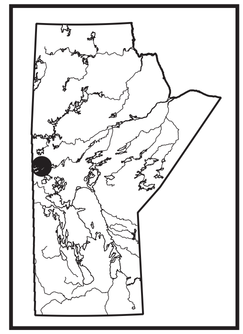
December, 2012

NOTE: The PDF of GS-8 from Report of Activities 2012 has been reprinted with minor changes to the layout.

GS-8 Geological investigations in the Brunne Lake area of the Flin Flon Belt, west-central Manitoba (parts of NTS 63K11, 14)

by S. Gagné



Gagné, S., 2012: Geological investigations in the Brunne Lake area of the Flin Flon Belt, west-central Manitoba (parts of NTS 63K11, 14); *in* Report of Activities 2012, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 90–103.

Summary

Results from geological investigations in the Brunne Lake area during the 2012 field season have been used to update the geological map of the area. A crescent-shaped narrow belt of supracrustal rocks dominated by mafic volcanic rocks and synvolcanic gabbro dikes, with minor shallow porphyritic intrusions and felsic volcaniclastic horizons, passes through Copper Lake and Brunne Lake. The package of supracrustal rocks has been intruded by various plutons. Five main intrusive complexes occur within the map area: 1) syenogranite to the northeast; 2) quartz monzodiorite to the west; 3) granodiorite to quartz diorite to the southeast; 4) monzogranite in the centre of the supracrustal belt and to the southwest; and, 5) gabbro and diorite to the east. The geochemical signature of the basaltic rocks displays characteristics of both mid-ocean–ridge and back-arc–basin environments. Gabbro dikes show a very similar chemistry to the basalt for both the major and trace elements. Granitoid rocks generally are of calc-alkaline affinity and are characterized by a volcanic-arc signature.

The main foliation observed in the supracrustal rocks is the flattening plane in which lies the stretching lineation. On the northwestern flank of the supracrustal belt, the main foliation is subvertical and consistently strikes 040°. The stretching lineation typically plunges moderately (50–65°) to the northeast but it steepens progressively as it gets closer to the high-strain zones, till eventually it is downdip within the shear zone. On the northwestern flank, a macroscopic, tight antiformal structure is evidenced by changes in facing directions revealed by basalt pillows. Two major high-strain zones affect the supracrustal rocks. A narrow (50–100 m) high-strain zone striking 040°, characterized by ductile fabric and dextral-shear sense, trends along the northern margin of the supracrustal package from the eastern end of Copper Lake to the Gurney mine. The second major shear zone straddles across Brunne Lake for 100–600 m, widening from west to east, where it splays out. The latter shear zone is characterized by a ductile, mylonitic fabric and a pervasive carbonate impregnation of the rocks.

Introduction

The Flin Flon Belt is part of the Reindeer Zone of the Trans-Hudson Orogen (THO). It is one of the largest Paleoproterozoic volcanogenic massive sulphide (VMS) districts in the world. Detailed mapping (1:20 000 scale or greater) and geochemical studies have historically been focused on the Flin Flon mining camp. The Elbow and Athapapuskow lakes areas have also been the focus of detailed studies (Syme, 1988; Whalen, 1991; Stern et al., 1995a; Syme and Whalen, in press), all of which provide a solid framework for understanding the geological evolution of the belt. An area spanning about 30 km between the eastern margin of the Flin Flon mining camp and the Elbow Lake region consists mostly of granitoid rocks, but also contains two significant supracrustal belts that have not been examined since the 1950s (Podolsky, 1951; McGlynn, 1959); one of these belts is referred to as the Brunne Lake belt. Forest fires during the summer of 2010 cleared the vegetation from the outcrop in this belt and thus provided better access and an opportunity to investigate the local geology. The supracrustal and intrusive rocks in the Brunne Lake area provide new information pertaining to the evolution and tectonic assembly of the Flin Flon Belt. A better understanding of the local geology and its tectonic setting will also help improve the level of knowledge of the area's mineral potential.

The results from geological mapping conducted in the Brunne Lake area during the 2012 field season are presented as a new 1:10 000 geological map (Gagné, 2012). This paper discusses the results of this mapping, briefly describes the main geological features of the Brunne Lake area and presents new geochemical data.

Previous work

The Brunne Lake area has seen minimal geoscientific investigation in the past 60 years. Prospecting in the area started as early as 1915 (Hage, 1944) and the earliest concerted geological work in the region was by Bruce (1918). The Gurney mine property was first staked in 1919 and produced about 28 000 ounces of gold from 1937 to 1939. The geology of the deposit was briefly described by Hage (1944). Although sporadic exploration activities have taken place since, the most recent systematic geological mapping of the area dates back to the 1950s and was carried out by the Geological Survey of Canada (Podolsky, 1951; McGlynn, 1959). Podolsky (1951) mapped the Brunne Lake area at a scale of 1:40 000 and McGlynn (1959) mapped the Elbow–Hemming lakes area at a scale of 1:63 360; the latter map area also includes the northernmost portion of Copper Lake.

Regional geology

The Brunne Lake area is situated within the central portion of the Paleoproterozoic Flin Flon–Snow Lake greenstone belt, which is part of the juvenile Reindeer Zone of the THO (Figure GS-8-1). The belt consists of a complex collage of distinct tectonostratigraphic packages, which were joined together during the 2.0–1.8 Ga amalgamation of several Archean cratons into Laurentia (Hoffman, 1988). The belt extends from east to west for more than 250 km and is about 50 km wide from north to south. It is bounded to the north by the Kisseynew Domain, to the east by reworked Archean domains of the THO external zone and to the west by the Wollaston fold belt. To the south, it is unconformably overlain by Paleozoic sedimentary rocks (Figure GS-8-1).

The Flin Flon Belt consists of a series of tectonostratigraphic assemblages (juvenile arc, juvenile ocean-floor back-arc, ocean plateau, ocean-island basalt; Stern et al., 1995a), which were intruded by evolved plutonic-arc and early to late successor-arc plutons ranging in age from 1.83 to 1.92 Ga (Whalen et al., 1999).

The Flin Flon Belt records a broad range of peak metamorphic conditions. At Brunne Lake, mineral assemblages indicate upper-greenschist- to lower-amphibolite–facies metamorphism. However, in the interest of brevity, the prefix 'meta-' is not used in this report and the rocks are described in terms of their protoliths.

Local geology

The geology of the Brunne Lake area consists of a narrow, arcuate tract of supracrustal rocks dominated by pillowed basalt, synvolcanic gabbro dikes and sills, minor amounts of mafic volcaniclastic and epiclastic rocks, and felsic volcaniclastic rocks. Hypabyssal porphyry intrusions crosscut the supracrustal rocks and both are intruded by diverse plutonic rocks.

The following section provides preliminary field descriptions of rock types encountered in the Brunne Lake area. Unit numbers in this report correspond to those on Preliminary Map PMAP2012-6 (Gagné, 2012); Figure GS-8-2 represents a simplified version of this map.

Supracrustal rocks: volcanic and subvolcanic intrusive rocks

Basalt and synvolcanic gabbro (unit 1)

Unit 1 includes basaltic flows (pillowed and massive), thin horizons of mafic and felsic volcaniclastic rocks and gabbro dikes of various width (0.2 m to tens of metres). It is divided into five subunits (1a, 1b, 1c, 1d and 1e) based on the dominant exposed rock types, level of alteration and amount of strain; contacts between these subunits are generally gradational.

Pillowed basalt (subunit 1a)

Subunit 1a is characterized by abundant pillowed basalt flows accompanied by lesser amounts of massive basalt flows, thin horizons of mafic and felsic volcaniclastic rocks, and gabbroic dikes. The basalt weathers from medium green to dark green. Pillows range up to 2.0 m in diameter, but average between 0.4 and 1.0 m (Figure GS-8-3a), with relatively thin selvages (2–6 mm). The pillowed flows vary from aphyric to plagioclase-phyric, to plagioclase-pyroxene–phyric, with the proportion of plagioclase and pyroxene phenocrysts varying up to 20% and 5% respectively. Some massive flows (0.5–3 m) with ameboid pillow-breccia tops (Figure GS-8-3b) are intercalated with pillowed flows. Amygdules are few (2–7% locally) and many flows are nonamygdaloidal; amygdules vary from 2 to 8 mm in diameter and are generally filled with quartz or epidote. The younging directions were observed locally using pillow asymmetry. Synvolcanic gabbro dikes that range in width from 0.2 m up to tens of metres are common. This unit also contains minor amounts (<3%) of thin (0.2–3 m) volcaniclastic horizons, which vary in composition from a plagioclase-pyroxene–phyric mafic crystal tuff, to heterolithic mafic lapilli tuff, to dacitic quartz-feldspar–phyric tuff and heterolithic felsic lapilli tuff.

Massive basalt (subunit 1b)

Subunit 1b is similar to subunit 1a, but contains abundant massive basalt flows, with lesser pillowed flows. The massive flows are 1 to 5 m thick, generally nonamygdaloidal and aphyric to slightly plagioclase-phyric. Massive flows are typically intercalated with pillowed flows and are locally capped by ameboid pillow breccia and autoclastic breccia. Thicker flows locally show polygonal jointing.

Gabbro (subunit 1c)

Subunit 1c consists mostly of gabbro, associated with lesser amounts of basaltic flows (pillowed and massive), and thin horizons of mafic and felsic volcaniclastic rocks. This medium-grained (2–4 mm) and equigranular gabbro has a granoblastic texture and varies from massive to weakly foliated, except near a major shear zone, where it shows well-developed mineral foliation. It locally has a weakly to moderately developed mineral lineation. A minor phase of the gabbro shows a plagioclase-phyric texture with phenocrysts up to 1.3 cm in size. In several outcrops, the gabbro clearly intrudes basalt and mafic volcaniclastic horizons. Smaller gabbro dikes are subparallel to the stratigraphy.

Mafic tectonite (subunit 1d)

This subunit is a very distinct horizon characterized by ductile mylonitic fabric and pervasive carbonate alteration, and appears to be mostly hosted by mafic

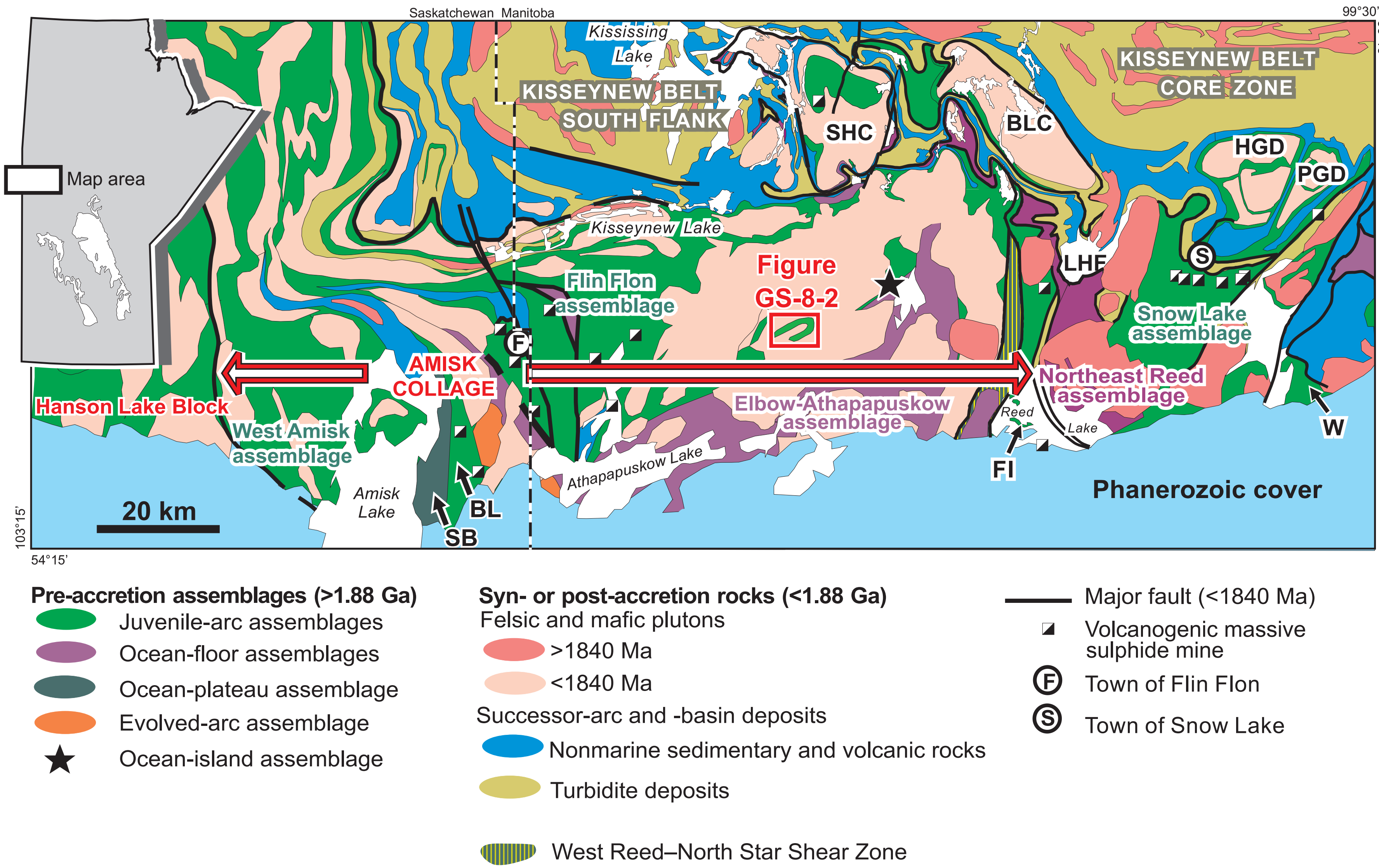


Figure GS-8-1: *Geology of the Flin Flon–Snow Lake greenstone belt, in west-central Manitoba, showing the location of Figure GS-8-2 (modified from Syme et al., 1998). Abbreviations: BL, Birch Lake; BLC, Batty Lake complex; FI, Fourmile Island; HGD, Herblet gneiss dome; LHF, Loonhead Lake Fault; PGD, Pulver gneiss dome; SB, Sandy Bay; SHC, Sherridon–Hutchinson Lake complex; W, Schist-Wekusko assemblage.*

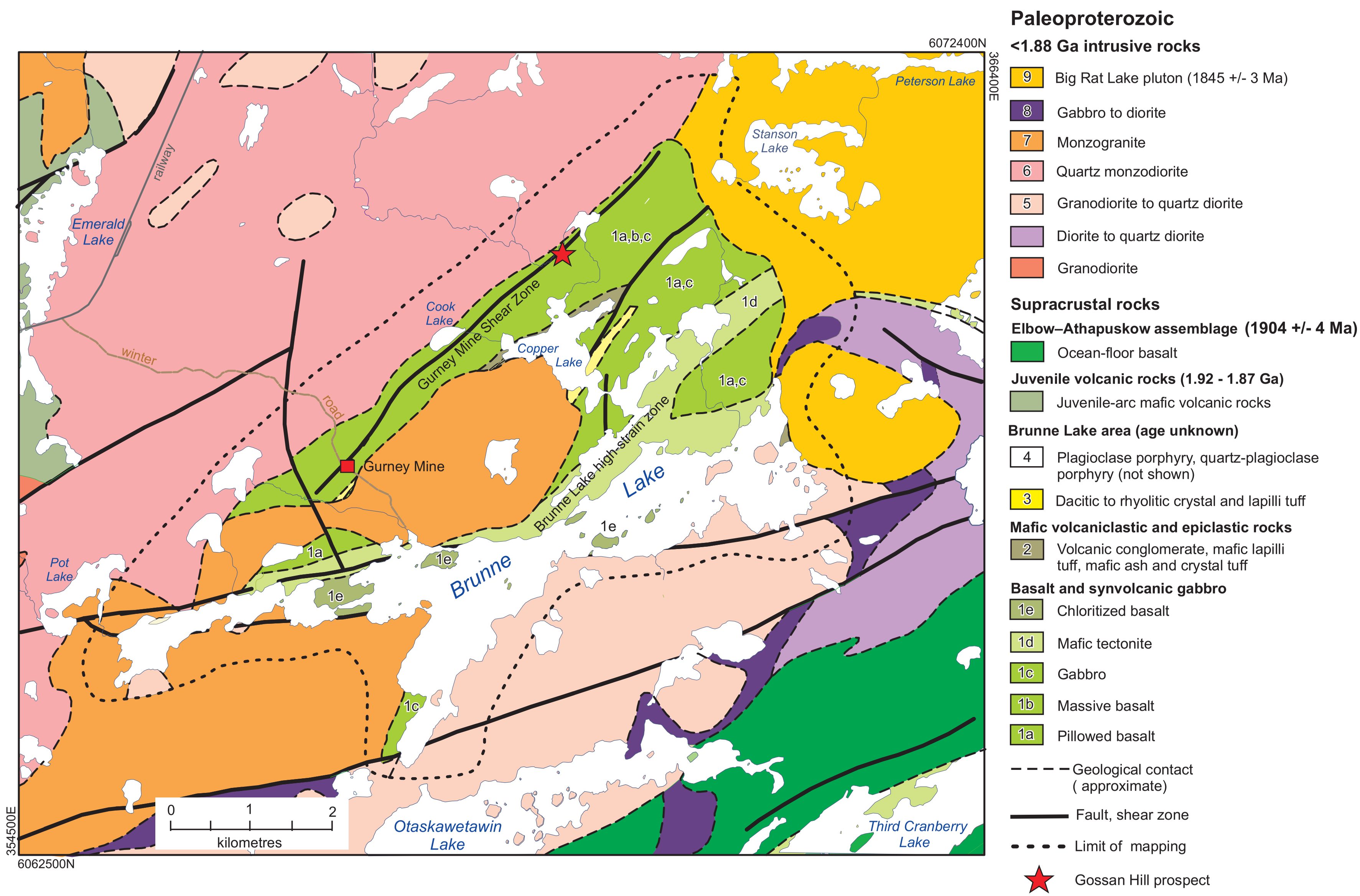


Figure GS-8-2: *Simplified geology of the Brunne Lake area, west-central Manitoba. Unit numbers correspond to those on Preliminary Map PMAP2012-6 (Gagné, 2012).*

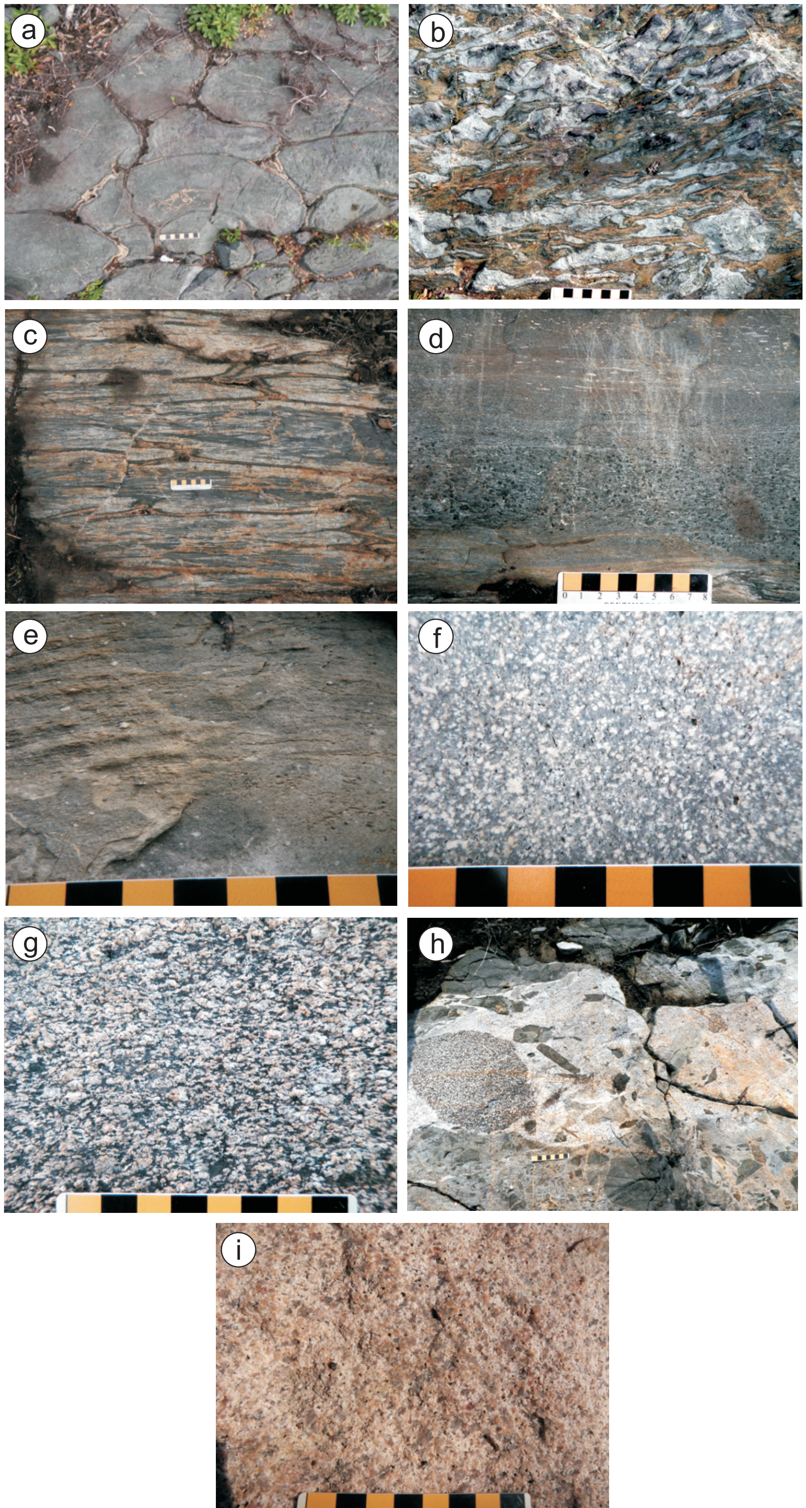


Figure GS-8-3: *Outcrop photographs of representative rock types from the Brunne Lake area, west-central Manitoba.* ***a)*** *pillowed basalt from subunit 1a, 500 m north of Copper Lake;* ***b)*** *ameboid breccia from subunit 1a with thin selvages on ameboid fragments, 700 m southwest of Pot Lake;* ***c)*** *strongly altered and flattened pillowed basalt in subunit 1d, near the northern margin of the Brunne Lake high-strain zone in the southern bay of Copper Lake;* ***d)*** *mafic crystal tuff from subunit 2a showing a pyroxene-rich 4 cm horizon with gradational boundaries, northern shore of Copper Lake;* ***e)*** *felsic tuff from unit 3 with 3–12% plagioclase phenocrysts (0.5–2 mm) and 1% of blue quartz (0.5–2 mm), 400 m inland, east from the central portion of Copper Lake;* ***f)*** *plagioclase porphyritic dike from unit 4, which intruded the supracrustal rocks of unit 1, north of Copper Lake;* ***g)*** *quartz monzodiorite from unit 6, 200 m west of Cook Lake;* ***h)*** *agmatitic portion of quartz monzodiorite from unit 6 showing fragments of different gabbroic composition, north of Cook Lake;* ***i)*** *monzogranite from unit 7, near the Gurney mine site. Scale bar is 8 cm.*

volcanic rocks. In the core of this subunit, the rocks are so deformed and carbonatized that it is generally very difficult to determine protoliths. Remnant pillow selvages indicate that the protolith for this unit was, at least locally, basaltic flows (Figure GS-8-3c). Although the transition from fresh basalt to mafic tectonite is fairly rapid, it is locally possible to observe a progression from subunits 1a, 1b or 1c into subunit 1d along the outer margin of the zone.

Chloritized basalt (subunit 1e)

Basaltic rocks found along the southern shore of Brunne Lake and on several of the islands have a very distinct buff to brownish colour on weathered surface. The rocks consist of aphyric massive to pillowed flows and are generally weakly foliated, except within a short distance (<50 m) from the carbonatized mafic tectonite zone. In contrast to the mafic tectonite from unit 1d, these rocks contain little carbonate. A variable amount of chlorite is present, from 10 to 50%. The rocks also locally display good exposures of jigsaw-fit autoclastic breccia, with angular fragments and very little matrix. Synvolcanic gabbro dikes ranging in width from 0.2 m up to tens of metres are locally observed.

Mafic volcaniclastic and epiclastic rocks (unit 2)

Within the Brunne Lake supracrustal package, mafic volcaniclastic and epiclastic rocks represent a small proportion of the observed rock types. They form a few mappable units, but they also occur locally within unit 1 as thin interflow horizons (0.2–3 m).

Mafic ash and crystal tuff (subunit 2a)

Subunit 2a is characterized by crudely-bedded mafic ash tuff and crystal tuff with variable crystal content. The bedding is defined by variation in crystal abundance, size and composition. The crystal component varies from plagioclase, to pyroxene, to plagioclase and pyroxene (Figure GS-8-3d).

Mafic lapilli tuff (subunit 2b)

Subunit 2b is characterized by crudely-bedded heterolithic lapilli tuff, interbedded with minor amounts of mafic ash and crystal tuff. Clast types include aphyric, plagioclase-phyric and pyroxene-phyric basalt, with fragment sizes ranging from 2 to 35 cm. Some horizons locally contain up to 10% of broken quartz and epidote amygdules.

Volcanic conglomerate (subunit 2c)

A very distinctive, thin unit of coarse volcanic conglomerate was observed in two locations. The volcanic conglomerate is heterolithic, crudely stratified, clast supported and poorly to moderately sorted. The clasts consist of mafic to intermediate flow (mostly plagioclase-phyric and aphyric) and intrusive rocks; felsic clasts are absent. The matrix is feldspar-rich, with lesser amounts of pyroxene crystals. Clasts are subrounded to well rounded and pebble to cobble size. The conglomerate contains thin layers of thin-bedded (0.5–10 cm), crystal-rich epiclastic sedimentary rocks, with up to 40% plagioclase crystals (2–7 mm).

Dacitic to rhyolitic crystal and lapilli tuff (unit 3)

This unit is approximately 100 m thick and consists of plagioclase- and quartz-phyric dacitic to rhyolitic tuff and lapilli tuff. It is readily distinguished by its felsic composition and the presence of quartz phenocrysts, which are locally deep blue in colour. These rocks are typically thinly bedded, with 5–15% plagioclase phenocrysts (0.5–3 mm), 1–3% quartz phenocrysts (0.5–2 mm) and lapilli-size plagioclase-phyric felsic fragments (Figure GS-8-3e).

Plagioclase and quartz-plagioclase porphyritic dikes (unit 4)

Dikes of high-level intrusive rocks intrude the supracrustal rocks; the composition of these massive plagioclase to quartz-plagioclase porphyritic dikes ranges from felsic to intermediate. Plagioclase phenocrysts vary from 10 to 25% in abundance and range from 3 to 6 mm in size (Figure GS-8-3f). These dikes, which intrude rocks from unit 1, are 10 cm to 5 m thick, with sharp contacts, and generally strike between 340 and 030°.

Intrusive rocks

Granodiorite to quartz diorite (unit 5)

This unit represents a multiphase intrusion that forms a large continuous body along the southeastern shore of Brunne Lake. Unit 5 also occurs as smaller bodies along the southwestern shore of Brunne Lake within unit 7; since the contact between these units was not observed, the age relationship is unclear. Unit 5 ranges in composition from granodiorite, to tonalite, to quartz diorite and diorite. These rocks are homogeneous, equigranular and medium- to coarse-grained, and vary from massive to moderately foliated. The dominant phase is a light to medium grey granodiorite, which weathers light grey to buff. Biotite is the main mafic mineral (2–7%; 1–3 mm in size), although more mafic phases (quartz diorite and diorite) typically also contain 5–15% of hornblende (1–5 mm in size). Contacts between the various phases of unit 5 are gradational. Magnetite locally occurs as an accessory mineral (<1%).

Quartz monzodiorite (unit 6)

This unit consists of moderately to well foliated, equigranular to locally plagioclase-porphyritic, medium-to coarse-grained quartz monzodiorite. This rock typically contains hornblende (15–25%; 1–5 mm in size; Figure GS-8-3g) as the major ferromagnesian mineral phase. Along its margin with supracrustal rocks, the monzodiorite comprises a zone of agmatite with a matrix of granodiorite/quartz monzodiorite (Figure GS-8-3h) and varying percentages (40–70%) of inclusions of older intrusive and supracrustal rocks. The agmatitic phase of the quartz monzodiorite consists of mainly subangular to subrounded mafic igneous inclusions (5 cm to >1 m). The supracrustal xenoliths consist mainly of aphyric to plagioclase-phyric fragments of basalt. Within 100 m of the external contact, the proportion of xenoliths in the quartz monzodiorite drops to about 5%.

Monzogranite (unit 7)

A buff to light grey monzogranite, weathering beige to grey-brown, occupies the core of the supracrustal sequence and extends to the southwestern shore of Brunne Lake. The monzogranite is generally homogeneous, equigranular and medium- to coarse-grained, with minor biotite (1–4%; 1–2 mm in size; Figure GS-8-3i). The rock varies from massive to moderately foliated; the latter is better developed close to the pluton margin. Near the Gurney mine, the monzogranite is injected by narrow quartz veins (0.5–5 cm), which show silicification and potassic alteration along the vein margin.

Gabbro to diorite (unit 8)

This unit consist mostly of gabbro, with subordinate diorite. The gabbro is generally medium- to coarse-grained, equigranular, massive to weakly foliated and contains a few angular inclusions of fine-grained mafic rock (basalt?). Locally, the gabbro is intruded by a fine- to medium-grained, equigranular quartz diorite.

Syenogranite: Big Rat Lake pluton (unit 9)

To the northeast, the package of mafic volcanic rocks is intruded by the Big Rat Lake pluton (Whalen, 1991). Although this pluton is a composite intrusion, which ranges in composition from diorite to granodiorite to granite (Whalen, 1991), the few outcrops that were examined in this study consisted of a medium to dark pink foliated biotite syenogranite, with a very uniform composition.

The pluton covers an area of about 20 km^2 between Copper Lake and Elbow Lake. A zircon U-Pb age determination obtained from a coarse-grained, equigranular, hornblende-biotite granodiorite sampled along the northeastern margin of the pluton indicates a crystallization date of 1845 ±3 Ma (Whalen and Hunt, 1994). Hornblende and biotite mineral dates of 1757 ±21 Ma and 1768 ±22 Ma, respectively, obtained by the K-Ar method from this same sample probably record younger metamorphic overprinting (Hunt and Roddick, 1992).

Structural geology and metamorphism

Because of the narrow width of the supracrustal belt, most rocks lie within the metamorphic aureole of large neighbouring granitoid plutons and are thus affected by upper-greenschist– to lower-amphibolite–facies metamorphism. Hornfelsed basaltic rocks are characterized by dark green to black colour and consist of fine-grained recrystallized hornblende and plagioclase. Primary volcanic structures are generally well preserved outside of high-strain zones.

Primary layering (S_0) is only locally observed within fine-grained felsic tuffs and mafic volcaniclastic rocks. Only a few outcrops showed graded beds that could be used to determine convincing younging directions within the supracrustal sequence. Using asymmetry of basalt pillows, several facing directions were obtained for the northwestern flank of the crescent-shaped package of supracrustal rocks. The younging directions (n=18) indicate the presence of a large-scale, northeast-trending, tight to isoclinal fold.

The main planar fabric observed along the northwestern flank is a penetrative foliation, which varies from weakly developed in basalt pillows farther away from shear zones to strongly developed within the shear zone (Figure GS-8-4a). This foliation (S_1) is the oldest fabric recognized and is defined by flattened pillows and clasts. It is assigned to the first deformation event (D_1). Along the northwestern flank, S_1 very consistently strikes 035–040° and is subvertical (Figure GS-8-4b). Measurements of the S_0-S_1 intersection lineation indicate that D_1 folds (including the macroscopic isoclinal fold on the northwestern flank) plunge shallowly to the northeast.

Locally, along the northwestern flank, a less prominent late foliation (S_2) is recognizable; it generally strikes 10–15° counter-clockwise from the main foliation, with similar or slightly shallower dip. No folds associated with S_2 were recognized.

Volcanic rocks throughout the map area contain a well-developed stretching lineation. The lineation is defined by elongate lapilli and amygdules, as well as a mineral lineation defined by amphibole. Along the northwestern flank, the lineation plunges steeply in the plane of the subvertical foliation (Figure GS-8-4c). Away from the high-strain zones, the stretching lineation is less developed and trends more east to northeast, with a moderate plunge striking 40–55°.

Two main shear zones are recognized in the Brunne Lake area. The Gurney Mine Shear Zone occupies the northern side of the northwestern flank, very close to the contact with the quartz monzodiorite (Figure GS-8-2). It is characterized by a strongly developed subvertical foliation and downdip stretching lineation. Asymmetric

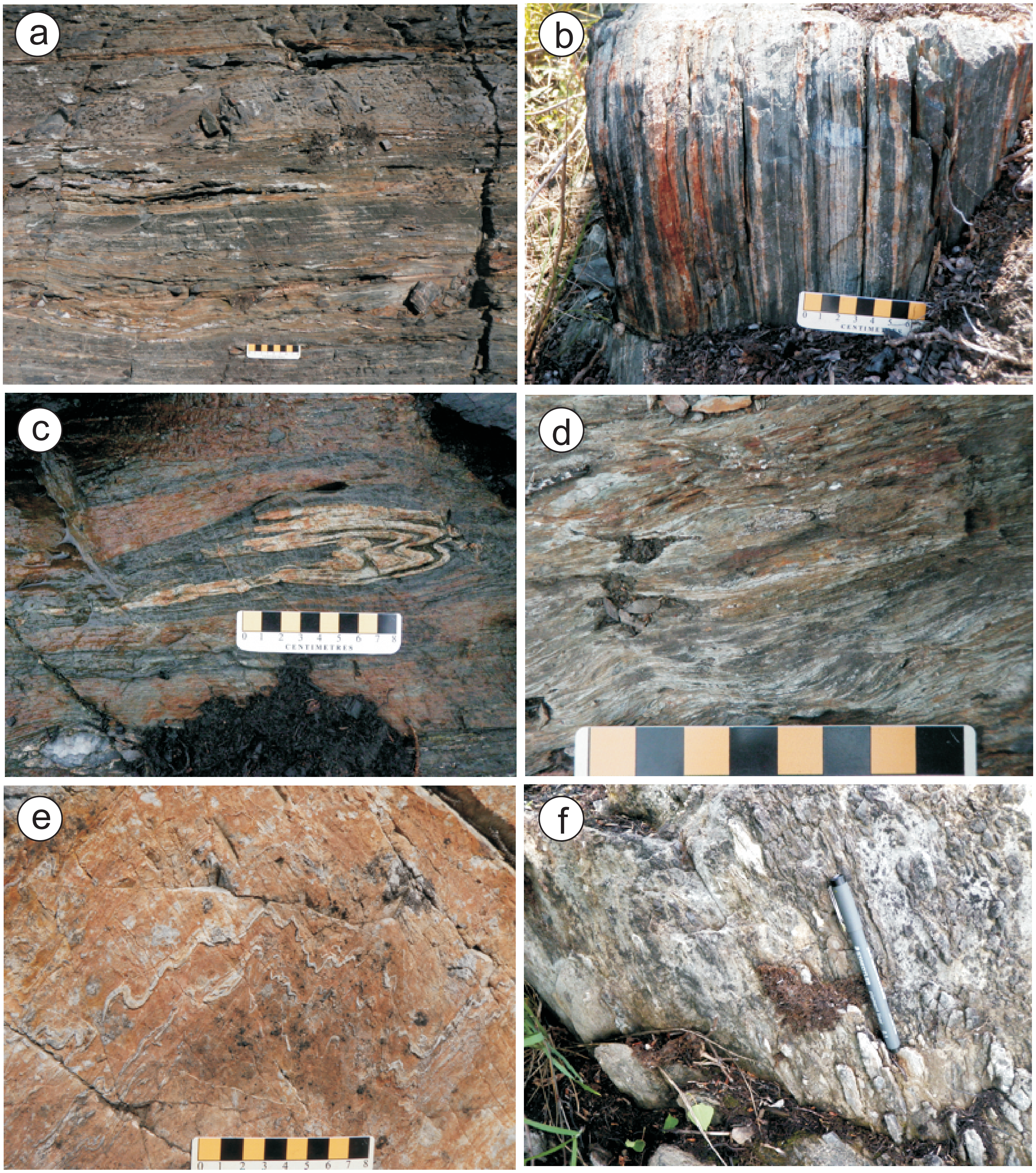


Figure GS-8-4: *Outcrop photographs from the Brunne Lake area, west-central Manitoba:* ***a)*** *main foliation (S_1) and associated flattening shown in aphyric pillowed basalt of unit 1a, 1 km south of Peterson Lake;* ***b)*** *strongly developed subvertical foliation in ameboid breccia within the Gurney Mine Shear Zone in unit 1a, 1 km from the northeastern end of the shear zone;* ***c)*** *well-developed stretching lineation in carbonatized mafic tectonite from unit 1d, southeastern shore of Copper Lake;* ***d)*** *shear bands in epidote-chlorite–altered gabbro from unit 1a indicating a dextral sense of motion for the Gurney Mine Shear Zone, 500 m north of Copper Lake, in the Gossan Hill property area;* ***e)*** *z-asymmetric drag fold in altered mafic tuff in unit 1, associated with an unnamed shear zone, 500 m northeast of Copper Lake;* ***f)*** *rootless intrafolial fold with axial plane subparallel to the main shear-zone foliation in unit 1a, 300 m from the northeastern end of the Gurney Mine Shear Zone. Scale bar is 8 cm.*

fabrics on horizontal outcrop surfaces, including porphyroclasts, S-C fabrics (Figure GS-8-4d) and shear bands, indicate a component of dextral strike-slip shear. Coupled with the steep stretching lineation, the structural geometry and kinematics of this shear zone may indicate two increments of movement (i.e., dextral strike slip and normal or reverse dip slip) or transpressional deformation (i.e., coeval strike slip and vertical stretching). The high-strain rocks within the shear zone are locally intensely altered. Intense patchy silicification and epidote alteration are characteristic of the shear zone along the northwestern flank. Dextral drag folds (Figure GS-8-4e) and rootless folds (Figure GS-8-4f) of S_1 within the shear zone and the local weak development of S_2 fabric suggest that the shear zone formed late–post D_1.

The second shear zone, the Brunne Lake mylonite zone, trends along the northern shore of Brunne Lake, on the southeastern flank of the package of supracrustal rocks (Figure GS-8-2); it consists of a broad zone of carbonate-rich (5–35%) mafic tectonite, with a structure varying from moderately sheared to protomylonitic. The protolith of the mafic tectonite is generally unknown, but pillow selvages are preserved locally. The shear zone is characterized by a penetrative, subvertical, mylonitic foliation and a near-downdip stretching lineation. However, no reliable kinematic indicators could be identified to establish the sense of shear. This shear zone can be followed from the western end of Brunne Lake, where it is only 50–100 m thick, to the eastern extent of the supracrustal rocks for a total length of 8 km. The tectonite zone becomes broader from west to east, to reach a width of 800–900 m near the eastern end of Brunne Lake; two kilometres before its eastern termination, the zone of mafic tectonite splays out.

About 1 km south of the Gurney Mine Shear Zone, another narrow (100 m) subparallel and ductile shear zone is observed; sparse exposure and extensive bog hindered the tracing of this zone. Although it did not appear to be a major feature in the field, this ductile structure coincides with a sharp change in orientation of S_1 between rocks on the northwestern flank and in the centre of the supracrustal belt, perhaps indicating that this shear zone divides two distinct structural domains.

Geochemistry

Thirty-five samples representing most of the major rock types from the Brunne Lake area were collected for chemical analysis during the geological mapping program. The geochemical sampling program was designed to assemble a representative suite of samples from the various lithological units of the Brunne Lake area, with the purpose of characterizing the trace- and rare earth element (REE) geochemistry. These data will also help with correlations and comparisons to other volcanic rocks in the Elbow and Athapapuskow lakes areas.

The samples are mainly from mesoscopically least-altered rocks, but do include some altered rocks. All samples were trimmed to remove weathered surfaces, joints and veinlets; some samples contain minor amygdules. Altered samples are not included on any of the geochemical plots in this report, except where noted. The trimmed samples were prepared in the Manitoba Geological Survey rock laboratory and analyzed by Activation Laboratories Ltd. (Ancaster, Ontario). Major and minor elements were analyzed by inductively coupled plasma–emission spectrometry and trace elements were analyzed using inductively coupled plasma–mass spectrometry. The resulting data are presented in Data Repository Item DRI2012005[1].

Supracrustal rocks

Basalt and synvolcanic gabbro (unit 1)

All basalt samples plot within the basalt field on the Zr/TiO_2 vs. Nb/Y diagram, which uses elements unaffected by typical hydrothermal seafloor alteration. On a diagram representing SiO_2 vs. total alkali content (Na_2O + K_2O), unaltered samples show a basaltic to slightly andesitic composition, whereas the altered samples all plot in the picro-basalt field and their alkali total is very low. Those same altered samples also have higher 'loss on ignition' numbers (LOI; 6–7 wt. %) and MgO content (15–25 wt. %) compared to the unaltered basalt (LOI <1%; MgO 8–9 wt. %). These chemical changes are very similar to some examples of magnesium-rich chloritic alteration described in modern seamount environments (Humphris et al., 1998). The four gabbro samples all showed major-element composition and trace-element signatures very similar to those of the unaltered basalt. This strongly suggests that the gabbro is synvolcanic and that it originated from the same magma as the basalt. Unaltered basalt from the Brunne Lake area displays a flat to slightly enriched light REE (LREE) profile on a chondrite-normalized trace-element diagram (Figure GS-8-5a), whereas altered samples are slightly depleted in LREE. On a primitive mantle-normalized incompatible trace-element diagram, the basalt signature includes positive Th and negative Nb anomalies, whereas that for Zr is slightly depleted (Figure GS-8-5b). On a Th-Zr-Nb discrimination diagram, the basalt samples all fall within the arc-basalt field, whereas on a Zr-(Ti/100)-(Y/3) diagram, most show an ocean-floor signature.

[1] MGS Data Repository Item DRI2012005, containing the data or other information sources used to compile this report, is available online to download free of charge at http://www2.gov.mb.ca/itm-cat/web/freedownloads.html, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Innovation, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, Manitoba R3G 3P2, Canada.

Rhyolitic tuffs (unit 3)

The two samples of rhyolitic tuff analyzed display high REE contents, with slight LREE enrichment and a small negative Eu anomaly on a chondrite-normalized trace-element diagram (Figure GS-8-5c). On a primitive mantle-normalized incompatible trace-element diagram (Figure GS-8-5d), the felsic tuff displays a slightly negative slope with significant Nb, Ti, V and Sc anomalies.

Plagioclase and quartz-plagioclase porphyritic rocks (unit 4)

The porphyritic dikes display moderate REE contents with strong LREE enrichment on a chondrite-normalized trace-element diagram (Figure GS-8-5c). On a primitive mantle-normalized incompatible trace-element diagram (Figure GS-8-5d), the porphyritic dikes display a negative slope with significant Nb and small Ti, V and Sc anomalies.

Intrusive rocks

Granodiorite to quartz diorite (unit 5)

Both the granodiorite and the diorite samples have very similar trace-element patterns. Samples from unit 5 display moderate REE contents with strong LREE enrichment on a chondrite-normalized trace-element diagram (Figure GS-8-5e). On a primitive mantle-normalized incompatible trace-element diagram (Figure GS-8-5f), the samples from unit 5 show a negative slope with significant Nb and small Ti, V and Sc negative anomalies.

Quartz monzodiorite (unit 6)

The quartz-monzodiorite samples have trace-element patterns very similar to those of rocks from unit 5, except for the fact that unit 6 is slightly more enriched in REE. Samples from unit 6 display moderate REE contents with strong LREE enrichment on a chondrite-normalized trace-element diagram (Figure GS-8-5e). On a primitive mantle-normalized incompatible trace-element diagram (Figure GS-8-5f), the quartz-monzodiorite samples show negative slopes with significant Nb and small Ti, V and Sc negative anomalies.

Monzogranite (unit 7)

The monzogranite displays moderate REE contents with strong LREE enrichment on a chondrite-normalized trace-element diagram (Figure GS-8-5g). On a primitive mantle-normalized incompatible trace-element diagram (Figure GS-8-5h), the monzogranite is characterized by a moderate negative slope and marked negative Ti, V and Sc anomalies.

Big Rat Lake pluton (unit 9)

The syenogranite displays high REE contents, with flat to slightly LREE-enriched profiles and large negative-Eu anomalies on a chondrite-normalized trace-element diagram (Figure GS-8-5g). On a primitive mantle-normalized incompatible trace-element diagram (Figure GS-8-5h), the syenogranite also shows flat profiles with large positive Th, and large negative Eu, Ti, V and Sc anomalies.

Synthesis of geochemical data

One goal of this geochemical study was to characterize the geochemical signature of the rocks in the Brunne Lake area and to compare the results with the extensive geochemical dataset from the western and central Flin Flon Belt in order to gain a better understanding of the tectonic affinity of the rocks studied.

All fresh samples of the Brunne Lake basalt (unit 1) display common geochemical characteristics. The trace-element geochemical signature of the basalt is very similar to that of McDougalls Point basalt from the southwestern area of Elbow Lake (Stern et al., 1995b; Babechuk and Kamber, 2011; Syme and Whalen, in press). This signature exhibits both back-arc and ocean-floor geochemical characteristics (e.g., lower TiO_2 and higher Th/Nb ratios) and was interpreted by Stern et al. (1995b) as reflecting magma generation in a back-arc spreading environment.

The samples from the rhyolitic tuff (unit 3) and the porphyritic dikes (unit 4) show distinct whole-rock geochemistry. The flat heavy REE profile and the slight LREE enrichment indicate that the rhyolitic tuff originated from a magma source distinct from that of the porphyritic dykes, which show a steeper negative REE slope. Both unit 3 and 4 rocks showed a negative Nb anomaly, suggesting a subduction-related origin in an arc setting for the magma, which is consistent with the interpretation of the basalt geochemical characteristics.

Units 5, 6 and 7 have different REE content, but they all exhibit parallel trace-element signatures (Figures GS-8-5e–h), with a marked negative-Nb anomaly indicative of subduction in an arc environment. These plutonic rocks show geochemical characteristics very similar to those associated with early and middle successor-arc plutonism, as defined by Whalen et al. (1999), including medium-K composition, steep REE patterns and no Eu anomalies. Whalen et al. (1999) interpreted this signature as indicative of melting from a basaltic source under high-pressure conditions, with residual garnet and/or amphibole, and no plagioclase.

Both units 7 and 9 are biotite granite previously mapped as the same unit. However, new geochemical data revealed their distinct origin. Unit 9, interpreted to be a marginal phase of the Big Rat Lake pluton, has higher Rb/Sr ratios (2.5:25) than any other rocks analyzed in

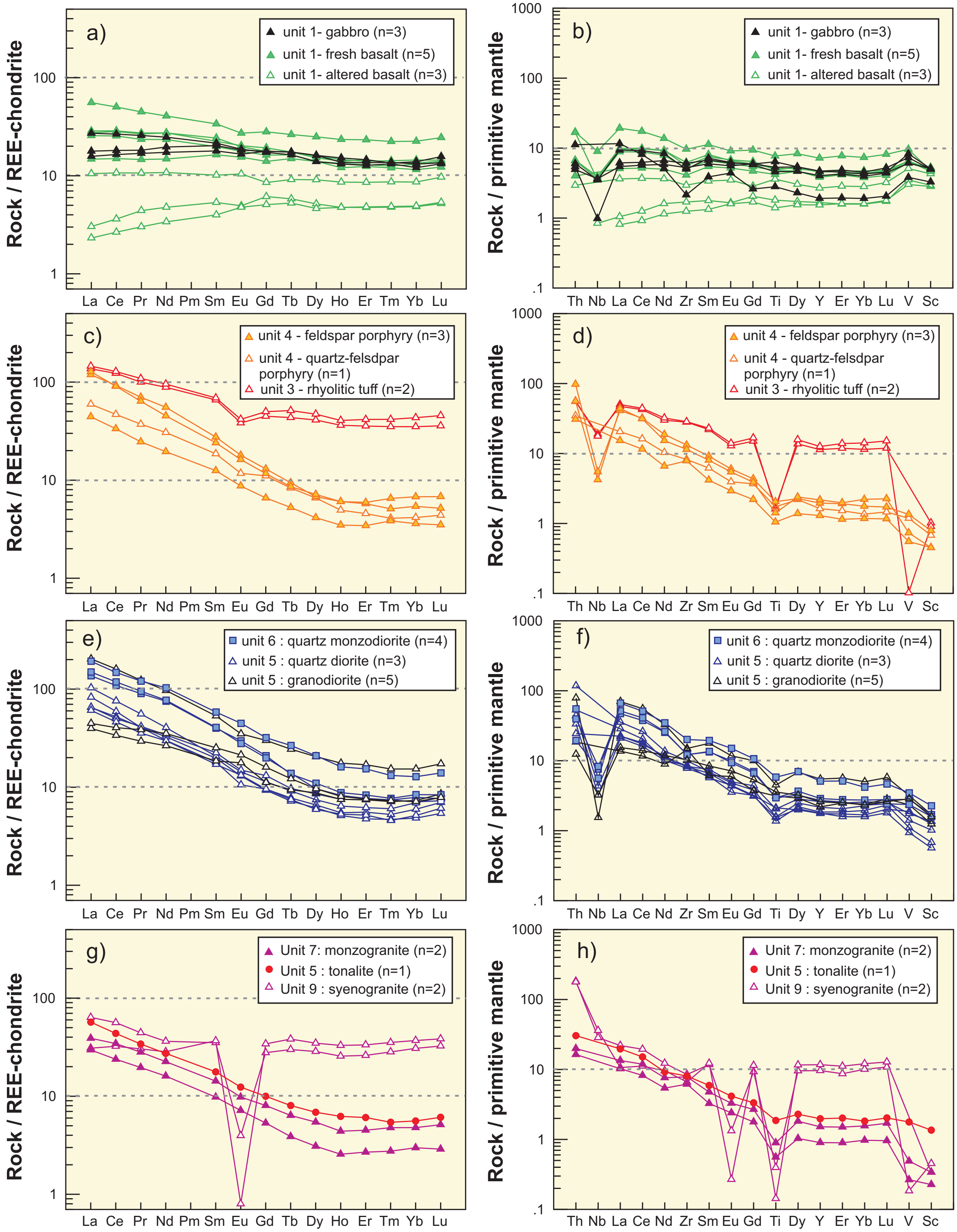


Figure GS-8-5: *Chondrite-normalized rare earth element (REE) plots (normalizing values from McDonough and Sun, 1995) and mantle-normalized incompatible trace-element plots (normalizing values from Sun and McDonough, 1989) for rocks of the Brunne Lake area, west-central Manitoba:* ***a-b)*** *samples from unit 1 (fresh and altered basalt, and gabbro);* ***c-d)*** *samples from unit 3 (quartz-plagioclase–phyric rhyolitic tuff) and 4 (plagioclase and quartz-plagioclase porphyritic dykes);* ***e-f)*** *samples from unit 5 (granodiorite and quartz diorite) and 6;* ***g-h)*** *samples from units 5 (tonalite), 7 and 9.*

this study, which range between 0.05 and 0.1, indicating that it represents a much more evolved magma. The monzogranite (unit 7) and syenogranite (unit 9) show very distinct geochemical signatures, indicating the existence of two distinct magmatic sources as well as, possibly, tectonic environments.

Economic considerations

The Brunne Lake area is host to a former gold producer, the Gurney mine (Figure GS-8-2), and several gold showings. Several gossans observed in the Brunne Lake area (Figure GS-8-6a) generally show a strong spatial association with major or subsidiary shear zones

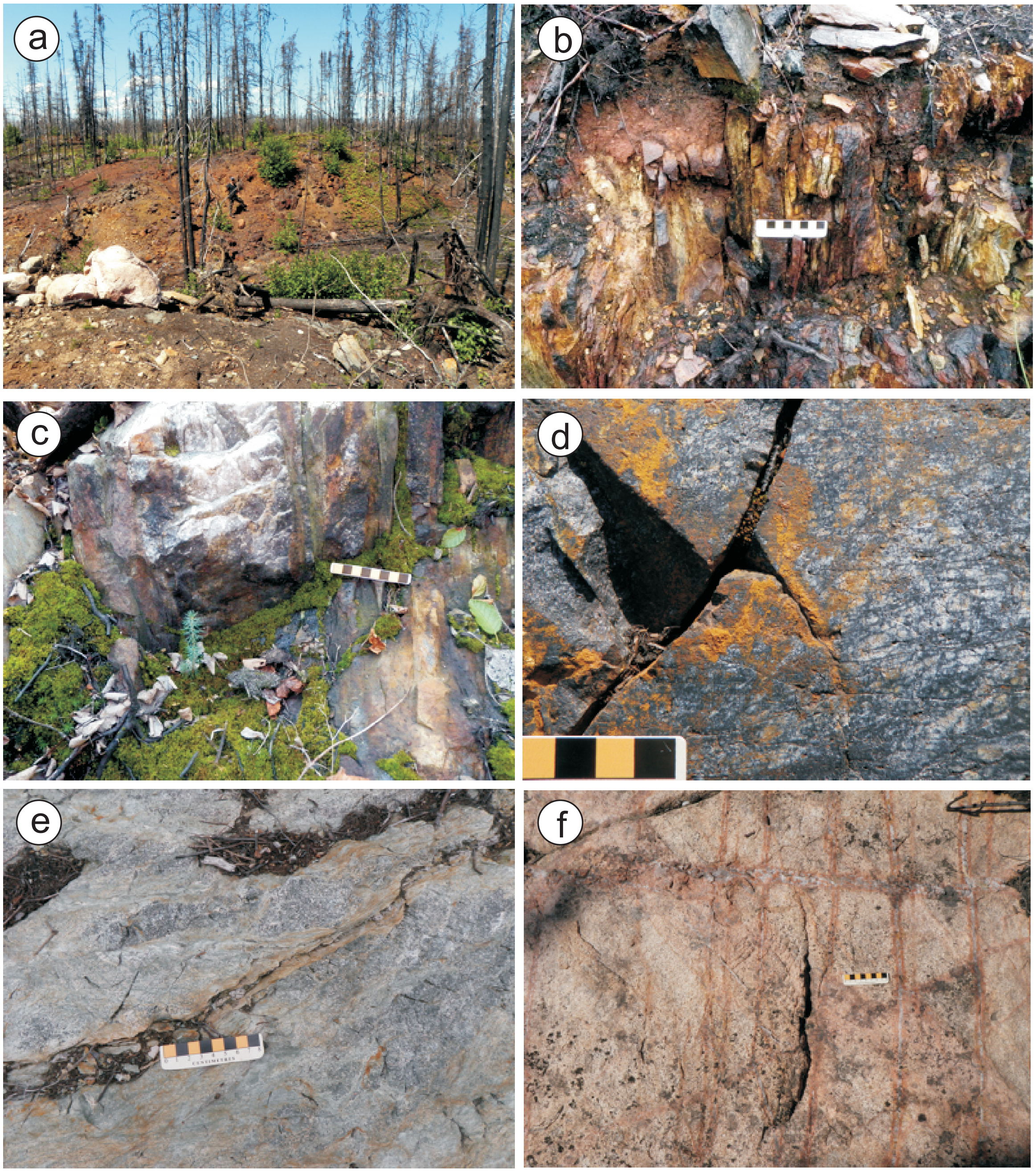


Figure GS-8-6: *Outcrop photographs of mineralized rocks from the Brunne Lake area, west-central Manitoba:* ***a)*** *gossanous horizon in the immediate hangingwall of the northern shear zone in the Gossan Hill property area, consisting of gabbro with 5–15% of fine-grained interstitial pyrrhotite;* ***b)*** *gossanous, mineralized (5–15% fine pyrrhotite), strongly altered and tectonized rock, northeastern end of the Gurney Mine Shear Zone;* ***c)*** *subvertical quartz-carbonate vein in tectonized gabbro, along an unnamed shear zone 700 m northeast of Copper Lake;* ***d)*** *completely silicified and mineralized (2–5% pyrrhotite) mafic volcanic rock in a shear zone, along the northern margin of the Brunne Lake high-strain zone on the eastern side of Copper Lake;* ***e)*** *sheared epidote-chlorite–altered gabbro in the footwall of the Gurney Mine Shear Zone, in the Gossan Hill property area;* ***f)*** *set of parallel, narrow (0.5–2 cm), closely spaced (10–30 cm) quartz veins in monzogranite with K-feldspar+quartz alteration haloes; 650 m northeast of the Gurney mine. Scale bar is 8 cm.*

and display a strong subvertical fabric (Figure GS-8-6b). Fine-grained disseminated pyrrhotite (5–25%) is the main sulphide mineral identified in the gossans. Locally, trace amounts of chalcopyrite, galena and pyrite were observed. The gossans were generally associated with a pervasive silica-replacement–type alteration. Examples of both massive and composite quartz-carbonate shear-type veins (Figure GS-8-6c) were observed in the shear zones. The wallrocks vary from gossanous (Figure GS-8-6b) to weakly or intensely silicified (Figure GS-8-6d) or epidote-chlorite altered rock (Figure GS-8-6e). The relationship between the gold mineralization and the various alteration types has not been resolved and will be the focus of future studies. The monzogranite (unit 7) that forms the core of the supracrustal package is also locally mineralized. Near the Gurney mine, the monzogranite shows sets of narrow quartz veins (0.5–5 m) associated with silicification, saussuritization and potassic alteration of the wallrocks, locally with 1–0% pyrrhotite (Figure GS-8-6f).

By delineating major shear zones, including the Gurney Mine Shear Zone, and identifying subsidiary shear zones and associated gossans, this study aims to provide new targets for gold exploration. The Gurney Mine Shear Zone was found to be continuous over a distance of over 6 km. The presence of historic gold showings at both ends of this structure and scattered mineralized prospects in between suggest that the entire length of the shear zone should be a target for gold exploration.

The potential for volcanogenic massive sulphide deposits around Brunne Lake is thought to be rather low as nearly all VMS deposits in the Flin Flon Belt are associated with arc-assemblage rocks (Syme and Bailes, 1993) and the Brunne Lake mafic volcanic rocks show, for their part, a geochemical affinity to the rocks of the ocean-floor assemblage.

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