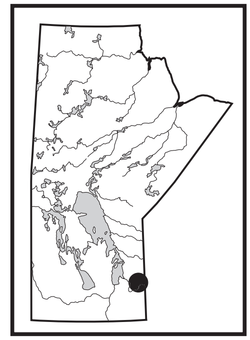
GS-11 Stratigraphic investigations in the Bird River greenstone belt, Manitoba (part of NTS 52L5, 6)

by H.P. Gilbert



Gilbert, H.P., 2008: Stratigraphic investigations in the Bird River greenstone belt, Manitoba (part of NTS 52L5, 6); *in* Report of Activities 2008, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 121–138.

Summary

Geological mapping of the Neoarchean Bird River greenstone belt of southeastern Manitoba, initiated by the Manitoba Geological Survey in 2005, was finalized by completion of coverage in the southwestern part of the belt in 2008. Detailed, 1:20 000 scale mapping and concurrent geochemical investigations have resulted in a new stratigraphic framework and revised interpretation of the crustal setting of the supracrustal rocks. The Bird River Belt (BRB), located in the Bird River Subprovince (southwestern Superior Province), occurs in a transitional oceanic–continental-margin setting between older cratonic blocks—the North Caribou Superterrane to the north and the Winnipeg River Subprovince to the south. In the BRB, the predominant arc-type rocks are geochemically distinct from flanking, mid-ocean-ridge basalt (MORB)–type mafic volcanic sequences that may have formed in a back-arc setting, possibly associated with early arc rifting. The continental-arc magmatism spanned approximately 80 Ma (2.80–2.72 Ga). Two geochemically distinct arc-type sequences are recognized (north and south panels, respectively). The north panel rocks are akin to modern subduction-related rocks at active continental margins, whereas the south panel rocks document incipient rifting in an extensional tectonic regime. Subsequent to arc volcanism, orogenic sedimentation (2.71–2.70 Ga) resulted in the deposition of turbidites (Booster Lake Formation) and fluvial-alluvial deposits (Flanders Lake Formation). These orogenic sedimentary rocks may be stratigraphically equivalent and thus related to epiclastic rocks and metamorphic derivatives in the English River Subprovince, northeast of the BRB.

Base-metal mineralization prospects in the BRB include both magmatic types and stratigraphically associated occurrences. The Bird River Sill hosts base-metal and platinum-group-element (PGE) mineralization; elsewhere, base-metal mineralization commonly occurs at lithological contacts within the volcano-sedimentary sequences. The BRB is also host to the TANCO mine at Bernic Lake, wholly owned by the Cabot Corporation. The mine produces Ta, Li and Cs from rare-element pegmatite that accounts for approximately 80% of global reserves of Cs.

Introduction

The Manitoba Geological Survey (MGS) initiated a collaborative mapping project with the University of Waterloo in 2005 in the Neoarchean Bird River Belt (BRB) in southeastern Manitoba (Figure GS-11-1). This greenstone belt is host to both base-metal (Maskwa-Dumbarton mine) and rare-element pegmatite ore deposits (Tantalum Mining Corporation of Canada, Ltd. [TANCO] mine; Gilbert 2008a) and is currently the focus of several mineral exploration projects. The MGS mapping initiative was conceived in order to upgrade the existing, outdated maps of the area and to carry out targeted research in support of the ongoing mineral exploration. Since 2005, the author has conducted a program of stratigraphic mapping and geochemical investigations over the entire BRB, in conjunction with three postgraduate research projects that have been carried out at the University of Waterloo. These projects focused on 1) the setting of rare-element pegmatite bodies (Kremer, 2005; Kremer and Lin, 2006); 2) the geology of the PGE-bearing Bird River Sill (Mealin, 2005, 2006); and 3) the tectonic setting and structural-metamorphic history of the Bird River area (Duguet et al., 2005, 2006, 2007). The results of the various mapping projects were recently compiled and released, together with geochemical and geochronological data for key geological units (Gilbert et al., 2008).

In 2008, geological mapping by the author in the southwestern part of the greenstone belt completed the 1:20 000 scale mapping program in the BRB. Fieldwork this year focused on

- stratigraphic details and relationships between the main tectonostratigraphic components in the western BRB;
- stratigraphy and structure of the western part of the Bernic Lake Formation (BLF; Gilbert et al., 2008); and
- geology of the Shatford Lake area.

The latter two areas, previously mapped only at reconnaissance scale (Černý et al., 1981), are of particular interest in view of

- ongoing exploration in the southern BRB for rare-earth-element mineralization in pegmatites similar to that at the TANCO mine; and
- alteration domains (± sulphide mineralization) and stratabound base-metal sulphide mineralization along the southern margin of the BRB north panel (Gilbert, 2006, 2007a).

This report provides an up-to-date summary of the regional setting of the BRB and the geology of the Bird River area to serve as a framework for the new (2008) stratigraphic and structural data in the western part of the BRB, which are the main focus of the report. The final

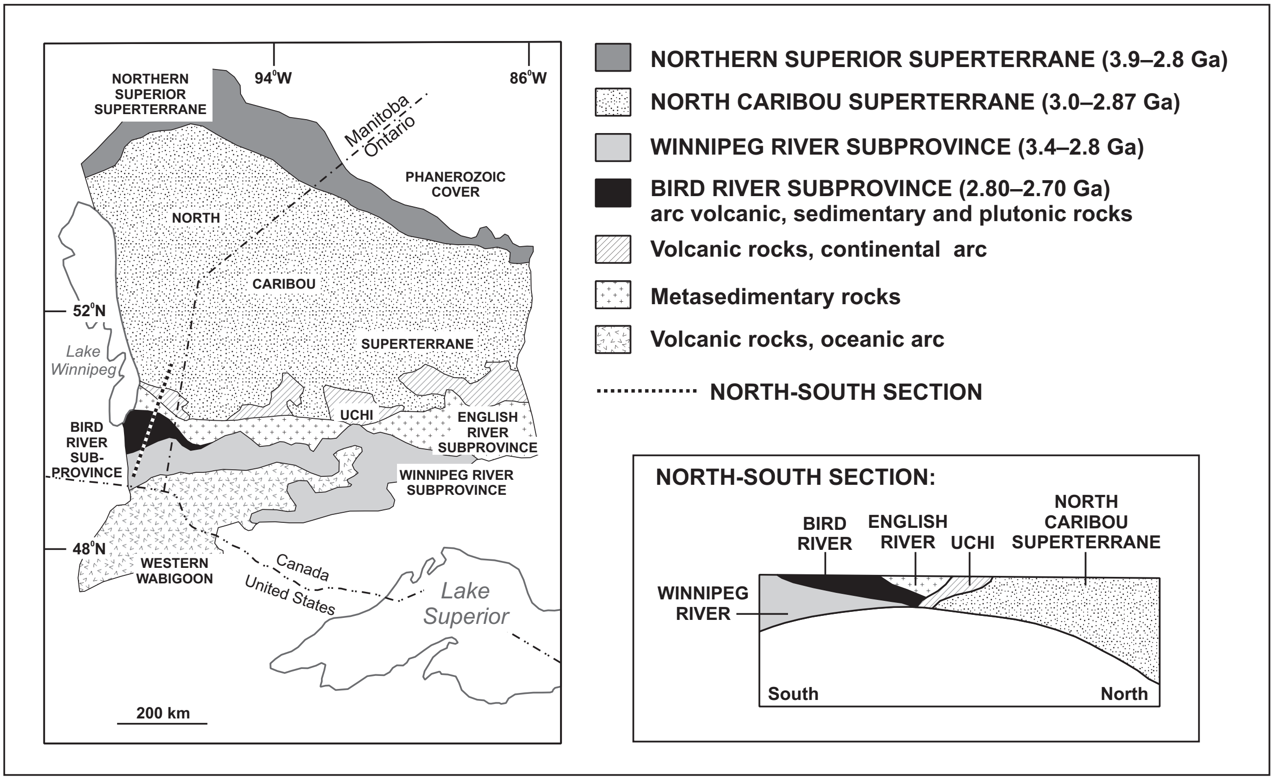


***Figure GS-11-1:** Schematic geology of the western Superior Province, showing the location of the Bird River Subprovince. Age data for superterranes and subprovinces are based on Percival et al. (2006b) and Gilbert et al. (2008).*

section provides a summary of the economic implications of 2008 mapping. Detailed descriptions of the stratigraphy and geochemistry of the main geological formations, as well as the structural geology and tectonic history of the BRB, are published in Gilbert (2005, 2006, 2007a), Duguet at al. (2005, 2006, 2007), Kremer (2005) , Mealin (2005, 2006), Kremer and Lin (2006) and Gilbert et al. (2008).

Previous work and current exploration

Mineral exploration and geological investigations in the Bird River area span the past century, dating from the pioneering work of Tyrrell (Tyrrell and Dowling, 1900). Economic interest in the region has focused largely on two resource types: rare-element–bearing pegmatite bodies and mafic to ultramafic intrusive rocks containing base metal and PGE mineralization (Gilbert, 2006). Investigation of a Cr showing on the Bird River in 1942 led to the discovery of a base-metal ore deposit at the northern margin of the Bird River Sill, where Cu and Ni were produced for a decade until the mid-1970s at the Maskwa-Dumbarton mine (Gilbert and Kremer, 2008). Feasibility studies are currently underway with the aim of opening a new mine at Maskwa that will extract more than 9 million tonnes of ore over a period of 8 years (Mustang Minerals Corp., 2007, 2008). In addition, Marathon PGM Corporation is prospecting for base metals and PGE in the vicinity of the Bird River Sill, on ground formerly held by Gossan Resources Ltd. (Marathon PGM Corporation, 2007, 2008). Current exploration also includes ongoing investigations for new sources of rare elements in settings similar to that of the TANCO pegmatite.

The first systematic geological mapping of the BRB was undertaken more than 50 years ago (Springer, 1948; Davies, 1952). Geological investigations were subsequently carried out by Trueman (1971), who completed a study of the Bird River Sill, and by Theyer (1981), Scoates (1983) and Scoates et al. (1987). The Bird River greenstone belt was mapped by Trueman (1980) as a Ph.D. thesis. Černý et al. (1981) provided a comprehensive study of the abundant pegmatite intrusions of the region, as well as a synthesis and interpretation of the regional geology. Prior to the current project, the most recent compilation of the geology of the area consisted of a Manitoba Geological Survey 1:250 000 scale geological map (Manitoba Energy and Mines, 1987).

Regional setting

The BRB, located in the southern part of the Bird River Subprovince, is part of an east-trending supracrustal belt that extends for 150 km from Lac du Bonnet in the west to Separation Lake (Ontario) in the east (Figure GS-11-1). The northern part of the Bird River Subprovince consists of the granitoid Maskwa Lake Batholith (Figure GS-11-2), which contains intrusive phases ranging from 2.85 to 2.73 Ga (Table GS-11-1). The BRB occurs in a transitional oceanic–continental-margin setting between flanking older cratonic blocks—the North

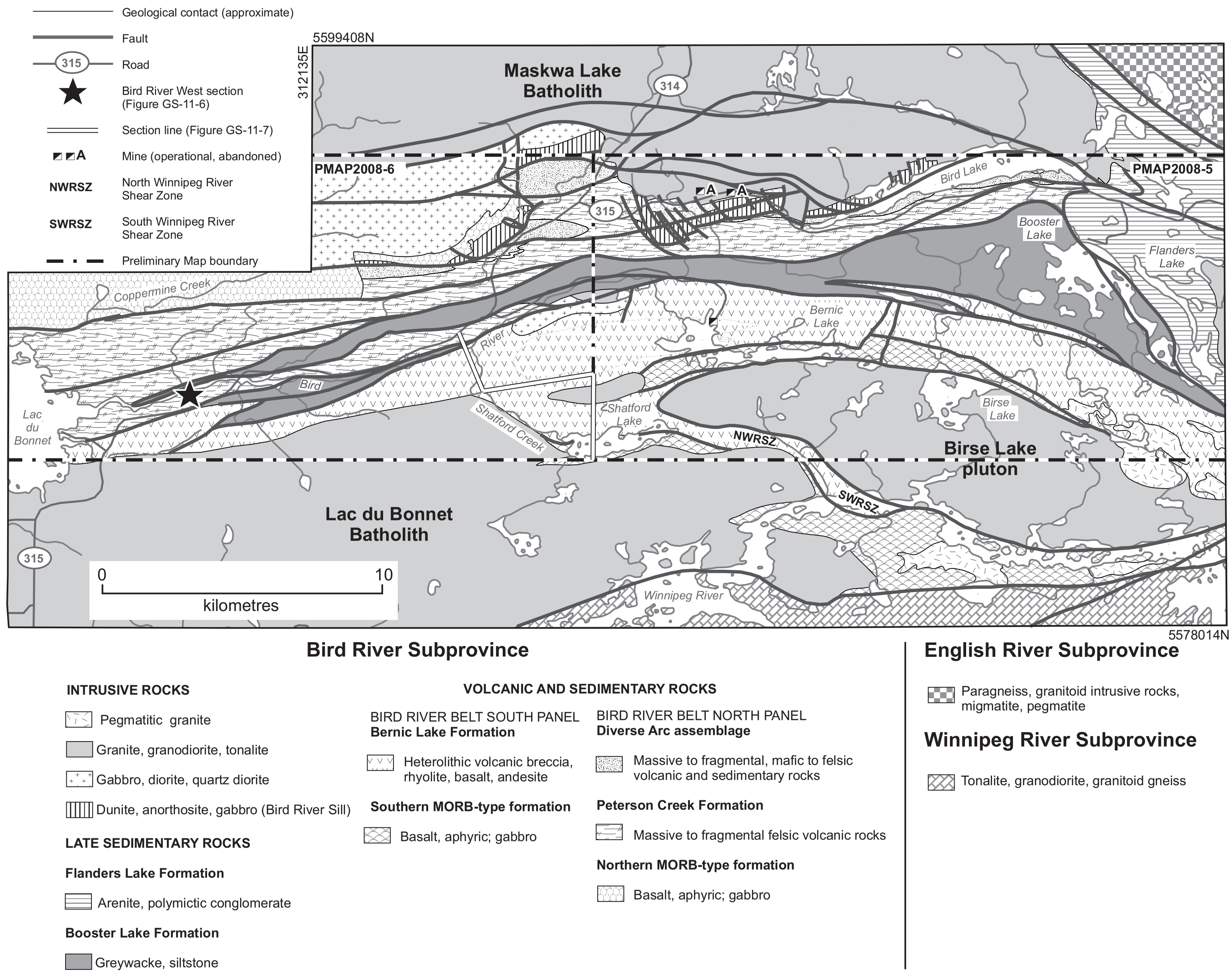


Figure GS-11-2: *Geology of the Bird River Belt, showing the main stratigraphic and structural features.*

Table GS-11-1: Principal geological formations, their ages and contact relations in the Bird River Belt.

Late intrusive rocks

Granite, pegmatite, granodiorite, tonalite, quartz diorite

(TANCO pegmatite, **2640 ±7 Ma**[(1)]; Marijane Lake pluton, **2645.6 ±1.3 Ma**[(2)]; Lac du Bonnet Batholith, **2660 ±3**[(3)] **Ma**)

Sedimentary rocks

FLANDERS LAKE FORMATION (**2697 ±18 Ma**[(4)])

Lithic arenite, polymictic conglomerate

== ***Fault, inferred*** ==

BOOSTER LAKE FORMATION (**2712 ±17 Ma**[(4)])

Greywacke-siltstone turbidite, conglomerate

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ***Unconformity, inferred*** ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Intrusive rocks

MISCELLANEOUS INTRUSIONS

Gabbro, diorite, quartz-feldspar porphyry; granodiorite

(Birse Lake pluton, **2723.2 ±0.7 Ma**[(2)]; Maskwa Lake Batholith II, **2725 ±6 Ma**[(3)]; Pointe du Bois Batholith, **2729 ±8.7 Ma**[(3)]; TANCO gabbro, **2723.1 ±0.8 Ma**[(2)])

Metavolcanic and metasedimentary rocks

BERNIC LAKE FORMATION (**2724.6 ±1.1 Ma**[(2)])

Basalt, andesite, dacite and rhyolite (massive to fragmental); related intrusive rocks and heterolithic volcanic fragmental rocks

PETERSON CREEK FORMATION (**2731.1 ±1 Ma**[(2)])

Dacite, rhyolite (massive to fragmental); felsic tuff and heterolithic felsic volcanic fragmental rocks

DIVERSE ARC ASSEMBLAGE (**2706 ±23 Ma**[(5)])

Basalt, andesite, rhyolite, related fragmental and intrusive rocks; heterolithic volcanic fragmental rocks; greywacke-siltstone turbidite, chert, iron formation; polymictic conglomerate (contains clasts derived from the Bird River Sill)

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ***Unconformity, inferred*** ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Intrusive rocks

BIRD RIVER SILL (**2744.7 ±5.2 Ma**[(3)])

Dunite, peridotite, picrite, anorthosite and gabbro

== ***Fault, inferred*** ==

Metavolcanic and metasedimentary rocks

MORB-type VOLCANIC ROCKS

Basalt (aphyric to plagioclase-phyric; locally pillowed, amygdaloidal or megacrystic); related volcanic breccia; oxide-facies iron formation

== ***Fault, inferred*** ==

EAGLENEST LAKE FORMATION

Greywacke-siltstone turbidite

Older intrusive rocks

Granodiorite, diorite (Maskwa Lake Batholith I, **2782 ±11 Ma**[(3)]**, 2852.8 ±1.1 Ma**[(2)]**, 2844 ±12 Ma**[(3)])

References for geochronological data: [(1)] Baadsgaard and Černý, 1993; [(2)] Gilbert et al., 2008; [(3)] Wang, 1993; [(4)] Gilbert, 2006; [(5)] Gilbert, unpublished data, 2007

Caribou Superterrane to the north and the Winnipeg River Subprovince to the south. Continental-arc magmatism and orogenic sedimentation in the Bird River Subprovince spanned approximately 100 Ma (2.80–2.70 Ga; Percival et al., 2006a). In contrast, a protracted 300 Ma history of similar magmatism and sedimentation has been documented in the Uchi Subprovince to the north (Figure GS-11-1), beginning with ca. 3.0 Ga rifting associated with northward subduction of oceanic lithosphere at the southern margin of the North Caribou Superterrane (Percival et al., 2006a). Possible correlations can be made among the younger supracrustal sequences of the two subprovinces, such as the >2722 Ma (Davis, 1994) Gem assemblage in the Rice Lake greenstone belt of the Uchi Subprovince (Anderson, 2005) and the 2724.6 ±1.1 Ma Bernic Lake Formation in the Bird River Subprovince (Table GS-11-1). Volcanic rocks in the Gem assemblage and Bernic Lake Formation are geochemically similar and appear to document incipient rifting of the continental-arc sequences.

Orogenic sedimentation (2712–2697 Ma) subsequent to continental-arc volcanism resulted in deposition of turbidites (Booster Lake Formation; Table GS-11-1) and penecontemporaneous fluvial-alluvial deposits (Flanders Lake Formation). These sedimentary rocks are interpreted as counterparts to similar formations in the Rice Lake greenstone belt to the north (Edmunds assemblage and San Antonio Formation, respectively; Anderson, 2005). Furthermore, these orogenic sedimentary rocks have been widely assumed to be stratigraphically equivalent and possibly related to epiclastic rocks and metamorphic derivatives in the English River Subprovince, which lies between the Uchi and Bird River subprovinces (Figure GS-11-1; Anderson, 2005; Hrabi and Cruden, 2006; Nitescu et al., 2006). Regional deformation, metamorphism and granitoid plutonism postdated the orogenic sedimentation; five generations of deformation have been documented to postdate orogenic sedimentation in the Rice Lake greenstone belt (Anderson, 2003, 2004). Orogenic sedimentation, subsequent magmatism and deformation mark the end of subduction-related volcanic activity, caused by collision of the Uchi continental-margin succession with the Winnipeg River Subprovince, which followed 2.72–2.71 Ga convergence of the North Caribou and Winnipeg River cratonic blocks (Lemkow et al., 2006). According to LITHOPROBE seismic-reflection data (Percival et al., 2006b), this collision appears to have resulted in underplating of the BRB by continental lithosphere at the margin of the Winnipeg River Subprovince (Figure GS-11-1).

Geology of the Bird River area

The BRB extends more than 50 km from Lac du Bonnet in the west to Flanders Lake in the east (Figure GS-11-2). The greenstone belt consists mainly of ca. 2.73 Ga arc-type volcanic rocks, divided into north and south panels that are geochemically distinct and separated in age by approximately 6 Ma (Gilbert, 2007a; Gilbert et al., 2008). Fault-bounded enclaves of relatively younger turbidites (Booster Lake Formation, <2712 ±17 Ma; Gilbert, 2006) extend through the centre of the greenstone belt between the north and south panels. Mid-ocean-ridge basalt (MORB)–type volcanic rocks (Lamprey Falls Formation of Černý et al., 1981) extend along both the northern and southern margins of the belt. The two MORB-type sequences are mapped as separate 'northern' and 'southern' MORB-type formations because structural and stratigraphic data in the intervening supracrustal terrane do not support a model in which these two sequences are stratigraphically equivalent (Gilbert et al., 2008). Contacts between MORB-type and arc-type rocks are interpreted as faults, although no contact relationships have been observed in the field. The northern MORB-type formation predates the 2744.7 ±5.2 Ma mafic–ultramafic Bird River Sill (Wang, 1993) and is the oldest known part of the BRB; a maximum age of 2832.3 ±0.9 Ma is indicated for the northern MORB-type formation by the relatively older Maskwa Lake Batholith (Gilbert et al., 2008). The southern MORB-type formation is intruded by the 2723.2 ±0.7 Ma Birse Lake pluton, which thus provides a minimum age for the volcanic rocks.

Arc-type rocks in the BRB north panel consist of the predominantly felsic volcanic Peterson Creek Formation (PCF, 2731.1 ±1 Ma) and the volcanosedimentary Diverse Arc assemblage (DAA; Gilbert, 2007a). These two supracrustal suites are geochemically similar but lithostratigraphically distinct; the DAA consists of a wide variety of massive to fragmental volcanic and epiclastic rocks, as well as chert and iron formation. The relative ages of the PCF and DAA are uncertain, but detrital zircon data for the DAA (2706 ±23 Ma; Gilbert, unpublished data, 2007) suggest a slightly younger depositional age relative to PCF volcanism, possibly penecontemporaneous with deposition of the 2712 ±17 Ma Booster Lake Formation (Gilbert, 2006; Table GS-11-1).

Arc-type rocks in the BRB south panel, forming the 2724.6 ±1.1 Ma Bernic Lake Formation (BLF; Gilbert et al., 2008), are slightly younger than the 2731.1 ±1 Ma PCF rocks. The transitional, tholeiitic–calcalkaline BLF is compositionally distinct from the calcalkaline PCF and DAA (Figures GS-11-3, -4a to -4e) and is interpreted to represent an environment of incipient arc rifting, in contrast to the subduction-related setting of the BRB north panel rocks (Gilbert et al., 2008). The BLF is subdivided geochemically into a southern part and a northern (more evolved, inferred younger) part (Figure GS-11-4e; Gilbert, 2007a). Within this formation, geochemical data indicate a transition from a convergent setting at lower stratigraphic levels to an extensional setting in the upper part of the sequence (Gilbert et al., 2008).

Orogenic sedimentary formations (Booster Lake, 2712 ±17 Ma; Flanders Lake, 2697 ±18 Ma) are derived

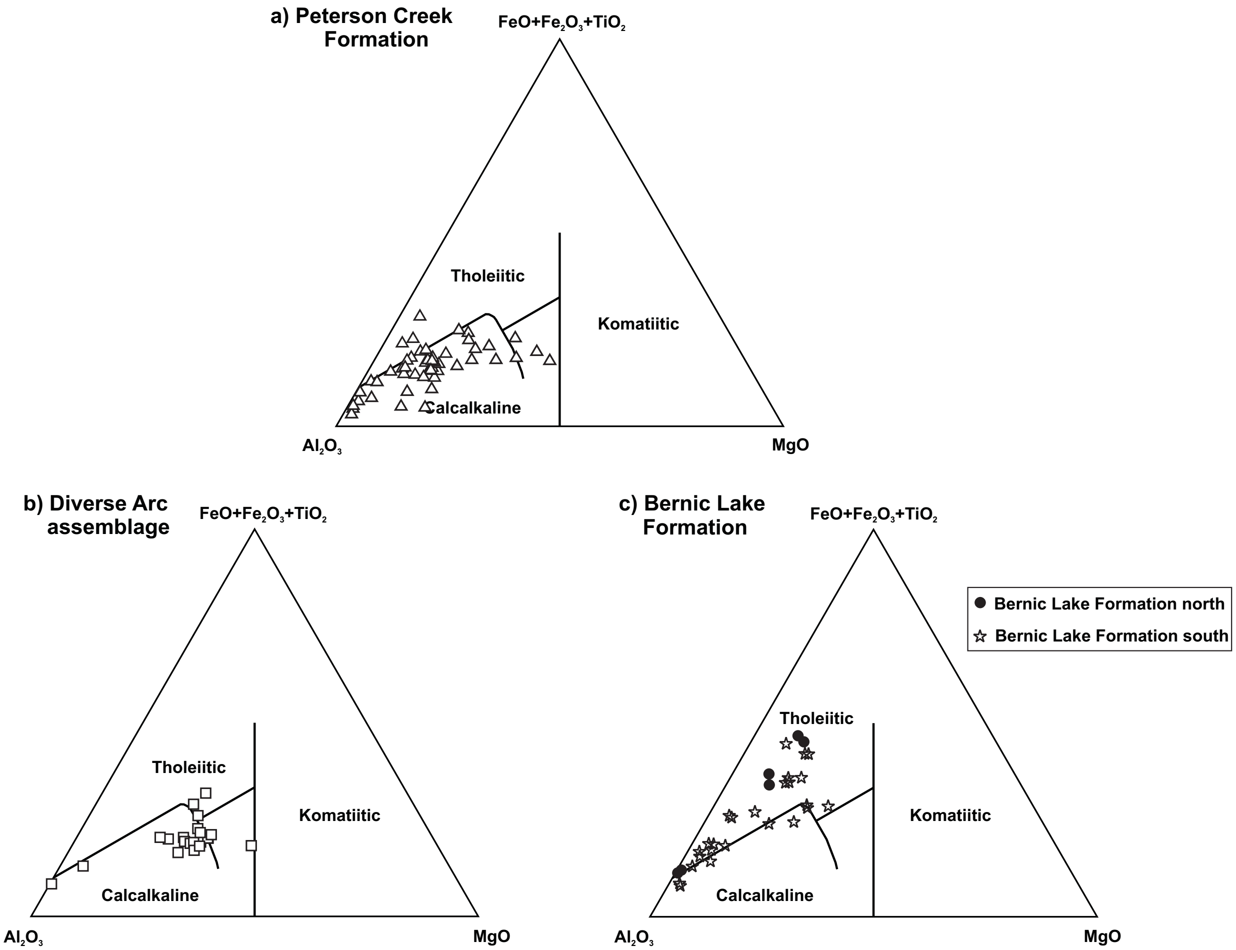


Figure GS-11-3: *Al_2O_3–[FeO^t+TiO_2]–MgO ternary diagram of mafic to felsic volcanic rocks (Jensen, 1976) from the Bird River Belt:* ***a)*** *Peterson Creek Formation,* ***b)*** *Diverse Arc assemblage,* ***c)*** *Bernic Lake Formation.*

mainly from terranes of two distinct ages, according to relative frequency distribution diagrams of detrital zircon U-Pb ages (Gilbert, 2006). Zircons between 2710 and 2730 Ma are interpreted as derived from volcanosedimentary rocks of the BRB or a contiguous supracrustal belt, whereas the ca. 3025 Ma zircon population is attributed to older granitoid rocks not exposed or preserved in the BRB, or derived from terranes flanking the BRB (Gilbert, 2007a). These sedimentary formations are assumed to be in fault contact with the older BRB volcanic rocks, but their contact relationships have not been observed. Contacts between analogous turbidite and volcanic rocks in the Rice Lake Belt within the Uchi Subprovince north of Bird Lake (Figure GS-11-1) are locally unconformable (Anderson, 2005).

Stratigraphy and structure of the western Bird River Belt

The tectonostratigraphically distinct north and south panels of the BRB are separated, in the central and eastern parts of the BRB, by the fault-bounded enclave of Booster Lake Formation turbidites that extends through the centre of the greenstone belt for approximately 44 km (Gilbert, 2007a; Figure GS-11-2). In the western BRB, however, recently acquired geochemical data have identified an enclave of north panel rocks within a terrane that was previously mapped as part of the south panel (Gilbert, 2007b). Furthermore, the new mapping suggests that the north and south panels in the western BRB are in fault contact within a tectonic zone containing several fault slices of the Booster Lake Formation (Gilbert, 2008). The fault zone is characterized by a history of repeated movement that includes 1) the initial juxtaposition of the north and south arc-type panels of the BRB; 2) tectonic emplacement of Booster Lake Formation turbidite enclaves; and 3) localized shearing of both Booster Lake strata and contiguous arc-type volcanic rocks.

BRB north panel

The north panel of the BRB consists largely of a monotonous sequence of massive and fragmental volcanic rocks of the PCF (Figures GS-11-2, -5a, -5b). At the west end of the greenstone belt, this section is approximately 4 km wide and extends northwards from the mouth of the Bird River at Lac du Bonnet to the contact with the northern MORB-type formation at Coppermine Creek

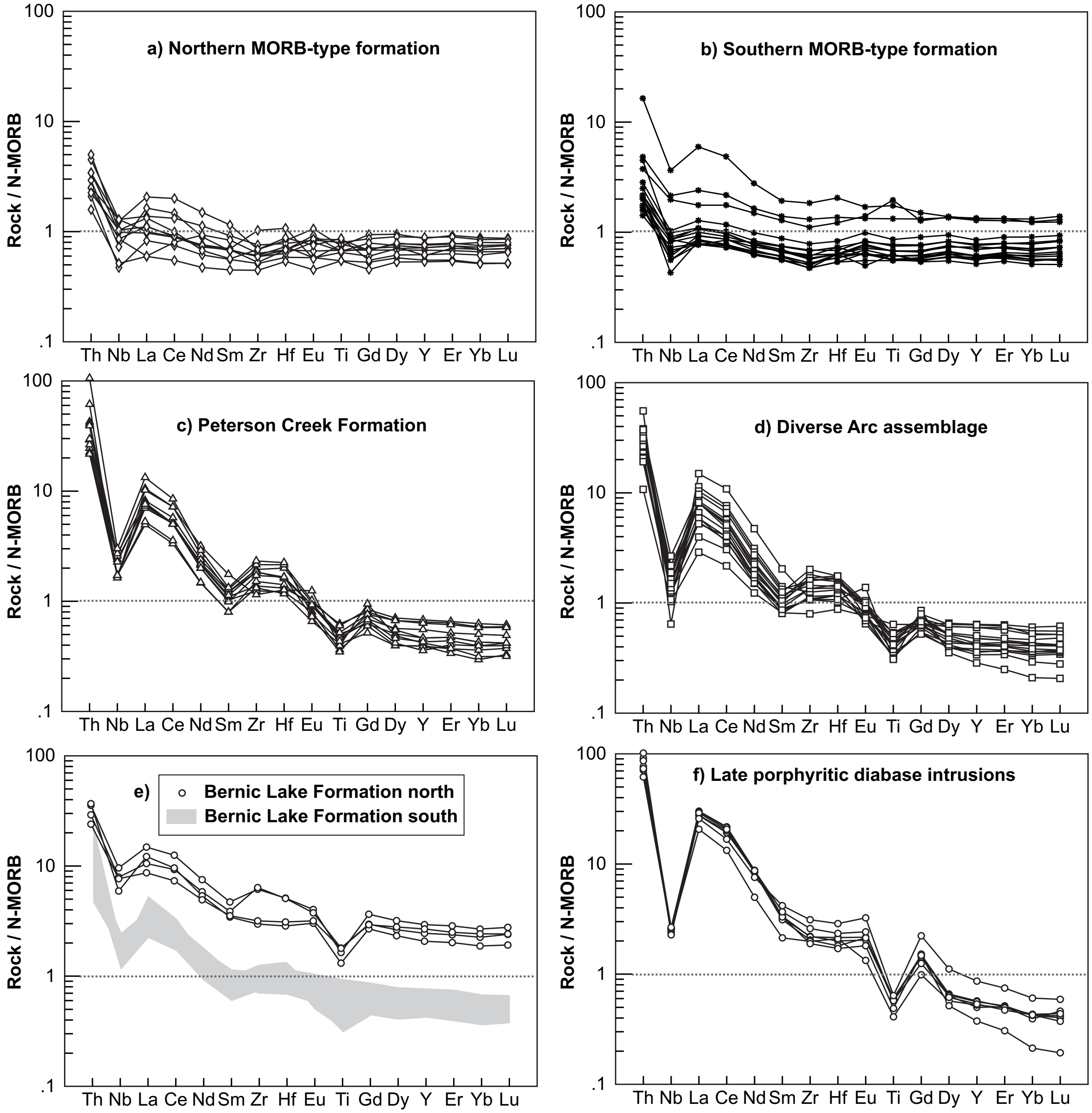


Figure GS-11-4: *Normal mid-ocean-ridge basalt (N-MORB)–normalized incompatible element plots of mafic to intermediate volcanic rocks from the Bird River Belt (normalizing values* from *Sun and McDonough, 1989):* ***a)*** *northern MORB-type formation,* ***b)*** *southern MORB-type formation,* ***c)*** *Peterson Creek Formation,* ***d)*** *Diverse Arc assemblage,* ***e)*** *Bernic Lake Formation (north and south),* ***f)*** *late porphyritic diabase intrusions.*

(Gilbert, 2008). In contrast, the southern margin of the BRB north panel, 5 km east of Lac du Bonnet, is more lithologically diverse within a 0.5 km wide section between the Bird River and PR 315 ('Bird River West' section; Figures GS-11-6, -2). Although the sequence there is largely devoid of stratigraphic-facing indicators, south-facing tops are indicated by graded bedding in turbidites within this section, suggesting that it may represent the stratigraphically upper part of the north panel sequence. Based on lithostratigraphic criteria established farther east within the north panel (Gilbert, 2007a), the Bird River West section contains both PCF- and DAA-type strata, suggesting that these two parts of the north panel may be partly equivalent in age, rather than stratigraphically distinct as previously defined.

Bird River West section

The northernmost (inferred basal) member of the Bird River West section (Figure GS-11-6) consists of a >2 m thick unit of ankerite±calcite–bearing carbonate that occurs on the south shore of Bird River (Gilbert, 2008, unit 4d). The same unit farther east at the mouth

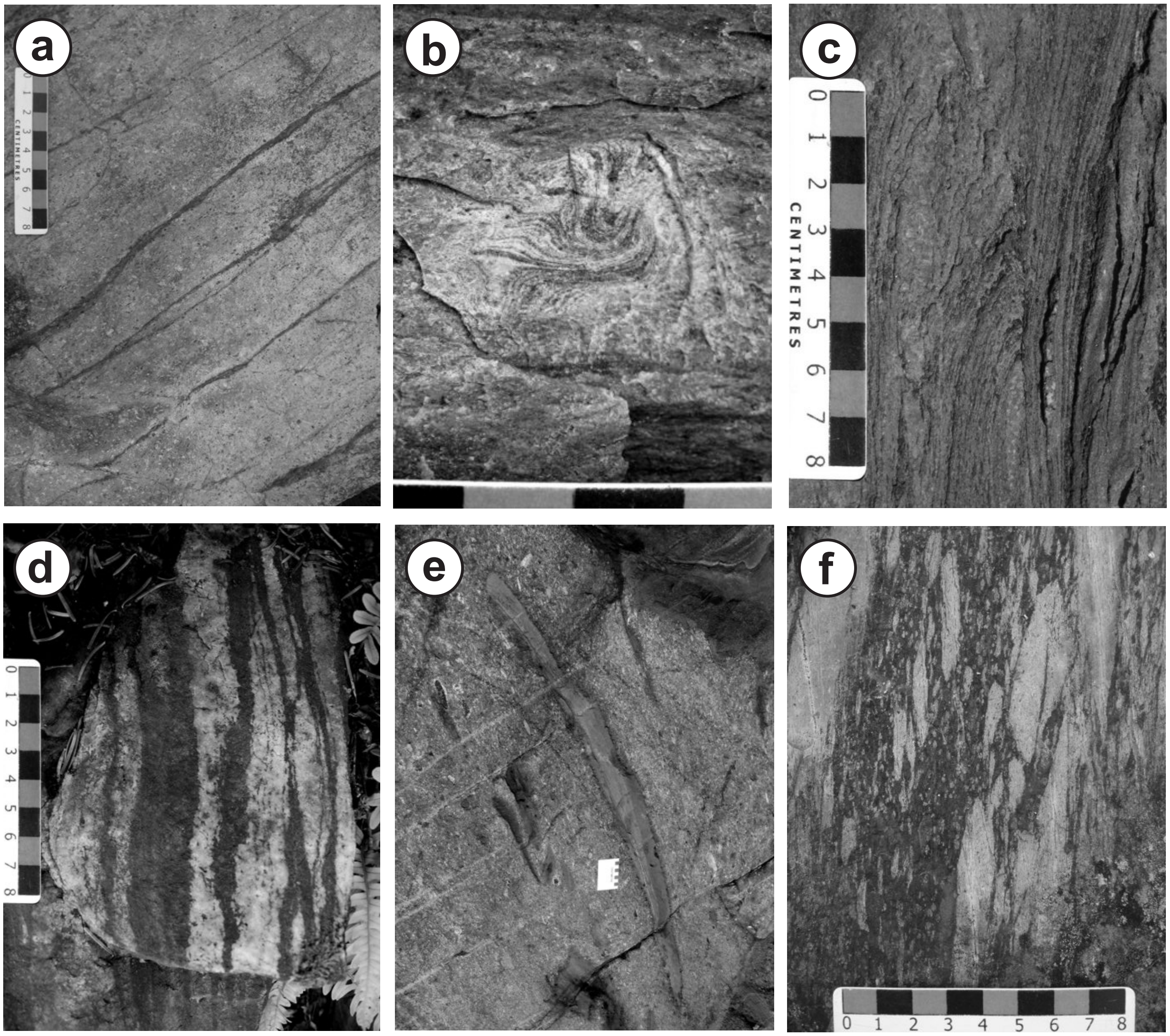


***Figure GS-11-5:** Outcrop photographs of massive to fragmental volcanic and sedimentary rocks in the north and south panels of the Bird River Belt: **a)** massive rhyolite with subparallel chlorite-filled fractures (±garnet porphyroblasts) resulting from thermal stress during cooling of the flow, Peterson Creek Formation (UTM 335633E, 5592842N); **b)** finely flow-laminated clast in felsic volcanic breccia, contorted due to turbulent flow in the flow from which it was derived, Peterson Creek Formation (UTM 335694E, 5592791N); **c)** thinly laminated ankeritic carbonate bed, Diverse Arc assemblage, Bird River West section (UTM 310280E, 5587794N); **d)** oxide-facies, magnetiferous iron formation, Diverse Arc assemblage, Bird River West section (UTM 306667E, 5587012N); **e)** mass-flow deposit with pyroclastic and epiclastic detritus, Diverse Arc assemblage, south (upper?) end of Bird River West section (UTM 307375E, 5586964N); **f)** monolithic felsic volcanic breccia with garnetiferous chloritic matrix, gradational with fragmental to massive rhyolite, lower BLF close to the west end of the Birse Lake pluton (UTM 323861E, 5586719E). All UTM co-ordinates are Zone 15, NAD83.*

of Peterson Creek is 10 m thick (Figure GS-11-5c) and locally mineralized with pyrite; it is interlayered with greywacke, cherty siltstone and very fine grained amphibolite, possibly derived from calcareous mudstone. This carbo nate unit represents a significant break between the thick felsic volcanic flow and fragmental sequence north of Bird River, and the more diverse volcano-sedimentary sequence in the Bird River West section to the south (Figure GS-11-6). Immediately south of the ankeritic member, turbiditic greywacke-siltstone (unit 4a) and chert (unit 4b) are followed southward by thick (up to 30 m) units of unsorted felsic lapilli crystal-tuff (units 9a, 9b, 9c) and intercalated dacite (unit 10d). A unit of oxide-facies iron formation, up to 37 m wide (unit 4c; Figure GS-11-5d), occurs in the central part of the section between two members of PCF-type felsic crystal-tuff (units 9a, 9c). The southernmost member is a very coarse mass-flow deposit with felsic volcanic clasts and sporadic epiclastic fragments up to 1 m long (unit 6c; Figure GS-11-5e).

The Bird River West section documents alternating felsic volcanic activity and turbidite sedimentation; the

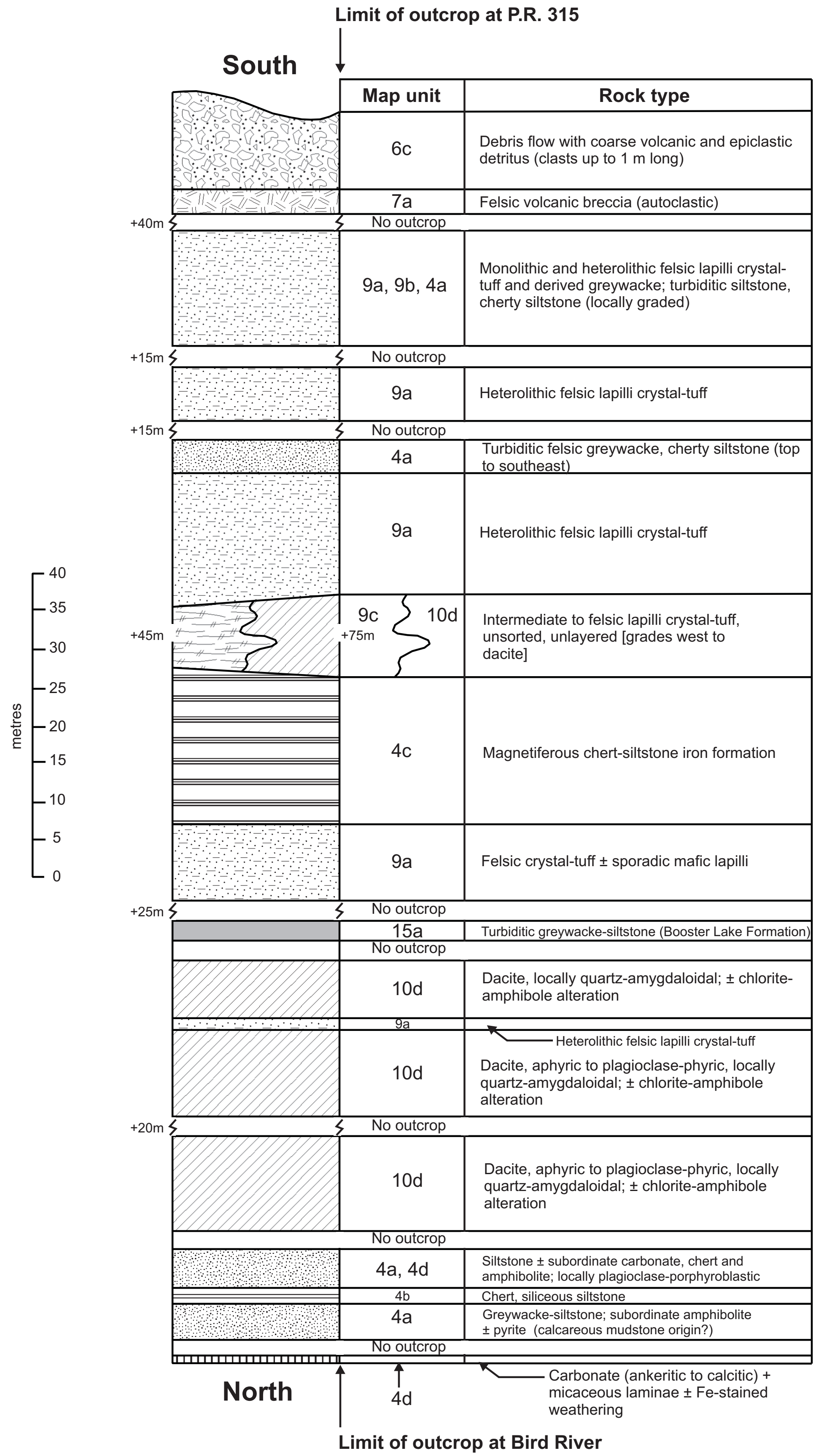


Figure GS-11-6: *Stratigraphic section through the south margin of the BRB north panel, 5 km east of Lac du Bonnet ('Bird River West' section). Location of section line is shown in Figures GS-11-2 and -8.*

resulting rocks are locally redeposited as coarse breccia units, possibly due to reworking by gravity-induced debris flows. The northernmost (carbonate) member in the section may be a shallow-water marine limestone deposit that represents the onset of sedimentation following a prolonged episode of felsic volcanism. Farther south in the sequence, the chert-magnetite iron formation is interpreted as a volcanic exhalative deposit associated with an ephemeral quiescent period, marking a hiatus in the volcanism and epiclastic sedimentation.

BRB south panel

New mapping in the south panel of the western BRB suggests that the BLF in that area is a mainly north-facing sequence consisting of three stratigraphic subdivisions, termed 'lower', 'middle' and 'upper' (Figure GS-11-7). The 'upper' subdivision, located in the vicinity of the junction of Shatford Creek with the Bird River (Figure GS-11-2), is of limited lateral extent (<4 km) and has no known counterpart in the eastern BRB. Geochemical data from 2008 sampling are not yet available; based on existing data, however, the 'lower' and 'middle' stratigraphic BLF subdivisions in the western BRB are provisionally correlated with the 'south' and 'north' parts of the BLF in the eastern BRB (Gilbert, 2006, 2007a).

The MORB-type basaltic rocks at Shatford Lake are lithologically similar to the southern MORB-type formation at Winnipeg River and were probably originally continuous with the latter (Figure GS-11-2). The mafic volcanic terrane between these two areas of MORB-type rocks was intruded by granitoid rocks that now constitute the eastern end of the Lac du Bonnet Batholith.

Lower BLF subdivision

Shatford Lake area

The lower BLF subdivision in the western BRB is best developed at Shatford Lake, where a felsic volcanic terrane, up to 1.7 km wide, extends from the north shore of the lake to the area north of Sarapu Lake (Gilbert, 2008; Gilbert and Kremer, 2008). These felsic volcanic rocks wrap around the western margin of the granitoid Birse Lake pluton and extend northeast to Bernic Lake, as well as southeast to the Winnipeg River (Černý et al., 1981; Gilbert, 2006), where they are terminated by the bounding North Winnipeg River and South Winnipeg River shear zones (Figure GS-11-2).

The Shatford Lake–Sarapu Lake felsic volcanic section, although devoid of stratigraphic-facing indicators, is interpreted as a north-facing monocline. This structural model is largely based on the monoclinal interpretation for the north-facing 'south part' of the BLF in the eastern BRB (Gilbert, 2007a), assumed to be stratigraphically equivalent to the lower BLF at Shatford Lake. A monoclinal structure is also supported by the consistently north-facing tops in MORB-type basalt units flanking both the north and south margins of the Shatford Lake–Sarapu Lake felsic volcanic section (Gilbert, 2008; Gilbert and Kremer, 2008). The structural data suggest that these basalts, as well as the intervening felsic volcanic rocks, are not tectonically folded around the Birse Lake pluton but have instead been shouldered aside and/or stoped away by the granitoid intrusion.

Massive to fragmental rhyolite units, at least 20 m thick, north of Shatford Lake are aphyric to sparsely plagioclase phyric and locally characterized by subparallel, anastomosing fractures, probably due to cooling stress after extrusion. Some massive units are characterized by zones of *in situ* brecciation that grade into volcanic breccia (Figure GS-11-5f). Subordinate heterolithic felsic fragmental deposits within the section contain felsic and minor intermediate to mafic clasts. The various felsic volcanic features are moderately well preserved on the shore of Shatford Lake, but the rhyolitic rocks are strongly deformed and altered in a 0.5 km wide, east-trending zone immediately north of the lake. Diffuse hornblende±chlorite±garnet porphyroblastic domains with gneissic foliation are typical of altered felsic volcanic rocks, both within this zone and sporadically elsewhere in the Shatford Lake–Sarapu Lake section.

Coarse-grained mafic units of garnet amphibolite and massive garnetite, up to 10 m thick, occur at two localities within the lower BLF subdivision: 1) at the south (basal?) margin of the subdivision (north shore of Shatford Lake; UTM 321621E, 5585311N[1]), and 2) 2 km to the northeast (UTM 322859E, 5586717N). These rocks are interpreted as original hydrothermal alteration zones, initially represented by chloritic schist but subsequently recrystallized to coarser grained amphibolite at medium metamorphic grade. These zones are also characterized by disseminated pyrite-pyrrhotite mineralization.

Oxide-facies iron formation within the felsic volcanic section north of Shatford Lake is associated with a conspicuous aeromagnetic positive anomaly at the western margin of the Birse Lake pluton (Geological Survey of Canada, 1966). The iron formation is up to 40 m wide and occurs 1) 0.8 km north of Shatford Lake, at the contact between rhyolite and the Birse Lake pluton, and 2) within the felsic volcanic sequence 0.45 km to the south. Magnetite in these rocks occurs both within chert layers and as fine trails or meandering stringers within siliceous rocks that may include felsic intrusive types. Iron formation is interpreted as a product of volcanic exhalative activity marking a periodic break in the ongoing felsic volcanism.

[1] All UTM co-ordinates are in Zone 15, NAD83

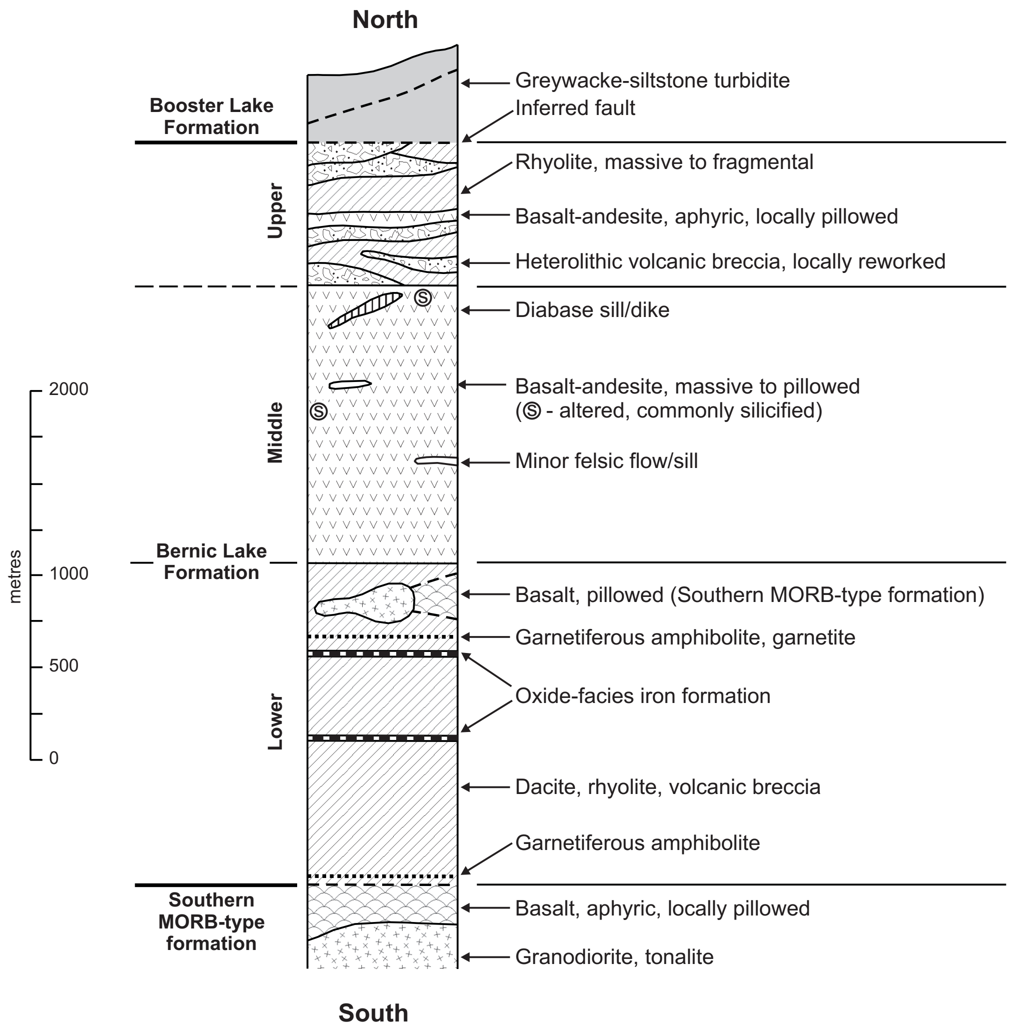


Figure GS-11-7: *Composite section through the Bernic Lake Formation from Shatford Lake to the junction of Shatford Creek with the Bird River (section line is shown in Figures GS-11-2 and -8).*

Lac du Bonnet area

Strongly deformed strata of the lower BLF are exposed in a shoreline section at Lac du Bonnet and in scattered outcrops for up to 1.5 km to the east, but the lower part of the BLF is largely absent elsewhere in the area between Lac du Bonnet and Shatford Lake, due to the emplacement of the 2660 ±3 Ma Lac du Bonnet Batholith (Gilbert, 2008; Table GS-11-1). Sporadic minor enclaves of lower BLF rocks, however, have been reported to exist within this granitoid terrane (C. Galeschuk, pers. comm., 2007). In the Lac du Bonnet section, massive rhyolitic units up to 20 m thick are intercalated with highly attenuated fragmental units and derived felsic gneiss with sporadic garnet.

The 0.2 km wide lower BLF shoreline section at Lac du Bonnet is much reduced in thickness compared to the stratigraphically equivalent sections at Shatford Lake (1.7 km) and in the eastern BRB (1.6 km). The lower BLF sequence is best developed in the eastern BRB (Gilbert, 2006, Figure GS-17-4), where the sequence is lithologically more varied than farther west in the greenstone belt.

Middle BLF subdivision

Mafic flow units that form the middle BLF subdivision in the western BRB extend for more than 25 km from the shore of Lac du Bonnet to the area north of Bernic Lake (Figures GS-11-2, -8). This subdivision consists very largely of pillowed basalt–andesite; subordinate felsic volcanic and related intrusive units (<60 m thick) constitute less than 10% of the section (Figure GS-11-7). The middle BLF subdivision is up to 1.5 km wide, but this amount is probably twice the actual thickness due to structural repetition caused by folding (Gilbert, 2008). The mafic volcanic sequence rapidly decreases in width to only 0.4 km at the east shore of Lac du Bonnet.

Pillowed basalt–andesite of the middle BLF is typically aphyric, but minor plagioclase-phyric flows occur sporadically within the sequence. Sparsely developed quartz amygdules occur locally and large (20 by 4 cm) open vugs occur in some pillow cores. A single 25 m thick unit of spherulitic pillowed basalt occurs in the upper part of the section (Figure GS-11-9a). Pillows (0.5–2 m long) are typically only moderately deformed and serve as reliable top indicators (Figure GS-11-9b); ‘mattress pillows’

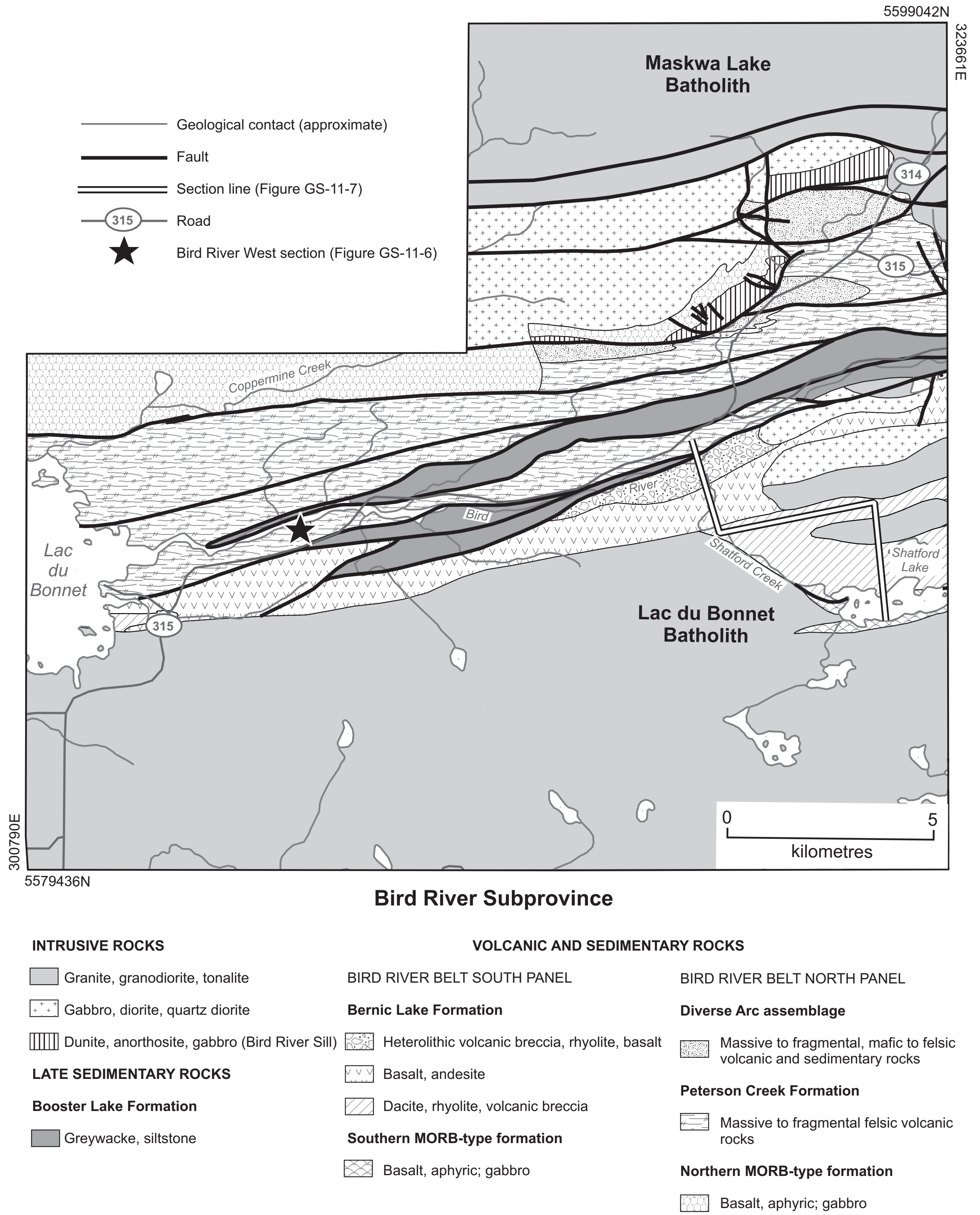


***Figure GS-11-8**: Geology of the western part of the Bird River Belt, showing the subdivisions in the Bernic Lake Formation.*

up to 5 by 1.5 m in size were observed in several units. Alteration is locally conspicuous in the mafic volcanic sequence; silicification (± feldspathic alteration) is widespread (Figure GS-11-9c) and diffuse zones of porphyroblastic hornblende, possibly derived from earlier chloritic alteration, are locally pervasive. Minor epidotization and zones of garnet blastesis occur locally.

An exceptionally well preserved example of silicic alteration occurs at the northern (upper) margin of the middle BLF subdivision (Figure GS-11-7), immediately south of the contact with the Shatford Creek section to the north (*see* below). A white-weathered, pervasively silicified, vesicular pillowed flow at that locality (Figure GS-11-9d) is gradational with equally silicic flow-top breccia to the north. A westward flow direction is indicated by the localized lateral gradation west from the

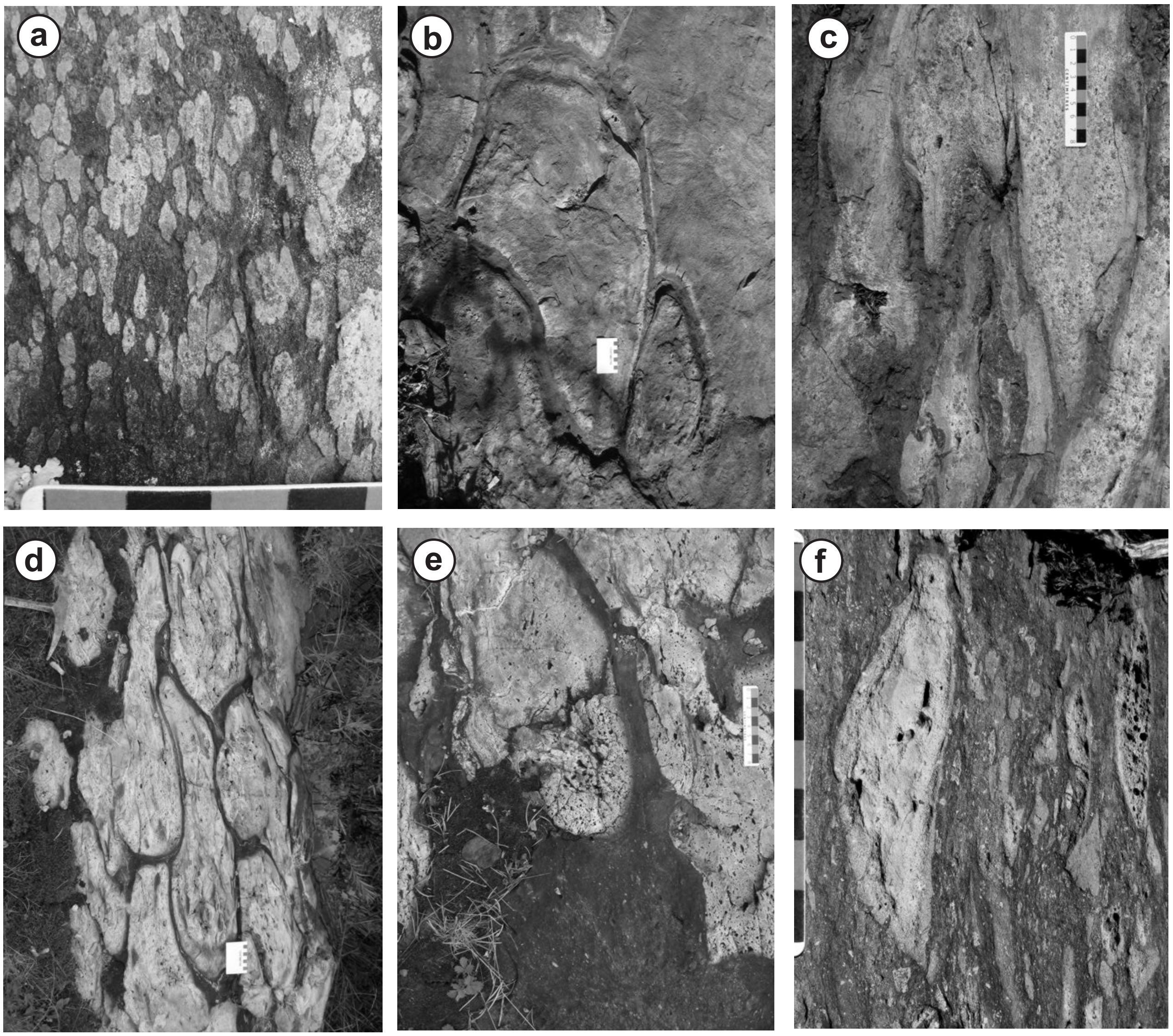


***Figure GS-11-9:** Outcrop photographs of massive and fragmental volcanic and sedimentary rocks in the middle and upper subdivisions of the Bernic Lake Formation (BLF), western Bird River Belt: **a)** spherulitic pillowed basalt, middle BLF (UTM 308361E, 5586796N); **b)** undeformed pillows in moderately altered basalt, with silicification occurring at pillow margins and locally within pillows, middle BLF (UTM 307882E, 5586364N); **c)** metasomatic alteration in pillowed basalt, middle BLF; pale-weathered, silicified pillows contain garnet (dark spots), and coarser grained garnet porphyroblasts (up to 1 cm) are abundant in pillow selvages (UTM 306320E, 5585644N); **d)** white-weathered, silicified, vesicular pillowed basalt at the top of the middle BLF; base of photo is the upper (north) part of the flow unit; the flow is gradational with dark-weathered hyaloclastic tuff a few metres to the west (shown in Figure GS-11-9e; UTM 318808E, 5588758N); **e)** close-up of silicified, vesicular pillowed basalt, gradational with dark-weathered hyaloclastic tuff, top of the middle BLF; the lensoid tuff unit (0.7 by >4 m) is continuous with interpillow detritus deposited between pillow selvages (UTM 318808E, 5588758N); **f)** pyroclastic breccia with a pale-weathered clast showing both rounded and pointed terminations, suggesting a projectile origin, upper BLF (Shatford Creek section); the fragment margin is grey (possibly chilled); clasts in this breccia deposit are variously massive to vesicular (UTM 316110E, 5587939N). All UTM co-ordinates are in Zone 15, NAD83.*

massive flow to autoclastic breccia. The lensoid breccia unit (10 by 25 m) contains a hyaloclastic lapilli-tuff matrix with both mafic and highly silicic, angular fragments (0.2–3 cm long). The dark grey (originally glassy?) tuff, which also occupies interpillow zones (Figure GS-11-9e), is unaltered, indicating that silicification occurred at the sea floor after pillow rinds (and associated hyaloclastic detritus) had been formed but before final cooling and fragmentation of the pillows.

Upper BLF subdivision

The upper BLF subdivision extends northward from the (unexposed) contact with the middle BLF subdivision to the south shore of the Bird River, in the vicinity of the junction with Shatford Creek (Gilbert, 2008). It is a north-facing, 0.75 km thick sequence of diverse, massive to fragmental volcanic rocks that extends laterally for 3–4 km (‘Shatford Creek section’, Figure GS-11-7). Stratigraphically equivalent rocks along strike to the west consist largely of pervasively silicified, massive to pillowed mafic volcanic flows that are, in turn, overlain by north-facing, unaltered, pillowed basalt–andesite forming the uppermost member of the BLF.

The Shatford Creek section contains, in order of abundance, the following lithological components: felsic pyroclastic breccia, heterolithic volcanic fragmental rocks (probable debris flows), massive to pillowed basalt–andesite and associated autoclastic breccia, and rhyolite with related felsic sills (Figure GS-11-7). The various volcanic fragmental rock types and massive felsic flows are partly intercalated, whereas basalt–andesite is largely confined to an approximately 100 m wide unit that extends laterally for 1.5 km through the central part of the Shatford Creek section (Gilbert, 2008). Silicic alteration is less conspicuous than in the immediately underlying middle BLF subdivision; in fact, much of the Shatford Creek section is unaltered and exceptionally well preserved.

Felsic pyroclastic breccia consists mainly of unsorted, angular felsic fragments, locally accompanied by sporadic ovoid, concentrically zoned clasts with ‘tails’, suggesting a projectile origin (Figure GS-11-9f). Some clasts display truncated primary features such as bleached margins and internal breccia texture, suggesting that they were fragmented and incorporated into the deposit following a violent explosive event (Figure GS-11-10a, -10b). Elsewhere in the felsic pyroclastic breccia, amoeboid clasts with tentacle-like arms suggest that the fragments were still plastic during incorporation into the unconsolidated tuffaceous matrix (Figure GS-11-10c). Medium to coarse vesicular texture is conspicuous in many fragments. The various textures indicate that this felsic breccia type was associated with an explosive pyroclastic event that shattered a pre-existing volcanic edifice, resulting in abundant coarse detritus. This detritus was then incorporated into the deposit, together with still-plastic fragments derived from the rapidly ejected, volatile magma.

Heterolithic volcanic fragmental rocks of probable debris-flow origin are distinguished from pyroclastic breccia by the presence of both felsic and mafic clast types (Figure GS-11-10d). Clasts in debris flows range from lapilli size to blocks up to 0.5 m long, whereas pyroclastic breccia is typically less coarse (fragments generally less than 0.3 m). The reworked heterolithic rocks are interpreted to be derived largely from pyroclastic and autoclastic deposits but may also include detritus eroded from the substrate during emplacement of the mass flow.

Basalt–andesite flows in the central part of the Shatford Creek section are not unlike mafic flow units in the underlying middle BLF subdivision, but pillows are relatively less abundant and somewhat smaller (<1.5 m). Several flows indicate a northward facing-direction, concordant with the north-facing units both immediately to the south and within overlying flows along-strike to the west of the Shatford Creek section (Gilbert, 2008). Massive rhyolite, up to 60 m thick, in the Shatford Creek section is sparsely plagioclase phyric and locally displays subparallel, evenly spaced fractures attributed to thermal contraction during cooling. The massive felsic flows are locally characterized by zones of *in situ* brecciation gradational to autoclastic breccia (Figure GS-11-10e). These monolithic rhyolite breccia zones range from 1 to >18 m in thickness and locally contain sporadic tabular blocks of massive rhyolite up to several metres long.

The Shatford Creek section in the upper BLF represents the youngest part of the volcanic sequence in the western BRB. It marks the onset of felsic and associated pyroclastic volcanism, following a period of predominantly mafic volcanic extrusion in the underlying middle part of the BLF. Coarse, intraformational mass-flow deposits in the upper BLF may have been trigged by gravity-induced slumping of volcanic detritus, possibly deposited originally as an emergent topographic feature in a subaqueous to subaerial environment. No epiclastic rocks are preserved in the Shatford Creek section, but (at least) ephemeral subaqueous conditions are indicated by the presence of pillowed mafic volcanic flows, both within and at the top of the sequence.

Southern MORB-type formation

Shatford Lake, at the southern margin of the BRB, intersects the ‘South Winnipeg River Shear Zone’ (Gilbert et al., 2008), a major structural zone that juxtaposes arc-type felsic volcanic rocks to the north (lower BLF subdivision) against the southern MORB-type formation to the south (Figures GS-11-2, -8). The MORB-type basalt extends along the south shore of Shatford Lake and underlies most islands in the area to the north. The flows are typically massive and undeformed; subordinate pillowed units (Figure GS-11-10f), which are invariably north facing, locally contain minor zones of flow breccia with pale-weathered, angular fragments. Pillows

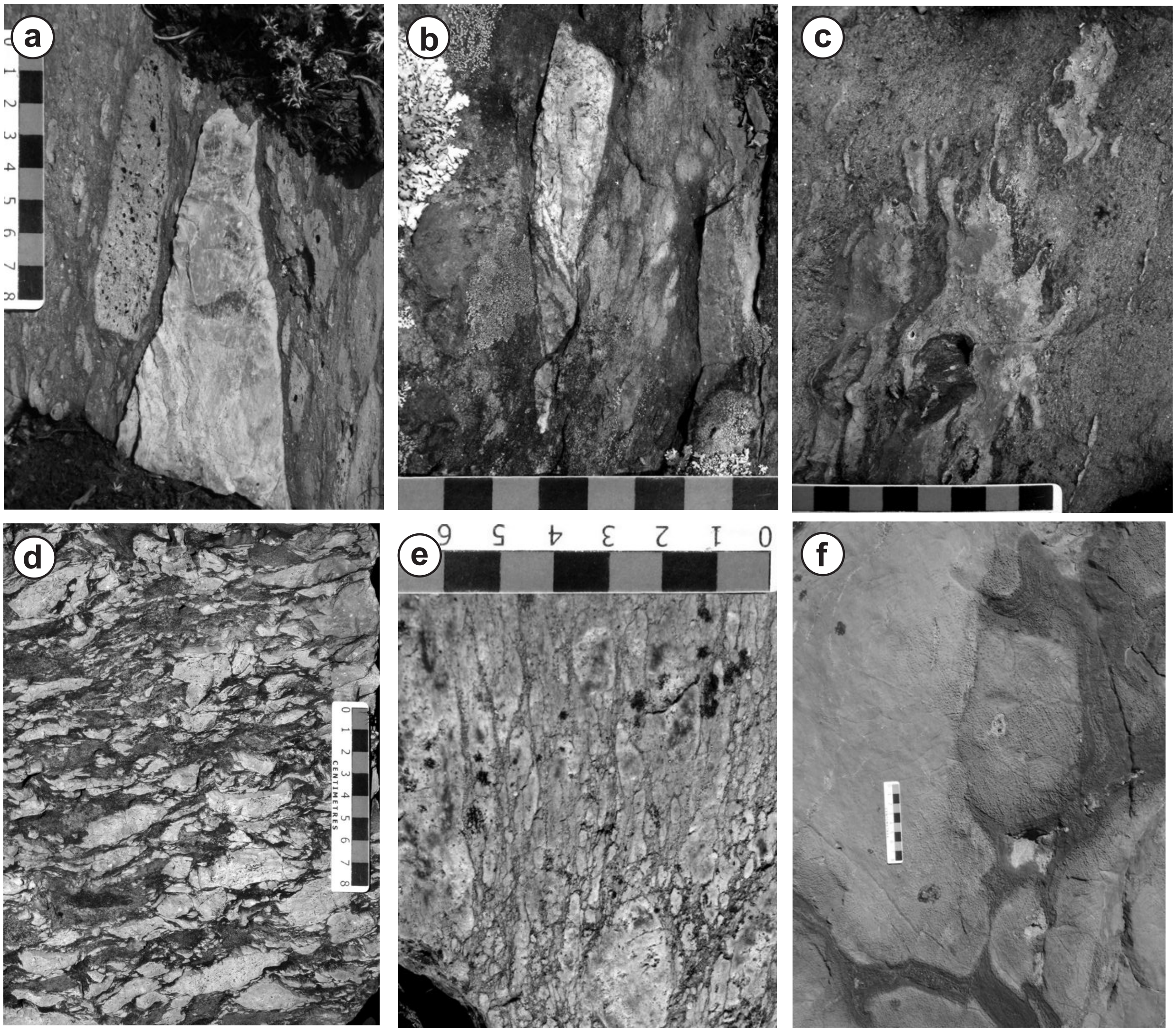


Figure GS-11-10: *Outcrop photographs of volcanic fragmental rocks in the upper part of the Bernic Lake Formation and MORB-type basalt at Shatford Lake, western Bird River Belt:* ***a)*** *angular felsic clast in heterolithic breccia, showing truncation of both the marginal bleached zone and the internal structure of the fragment, upper BLF (Shatford Creek section); this unit is interpreted to contain pyroclastic detritus derived from previous volcanic rocks, as well as primary, magma-derived clasts (UTM 316110E, 5587939N);* ***b)*** *tabular, white-weathered rhyolite fragment in volcanic breccia showing gradation from massive to fragmental internal zones, probably derived from a brecciated flow margin, upper BLF (Shatford Creek section); this volcanic breccia unit is interpreted as a pyroclastic deposit, similar to that shown in Figure GS-11-10a (UTM 316759E, 5588220N);* ***c)*** *irregular amoeboid clasts, possibly deformed while still hot and plastic during transport by a debris flow, upper BLF (Shatford Creek section); the unit is also interpreted as pyroclastic in origin, derived from previously deposited volcanic rocks, as well as primary, magma-derived clasts (UTM 318712E, 5588781N);* ***d)*** *heterolithic volcanic breccia with angular felsic and subordinate mafic fragments, interpreted as a reworked mass-flow deposit, upper BLF (Shatford Creek section; UTM 317673E, 5588501N);* ***e)*** *rhyolite with* in situ *brecciation, gradational with autoclastic breccia, upper BLF (Shatford Creek section; UTM 317829E, 5588627N);* ***f)*** *pillows in southern MORB-type formation at Shatford Lake (UTM 321210E, 5585146N); note that one pillow is truncated by an overlying basaltic pillowed flow. All UTM co-ordinates are in Zone 15, NAD83.*

are relatively small (0.3–1 m long) compared to those in stratigraphically equivalent rocks at Winnipeg River (Gilbert, 2006); mafic flows in both areas locally exhibit primary polygonal jointing. In contrast to the southern MORB-type formation at Winnipeg River, alteration is rare in the MORB-type basalt at Shatford Lake.

One altered flow close to the east end of the lake (UTM 324062E, 5585417N) contains porphyroblastic stringers and irregularly shaped aggregates of garnetite; trenching in the basalt nearby attests to possible hydrothermal mineralization. Although no direct evidence for base-metal sulphides was found in outcrop at this locality, basalt approximately 1 km farther west is mineralized with pyrite and partly silicified adjacent to a felsic porphyry dike. A thin (35 cm), magnetiferous chert-siltstone layer is intercalated with basalt on an island in central

Shatford Lake and marks a short stratigraphic break close to the top of the mafic volcanic sequence. A moderate-sized, aeromagnetic positive anomaly coincident with this member (P. Vanstone, pers. comm., 2007) suggests that it is part of a thicker stratigraphic unit.

Economic considerations

Geochemical sampling at a dozen mineralized localities in the western BRB targeted the economic potential for stratabound mineralization that exists within the greenstone belt. Stratigraphically (± locally structurally) controlled mineralization (pyrite±pyrrhotite and possibly other base-metal sulphides; 2008 assay results are pending) was documented in all the main subdivisions described in this report. The various settings are classified as follows:

1) BRB north panel
   a) oxide-facies iron formation within the DAA, Bird River West section (UTM 307458E, 5587286N and 306667E, 5587012N)
   b) iron formation at the south margin of the PCF, adjacent to the faulted contact with the Booster Lake Formation, south of Bird Lake (UTM 335340E, 5592394N)
2) BRB south panel
   a) oxide-facies iron formation within the lower BLF subdivision north of Shatford Lake UTM 3233673E, 5586201N) and at the contact of the lower BLF subdivision with the Birse Lake pluton (UTM 324023E, 5586578N)
   b) garnetiferous amphibolite units (former chloritic hydrothermal alteration zones?) at the south (basal?) margin of the lower BLF subdivision at Shatford Lake (UTM 321621E, 5585311N) and within the section farther north (UTM 322859E, 5586717N)
   c) felsic volcanic rock (lower BLF subdivision) in contact with the Lac du Bonnet Batholith at a roadside outcrop on PR 315, east of Lac du Bonnet (UTM 304296E, 5584883N)
   d) felsic tuff layer within dacite at the south margin of the middle BLF subdivision, 2 km east of Lac du Bonnet (UTM 306523E, 5585583N)
   e) conformable zone within a dacite flow (middle BLF subdivision) close to the contact with the upper BLF subdivision (UTM 314114E, 5587221N)

Although volcanogenic massive sulphide (VMS) mineralization has not been positively identified in the BRB, a possible volcanic-derived component in the Cu-Ni-Zn–bearing massive sulphide ore deposit at the former Maskwa-Dumbarton mine has long been debated. The numerous stratigraphically controlled mineralized occurrences listed above provide further support for the existence of potential VMS ore deposits within the BRB.

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