weathered (due to lichen cover) and grey-green when fresh. Marble at this location consists of carbonate with diopside (10–20%), phlogopite (2–3%), serpentinized olivine (3–5%), graphite (1%) and both pyrite and chalcopyrite (trace to 1%). Diopside gneiss contains sparse chert layers 20–40 cm wide. The chert is internally layered and composed of quartz (95–98%); pyrite, chalcopyrite and pyrrhotite (trace to 1%); and trace amounts of graphite, titanite and diopside.

More diopside-rich zones (25–35% diopside) within the gneiss are characterized by rusty weathering and abundant sulphides (2–3% pyrrhotite and minor chalcopyrite). Local gossanous layers occur throughout the diopside gneiss and marble unit. Pending the results of whole-rock geochemistry, the diopside gneiss and associated marble are tentatively interpreted as carbonate-altered mafic volcanic rocks.

Burntwood group rocks

Garnet-biotite greywacke (unit 2)

Outcrops of Burntwood group garnet-biotite greywacke were described in detail by Martins and Couëslan (2019b) and will not be described again here. Outcrops in the northern arm of Russell Lake have similar characteristics, consisting of monotonous and rhythmically interbedded psammitic and pelitic layers with local pods of calcsilicate and sparse iron formation. The lack of unique marker horizons, combined with ubiquitous isoclinal folding, does not allow for the subdivision of Burntwood group rocks into smaller stratigraphic packages, nor for the tracing of stratigraphy between outcrops. However, it is noted that, toward the east end of the northern arm of Russell Lake, Burntwood group rocks are typically more pelitic.

As pointed out by Martins and Couëslan (2019b), the Russell–McCallum lakes area shows clear evidence of, and economic potential for, graphite mineralization. Assay results from

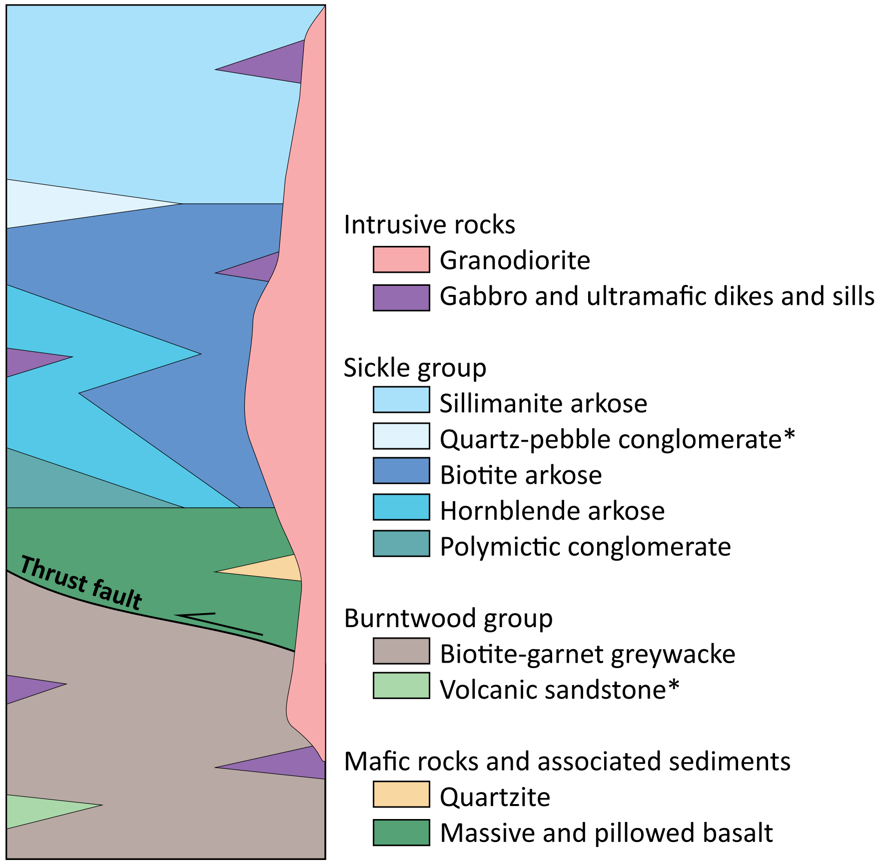

Figure GS2020-5-3: *Idealized, schematic stratigraphic column of the Burntwood and Sickle group rocks at Russell Lake; asterisks indicate rock units not observed in the northern arm of the lake (modified from Martins and Couëslan, 2019b).*

the 2019 field season revealed up to 3.31 wt. % total carbon in Burntwood group rocks (Martins and Couëslan, 2020b). The same authors also noticed that it is not possible to obtain a clear relationship between the graphite content and the composition of the Burntwood group rocks (psammitic versus pelitic bulk compositions), and that it is possible the graphite is widespread throughout the Burntwood group sequence. Graphitic horizons can also be associated with enrichments in several transition metals. A graphitic sulphide-facies iron formation (>5 m thick) on the west shore of McCallum Lake was found to contain 0.82 wt. % total carbon, 63.8 ppm Co, 609 ppm Cu, 377 ppm Ni, 73.8 ppm Mo and 22.2 ppm U (Martins and Couëslan, 2020b).

Sickle group rocks (units 3–6)

Martins and Couëslan (2019b) distinguished five different arkosic rock units within the Sickle group (listed by inferred stratigraphic order): polymictic conglomerate, hornblende arkose, biotite arkose, quartz-pebble conglomerate and sillimanite arkose. In the northern arm of Russell Lake, the quartz-pebble conglomerate is absent, whereas all other units were identified. A sillimanite-garnet arkosic unit was identified in the northern arm of Russell Lake that was not distinguished by Martins and Couëslan (2019b).

Polymictic conglomerate (unit 3)

Polymictic conglomerate is well exposed in the central area of Russell Lake's northern arm, in contrast to the rare outcrops found in the south basin of the lake. Outcrops of this unit are highly deformed (L>S), but pebbles and cobbles are discernible (Figure GS2020-5-4d). The polymictic conglomerate is magnetic and varies from matrix to clast supported, with clasts varying in size (up to 30 cm but typically <15 cm across). Composition of the clasts varies from felsic to mafic (local quartz cobbles and pebbles were observed) and the matrix is plagioclase rich, with hornblende (15–20%), quartz (10–20%), green amphibole (5–10%), biotite (5–8%) and magnetite (trace to 1%). Discrete late quartz veins cut the unit.

Hornblende arkose (unit 4)

This unit typically occurs at the contact with massive basalt (unit 1a). It is overlain by biotite arkose (unit 5) and locally underlain by polymictic conglomerate (unit 3; Martins and Couëslan, 2019a, b). Where it was observed in the northern arm of Russell Lake, the unit is layered. Compositional layering consists of 2–4 cm wide light grey layers alternating with 5–10 cm wide dark grey layers, and reflects variations in the mafic mineral content. Hornblende arkose is medium grey and weathers to dark grey, and is foliated, nonmagnetic to weakly

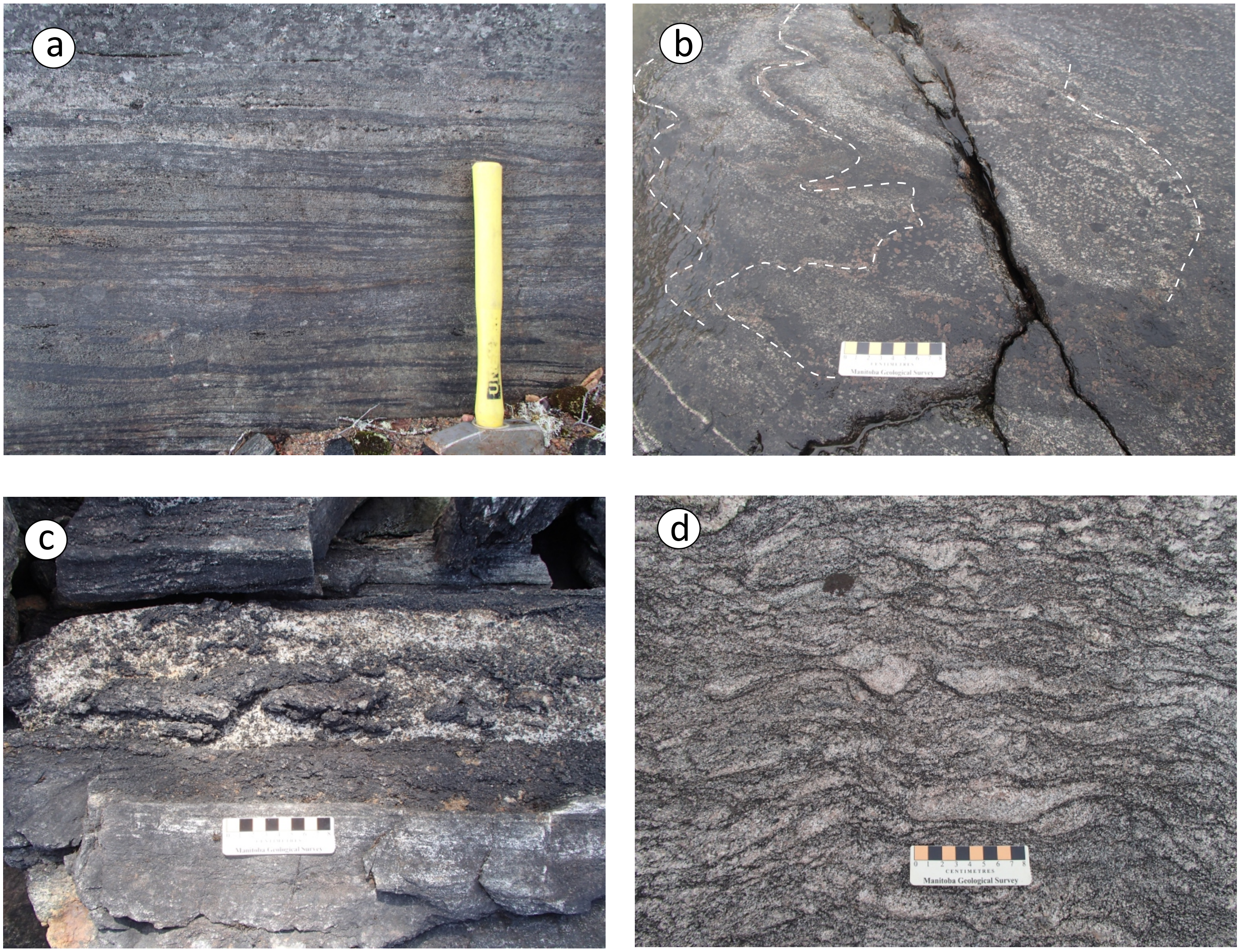

***Figure GS2020-5-4:** Outcrop photographs from the northern arm of Russell Lake: **a)** massive basalt (unit 1a, with green layers that could be the product of calcsilicate alteration; **b)** pillowed basalt (unit 1b) characterized by dark pillow selvages (dashed lines); **c)** recessively weathered marble associated with diopside gneiss (unit 1d); **d)** polymictic conglomerate (unit 3).*

magnetic and medium grained. It contains feldspar (40–50%), quartz (25–30%), hornblende (15–20%, locally up to 30%), biotite (5–7%) and magnetite (trace).

Biotite arkose (unit 5)

Biotite arkose is light pink-grey and weathers to light grey. It is medium to coarse grained, layered to locally laminated, magnetic and foliated with minor isoclinal folds. Composition of the biotite arkose is similar to that described by Martins and Couëslan (2019b), typically consisting of quartz (30–40%, locally up to 50%), feldspar (20–30%), biotite (7–10%, locally up to 20% in more aluminous layers) and magnetite (trace to locally 2%). Layering typically consists of thin biotite-enriched laminations (2–3 mm) alternating with thicker quartzofeldspathic layers (<10 cm). Local calcsilicate layers and nodules are composed mostly of epidote, quartz and plagioclase, with local carbonate. Local pods of leucosome were also identified (commonly <7 cm wide).

Sillimanite arkose (unit 6)

Sillimanite arkose is dark grey when weathered to light pinkish grey when fresh. It is medium grained, foliated, bedded and magnetic, and locally contains calcsilicate layers. Sillimanite arkose contains quartz (30–40%, locally up to 50%), plagioclase and K-feldspar (30–50%), biotite (3–5%), sillimanite (up to 20% in the more aluminous layers) and magnetite (trace to 1%). As described by Martins and Couëslan (2019b), the amount of sillimanite in this unit can be variable, with less aluminous horizons containing 3–5% and more aluminous sections containing higher modal percentages. Sillimanite commonly occurs along foliation planes; in more aluminous layers, it occurs as abundant sillimanite knots that are typically 2–10 cm in size.

Sillimanite-garnet arkose (unit 7)

A sillimanite-garnet arkosic unit was identified in several outcrops in the northern arm of Russell Lake. This unit contains sillimanite, garnet and locally cordierite. Martins and Couëslan (2019b) identified a similar unit in very few outcrops in the south basin of Russell Lake. At the time, the authors suggested this was a variety of biotite arkose.

Typically, the sillimanite-garnet arkose is magnetic, pinkish grey when weathered and medium grey when fresh, fine grained, well banded and foliated, and migmatitic with minor injections of felsic melt. Mineralogy is highly variable, namely quartz (40–50%), K-feldspar (10–30%), biotite (15–20%), plagioclase (10–15%), sillimanite (up to 7%), garnet (up to 5%), cordierite (2–3%), magnetite (trace to 1%) and trace amounts of pyrite. Locally, a porphyroblastic texture was observed in this unit, with a higher K-feldspar and biotite content than what is typically described for the sillimanite arkose unit elsewhere on Russell Lake, as well as sparse garnet (Figure GS2020-5-5a). In some occurrences, the sillimanite-garnet arkose can be difficult to differentiate from the Burntwood group greywacke, but the arkose is typically magnetic and does not contain graphite.

The stratigraphic position of the sillimanite-garnet arkose is presently unknown. It is possible that this unit represents a shoreface deposit, which would be transitional between the coeval terrestrial Sickle and marine Burntwood groups. The sillimanite-garnet arkose is similar to descriptions of interlayered pelite and quartzite considered as the shallow-water marine facies that forms the top of the Burntwood group (Zwanzig and Bailes, 2010). Alternatively, it could represent compositional variations of either the sillimanite arkose or biotite arkose, and/or the effects of varying metamorphic conditions that resulted in different metamorphic mineral assemblages (e.g., the incongruent reaction of biotite + sillimanite + quartz to produce cordierite + garnet + melt/K-feldspar). Another possible interpretation is that this sillimanite-garnet arkose is a basal unit of the Sickle group, as described by Lenton (1981), who also noted a pelitic gneiss with variable stratigraphic position.

Further investigation, including petrography and results from whole-rock geochemistry, is required. Current field observations favour the interpretation of the sillimanite-garnet arkose as a separate, mappable arkosic unit with an unknown position in the current stratigraphy.

Figure GS2020-5-5: *Outcrop photographs of rocks from the Russell Lake area:* ***a)*** *porphyroblastic texture of garnet-sillimanite arkose, Sickle group (unit 7);* ***b)*** *mafic xenoliths in granodiorite (unit 9);* ***c)*** *altered tonalite (unit 10) that appears bleached.*

Mafic dikes (unit 8)

Mafic to ultramafic dikes and sills were identified in the south basin of Russell Lake intruding rocks of both the Sickle and Burntwood groups. Although also present in the current map area, their occurrence is not as prevalent. The intrusions are typically <40 cm in width but reach up to 2 m. They are black, medium grained, foliated and locally boudinaged, and range from nonmagnetic to magnetic. The composition is similar to what was described by Martins and Couëslan (2019b), namely hornblende (70–80%), plagioclase (10–15%, locally up to 30%), biotite (1–2%) and trace amounts of magnetite. The mapped dikes are not large enough to be represented at the 1:20 000 mapping scale.

Granodiorite (unit 9)

Granodiorite is medium to dark pinkish grey and weathers light grey to beige. The rock is medium to coarse grained, foliated and slightly magnetic. It is relatively homogeneous, with local pods of leucosome and pegmatite injections. Local exposures display a discontinuous, almost subhorizontal gneissosity. This granodiorite is typically composed of 40–50% plagioclase, 20–30% quartz, 15–20% K-feldspar and 5–8% biotite, with trace amounts of apatite. Local outcrops of granodiorite contain xenoliths of massive basalt (unit 1a) that vary in size from 5 to 30 cm. The rafts are usually rotated and randomly oriented (Figure GS2020-5-5b). Local, partially digested xenoliths of Burntwood and Sickle group rocks can also be present in this granodiorite.

Tonalite (unit 10)

Tonalite is nonmagnetic to slightly magnetic, pale beige-white where weathered and light grey-blue where fresh. This unit is medium to coarse grained, foliated and cut by late brittle faults (trending mainly east). Local shear bands 10–50 cm in width exhibit sinistral sense of movement. It typically contains green-brown amphibole or pyroxene (3–5%), biotite (5–8%), titanite (trace amounts) and local graphite (1%), with the remainder being quartz and plagioclase (locally epidotized). In some outcrops, the only mafic mineral identified is biotite. Locally, a ‘pockmarked’ texture is caused by the weathering of aggregates of biotite, dark green amphibole and garnet. The pockmarks are 0.5–0.8 cm wide and make up as much as 5% of the weathered surface. An aplitic phase of the tonalite is locally present. Rare xenoliths of the local country rock were also observed.

In general, pods of carbonate alteration (~20 cm wide) are rare in tonalite; however, one outcrop was characterized by pervasive alteration. The altered tonalite appears bleached (Figure GS2020-5-5c) where weathered and is medium grey where fresh. It is medium to coarse grained, strongly gneissic and nonmagnetic. Composition is similar to the unaltered tonalite. Scapolite was identified in association with carbonate pods. The carbonate pods could be cogenetic with the carbonate alteration observed in the mafic volcanic rocks. That would suggest that the tonalite was emplaced within the volcanic package prior to widespread carbonate alteration. Alternatively, the strong gneissosity could indicate primary compositional layering and the altered rock could represent altered felsic volcanic rock. Results from whole-rock geochemistry may help refine this interpretation.

Granitic pegmatite (unit 11)

As described by Martins and Couëslan (2019b), pegmatite bodies are common in the Russell Lake area and cut all other map units; however, multiple generations of intrusions are present. The pegmatite bodies are typically plagioclase dominant, but K-feldspar–dominant pegmatite bodies are also present. Other major constituents are quartz and biotite. Common accessory minerals are magnetite, muscovite, garnet and locally cordierite and sillimanite. Pegmatite bodies typically dip steeply and occur either discordant to the main foliation and gneissosity or concordant and locally folded (most likely by F_3). Most pegmatite dikes are <2 m wide (some can be up to 30 m) and unzoned or very crudely zoned, with characteristic granitic pegmatite textures such as graphic and locally comb textures. Dikes locally display both pegmatitic and aplitic zones.

Metamorphism and structure

Martins and Couëslan (2019b) provided a detailed description of the metamorphic history and structural geology of the Russell Lake area in which they summarized and integrated findings from previous workers (e.g., McRitchie 1975a, b; Lenton, 1981).

In the northern arm of Russell Lake, observations are similar to those in the southern basin, so this information will not be repeated here. However, a higher percentage of leucosome in some outcrops of the Sickle and Burntwood rocks suggests an increase in metamorphic grade in the northern arm of Russell Lake.

The majority of structures measured in outcrops are interpreted to be the result of D_3 deformation that resulted in northeast-trending isoclinal folds and associated strong linear and planar fabrics in the direction of the F_3 fold axes. Most linear fabrics observed in the map area parallel regional F_3 fold axes. Structures resulting from the D_4 and D_5 deformations are manifested by brittle faults that trend northwest. As in the south basin, the observed brittle structures postdate all phases of folding.

Economic considerations

Natural graphite has several uses, including anode material for Li-ion batteries, brake linings, lubricants, powdered metals, refractory applications and steelmaking (U.S. Geological Survey, 2019). Currently, natural graphite is a much-sought-after commodity, mainly due to anticipated demand associated with the production of Li-ion batteries. Graphite is listed by the U.S. Department of the Interior as one of 35 critical minerals for the United States (U.S. Department of the Interior) and by the European Commission as part of its list of critical raw materials for the European Union (European Commission, 2020). Total carbon analytical results from the 2019 field season (Martins and Couëslan, 2020b) revealed up to 3.31 wt. % total carbon in greywacke of the Burntwood group. Assay results of rusty layers associated with these rocks did not reveal any significant anomalies in Cu, Zn, Au or Ag. Another occurrence of graphite in the study area is graphite horizons associated with quartzite (unit 1c; found associated with massive basalt) identified during the 2020 field season in the northern arm of Russell Lake. Assay results are pending.

The diopside gneiss and marble association (unit 1d) is tentatively interpreted as carbonate-altered mafic rocks. Pervasive carbonate alteration in mafic rocks can be associated with precious and base-metal mineralization. Assays and whole-rock geochemistry will help with these interpretations.

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