GS-5 Stratigraphic and structural setting of gold deposits in the vicinity of the Central Manitoba mine, Rice Lake greenstone belt, southeastern Manitoba (part of NTS 52L14)

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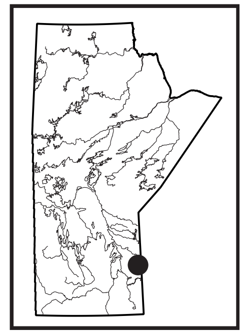

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Summary

The Rice Lake greenstone belt is situated in the western portion of the Uchi subprovince of the Archean Superior province[2] and is the most important lode-gold district in Manitoba. The southeastern portion of this belt includes several gold deposits, most of which are clustered in the vicinity of the past-producing Central Manitoba mine. In the summer of 2013, detailed geological mapping (1:5000 scale) was carried out in the mine area in order to better understand the stratigraphic and structural setting of gold deposits. Based on this work, a revised stratigraphic sequence is proposed and several generations of deformation structures are recognized. This report provides an overview of these results and includes a brief discussion of possible metallogenic processes based on the stratigraphic setting, structural geology, alteration zonation and style of mineralization.

Introduction

The Rice Lake greenstone belt lies in the western portion of the Uchi subprovince of the Superior province and is the most productive lode-gold district in Manitoba. Several past-producing gold mines are located on the southeastern side of the Ross River pluton in the Rice Lake belt. In order to improve understanding of the stratigraphic and structural setting of these deposits and to better constrain exploration models for shear-related lode-gold deposits within this highly prospective area, detailed bedrock mapping (1:5000 scale) was carried out by the first author in the vicinity of the Central Manitoba mine during the summer of 2013. The bedrock mapping is supplemented by analysis of mineralized drillcore. Approximately 180 samples have been collected for petrographic and microstructural examination, geochemical analysis, and U-Pb and Re-Os geochronological studies. This report provides a summary of results from the second year of fieldwork of the first author's Ph.D. thesis project, which is being funded by Bison Gold Resources Inc. and a Collaborative Research and Development grant from the Natural Sciences and Engineering Research Council of Canada, with in-kind and logistical support from the Manitoba Geological Survey.

The report includes detailed descriptions of the stratigraphic sequence, deformation structures and gold occurrences in the map area, following a brief introduction to the regional geology. The structural mapping was focused on establishing the various generations of ductile deformation structures on the basis of overprinting relationships and fold styles.

Regional geological setting

The Rice Lake greenstone belt is situated approximately 170 km northeast of Winnipeg, Manitoba, in the western portion of the Uchi subprovince of the Superior province (Figure GS-5-1). This belt hosts several significant gold deposits, which are localized on the northwestern and southeastern margins of the Ross River pluton. The Rice Lake belt consists of Neoarchean mafic, intermediate and felsic metavolcanic and metasedimentary rocks, and subvolcanic intrusions (Poulsen et al., 1996; Bailes et al., 2003; Anderson, 2008). It is flanked on the north by the Wanipigow River plutonic complex of the granitoid-dominated North Caribou terrane. To the south, the supracrustal rocks are flanked by the Manigotagan gneissic belt of the English River subprovince. The northern and southern interfaces of the Rice Lake greenstone belt are defined by the Wanipigow and Beresford Lake shear zones, and by the Manigotagan shear zone, respectively. These major structures are east- to southeast-trending, subvertical, crustal-scale ductile faults that show evidence for late-orogenic dextral transcurrent-shear deformation (Poulsen et al., 1996; Anderson, 2008). Supracrustal rocks within the Rice Lake belt are divided into four lithotectonic assemblages: the mainly volcanic Bidou and Gem assemblages, and the mainly sedimentary Edmunds and San Antonio assemblages (e.g., Poulsen et al., 1996; Bailes et al., 2003; Anderson, 2008). The basalt-dominated Bidou assemblage defines the core of the Rice Lake belt and is intruded by the tonalite-dominated Ross River pluton, which has yielded U-Pb zircon ages of 2728 ±8 Ma (Turek et al., 1989) and 2724 ±2 Ma (Anderson, 2008).

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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).

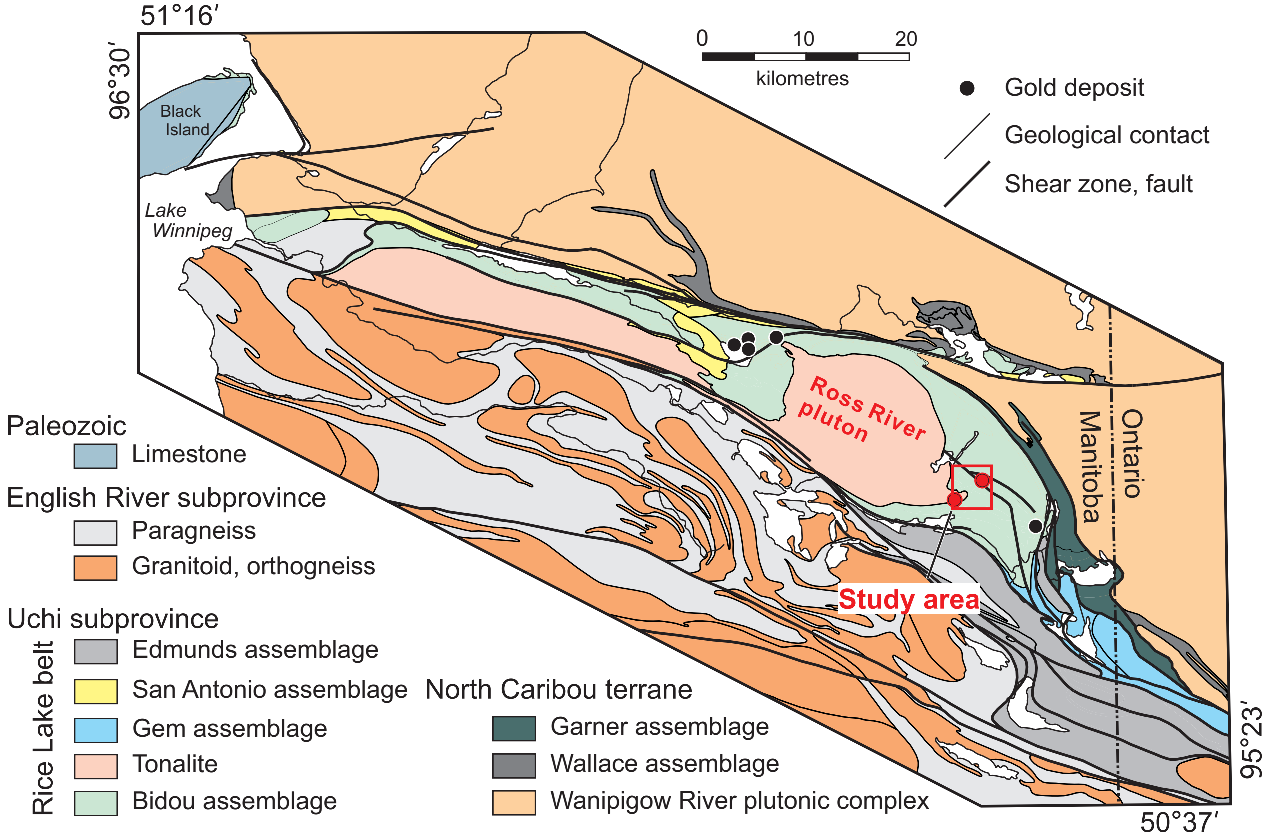

***Figure GS-5-1**: Simplified geology of the Rice Lake greenstone belt, southeastern Manitoba, showing the principal lithotectonic assemblages, major gold deposits and location of the study area (modified from Anderson, 2011).*

Description of stratigraphic units

The southeastern portion of the Rice Lake belt around the southeastern margin of the Ross River pluton has been mapped and investigated by previous workers at a variety of scales (Stockwell and Lord, 1939; Stockwell, 1945; Campbell, 1971; Zwanzig, 1971; Brommecker, 1991, 1996). In particular, regional geology maps by Stockwell (1945, scale 1:63 360 or 1 inch to 1 mile) and reports and accompanying detailed maps by Stockwell and Lord (1939, scale 1:12 000 or 1 inch to 1000 feet) provide excellent descriptions of the regional and local geology as well as gold occurrences in the Halfway Lake–Beresford Lake area.

In 2013, detailed geological mapping at a scale of 1:5000 was conducted in the vicinity of the Central Manitoba mine within the Halfway Lake–Long Lake–Wentworth Lake area (Figure GS-5-2). Metamorphic mineral assemblages in this area record greenschist-facies regional metamorphism. However, since primary textures and structures are typically preserved, the prefix ‘meta’ is omitted from rock units for brevity. The well-established stratigraphic sequence in this area provides fundamental information to interpret the depositional and tectonic setting of the country rocks.

In general, the map area is underlain by mafic volcanic rocks, with subordinate intermediate to felsic volcaniclastic rocks and turbiditic wacke of the Bidou assemblage. Gabbroic and hornblendite sills and dikes intrude the volcano-sedimentary rocks of the Bidou assemblage, and are cut by dominantly tonalitic to granodioritic intrusive rocks of the Ross River pluton. The southeastern margin of the Ross River pluton consists of various felsic intrusive phases, as documented in detail by Zhou et al. (2012a, b). Numerous feldspar±quartz porphyry dikes and aplite dikes intrude the southeastern margin of the Ross River pluton and the adjacent Bidou assemblage.

Bidou assemblage

Massive and pillowed, aphyric to plagioclase-phyric basalt (unit 1)

Basaltic lavas (unit 1) are one of the most abundant and well-exposed rocks within the southern part of the map area. They are typically greyish green or reddish brown on weathered surfaces and greyish green to black on fresh surfaces. Based on primary structures, this unit can be divided into massive basalt (subunit 1a) and pillowed basalt (subunit 1b). The massive basalt consists chiefly of euhedral plagioclase and amphibole (0.5 mm),

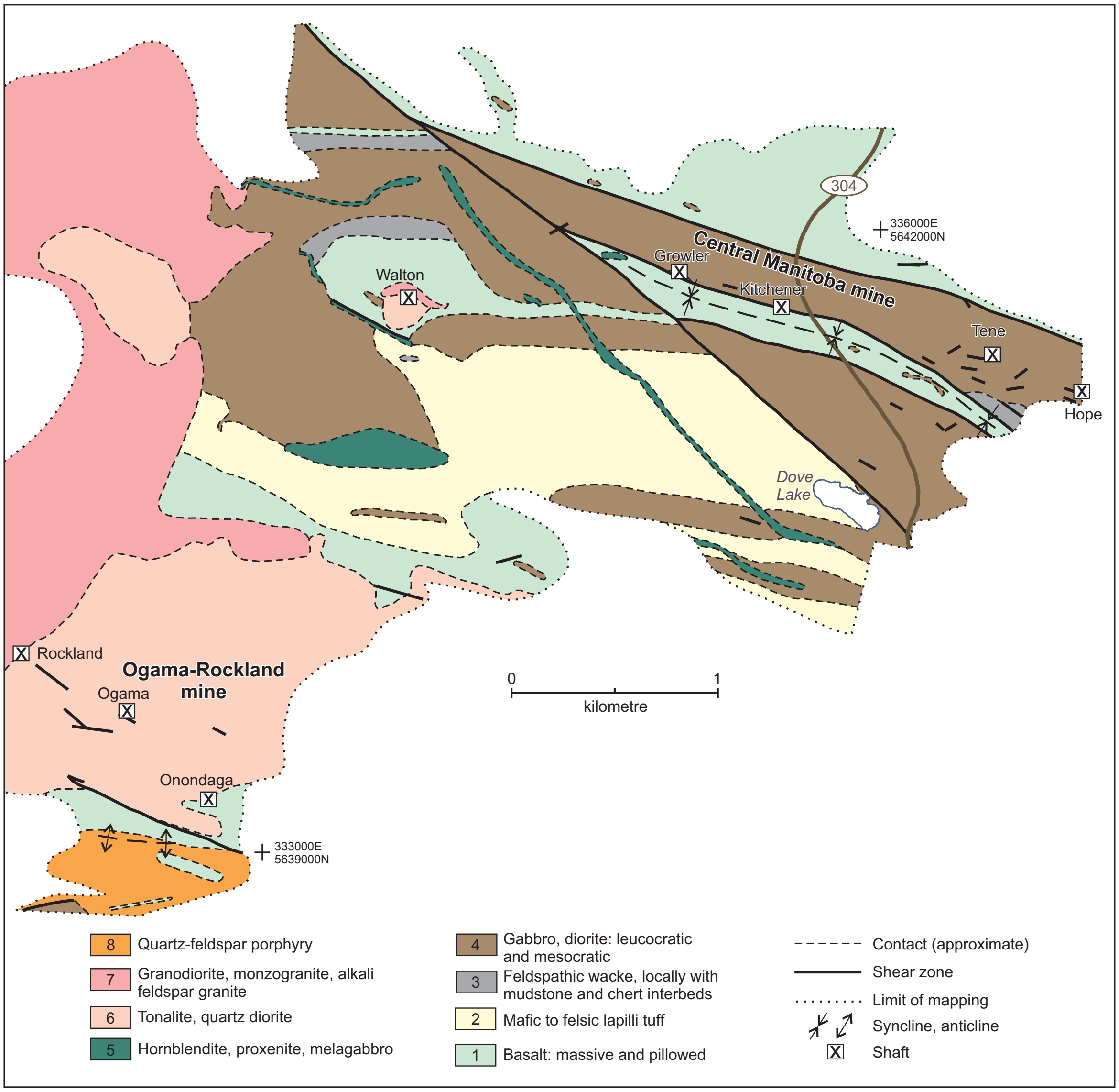

Figure GS-5-2: *Simplified geology of the Central Manitoba mine area.*

with lesser biotite, sericite, quartz, epidote, carbonate and minor opaque minerals, which appear to be magnetite and pyrite. The plagioclase is highly altered to sericite and clay minerals. Where basalt is strongly foliated, chlorite replaces amphibole entirely and forms chlorite schist. Massive basalt has aphyric or porphyritic textures. Rare bands of volcanic breccia are interpreted as the upper, fragmental parts of basaltic flows in this area.

On many outcrops the mafic lavas display pillow-like structures (subunit 1b). The pillows vary in diameter from 10 to 80 cm and typically have a ratio of long axis to short axis from 1:1 to 2:1 (Figure GS-5-3a); however, where strongly foliated, pillows are flattened and the aspect ratio increases to >7:1 (Figure GS-5-3b). Downward-pointing cusps of pillows provide reliable younging indicators in this unit (Figure GS-5-3b) and allow for the identification of macroscopic folds within the map area. In some places, vesicles are present and sometimes partly or wholly filled with quartz or carbonate. Close to the contact with the southeastern apophysis of the Ross River pluton, the basalt contains radial pipe vesicles that are partly or entirely filled with quartz and/or carbonate (Figure GS-5-3c).

Mafic lavas underlie interbedded feldspathic wacke, mudstone, chert and felsic to intermediate crystal-lapilli tuff in many locations, but are locally also interlayered with these rocks. Most of the east-trending contacts are overprinted by shear fractures or shear zones.

Mafic to felsic lapilli tuff (unit 2)

This unit is subdivided into mafic lapilli tuff (subunit 2a) and felsic tuff and lapilli tuff (subunit 2b), which are interbedded in some locations.

Figure GS-5-3: *Outcrop photographs of pillowed basalt (subunit 1b) in the Central Manitoba mine area:* ***a)*** *weakly-flattened pillow-basalt flow;* ***b)*** *strongly-flattened pillow-basalt flow, younging to the south (compass points north);* ***c)*** *quartz-carbonate amygdules (radial pipe vesicles) in porphyritic pillowed basalt.*

Mafic lapilli tuff (subunit 2a) typically has dark to black weathered and fresh surfaces. It is composed of 20–25% subrounded feldspar grains that range in size from 0.5 to 2 mm; 15–20% irregular, sharply angular to rounded felsic clasts, varying from 1 to 4 mm; and 55–60% dark grey, very fine-grained matrix material. Felsic tuff and lapilli tuff (subunit 2b), for the most part, overlies the mafic lapilli tuff. It usually weathers greyish white and has a pale white or greyish green fresh surface. It chiefly consists of 40–50% feldspar grains, 5–15% felsic clasts, 15–20% quartz and 25–30% very fine-grained groundmass. Feldspar grains, ranging in size from 1 to 3 mm, are principally subrounded and equant, with a few euhedral tabular elongate crystals. Felsic lapilli are mostly light grey, subangular to subrounded, ranging from 4 to 8 mm in size. In most locations, this unit is massive, with no visible ductile deformation structures. However, along one contact with a gabbroic sill, the felsic lapilli tuff contains a steep foliation defined by a preferred orientation of elongate quartz, feldspar and felsic lapilli (Figure GS-5-4a).

Massive and bedded feldspathic wacke, with subordinate interbedded mudstone and chert (unit 3)

This unit mainly consists of massive and bedded feldspathic wacke (subunits 3a and 3b, respectively). In some locations, bedded feldspathic wacke is interlayered with mudstone and, rarely, chert (subunit 3c).

The massive feldspathic wacke (subunit 3a) typically has a greenish grey or greyish white weathered surface; the fresh surfaces are usually dark grey or greyish white. The feldspathic wacke is composed of approximately 50% subrounded and tabular feldspar (1–3 mm), 5–10% dark blue rounded quartz grains (0.5–1 mm), and 40% greyish dark, very fine-grained matrix material. In most places, massive feldspathic wacke resembles felsic lapilli tuff (unit 2) in general appearance, except that massive feldspathic wacke does not contain felsic lapilli. It is

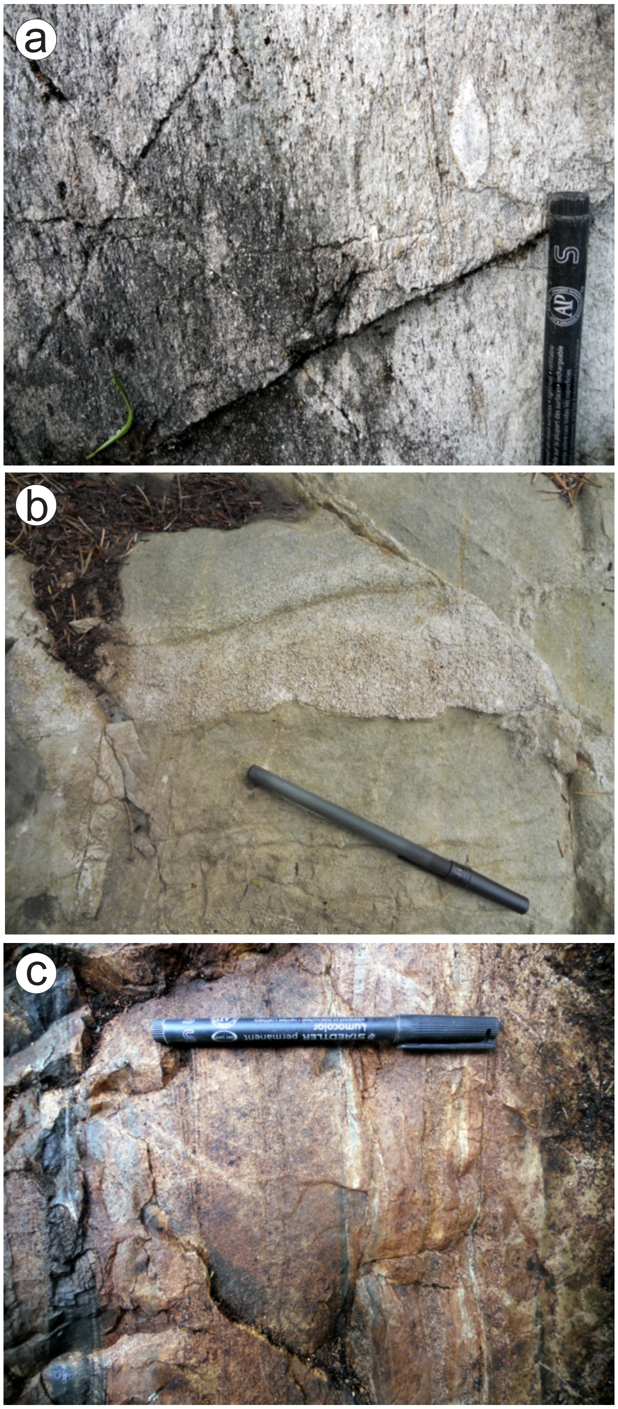

***Figure GS-5-4:** Outcrop photographs of lapilli tuff and wacke and their associated rocks in the Central Manitoba mine area: **a)** foliated felsic lapilli tuff (subunit 2b); **b)** turbiditic wacke illustrating normally-graded beds and prominent scour structure; **c)** interbedded chert, feldspathic wacke and mudstone.*

possible that the massive wacke developed via a range of volcanic and sedimentary processes and is not exclusively of epiclastic origin.

Bedded feldspathic wacke (subunit 3b) weathers light grey and has a greyish green fresh surface. It chiefly consists of round to subangular plagioclase fragments, a few small quartz grains and a matrix of fine-grained feldspar and quartz, with various amounts of sericite, chlorite, epidote and carbonate. Each bed, most ranging in thickness from 2 to 20 cm, has a coarse pebbly base and fines toward the top. The coarse-grained base of some beds is scoured deeply into the underlying mudstone, displaying a typical scour structure and providing unambiguous younging directions (Figure GS-5-4b). Bedded feldspathic wacke locally contains thin chert interbeds (subunit 3c), which are dark grey to black and occur as lenses and thin beds generally less than 2 cm thick (Figure GS-5-4c).

Mafic intrusions

Mafic intrusions are prominent within the map area and mostly consist of gabbroic and dioritic sills and dikes, as well as some minor irregular bodies. Most gabbroic intrusions have a characteristic spotted appearance; however, fine-grained sill-like gabbro bodies can be difficult to distinguish from adjacent basalt flows. Some gabbro sills are likely comagmatic with the basaltic flows. Thicker gabbroic sills are differentiated and layered locally, and consist of plagioclase-rich layers (plagioclase >70%) alternating with amphibole–chlorite-rich (after primary pyroxene) layers (Figure GS-5-5a). The igneous layering is also defined by variations in modal composition on a macroscopic scale. Consequently, gabbroic intrusions are divided, based on the colour index M (dark minerals), into leucocratic (M <35%), mesocratic (35%< M <65%), melanocratic (65%< M <90%) and holomelanocratic varieties (M >90%). It is difficult to define the contacts between melanocratic and holomelanocratic gabbro in the field, therefore these two rocks are grouped into one unit (subunit 5c).

Gabbroic and dioritic sills and dikes (unit 4)

Gabbroic rocks in the map area are subdivided into leucocratic gabbro (subunit 4a), mesocratic gabbro (subunit 4b) and quartz diorite (subunit 4c).

Leucocratic gabbro consists of euhedral amphibole, plagioclase and secondary actinolite and chlorite (after primary pyroxene), ranging from 2 to 5 mm. It locally contains pegmatitic pods composed of very coarse-grained acicular hornblende crystals up to 3 cm in length, with minor plagioclase, and locally contains anhedral blue quartz (Figure GS-5-5b). The pegmatitic pods likely represent hydrous late-stage segregations from the gabbroic magma. Mesocratic gabbro consists of approximately equal amounts of euhedral mafic minerals and plagioclase (Figure GS-5-5c); the grain size varies from 2 to 5 mm. Isolated outcrops of quartz diorite are composed of medium-grained euhedral hornblende, subhedral to euhedral feldspar and abundant anhedral quartz grains.

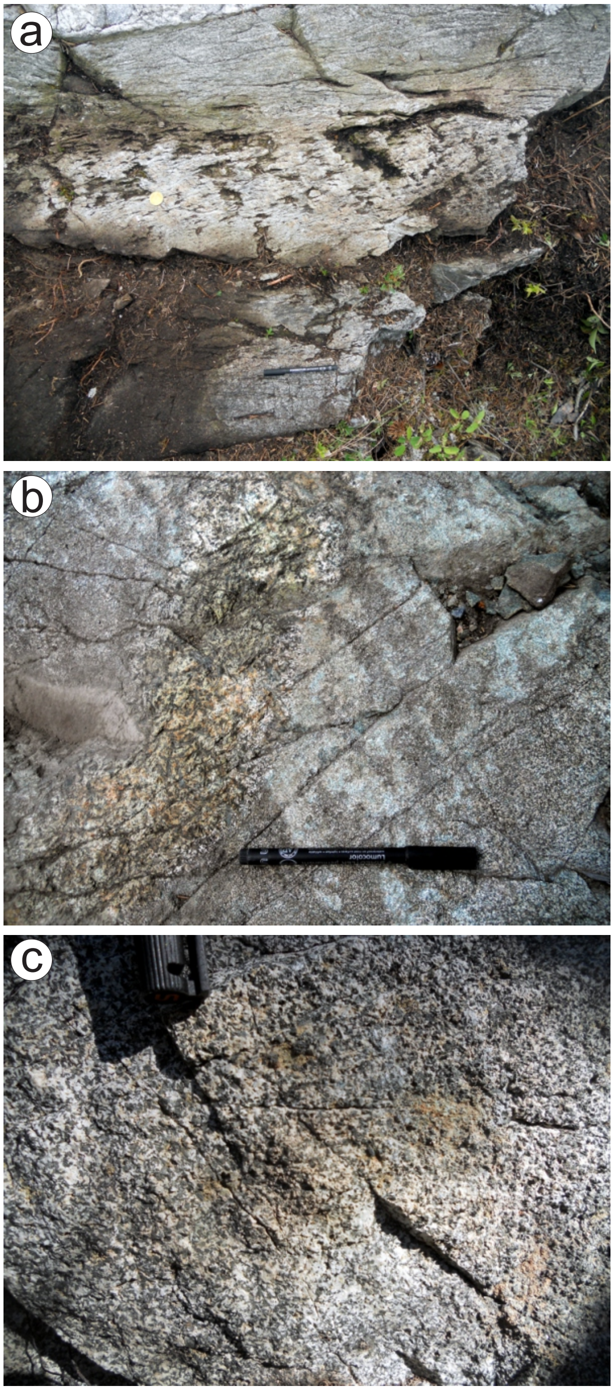

***Figure GS-5-5:** Outcrop photographs of gabbroic intrusions in the Central Manitoba mine area: **a)** strongly-foliated differentiated (layered) mesocratic and leucocratic gabbro; **b)** pegmatitic segregation in leucocratic gabbro (subunit 4a); **c)** equigranular mesocratic gabbro (subunit 4b).*

Hornblendite, pyroxenite, melagabbro (unit 5)

Based on variations in cumulate mafic-mineral phases, this ultramafic unit is divided into hornblendite (subunit 5a), pyroxenite (subunit 5b) and melagabbro (subunit 5c). Hornblendite is dark grey to black, consisting of more than 90% euhedral coarse-grained hornblende. Pyroxenite is similar in appearance to hornblendite, but actinolite and chlorite (after primary pyroxene) are the principal minerals; this rock seldom contains quartz grains. Although melagabbro has a similar grain size, it has more plagioclase and thus a lower colour index. Salt and pepper texture can be recognized in the melagabbro, but rarely in hornblendite or pyroxenite.

Ross River pluton

Various intrusive phases of the Ross River pluton were described in detail by Zhou et al. (2012b). Therefore, the following sections only summarize key features of previously recognized phases and one additional porphyry intrusion (unit 8).

Tonalite, minor quartz diorite (unit 6)

Tonalite (subunit 6a) and quartz diorite (subunit 6b) are mostly porphyritic with coarse phenocrysts of plagioclase, quartz and biotite±hornblende in a medium- to coarse-grained crystalline matrix of feldspar, quartz, biotite, sericite, carbonate and magnetite. Some exposures of tonalite and quartz diorite are sparsely porphyritic to equigranular. Close to the Ogama–Rockland mine, tonalite and quartz diorite are weakly to moderately foliated; the foliation is defined by elongate quartz, feldspar, biotite±hornblende, and strikes 050–070°. At other locations, coarse-grained varieties are massive, with no discernible ductile deformation fabrics.

Granodiorite, monzogranite and alkali feldspar granite (unit 7)

Granodiorite (subunit 7a) is typically porphyritic with coarse phenocrysts of K-feldspar, plagioclase, quartz and biotite±hornblende in a medium-grained matrix of K-feldspar, plagioclase, quartz, biotite, sericite, carbonate and magnetite. A few outcrops also display an equigranular texture. Penetrative foliation similar to tonalite is observed in some outcrops. The contact between tonalite and granodiorite is gradational. Monzogranite (subunit 7b) and alkali feldspar granite (subunit 7c) only occur as small isolated bodies within the granodiorite.

Porphyry phase (unit 8)

In 2013, a distinctive porphyry intrusion was identified in the southern portion of the map area. It contains angular feldspar and subangular to subrounded quartz phenocrysts in a dark grey, fine- to very fine-grained felsic matrix (Figure GS-5-6a). The porphyry intrusion, which varies from 100 to 300 m in thickness, strikes west to west-southwest and can be traced along strike for approximately 300 m. Contacts are sharp, planar and concordant to the basalt flows. A thin (20–40 cm), dark grey, aphanitic chilled margin of felsic composition occurs at the

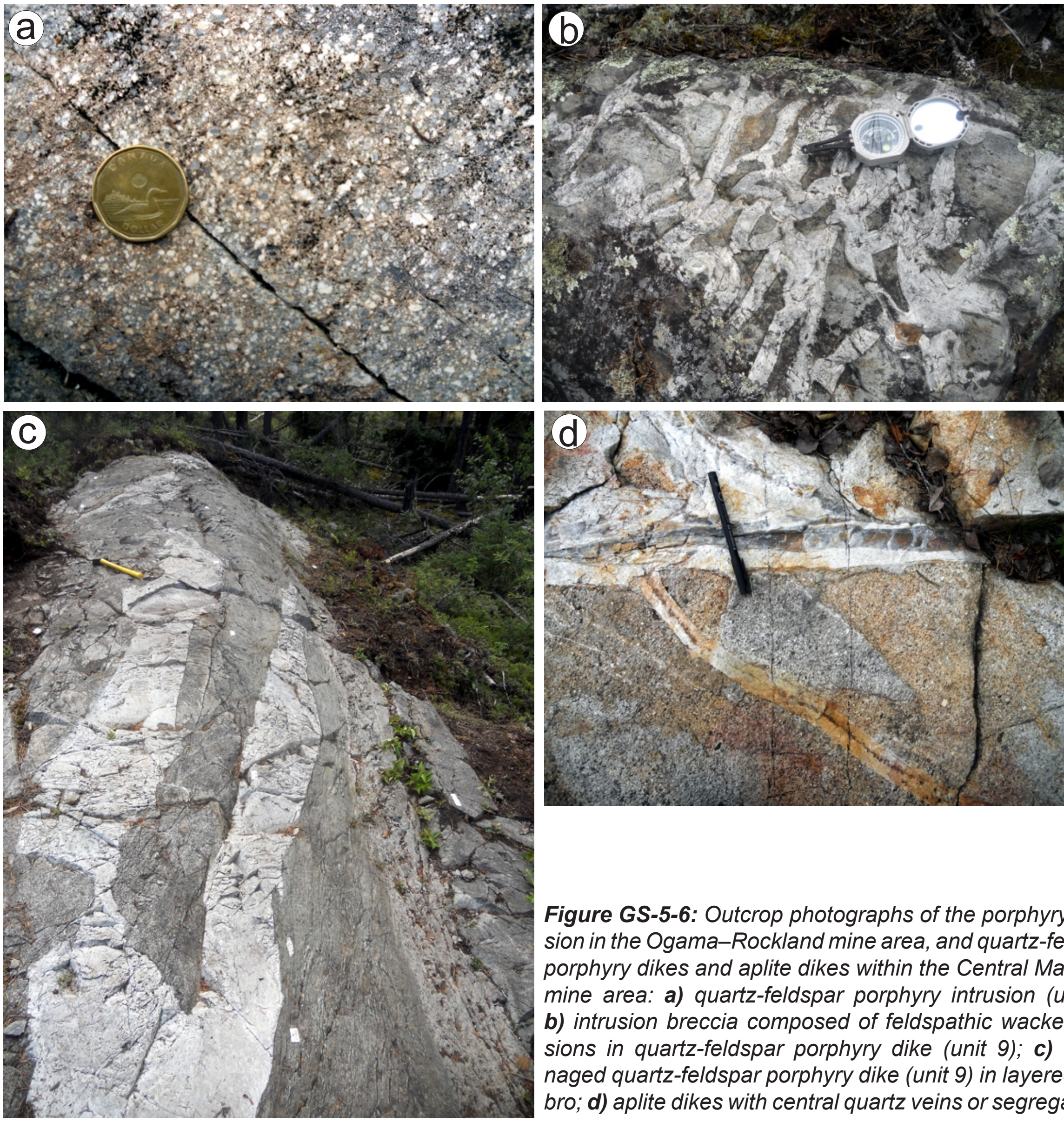

***Figure GS-5-6:** Outcrop photographs of the porphyry intrusion in the Ogama–Rockland mine area, and quartz-feldspar porphyry dikes and aplite dikes within the Central Manitoba mine area: **a)** quartz-feldspar porphyry intrusion (unit 8); **b)** intrusion breccia composed of feldspathic wacke inclusions in quartz-feldspar porphyry dike (unit 9); **c)** boudinaged quartz-feldspar porphyry dike (unit 9) in layered gabbro; **d)** aplite dikes with central quartz veins or segregations.*

contact with massive aphyric basalt. This chilled margin locally contains dark grey, rounded quartz grains ranging from 0.5 to 1 mm. It strikes west to west-southwest (260–270°), dips subvertically and gradually thins, and eventually pinches out, to the east. This porphyry phase is interpreted as being genetically associated with the Ross River pluton on the basis of textural characteristics.

Felsic dikes

Felsic dikes were also described in detail by Zhou et al. (2012b); the following sections only summarize key features and new discoveries.

Quartz-feldspar porphyry dikes (unit 9)

Quartz-feldspar porphyry dikes are abundant within the map area, and intrude the southeastern margin of the Ross River pluton, gabbroic sills and supracrustal rocks of the Bidou assemblage. Feldspathic wacke of unit 3 in particular is intruded by thin quartz-feldspar porphyry dike swarms, which locally constitute intrusion breccia (Figure GS-5-6b). Quartz-feldspar porphyry dikes also intrude the differentiated gabbroic sills and are locally boudinaged (Figure GS-5-6c).

Aplite dikes (unit 10)

Aplite dikes are numerous within the southeastern margin of the Ross River pluton as well as the adjacent gabbroic intrusions. In the area of the Ogama–Rockland mine, they are spatially associated with mineralized (Au) quartz veins. Some of the dikes include discontinuous quartz segregations, which would suggest that at least some of the associated quartz veins may represent late-stage segregations from granitic magmas (Figure GS-5-6d). This association, and its possible relationship to gold mineralization and the Ross River pluton, is the focus of ongoing detailed petrographic and geochemical studies as part of this project.

Structural geology

On the basis of overprinting relationships and fold styles, four generations of ductile deformation structures have been recognized in the Halfway Lake–Long Lake–Wentworth Lake area. Younging indicators (e.g., downward-pointing pillow cusps, variations in amygdule density in mafic lavas, and normally-graded beds, load structures and scours in turbiditic sandstone) are common in the study area. Younging reversals, coupled with changes in bedding-cleavage angular relationships, were used to constrain the geometry of folds in the study area.

D_1 structures

Structures associated with D_1 deformation are well developed in mafic lava flows south of the Ross River pluton. A prominent S_1 fabric is defined by flattened pillows (Figure GS-5-3a, b) and a closely-spaced, penetrative, fracture cleavage within the mafic lava flows. The S_1 cleavage strikes west (~270°) and dips steeply (75–85°) to the north. On horizontal surfaces, S_1-cleavage planes are Z-asymmetrically folded or kinked and overprinted by a spaced shear-band cleavage associated with later dextral shear (Figure GS-5-7a). A steep ridge-in-groove lineation (L_1) is well developed on S_1-cleavage planes on the southern contact of the pluton. The L_1 lineation plunges steeply (84°) to the north (Zhou et al., 2012b, Figure GS-5-3a). Macroscopic tight to isoclinal, upright folds (F_1) in basalt flows to the south of the Ross River pluton are interpreted on the basis of map patterns, younging reversals and S_0–S_1 vergence. The F_1 axial planes strike west and dip steeply to the north, parallel to S_1. No associated

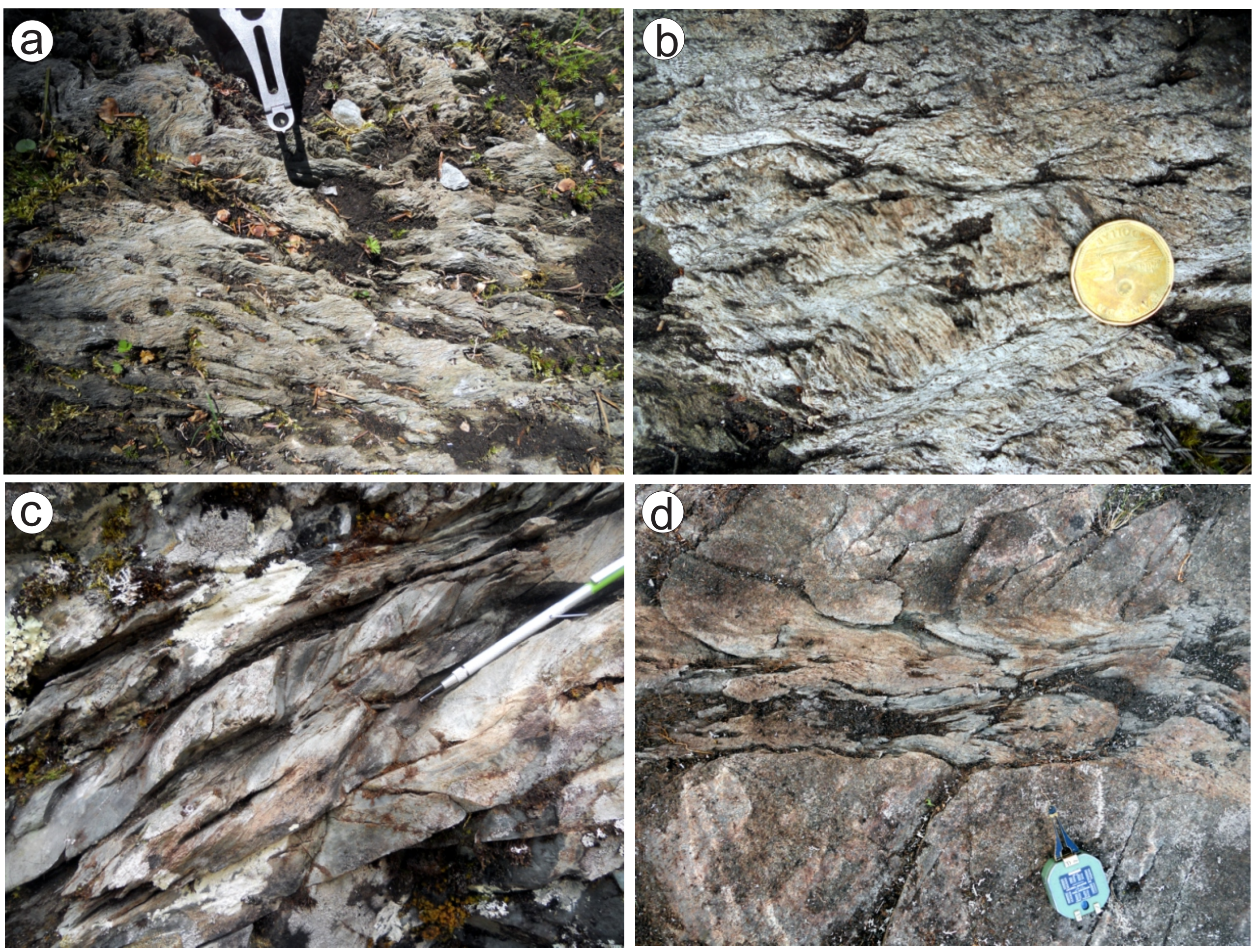

***Figure GS-5-7:** Outcrop photographs of deformation structures in the Central Manitoba and Ogama–Rockland mines areas: **a)** S_1 cleavage overprinted by Z-folds (to left of compass) and shear-band cleavage (north is to the top); **b)** S_2 cleavage overprinted by S_3 crenulation cleavage (north is to the top); **c)** S–C fabric indicating dextral sense of shear; **d)** deflection of external foliation along a discrete shear zone in gabbro indicates sinistral sense of shear.*

small-scale F_1 folds were identified on an outcrop scale. An alternative interpretation is that the macroscopic 'F_1' fold is a result of later (D_2, D_3 or D_4) deformation, since no overprinting relationship is observed between this macroscopic fold and the regional Beresford Lake anticline (see below). Microstructural investigations of oriented thin sections will be used to test these hypotheses.

D_2 structures

Structures associated with D_2 deformation are pervasive throughout the map area. At an outcrop scale, D_2 deformation manifests itself by a closely-spaced (5–20 cm) or very closely-spaced (<1 cm) S_2 fracture cleavage defined by preferred alignment of chlorite or sericite. The S_2 cleavage is well developed in sedimentary and volcanic rocks of the Bidou assemblage, as well as in layered gabbroic intrusions. The S_2 cleavage mostly strikes northwest (305–320°) and is steeply dipping, indicating northeast–southwest shortening. The orientation of this fabric is compatible with an axial-planar relationship to the regional-scale Beresford Lake anticline, suggesting this fold may also represent a D_2 structure. This hypothesis will be further evaluated by microstructural examination of overprinting relationships in oriented thin sections.

D_3 structures

Structures associated with D_3 deformation are only rarely observed. One example occurs in a differentiated gabbroic sill close to the Kitchener shaft of the Central Manitoba mine, where the S_2 cleavage is overprinted by a spaced crenulation cleavage (Figure GS-5-7b).

D_4 structures

Structures associated with D_4 deformation are the youngest deformation structures identified in the map area: they include Z-asymmetric folds and kink bands within schistose basalt, and S–C fabrics in chloritic mylonite within discrete ductile shear zones (Figure GS-5-7c) within massive basalt and plutonic rocks. The thickness of the shear zones varies from tens of centimetres to several metres. Two types of foliations are well developed in the ductile shear zones: shear foliations (C surfaces) are defined by curviplanar surfaces or zones of sericite, chlorite and/or recrystallized quartz, and typically parallel the shear zone boundary; mylonitic foliations (S surfaces) are shape fabrics that curve acutely into the shear foliations, and are defined by feldspar and/or quartz porphyroclasts and biotite, sericite or chlorite. Ridge-in-groove and tourmaline lineations on shear foliations mostly plunge shallowly or moderately toward the west to northwest. Ductile shear zones that strike northwest contain dextral shear-sense indicators, whereas shear zones that strike north to northeast contain sinistral shear-sense indicators (Figure GS-5-7d), suggesting they may represent a conjugate set.

Economic considerations

The mostly shear-related vein-type (Stockwell and Lord, 1939; Brommecker, 1991, 1996) gold deposits in the vicinity of the Central Manitoba mine are hosted by gabbro sills, basalt flows, felsic lapilli tuff and bedded feldspathic wacke. Gold mineralization occurs principally in quartz (±carbonate) veins along west- to northwest-trending dextral shear zones and associated tension-gash arrays; minor veins also occur along north- to northeast-trending sinistral shear zones (Zhou et al., 2012b). West- to northwest-striking lithological boundaries (representing zones of competency contrast) control the location of most shear zones. Gold typically occurs as free grains or as inclusions within pyrite, chalcopyrite, pyrrhotite and other sulphide minerals. Symmetric zonation of sericite-ankerite-chlorite alteration is prominent perpendicular to mineralized veins and thus provides an important exploration guide. Ongoing detailed structural analysis of the Ogama–Rockland and Central Manitoba mines areas will provide new constraints on the structural controls and settings of mineralized veins, with important implications for understanding the tectonic evolution and regional metallogeny of the Rice Lake belt.

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