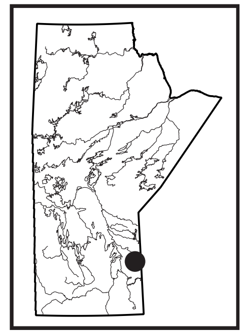
# GS-4 Preliminary bedrock geology of the eastern extension of the Rice Lake mine trend, Rice Lake greenstone belt, southeastern Manitoba (parts of NTS 52M3, 4)

by S.D. Anderson



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## Summary

The eastern extension of the Rice Lake mine trend was mapped at 1:10 000 scale in June 2013, taking advantage of a forest fire that burned across a 6.5 km wide swath of favourable stratigraphy in October 2011, resulting in exceptionally clean bedrock exposures in an area that had not been mapped by the Manitoba Geological Survey in more than 60 years. The map area is located in the central portion of the Archean Rice Lake greenstone belt, less than 1 km to the east along strike of the easternmost deposit in the mine trend. This area is underlain by an upright succession of felsic volcanic and volcaniclastic rocks, turbiditic epiclastic rocks, pillowed and massive basalt flows, and associated subvolcanic intrusions, mostly corresponding to the Rainy Lake Road unit of the Gem assemblage. The Rainy Lake Road unit is intruded at the base by synvolcanic granodiorite–tonalite of the Ross River pluton and dips steeply north on the north limb of the regional-scale Beresford Lake anticline, which is truncated to the north by the Wanipigow fault. Early deformation structures, including pervasive planar-linear (S-L) shape fabrics and minor folds, record regional northeast–southwest shortening. Later deformation structures record a major change in kinematic frame to northwest–southeast shortening, which was mostly accommodated by dextral transcurrent shear deformation along the Wanipigow fault and subsidiary structures. The stratigraphy, depositional setting and structural evolution of the Rainy Lake Road unit, coupled with the presence of significant gold and base-metal occurrences, indicate good potential for orogenic lode-gold and volcanic-hosted massive sulphide deposits.

## Introduction

The Rice Lake mine trend is located 155 km northeast of Winnipeg, Manitoba, in the central portion of the Archean Rice Lake greenstone belt[1] of the western Superior province. The trend is hosted by a north-younging stratigraphic succession of Neoarchean (ca. 2.73–2.72 Ga) volcanic, volcaniclastic, epiclastic and subvolcanic intrusive rocks, and includes several significant gold deposits, the largest of which is the Rice Lake deposit in Bissett. Within the trend, auriferous quartz-carbonate veins occur within brittle-ductile shear zones and cogenetic arrays of shear and tensile fractures that accommodated northeast–southwest shortening during regional compressional deformation (Anderson, 2013c). With reserves and resources of more than 3 million oz. Au (Ginn and Michaud, 2013) and past production of 1.7 million oz. Au, the Rice Lake mine trend is the most significant lode gold camp in Manitoba.

In 2002, the Manitoba Geological Survey (MGS) initiated a program of 1:20 000 scale bedrock mapping, structural analysis, lithogeochemistry, U-Pb geochronology and Sm-Nd isotopic analysis in select portions of the Rice Lake greenstone belt, with the intention of providing an improved geological context and predictive framework for mineral exploration. Bedrock mapping of the Rice Lake area took place in 2004 and 2005 and the results of this work were released in 2008 (Anderson, 2008). Detailed stratigraphic and structural mapping of the mine trend at 1:5000 scale took place in 2011 (Anderson, 2011a–c).

In October 2011, shortly after the completion of the detailed mapping program, the quality of bedrock exposure along strike east of the mine trend was significantly improved by a forest fire that burned northward across a 6.5 km wide swath of favourable stratigraphy. The burn overlaps the easternmost portion of the area mapped at 1:20 000 scale by the MGS in 2004–2005 (Anderson, 2008) and provides an exceptional opportunity to extend new detailed mapping farther east, into an area last examined by the MGS more than 60 years ago (Russell, 1948; Davies, 1950), shortly after the initial mapping by the Geological Survey of Canada (Stockwell, 1938, 1945).

The 2013 study area encompasses 15.8 km$^2$ and extends south from the drift-filled valley of the Wanipigow River to the north margin of the Ross River pluton. The western boundary is located approximately 8 km east of Bissett (roughly coinciding with the Rainy Lake logging road, which served as the western firebreak) and the eastern boundary extends south from the access road to the abandoned Jeep mine, approximately 14 km east of Bissett on Provincial Road 304. The mapping, at 1:10 000 scale, was completed during a two-week period in June 2013 using detailed orthorectified aerial photographs for

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

navigation and plotting. This paper summarizes the preliminary results of this work with emphasis on lithostratigraphy of the Neoarchean supracrustal succession.

## Geological setting

The Rice Lake greenstone belt comprises Neoarchean and Mesoarchean supracrustal rocks and associated intrusions at the westernmost extent of the volcano-plutonic Uchi subprovince (Card and Ciesielski, 1986; Stott and Corfu, 1991) of the western Superior province (Figure GS-4-1). In Manitoba, the Uchi subprovince is flanked to the north by the metaplutonic Berens River subprovince and to the south by metasedimentary rocks and derived gneiss, migmatite and granitoid plutonic rocks of the English River subprovince (Card and Ciesielski, 1986). The Berens River subprovince and the Mesoarchean portions of the Uchi subprovince constitute the continental North Caribou terrane (NCT), which is regarded as the protocratonic nucleus of the western Superior province (e.g., Stott and Corfu, 1991; Thurston et al., 1991; Percival et al., 2006a, b). Neoarchean rocks in the Uchi and English River subprovinces are interpreted to represent a north-verging subduction-accretion complex that developed over a span of approximately 50 m.y. along the south margin of the NCT (e.g., Stott and Corfu, 1991; Poulsen et al., 1996; Percival et al., 2006a, b; Anderson, 2008, 2013b, c). The Rice Lake greenstone belt is structurally bounded by regional faults, including the Wanipigow fault (WF) on the north and Manigotagan fault on the south (Figure GS-4-1).

East of Rice Lake, the south margin of the NCT consists mostly of Mesoarchean tonalite, granodiorite and gabbro of the Wanipigow River plutonic complex (Turek et al., 1989; Bailes et al., 2003) and is juxtaposed to the south with Neoarchean supracrustal and intrusive rocks of the Rice Lake belt across the WF. This structure can be traced along strike to the east-southeast for more than 170 km to Red Lake, Ontario, and is interpreted to represent a crustal-scale structure of the type associated with major orogenic gold districts in other Archean greenstone belts. In the study area, the WF is largely concealed beneath a thick cover of glacial sand and clay along the valley of the Wanipigow River.

Immediately south of the WF, the Rice Lake belt consists of a north-younging succession of subaqueously deposited mafic, intermediate and felsic volcanic and volcaniclastic rocks, associated subvolcanic intrusions and derived epiclastic rocks. Although previously considered part of the ca. 2.75–2.73 Ga Bidou assemblage (e.g., Anderson, 2008), these rocks have been re-assigned to the

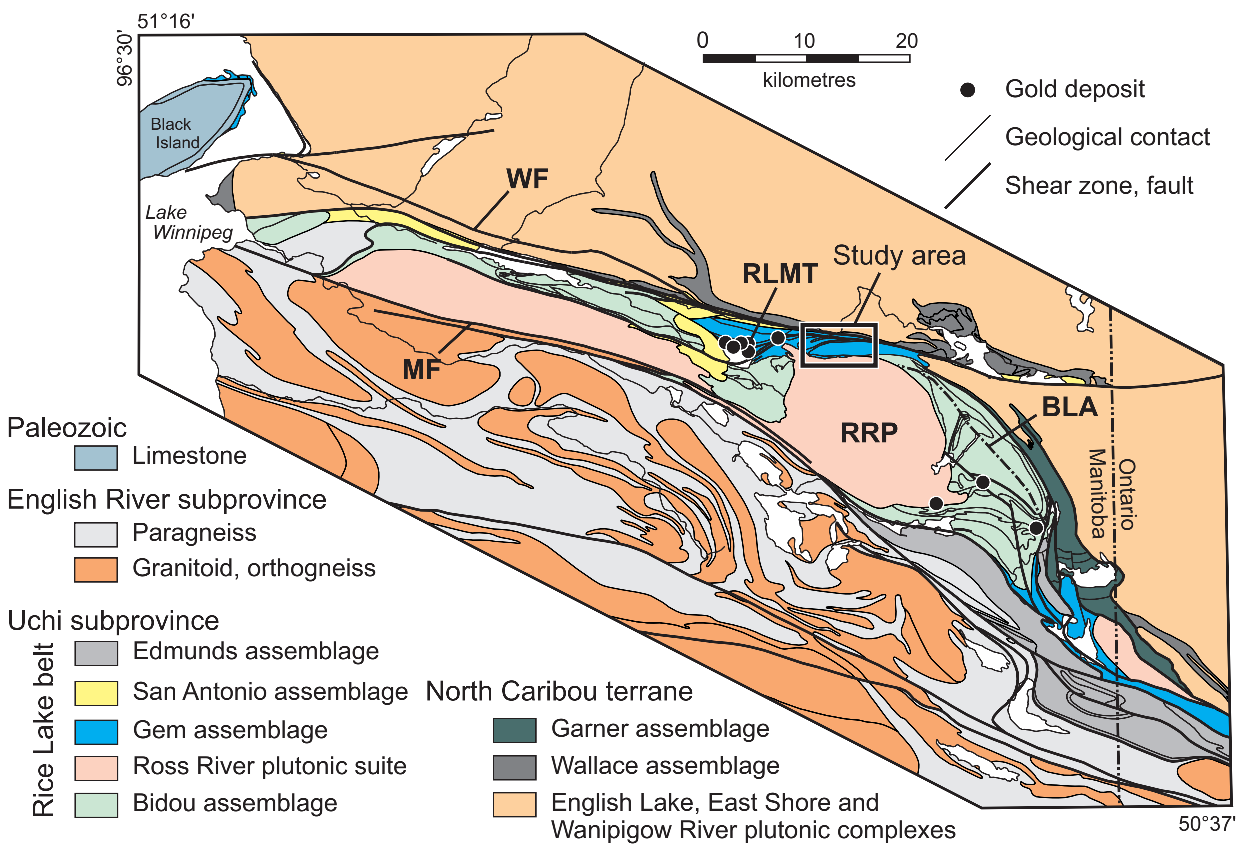


***Figure GS-4-1:*** *Simplified regional geology of the Rice Lake belt, showing the principal lithotectonic assemblages, major structures and gold deposits, and the location of the study area in relation to the Rice Lake mine trend (RLMT). Abbreviations: BLA, Beresford Lake anticline; MF, Manigotagan fault; RRP, Ross River pluton; WF, Wanipigow fault.*

ca. 2.73–2.72 Ga Gem assemblage on the basis new constraints from regional bedrock mapping, lithogeochemistry and U-Pb geochronology (Anderson, 2013b, c).

In the comparatively well studied section that hosts the Rice Lake mine trend along strike to the west (Figure GS-4-2), the Gem assemblage includes three distinct lithostratigraphic units (Rainy Lake road, Townsite and Round Lake), each characterized by distinctive lithological and geochemical associations. Abrupt lateral and vertical facies changes, deep erosional scours and the predominance of coarse epiclastic deposits, some of which were significantly reworked in subaerial settings, indicate a dynamic shallow-water depositional setting in contrast to the basinal-marine setting inferred for most of the underlying Bidou assemblage (Anderson, 2013b, c). West of Rice Lake, the Bidou and Gem assemblages are overlain by ca. 2.7 Ga (Percival et al., 2006a) fluvial-alluvial sedimentary rocks of the San Antonio assemblage along a pronounced angular unconformity (Figure GS-4-2).

Most of the current study area is underlain by felsic volcanic and volcaniclastic rocks, turbiditic epiclastic rocks, pillowed and massive basalt flows, and subvolcanic gabbro sills corresponding to the Rainy Lake Road unit of the Gem assemblage. This unit is intruded at the base by synvolcanic (ca. 2.72 Ga; Anderson, 2008) tonalite–granodiorite of the Ross River pluton and dips moderately to steeply north on the north limb of the regional Beresford Lake anticline (Figure GS-4-1). It is interpreted to record extension and incipient rifting of the Bidou assemblage, leading to the development of a short-lived

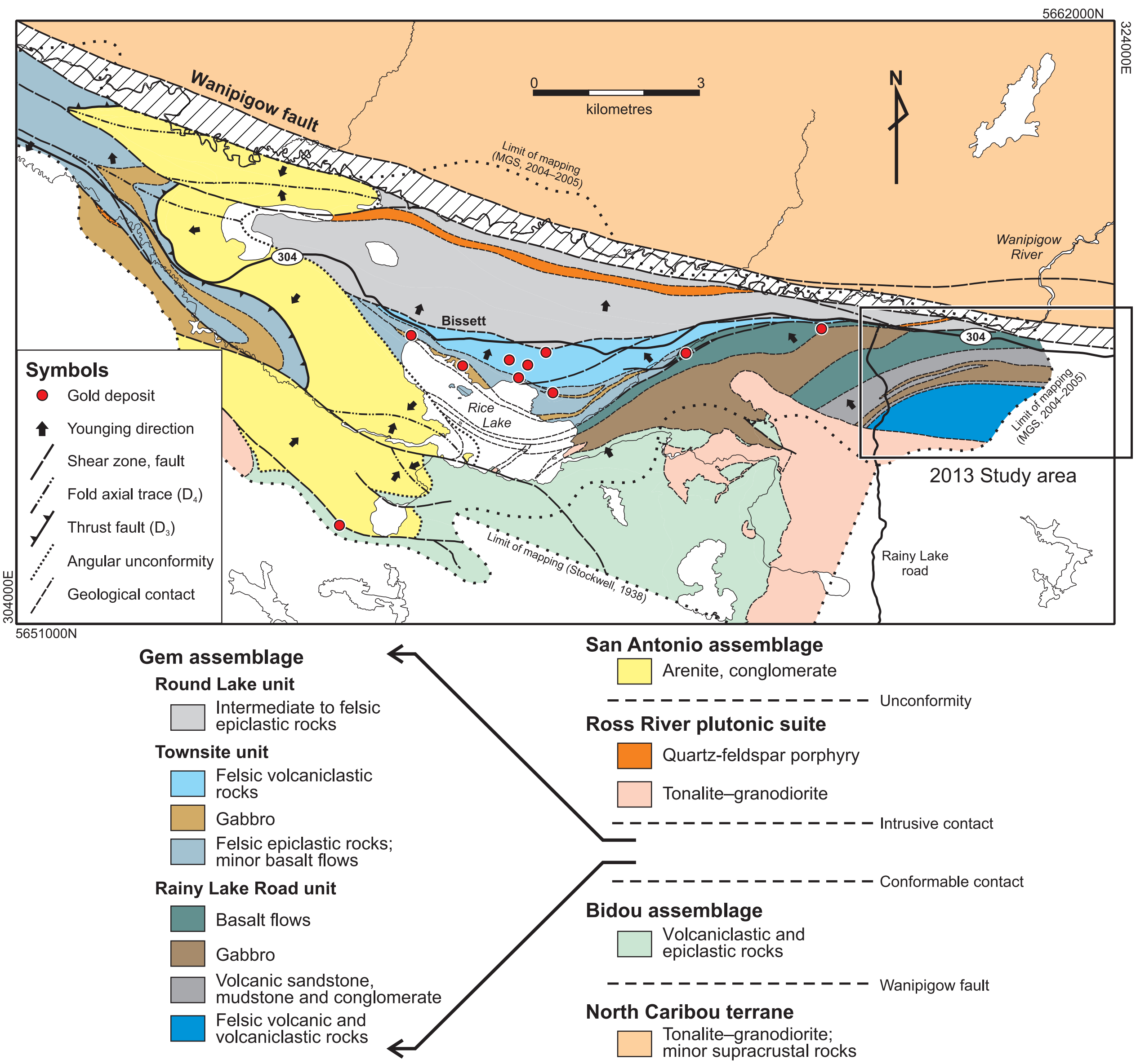


***Figure GS-4-2:** Simplified geology of the Rice Lake mine trend (after Anderson, 2008) showing the 2013 study area, which extends approximately 2 km beyond the eastern limit of this map.*

marine basin that is bounded to the west by a synvolcanic subsidence structure and was rapidly infilled by submarine turbidites and Fe-tholeiitic basalt flows, the latter of which are chemically analogous to modern back-arc basin basalt (Anderson, 2008, 2013c). As described below, the northern portion of the study area appears to include a fault-bounded panel of the Round Lake unit, which is structurally juxtaposed to the north with tectonized supracrustal rocks of unknown affinity along the WF.

As described by Anderson (2008, 2013c), the structural evolution of the area involved synvolcanic faulting ($D_1$) and early regional tilting ($D_2$) of the Bidou and Gem assemblages into a near-vertical orientation prior to the deposition (<2705 Ma; Percival et al., 2006a) of the unconformably overlying San Antonio assemblage. Following inversion and thrust imbrication of the San Antonio assemblage ($D_3$), regional ductile deformation in a kinematic frame of northeast–southwest shortening produced a pervasive planar-linear (S-L) shape fabric, upright doubly plunging folds (including the Beresford Lake anticline) and high-strain zones with sinistral-reverse oblique-slip kinematics ($D_4$). Most of the major gold deposits in the mine trend are hosted by conjugate arrays of brittle-ductile shear zones and associated fault-fill and extension veins emplaced in the late increments of this deformation. The latest episode of regional deformation ($D_5$) accommodated northwest–southeast shortening of the belt and was associated with strongly partitioned dextral transcurrent shear deformation along the Wanipigow and Manigotagan faults and their subsidiary structures.

## Description of units

Unit codes in this report correspond to those on PMAP2013-6 (Anderson, 2013a); a simplified version of this map is included herein as Figure GS-4-3 (it should be noted that several units are too small to define unique polygons on the map). Stratigraphic nomenclature corresponds to that used by Anderson (2008), except as indicated above. Metamorphic mineral assemblages throughout the area indicate low- to middle-greenschist–facies metamorphism. In the interest of brevity, however, the prefix ‘meta’ is omitted and the rocks are described in terms of known or inferred protoliths.

### *Rainy Lake Road unit*

#### Plagioclase-phyric dacite (unit 1)

Plagioclase-phyric dacite of unit 1 dominates the lower section of the Rainy Lake Road unit and is well exposed in the southern portion of the study area, north of the Ross River pluton. It includes coherent dacite flows (subunit 1a) and associated breccia and tuff breccia (subunit 1b) that are interlayered on meso- to macroscopic scales. Coherent dacite weathers buff to light grey and is dark grey on fresh surfaces. It contains tabular plagioclase phenocrysts (10–30%; 1–5 mm) in an aphanitic to very fine grained siliceous groundmass. The dacite also locally contains sparse amphibole and/or quartz phenocrysts (2–3%; <3 mm). Some outcrops are faintly flow banded or contain sparse (<5%) quartz amygdules up to 2 cm in diameter. The breccia and tuff breccia are monolithic to sparsely heterolithic, matrix to clast supported, unsorted and massive to crudely stratified. The clasts—plagioclase-phyric dacite, with minor aphyric dacite and basalt—are generally angular to very angular, with blocky, cuspate or polygonal shapes. They are locally up to 3 m in diameter but are typically less than 50 cm. Tabular flows of coherent dacite from 10 to 15 m thick are interstratified with 1–5 m thick layers of monolithic flow breccia in some outcrops. In others, coherent dacite forms large (>5 m) bulbous flow lobes within breccia and tuff breccia derived from the same material (Figure GS-4-4a).

#### Aphyric dacite (unit 2)

Aphyric dacite of unit 2 is only extensive in the southwest corner of the study area but also occurs along strike to the east as discrete lenses at the top of unit 1 or along the north margin of the Ross River pluton. Unit 2 includes coherent dacite flows (subunit 2a) and associated breccia and tuff breccia (subunit 2b). The coherent dacite is aphanitic to very fine grained and siliceous, and weathers light grey with dark grey fresh surfaces. It commonly has a bleached appearance and locally contains fracture-controlled chlorite alteration that produces false-fragmental textures in otherwise coherent dacite. Associated breccia and tuff breccia are monolithic, matrix to clast supported, poorly sorted and unstratified, and contain very angular to subrounded clasts of aphyric dacite up to 2 m across in a chloritic tuff matrix (Figure GS-4-4b). Local jigsaw-fit textures are indicative of autoclastic or hyaloclastic fragmentation of coherent flows.

#### Epiclastic rocks (unit 3)

Epiclastic rocks of unit 3 trend through the central portion of the study area and define the middle section of the Rainy Lake Road unit (Figure GS-4-3). Most of this unit consists of turbiditic volcanic sandstone and mudstone, with subordinate interlayers of conglomerate, iron formation, chert, felsic volcaniclastic rocks and basalt flows. These rocks are pervasively intruded by relatively resistant gabbro sills and are considered to be under-represented in outcrop due to preferential erosion; in many locations they are only exposed on the lowermost flanks of outcrop ridges underlain by gabbro.

The base of unit 3 is defined by a distinctive layer of heterolithic volcanic conglomerate that ranges up to 30 m in thickness and is traced for more than 4 km along strike. In the western portion of the study area, the conglomerate is massive to crudely stratified, matrix

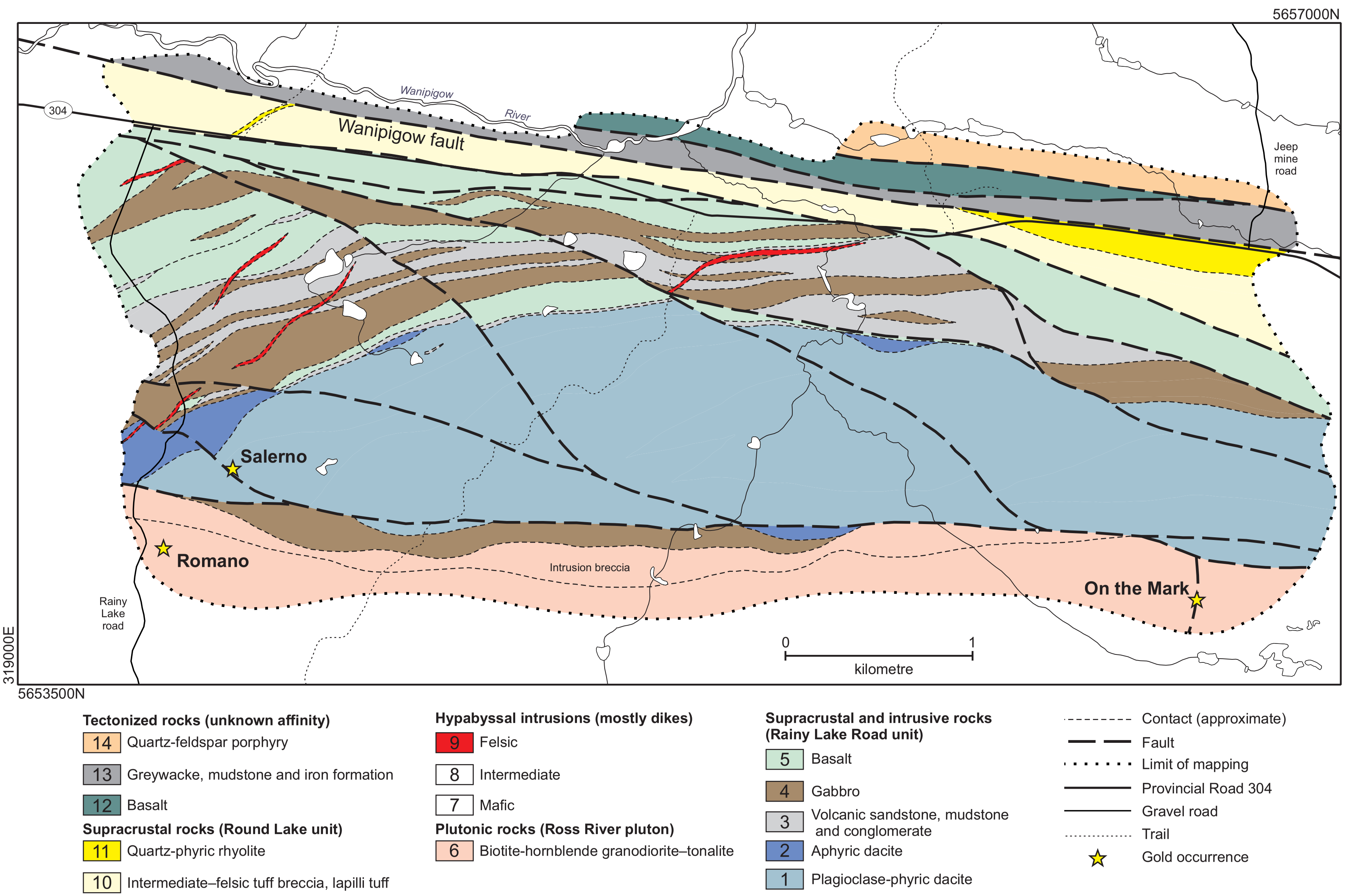


***Figure GS-4-3:*** *Simplified geology of the eastern extension of the Rice Lake mine trend, showing the locations of significant gold occurrences.*

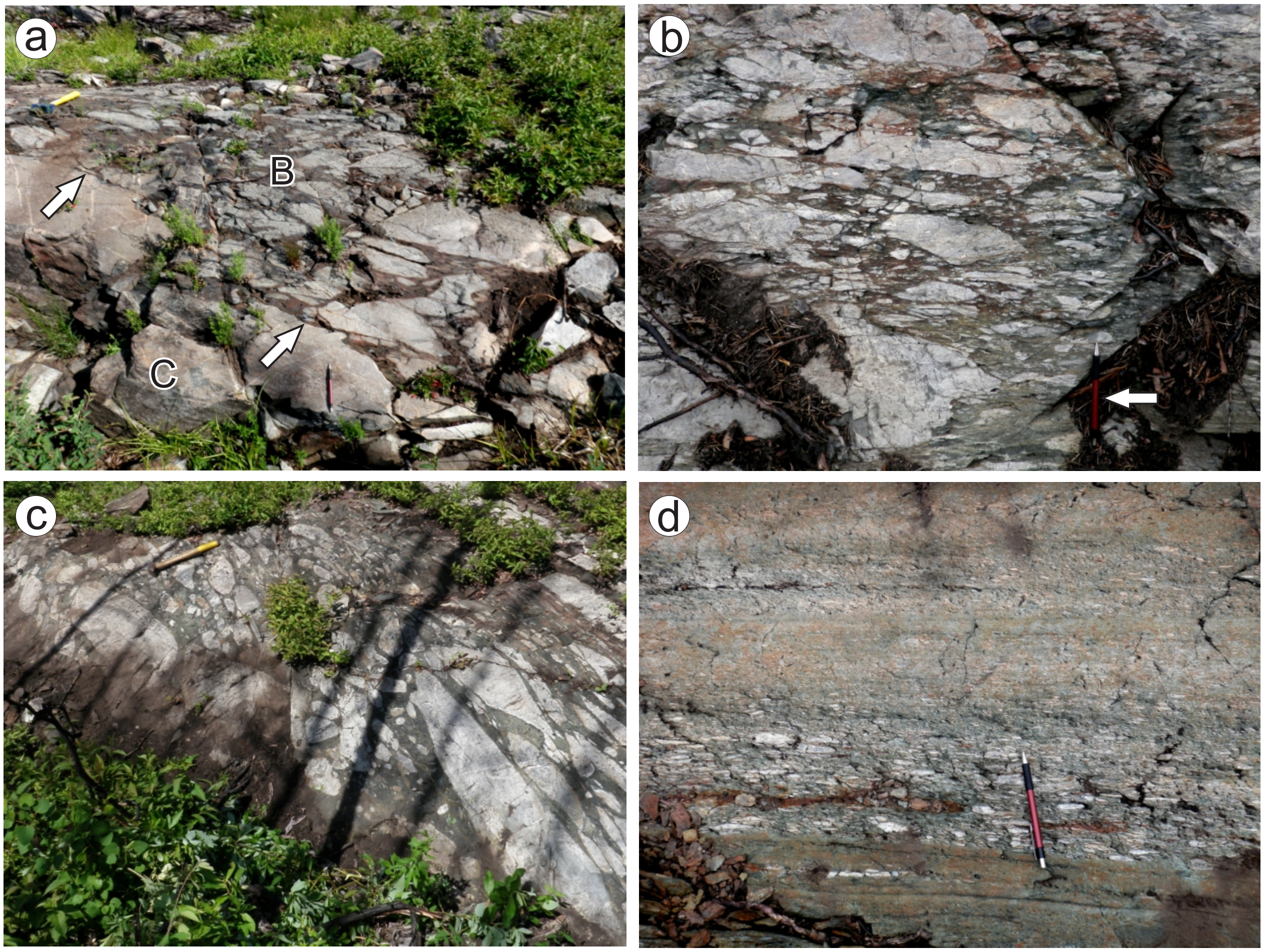


***Figure GS-4-4:** Outcrop photographs of the lower section of the Rainy Lake Road unit: **a)** sharp undulating contact (arrows) between coherent (C) and brecciated (B) dacite of unit 1; **b)** aphyric dacite breccia of subunit 2b, showing angular cuspate clasts and chloritic tuff matrix (arrow indicates pencil for scale); **c)** heterolithic boulder volcanic conglomerate in the western portion of unit 3, showing crude normally graded angular to well-rounded clasts; **d)** heterolithic pebble volcanic conglomerate in the eastern portion of unit 3, showing planar normally graded beds.*

supported and normally graded, and contains dacite boulders up to several metres in diameter (subunit 3a; Figure GS-4-4c). Toward the east along strike, the average clast size decreases and the conglomerate becomes increasingly well stratified (subunit 3b), with normally graded beds up to 1 m thick capped by planar-bedded volcanic sandstone (Figure GS-4-4d). These variations are attributed to increasing distance from a synvolcanic subsidence structure along the west margin of the basin (Anderson, 2008): the proximal (western) facies likely represents primary debris-flow deposits, whereas the distal (eastern) facies was significantly reworked. In both subunits, the clasts are poorly sorted, angular to subrounded, and include a small proportion of well-rounded subspherical clasts that apparently underwent significant subaerial transport prior to final deposition. Aphyric and porphyritic dacite are the dominant clast types. Subordinate clast types include mudstone, chert, iron formation, basalt and solid sulphide (pyrrhotite±chalcopyrite). The matrix consists of pebbly volcanic sandstone that is distinctly chloritic and contains up to 20% disseminated magnetite.

Thin (<1.5 m) lenses of laminated sulphidic mudstone or oxide-facies iron formation (subunit 3d) locally occur at the base or top of the basal volcanic conglomerate of unit 3, indicating that it was bracketed by periods of depositional quiescence. In one outcrop near the eastern extent of subunit 3a, the conglomerate is capped by a 1.5 m thick layer of faintly stratified lapilli tuff that contains up to 10% quartz phenocrysts, indicating coeval felsic volcanism. In all other locations, the conglomerate is overlain by massive amygdaloidal basalt flows (subunit 5a) that commonly have distinct dark bluish-grey or green weathered surfaces.

Interbedded volcanic sandstone and mudstone (subunit 3c) are the characteristic and dominant rock types of unit 3. The sandstone weathers buff to light grey or white and is dark grey on fresh surfaces. It consists of fine- to coarse-grained feldspathic or lithic greywacke that contains up to 10% detrital quartz and forms planar, massive to normally graded beds up to 50 cm thick. Some beds have deeply scoured basal contacts with well-developed pebble lags, and display reverse grading of mudstone rip-up clasts (Figure GS-4-5a); crossbeds were observed at only one location. The mudstone weathers light grey to black and is dark grey or black on fresh surfaces. It forms thin-bedded to laminated layers up to 20 cm thick and is locally sulphidic. Slump folds and load structures are common in these layers (Figure GS-4-5b). Some outcrops also contain minor magnetite beds or thin (<0.5 m) layers of oxide-facies iron formation, or normally graded interbeds (<1 m) of pebble conglomerate that contain abundant mudstone rip-up clasts. These features indicate deposition by turbidity currents in a periodically quiescent submarine fan setting. Younging criteria consistently indicate tops to the north.

Felsic tuff breccia and lapilli tuff (subunit 3e) occur as minor interbeds throughout unit 3, but are most abundant and thickest in the eastern portion of the unit, where they locally constitute the dominant rock types. These beds weather buff-white and consist largely of angular to subrounded clasts (<20 cm) of plagioclase-quartz–phyric rhyolite. The beds are up to 4 m thick and are typically monolithic, poorly sorted and clast supported; some are disrupted at the base by large-scale load structures. The beds vary from massive to graded, with the latter including both normal and compound types, and are capped by layers of thin-bedded felsic tuff or volcanic sandstone up to 50 cm thick (Figure GS-4-5c). Some beds also contain well-preserved pumice lapilli (Figure GS-4-5d) and are thus interpreted to represent resedimented pyroclastic deposits. These rocks indicate coeval felsic volcanism during basin infilling.

**Gabbro (unit 4)**

Gabbro occurs throughout the Rainy Lake Road unit and forms particularly abundant and thick (up to 300 m)

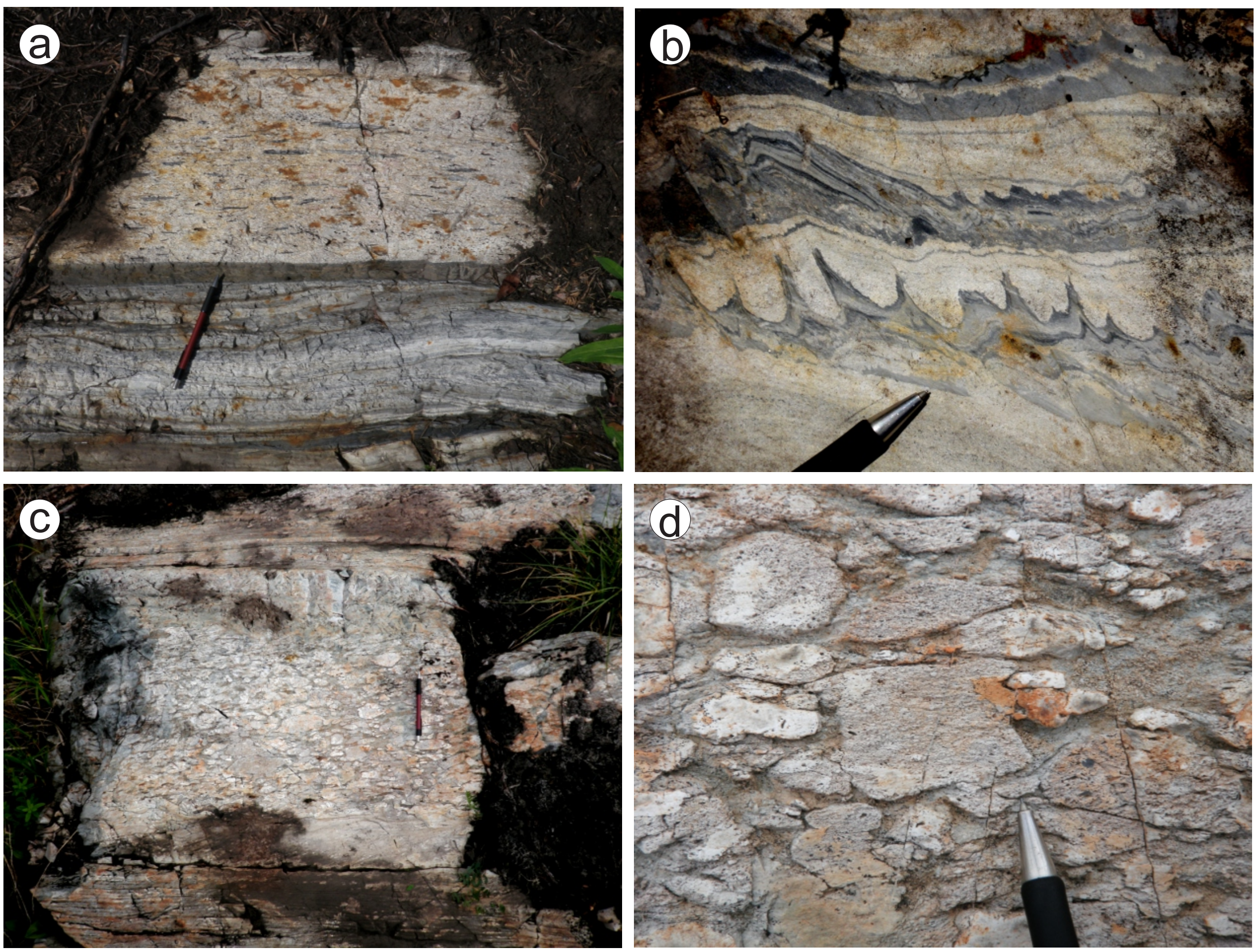


***Figure GS-4-5:** Outcrop photographs of unit 3 in the middle section of the Rainy Lake Road unit (pencil points north in each photo): **a)** planar-bedded volcanic sandstone and mudstone (subunit 3c); sandstone bed is normally graded but contains reversely graded mudstone rip-up clasts; **b)** thin, normally graded, volcanic sandstone beds and laminated mudstone beds showing well-developed load structures (subunit 3c); **c)** planar bed of felsic lapilli tuff showing compound (reverse to normal) size grading of angular rhyolite lapilli (subunit 3e); **d)** detail of c) showing weakly compacted, densely vesicular, pumice lapilli.*

sills in the middle and upper sections. Gabbro is also extensive along the north margin of the Ross River pluton in the western portion of the map area (Figure GS-4-3), where it lies in fault-modified intrusive contact to the north with dacitic volcaniclastic rocks and is intruded to the south by the pluton.

Equigranular mesogabbro (subunit 4a) predominates, with subordinate intervals of plagioclase-phyric to megaphyric mesogabbro (subunit 4b), layered mesogabbro (subunit 4c) and equigranular leucogabbro (subunit 4d). Based on geochemical constraints along strike to the west, these intrusions are interpreted to be comagmatic with associated flows of Fe-tholeiitic basalt (Anderson, 2008). The mesogabbro weathers light green to buff and is dark green on fresh surfaces, with a fine- to medium-grained, subophitic texture. It typically contains 40–60% plagioclase laths in a fine-grained groundmass of chlorite and actinolite. In some outcrops, the chlorite and actinolite define equant pseudomorphs (2–5 mm) after primary pyroxene crystals, resulting in a 'spotted' appearance. Sill contacts are sharp, planar and characterized by particularly thick (10–50 cm) chilled margins, the inner portions of which are commonly amygdaloidal. Some sills contain coarse-grained patches with up to 5% blue quartz or irregular zones of intrusion breccia that consist of angular blocks of mesogabbro in a more leucocratic matrix. Some sills also contain large rafts of bedded epiclastic rocks.

The thickest sills commonly contain intervals of plagioclase-phyric to megaphyric mesogabbro (subunit 4b), layered mesogabbro (subunit 4c) or equigranular leucogabbro (subunit 4d). Tabular to blocky phenocrysts and glomerocrysts of plagioclase range in size up to 2.5 cm in subunit 4b and typically account for less than 10% of the rock. These phenocrysts are locally concentrated (up to 70%) into laterally continuous layers up to 2 m thick (Figure GS-4-6a). Diffuse lower contacts, relatively sharp upper contacts and upward-increasing proportions of phenocrysts indicate that the layers result from upward movement and accumulation of crystals beneath density barriers in the cooling magma. Intervals of rhythmically

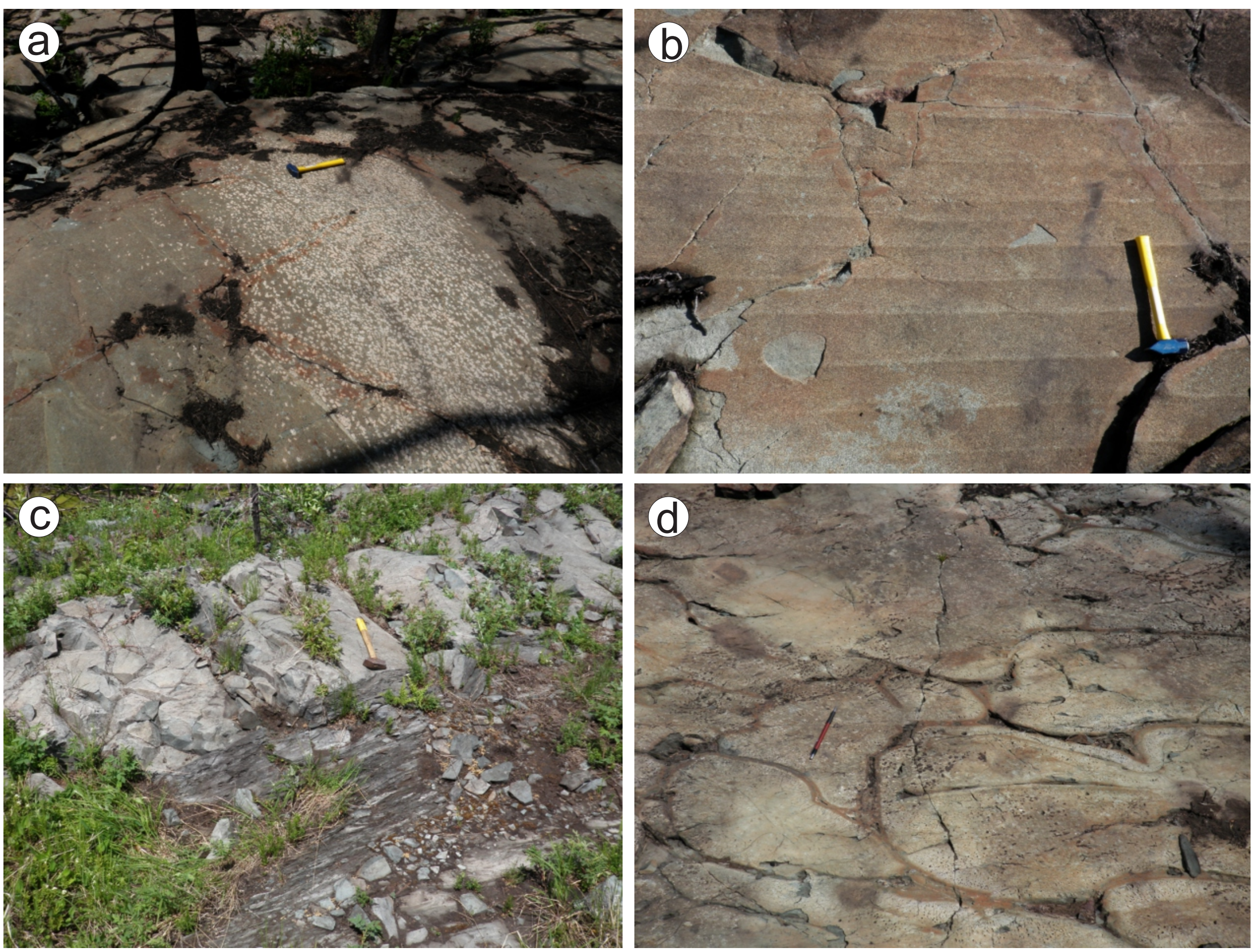


***Figure GS-4-6:*** *Outcrop photographs of units 4 and 5 in the middle and upper sections of the Rainy Lake Road unit (hammer or pencil points north in each photo):* ***a)*** *plagioclase-crystal–rich layer in mesogabbro (subunit 4b), interpreted to result from upward movement and accumulation of crystals beneath a density barrier in the cooling magma;* ***b)*** *rhythmic magmatic layering of leucogabbro and mesogabbro (subunit 4c);* ***c)*** *massive basalt flow (subunit 5a) showing sharp contact (below hammer) with underlying volcanic conglomerate (subunit 3a);* ***d)*** *pillowed basalt flow (subunit 5b).*

interlayered leucogabbro and mesogabbro (subunit 4c; Figure GS-4-6b) are up to 30 m thick in some locations. Planar layers in these intervals typically range from 5 to 20 cm thick, with sharp upper and lower contacts, and consistently grade upward from leucogabbro to mesogabbro, suggesting they formed by crystal settling of plagioclase. Intervals of homogeneous leucogabbro (>70% plagioclase; subunit 4d) are several tens of metres thick in places and also grade upward into mesogabbro.

**Basalt (unit 5)**

Basalt of unit 5 dominates the upper section of the Rainy Lake Road unit and consists mainly of massive (subunit 5a) and pillowed flows (subunit 5b), with subordinate intervals of flow breccia (subunit 5c). Geochemical data indicate the basalt is Fe-tholeiitic with a chemical affinity to modern back-arc basin basalt (Anderson, 2008) and is likely comagmatic with the associated gabbro sills. Basalt flows are also a significant component of unit 3, particularly near the base, but are not observed farther downsection in the Rainy Lake Road unit.

The basalt weathers light green to buff and is dark green on fresh surfaces. It is aphanitic to fine grained and is generally aphyric or (more rarely) sparsely plagioclase-phyric (<5%; <1 cm). It typically contains round to slightly elongate quartz and carbonate amygdules (<10%; <1 cm), which are concentrated along pillow selvages or flow contacts. Massive flows—where confidently distinguished from gabbro sills—are generally less than 10 m thick and grade upward into pillowed flows or thin (<2 m) layers of amoeboid-pillow breccia or pillow-fragment breccia; these 'compound' flows are up to 20 m thick. Basal flow-contacts are sharp (Figure GS-4-6c), with well-developed chilled margins (5–20 cm thick) that are amygdaloidal along their inner sides. As noted above, volcanic conglomerate at the base of unit 3 is overlain by a distinctive unit of massive basalt flows that is up to 150 m thick in the central portion of the study area and contains only minor pillowed flows and flow breccia. Pillowed flows of subunit 5b consist of bun-shaped to amoeboid pillows up to 1.5 m in maximum dimension, with only minor (<5%) hyaloclastite (Figure GS-4-6d). The pillows have thin (<1 cm) chloritic selvages and densely amygdaloidal inner margins. Some pillows contain thermal contraction fractures or patchy epidote alteration. Pillow cusps consistently indicate tops to the north.

### *Ross River plutonic suite*

**Biotite-hornblende granodiorite–tonalite (unit 6)**

Biotite-hornblende granodiorite–tonalite of unit 6 defines the north margin of the Ross River pluton, which is the namesake pluton of the synvolcanic (ca. 2730–2715 Ma; Turek et al., 1989; Anderson, 2008) Ross River plutonic suite. In the study area, the inner margin of the pluton consists of homogeneous porphyritic granodiorite–tonalite (subunit 6a) that lies in gradational contact to the north with intrusion breccia (subunit 6b) of the outer margin.

Granodiorite–tonalite of subunit 6a weathers buff to pink-grey and is pink-grey on fresh surfaces. It is characterized by a seriate porphyritic texture defined by euhedral to subhedral phenocrysts of feldspar (<40%; <1 cm) and amphibole (<15%; <5 mm), with lesser biotite (<5%; <5 mm) and quartz (<5%; <5 mm), in a medium-grained groundmass of feldspar, quartz and biotite. Subunit 6a is homogeneous in most outcrops, containing only sporadic minor aplite dikes or cognate xenoliths (Figure GS-4-7a) and a weak to moderate foliation. Intrusion breccia of subunit 6b is only observed along the outer margin of the pluton, where it varies from 50 to 200 m thick. It consists of angular inclusions of gabbro (mostly derived from subunits 4a and 4b), with lesser dacite or basalt, in a matrix of granodiorite–tonalite (Figure GS-4-7b). Many inclusions contain a penetrative planar fabric that does not carry across into the adjacent granodiorite–tonalite, which could be explained as a consequence of competency contrast, or alternatively may indicate the existence of fabric that predated—or formed during—pluton emplacement. The intrusion breccia includes irregular networks of pink-white aplite (feldspar-quartz) dikes that show mutual crosscutting relationships with granodiorite–tonalite and are not observed outside the pluton, indicating a comagmatic relationship. The intrusion breccia grades northward into intact gabbro or is sharply truncated by a discrete zone of brittle-ductile mylonite with well-developed dextral asymmetric fabrics and Z-folds.

### *Hypabyssal intrusions (mostly dikes)*

Dikes and minor sill-like intrusions of mafic, intermediate and felsic composition are abundant in the Rainy Lake Road unit (map units 1–5), but only rarely intrude the Ross River pluton (map unit 6) and are very scarce in the overlying Round Lake unit (map units 10–11). The intrusions vary from aphyric to coarsely porphyritic but are characterized everywhere by aphanitic to very fine grained groundmass. On the basis of weathering colour, phenocryst populations, mineralogy and apparent composition of the groundmass, three units were identified in the field. Intrusive contacts are sharp, planar to irregular, and prominently chilled. Most dikes trend northeast and are less than 2 m thick, thus do not form unique polygons on PMAP2013-6. Intrusions of more than one composition are often present in individual outcrops; compound dikes are common (Figure GS-4-7c). Contradictory crosscutting relationships of different compositional types from one outcrop to the next indicate broadly coeval emplacement.

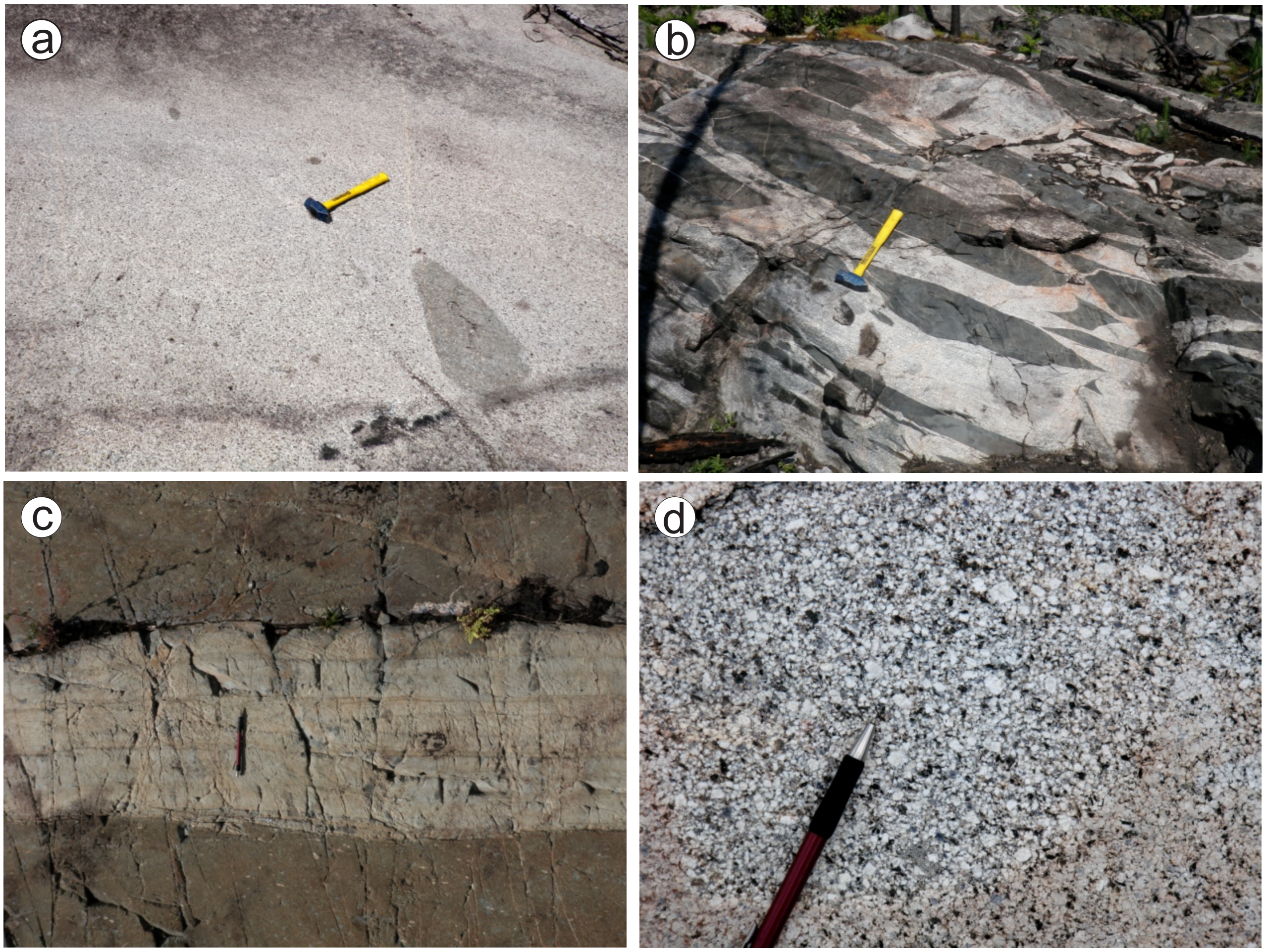

***Figure GS-4-7:*** *Outcrop photographs of intrusions in the Rainy Lake road section:* ***a)*** *homogeneous granodiorite–tonalite (subunit 6a) from the inner margin of the Ross River pluton, showing probable cognate xenoliths;* ***b)*** *intrusion breccia (subunit 6b) from the outer margin of the Ross River pluton, showing angular xenoliths of gabbro in foliated granodiorite–tonalite;* ***c)*** *compound dike of aphyric intermediate composition (subunit 8a) in porphyritic mesogabbro (subunit 4b);* ***d)*** *plagioclase-amphibole-quartz–phyric felsic dike (subunit 9c).*

**Mafic intrusions (unit 7)**

Mafic intrusions of unit 7 are characterized by buff to green-grey weathered surfaces and dark green fresh surfaces. They are similar in texture and appearance to basalt flows of unit 5, with which they are most commonly associated, and are likely comagmatic. They are aphyric (subunit 7a) or variably plagioclase-phyric (subunit 7b) with a chloritic groundmass and are commonly amygdaloidal. Swarms of these dikes locally constitute more than 50% of the outcrop in the middle and upper sections of the Rainy Lake Road unit.

**Intermediate intrusions (unit 8)**

Intermediate intrusions of unit 8 typically weather light grey and are green-grey on fresh surfaces. They are characterized by a very fine to fine-grained groundmass of densely packed (‘felty’) plagioclase laths, and vary from aphyric (subunit 8a) to plagioclase-phyric (subunit 8b) to plagioclase-amphibole–phyric (subunit 8c). The latter variety is most abundant and is characterized by distinctly blocky phenocrysts of plagioclase (<30%; <1 cm) and amphibole (<5%; <5 mm). Some of these dikes also contain well-developed flow banding.

**Felsic intrusions (unit 9)**

Felsic intrusions of unit 9 weather light grey to buff to pink-white and are generally dark grey on fresh surfaces. Fractured surfaces are conchoidal and appear to be highly siliceous. The intrusions vary from aphyric (subunit 9a) to plagioclase-quartz–phyric (subunit 9b) to plagioclase-amphibole-quartz–phyric (subunit 9c), with the latter forming the most abundant and thickest dikes. The aphyric dikes (subunit 9a) locally weather a distinctive light mauve-grey that is similar to felsic dikes hosted by gabbro in the Rice Lake mine. Dikes of subunit 9c weather buff to light cream-white and are light grey on fresh surfaces, with a seriate porphyritic texture defined by euhedral to subhedral phenocrysts of plagioclase (30%;

<1.5 cm), amphibole (<5%; <1 cm) and blue-grey quartz (<5%; <5 mm) in an aphanitic groundmass (Figure GS-4-7d). These dikes are up to 30 m thick and can be traced for considerable distances along strike in some locations.

### *Round Lake unit*

#### Intermediate to felsic tuff breccia, lapilli tuff (unit 10)

Intermediate volcaniclastic rocks of unit 10 are very strongly deformed and define a fault-bounded panel along the south flank of the Wanipigow fault, across the northern portion of the study area. The intensity of fabric development is such that primary textures are commonly obliterated; however, most outcrops are interpreted to consist of coarse volcaniclastic material. This unit shows a systematic northward progression in composition and texture from aphyric andesite (subunit 10a) to plagioclase-phyric andesite or dacite (subunit 10b) to plagioclase-quartz–phyric dacite or rhyolite (subunit 10c), similar to that observed along strike to the west in the type locality of the Round Lake unit north of Rice Lake (Anderson, 2008). These rocks typically weather greenish-grey or light brown and have light green–grey fresh surfaces. They contain up to 20% phenocrysts (plagioclase>quartz±amphibole) that are generally less than 3 mm in size. As indicated above, most outcrops have vague, coarse-fragmental textures defined by highly attenuated clasts of texturally variable, intermediate–felsic volcanic material; some outcrops appear to be crudely stratified. Subunit 10a locally includes coherent andesite that is of probable flow origin and is intruded by distinctive buff-pink aphyric to plagioclase-phyric felsic dikes, which are the only dikes observed in this section.

#### Quartz-phyric rhyolite (unit 11)

Quartz-phyric rhyolite of unit 11 is up to 150 m thick near the top of the fault-bounded panel and is well exposed in a high outcrop ridge just south of Provincial Road 304 in the eastern portion of the study area. This rock has a buff weathered surface and dark grey fresh surface, and contains relatively coarse phenocrysts of quartz and plagioclase (5–15%, 2–5 mm) within an aphanitic to fine-grained, feldspathic and siliceous groundmass. Near the eastern limit of this unit in the burned area, the quartz phenocrysts are up to 1 cm in diameter. The remarkable homogeneity of this unit suggests it may be an intrusion or cryptoflow; it is interpreted to be equivalent to the hypabyssal rhyolitic quartz-feldspar porphyry near the top of the Round Lake unit north of Rice Lake, which yielded a U-Pb zircon age of 2715 Ma (Anderson, 2008).

### *Supracrustal rocks of unknown affinity*

Supracrustal rocks of unknown affinity crop out in widely scattered localities along the drift-filled valley of the Wanipigow River, across the north margin of the study area (Figure GS-4-3). These rocks are characterized by penetrative and pervasive mylonitic foliations that almost completely obscure primary features. Given the high finite strains and widespread development of asymmetric fabrics and folds indicative of intense noncoaxial shear, the stratigraphic context of these rocks could not be established.

#### Pillowed basalt (unit 12)

Unit 12 consists of mafic tectonite and chloritic mylonite that weather light green-grey to brown and are dark green on fresh surfaces. Local epidote nodules, quartz amygdules and chloritic selvages indicate pillowed basalt as the most likely protolith. These rocks contain abundant transposed quartz veins but are otherwise homogeneous.

#### Greywacke, mudstone, iron formation (unit 13)

Unit 13 is characterized by very well developed tectonic layering that consists of alternating thin (<5 cm) layers of light grey quartzofeldspathic mylonite and chlorite-biotite phyllonite. In one location, it is apparent that these rocks were at least locally derived from thin-bedded greywacke-mudstone turbidites. At two other locations, unit 13 also includes minor interlayers of thin-bedded to laminated oxide-facies iron formation. Asymmetric folds are ubiquitous in this unit as a result of the pronounced planar anisotropy.

#### Quartz-feldspar porphyry (unit 14)

Unit 14 is exposed in two clusters of outcrops along the extreme northern boundary of the map area; both outcrop groups drop steeply off into the Wanipigow River valley, perhaps indicating the presence of a late fault scarp. The porphyry is buff to white on weathered surfaces and light green–grey on fresh surfaces. It contains subhedral plagioclase (5%; <5 mm) and quartz (1–3%; <2 mm) phenocrysts in a fine-grained feldspathic groundmass. Most outcrops appear to be homogeneous. Laminated fault-fill quartz veins, locally intense ankerite-sericite-pyrite alteration and widespread quartz-filled extension fractures—the latter forming sheeted arrays in places—are associated with discrete brittle-ductile shear zones in this unit, many of which have previously been trenched.

## Structural geology

Primary planar structures in the study area include beds, magmatic layers and flow contacts (collectively referred to as ‘primary layering’), as well as dike and sill margins. Primary layering dips steeply toward the north throughout most of the study area, but shows a gradual change in orientation toward the southwest, where it dips moderately to the northwest. With the exception of minor fold limbs, primary layering is upright everywhere. Dike margins strike subparallel or at a shallow counterclockwise angle to bedding, in keeping with the geometric relationships observed along strike to the west in the Rice Lake mine trend (Anderson, 2011b). Dike margins also change orientation toward the southwest, in concert with primary layering trends.

Apart from synsedimentary structures, the earliest deformation structure identified in the study area is a pervasive planar-linear (S-L) shape fabric defined by flattened and stretched primary features (Figure GS-4-8a, b), which corresponds to the third generation ($G_3$) of regional deformation structures described by Anderson (2008, 2011b). The $S_3$ shape fabric includes a continuous foliation defined by fine-grained chlorite, actinolite or sericite, and generally strikes west or west-northwest at a shallow clockwise angle to bedding—which thus faces west on $S_3$. This fabric dips steeply to moderately to the north. It is axial planar to rare open to tight S-folds ($F_3$; Figure GS-4-8a) that plunge moderately to the northwest and are interpreted to be parasitic to the north limb of the Beresford Lake anticline. The $S_3$ fabric is also axial planar to ptygmatic folds of north-trending dikes (Figure GS-4-8b). The $L_3$ stretching lineation is best developed in the south-central portion of the study area, where it plunges moderately to the northeast in the plane of the $S_3$ fabric. As with the primary layering and dikes, the $S_3$–$L_3$ fabric shows a systematic change in orientation toward the southwest, indicating the presence of a broad open fold that postdates $G_3$ structures and is interpreted to result from flattening or drag along the south margin of the WF during later deformation (see below).

The $G_3$ deformation structures are overprinted by ductile to brittle-ductile fabrics associated with strongly partitioned, dextral, transcurrent shear deformation. These


***Figure GS-4-8:*** *Outcrop photographs of deformation structures in the Rainy Lake Road unit:* ***a)*** *hinge of a small-scale $F_3$ fold, showing the near orthogonal relationship between bedding ($S_0$) and the $S_3$ shape fabric defined by flattened mudstone rip-up clasts;* ***b)*** *penetrative planar $S_3$ fabric (defined by flattened clasts) showing an axial planar relationship to ptygmatic folds in the margin of a highly discordant intermediate dike;* ***c)*** *thick $G_5$ high-strain zone near the south margin of the Wanipigow fault showing penetrative mylonitic foliation, asymmetric boudins and spaced shear-band cleavage; orientation of associated S-C fabric and shear bands (C'), and the sense of shear (dextral) are indicated (circle indicates hammer for scale);* ***d)*** *shallowly west-plunging $L_5$ lineation (black arrow) defined by stretched clasts and ductile striations in the south margin of the Wanipigow fault; steps (white arrows) indicate dextral-reverse oblique-slip in this location.*

fabrics are pervasive and penetrative along the south margin of the WF and correspond to the fifth generation ($G_5$) of regional deformation structures described by Anderson (2008, 2011b). Farther south, the $G_5$ fabrics are penetrative in discrete shear zones that splay to the southeast off the footwall of the WF (Figure GS-4-3). Outside these shear zones, the $G_5$ fabric is locally manifested as a spaced shear-band cleavage. The $G_5$ shear zones typically trend west-northwest, dip steeply to the north and are characterized by penetrative mylonitic $S_5$ foliations and packets of strongly asymmetric $F_5$ Z folds, the hinges of which have highly variable orientations and are locally curvilinear or sheath-like. Dextral kinematic indicators are well developed on horizontal outcrop surfaces and typically include S-C fabrics, shear bands (C′-fabric) and asymmetric boudins (Figure GS-4-8c). Stretched clasts, quartz ribbons or ductile striations define a lineation ($L_5$; Figure GS-4-8d) that plunges more shallowly than the local $L_3$ stretching lineation. Along the south margin of the WF, the $L_5$ lineation plunges shallowly east in the western portion of the study area and shallowly west in the east, indicating a complex strain geometry that may relate to incomplete overprinting of the early L fabric ($G_3$) or the transpressional character of $G_5$ deformation.

## Economic considerations

### *Orogenic gold*

Given its proximity to the known eastern extent of the Rice Lake mine trend and the south margin of the crustal-scale WF, the study area is considered to have excellent potential for quartz-carbonate vein (i.e., orogenic) gold deposits. The study area includes several significant occurrences of this type, most notably the On-the-Mark, Romano and Salerno prospects (Caron, 2010), which have recently attracted exploration interest. At each prospect, gold mineralization is hosted by fault-fill and extensional quartz-carbonate veins in, or adjacent to, discrete brittle-ductile shear zones. Each is also spatially associated with the Ross River pluton (Figure GS-4-3), hosted by granodiorite–tonalite of the inner margin (On-the-Mark and Romano) or by dacitic volcanic rocks immediately to the north (Salerno), indicating that structural anisotropy and competency contrast across the pluton margin may have been an important local control on gold mineralization.

This scenario is analogous to that documented in the Rice Lake mine trend, where the major gold deposits preferentially occur within chemically favourable or competent rock types or along major strength-anisotropies within the supracrustal succession. By analogy with the mine trend, the middle and upper sections of the Rainy Lake Road unit should, in several respects, be much more favourable exploration targets than the Ross River pluton, despite its association with the most significant gold occurrences in the study area. These sections include gabbro sills and basalt flows of Fe-tholeiitic composition, which are among the most important hosts to orogenic gold deposits worldwide. They are also pervasively intruded by relatively competent rock types, including gabbro and felsic porphyry, and contain very pronounced strength-anisotropies due to the large compositional variations between primary layers. It is therefore suggested that future exploration should be focused on establishing the locations of favourable structural sites in the middle and upper sections of the Rainy Lake Road unit, by way of detailed structural mapping and geophysical surveys.

### *Volcanic-hosted massive sulphide*

As described by Anderson (2008, 2013b), the Gem assemblage presents a prospective host for volcanic-hosted massive sulphide (VHMS) deposits, in that it shows many hallmarks of extensional geodynamic settings in major Archean or Paleoproterozoic VHMS districts elsewhere. The middle section of the Rainy Lake Road unit is interpreted to represent a relatively restricted marine basin that formed in the hangingwall of a synvolcanic subsidence structure located along strike to the west, in a location now occupied by an apophysis of the Ross River pluton (Anderson, 2008). The middle section contains occurrences of stringer-style chlorite-garnet alteration, layered solid sulphide (pyrite), black sulphidic chert and solid sulphide clasts (pyrrhotite±chalcopyrite) in coarse epiclastic deposits, indicating that hydrothermal circulation, seafloor discharge (exhalation) and localized sulphide deposition did indeed accompany basin infilling, probably in close proximity to a fault-controlled discharge site. As reported by Anderson (2008), grab samples of sulphidic volcanic conglomerate near the top of the middle section along the Rainy Lake road returned up to 5.5% Zn and 1.9 ppm Au, indicating potential for a base- and precious-metal–rich exhalative system.

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