Stratigraphy and Volcanic Geochemistry of the Bird River Greenstone Belt, Southeastern Manitoba (NTS 52L5 and 6)

by H.P. Gilbert

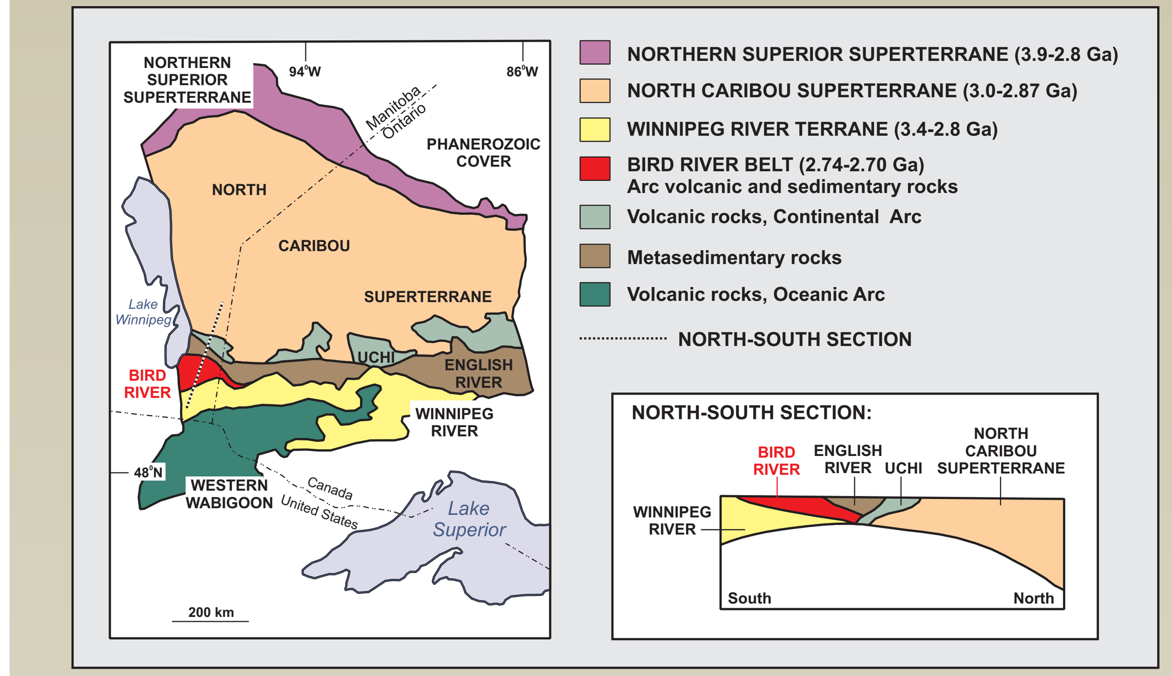

Figure 1. Simplified geology of the western Superior Province, showing the location of the Bird River Belt.

Introduction

The Bird River Belt (BRB) in southeastern Manitoba, located between the English River and Winnipeg River subprovinces, is part of a 150 km long, east-trending supracrustal belt that extends east to Separation Lake in Ontario (*Fig. 1*). The oldest rocks in the BRB are ocean-floor or back-arc volcanic sequences (Lamprey Falls Formation) that are intruded by the 2.745 Ma Bird River Sill, host to base-metal and platinum-group-element (PGE) mineralization. Arc-type rocks in the BRB (ca. 2.73 Ma) are separated into northern and southern structural panels (*Fig. 2*) by an elongate formation of fault-bounded turbidites (Booster Lake Formation). The arc-type north panel consists of a diverse sequence of sedimentary and volcanic rocks ('diverse arc assemblage') that appear to underlie a more homogeneous section of calcalkaline dacite and rhyolite (Peterson Creek Formation). Mafic to felsic arc volcanic rocks of the south panel (Bernic Lake Formation), which are slightly younger than the north panel rocks, are tholeiitic and include both normal and geochemically more evolved types.

Fluvial-alluvial sedimentary rocks (Flanders Lake Formation) overlie the arc volcanic strata at the east end of the BRB. Detrital zircon data suggest that both the turbiditic Booster Lake Formation and the fluvial-alluvial Flanders Lake Formation postdate the arc-type sequence by 10-20 Ma. These sedimentary formations are approximately contemporaneous with and lithologically similar to epiclastic rocks in the English River Subprovince, located northeast of the BRB. The Booster Lake and Flanders Lake formations may be structurally allochthonous counterparts of the English River Subprovince strata or alternatively may represent remnants of a formerly more extensive sedimentary basin that included the English River supracrustal rocks.

Stratigraphy

The previously published stratigraphy of the BRB (Cerny et al., 1981) is revised on the basis of detailed mapping and concurrent geochemical and geochronological investigations. Six main supracrustal formations are recognized, described in order of decreasing age:

- Lamprey Falls Formation (predating the 2.745 Ma Bird River Sill; Wang, 1993) consists almost entirely of MORB-type, back-arc basaltic rocks and associated gabbro. These rocks occur along the margins of both the north and south structural panels of the BRB. Gabbro of probable synvolcanic age is abundant and locally predominant in the Lamprey Falls Formation at the north flank of the BRB. The MORB-type basalt is mainly aphyric but includes plagioclase-megaphyric phases north of the BRB (*Fig. 3*).
- Diverse arc assemblage encompasses a wide variety of calcalkaline arc-type rocks in the north panel that include mafic to felsic volcanic flows, volcaniclastic and epiclastic rocks (commonly reworked by subaqueous mass flows), and minor chert and iron formation. The polymictic conglomerate shown in *Figure 4* is a stratigraphic marker unit that subdivides the sequence into lower and upper parts. The conglomerate consists of basalt and gabbro fragments probably derived from the Lamprey Falls Formation, as well detritus from the underlying diverse arc assemblage strata, e.g., leucogabbro from the Bird River Sill (*Figs 5a* and *5b*) as well as chert and tuff (*Figs 6a* and *6b*). Turbidite deposits occur both below and above the conglomerate unit (*Fig. 7*). Quartz-amygdaloidal andesite (*Fig. 8*) and rhyolitic flows are subordinate; a conspicuous spherulitic rhyolitic flow occurs in the lower part of the sequence (*Fig. 9*).
- Peterson Creek Formation (2.731.1 ±1 Ma; M. Duguet and D.W. Davis, pers. comm., 2006) is a calcalkaline sequence of massive dacite, rhyolite and volcaniclastic rocks within the north panel that is interpreted to overlie the diverse arc assemblage. Aphyric to porphyritic, massive volcanic flows are intercalated with reworked volcaniclastic breccia that contains felsic and subordinate mafic fragments. Flow lamination and *in situ* brecciation are locally characteristic of the felsic volcanic flows (*Fig. 10*). An unusual texture in some aphyric flows consists of two separate components: spheroidal to irregularly shaped, siliceous rhyolite bodies occur within a beige-yellow, sericitic rhyolite matrix (*Fig. 11*).
- Bernic Lake Formation (2.724.6 ±1.1 Ma; P. Kremer and D.W. Davis, pers. comm., 2006) is the arc-type, tholeiitic sequence that comprises the south panel of the BRB. It consists largely of massive and fragmental felsic volcanic rocks - not unlike those in the Peterson Creek Formation - as well as abundant basalt (*Fig. 12*). The Bernic Lake Formation is geochemically distinct from the calcalkaline Peterson Creek Formation, as well as being approximately 6 Ma younger. Most pillowed flows in the Bernic Lake Formation face north, consistent with the available geochemical data that indicate an overall northward direction of younging: volcanic rocks in the north part of the Bernic Lake Formation are geochemically more evolved than those in the sequence farther to the south. Pervasive alteration (chlorite-hornblende) is common and especially conspicuous in a zone along the north margin of the formation (*Fig. 13*). A distinctive 'iron formation' (carbonate-chert-siltstone-amphibolite) occurs in the west part of Bernic Lake Formation.
- Booster Lake Formation (2.712 ±17 Ma; Gilbert, 2006) is a sequence of turbiditic greywacke and siltstone that extends through the centre of the BRB (*Fig. 2*). Cyclic sedimentation and Bouma-type features are especially well developed in the east part of the BRB but the cyclic units (0.1-0.5 m) give way to more thickly bedded (0.2-2 m) deposits in the central and western parts of the sedimentary basin, where sporadic coarse-grained felsic wacke units probably represent lensoid channel deposits. Cordierite porphyroblasts occur sporadically throughout the formation. The Booster Lake Formation is characterized by patterns of repeated early folds, in which the axial traces are locally oblique to the faulted margins of the formation. These structures, which apparently predate tectonic emplacement of the fault-bounded sedimentary enclave, are interpreted as D1 in age. In addition to the main occurrence of the Booster Lake Formation in the central part of the greenstone belt, at least two major fault slices are emplaced within south panel of the BRB.
- Flanders Lake Formation (2.697 ±18 Ma; Gilbert, 2006) is a fluvial-alluvial, conglomerate-sandstone sequence characterized by localized crossbedding, graded bedding and scour-and-fill structure. The polymictic conglomerate contains a variety of volcanic, sedimentary and granitoid cobbles and sporadic boulders. Detrital zircon analysis suggests the Booster Lake and Flanders Lake formations contain detritus eroded from both the BRB volcanic sequence and the flanking granitoid terranes (English River and Winnipeg River subprovinces).

Geological Formations in the Bird River Belt

Late intrusive rocks

GRANITOID INTRUSIONS
Granite, granodiorite, tonalite
(Marijane Lake pluton 2645.6 ± 1.3 Ma1; Birse Lake pluton; 2723.2 ± 0.7 Ma2)

MAFIC INTRUSIONS
Diabase, gabbro

Sedimentary rocks

FLANDERS LAKE FORMATION (2697 ±18 Ma3)
Lithic arenite, polymictic conglomerate

Fault, inferred

BOOSTER LAKE FORMATION (2712 ± 17 Ma3)
Greywacke-siltstone turbidite, conglomerate

Unconformity, inferred

Intrusive rocks

MISCELLANEOUS INTRUSIONS
Gabbro, diorite, granodiorite (Maskwa Lake batholith II: 2725 ± 6 Ma4)

Metavolcanic and metasedimentary rocks

BERNIC LAKE FORMATION (2724.6 ± 1.1 Ma2)
Basalt to rhyolite (massive to fragmental); heterolithic volcanic breccia

PETERSON CREEK FORMATION (2731.1 ± 1 Ma1)
Dacite, rhyolite (massive to fragmental); related tuff and volcanic breccia

DIVERSE ARC ASSEMBLAGE
Basalt to rhyolite, heterolithic volcanic breccia; turbidite, chert, iron-formation; polymictic conglomerate

Unconformity, inferred

Intrusive rocks

BIRD RIVER SILL (2744.7 ± 5.2 Ma4
Peridotite, anorthosite, gabbro

Fault, inferred

Metavolcanic and metasedimentary rocks

LAMPREY FALLS FORMATION
Basalt, locally pillowed; related breccia and gabbro; oxide-facies iron formation

Fault, inferred

Older intrusive rocks

Granodiorite, diorite (Maskwa Lake batholith I: 2844 ± 12 Ma4)

REFERENCES FOR GEOCHRONOLOGICAL DATA
1 M. Duguet and D.W. Davis, 2006, pers. comm.
2 P. Kremer and D.W. Davis, 2006, pers. comm.
3 Gilbert, 2006
4 Wang, 1993

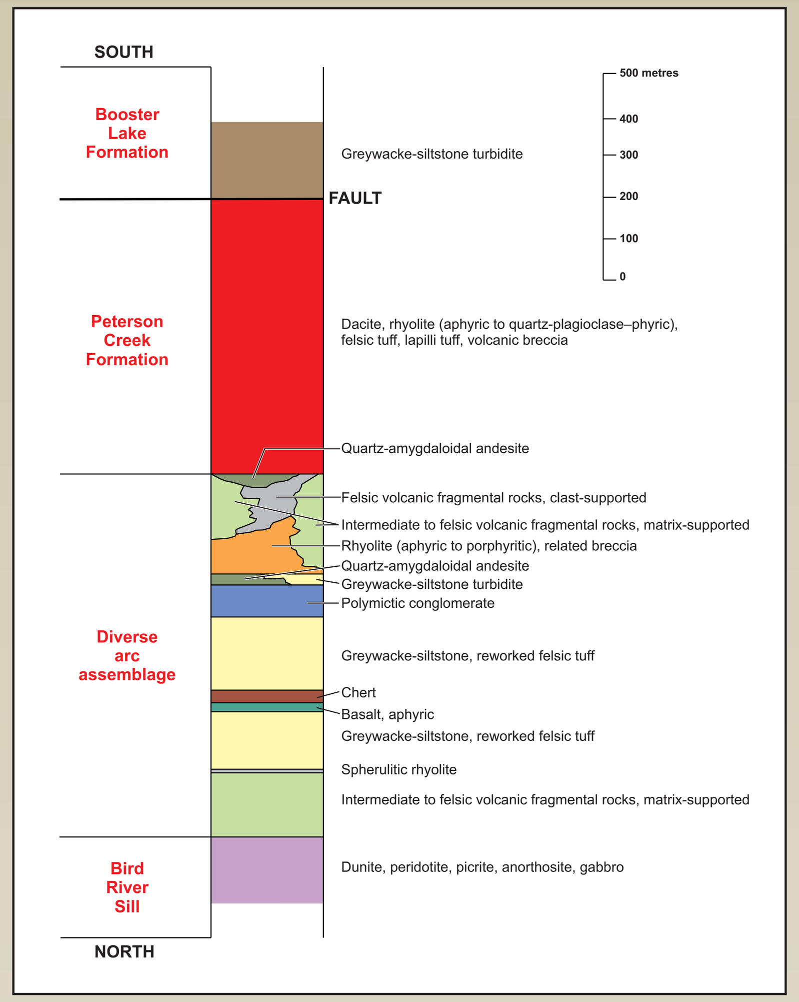

Figure 4. Stratigraphic column of the Highway Junction section, showing lithostratigraphic details of the diverse arc assemblage, north panel, Bird River Belt.

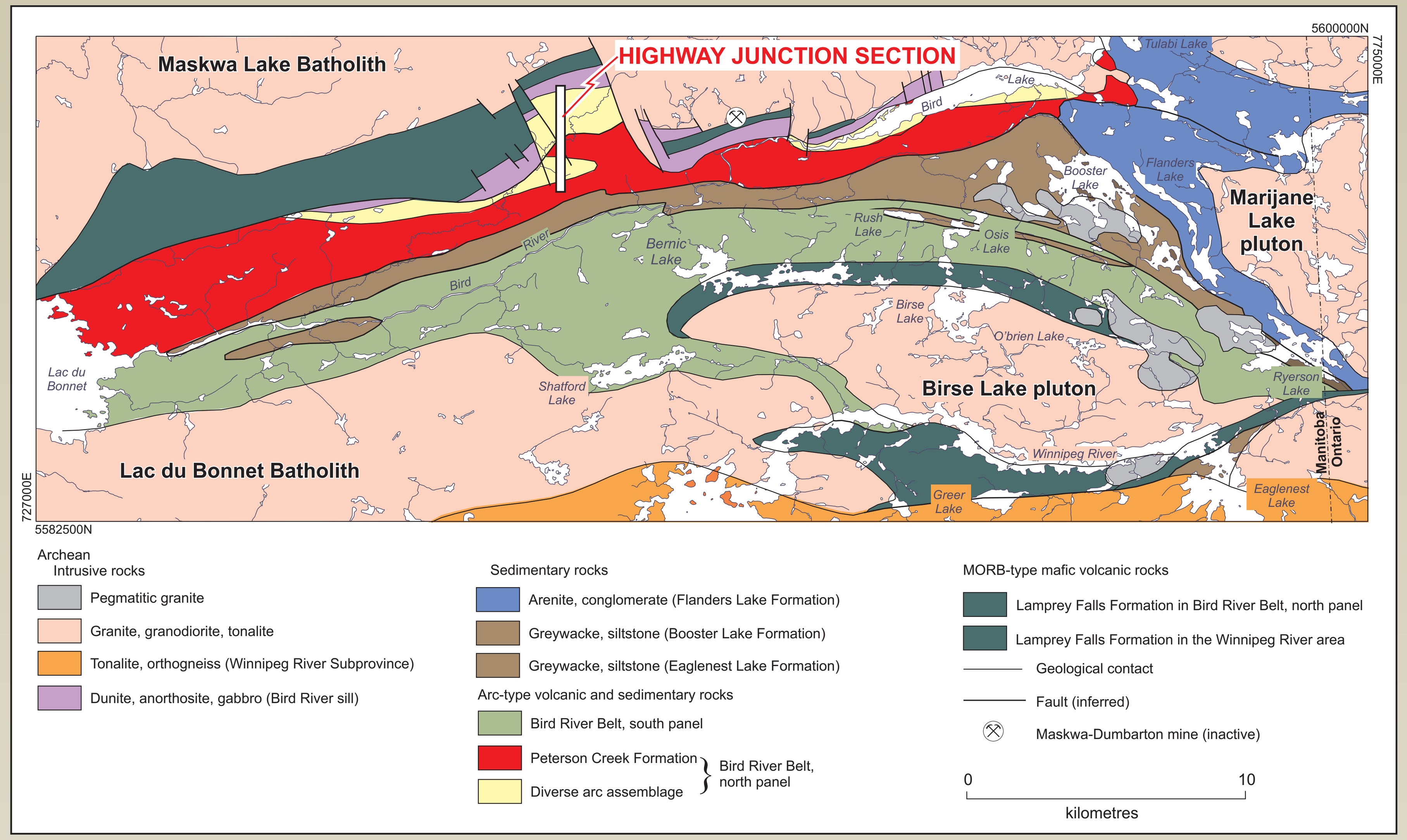

Figure 2. Generalized geology of the Bird River Belt showing the distribution of the northern and southern structural panels.

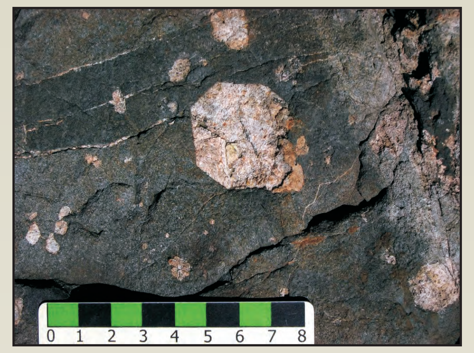

Figure 3. Plagiolase-megaphyric pillowed basalt (Lamprey Falls Formation; UTM 318638E, 5593286N).

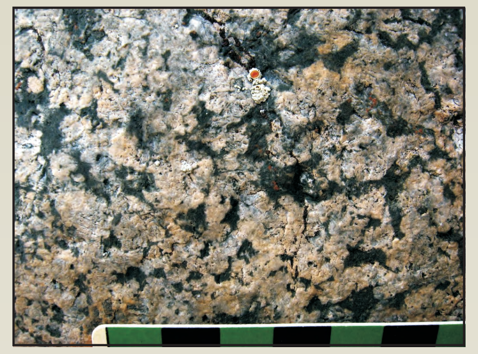

Figure 5a. Very coarse gained anorthositic gabbro, Bird River Sill (UTM 327474E, 5593008N).

Figure 5b. Anorthositic gabbro pebble in polymictic conglomerate, diverse arc assemblage (UTM 320520E, 5592649N).

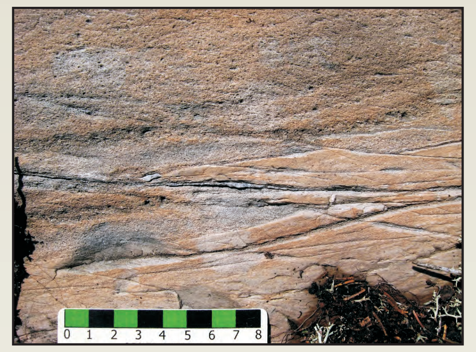

Figure 6a. Reworked felsic tuff, diverse arc assemblage (UTM 313661E, 5588214N).

Figure 6b. Reworked felsic tuff cobble in polymictic conglomerate, diverse arc assemblage (UTM 320520E, 5592649N).

Figure 7. Greywacke-siltstone turbidite showing scoured bedding surfaces, located in the axial zone of a D_1 anticline (UTM 320596E, 559279N). The plane of fragment flattening (parallel to S_1) is approximately normal to bedding.

Figure 8. Quartz-amygdaloidal pillowed andesite, diverse arc assemblage (UTM 316346E, 5591342N).

Figure 9. Spherulitic rhyolite flow with contorted flow lamination, diverse arc assemblage (UTM 319853E, 5594930N).

Figure 10. Aphyric rhyolite with in-situ brecciation and contorted flow lamination, Peterson Creek Formation (UTM 328312E, 5592469N).

Figure 11. Spheroidal siliceous rhyolite bodies within a felsic volcanic flow, Peterson Creek Formation (UTM 319154E, 5591226N).

Figure 12. Aphyric pillowed basalt, Bernic Lake Formation; at the east shore of Lac du Bonnet (UTM 303284E, 5585685N).

Figure 13. Altered felsic volcanic breccia with pervasive hornblende porphyroblasts in diffuse metasomatic zones; Bernic Lake Formation at the north margin of the BRB south panel (UTM 318651E, 5589777N).

Geochemistry of volcanic rocks

The four main stratigraphic components of volcanic rocks in the Bird River Belt have distinctive geochemical signatures that indicate their tectonic affinity, when compared with the signatures of modern volcanic rocks. The four volcanic components are, from oldest to youngest:

- Lamprey Falls Formation back-arc type basalt
- BRB north panel arc-type rocks (diverse arc assemblage and Peterson Creek Formation)
- Bernic Lake Formation, south part
- Bernic Lake Formation, north part

Lamprey Falls Formation basalt is characterized by nearly flat N-MORB-normalized trace-element profiles in which the light rare-earth elements (REE) are slightly elevated and Th is moderately increased (*Fig. 14*). Compared to arc-type rocks in the BRB, Lamprey Falls Formation basalt has lower SiO_2 (average <51%), La/Yb and Zr/Y ratios.

BRB north panel arc-type rocks (diverse arc assemblage and Peterson Creek Formation) are characterized by a negatively sloping trace-element profile with a pronounced Th/Nb anomaly, as well as depleted heavy REE and TiO2 (*Fig. 15*). SiO_2 exceeds 58% in almost all BRB north panel arc-type rocks. These rocks are calcalkaline, in contrast to the tholeiitic rock types of the Bernic Lake Formation in the BRB south panel (*Fig. 16a, 16b*).

Bernic Lake Formation volcanic rocks display REE patterns typical of modern arc volcanic rocks, but overall contents of these elements are elevated compared to arc-type rocks in the BRB north panel. Heavy REE depletion relative to light REE is progressively less pronounced from BRB north panel arc-type rocks to Bernic Lake Formation south part to Bernic Lake Formation north part rocks (*Fig. 15*). The distinctive patterns shown by mafic to intermediate rocks is also displayed by rhyolitic rocks (*Fig. 17*).

Tectonostratigraphy of the Bird River Belt

The abundance of felsic volcanic rocks in the Bird River Belt, which constitute approximately one third of the volcanic sequence, distinguishes this belt from some other Neoarchean greenstone belts in the Superior province in which dacite and rhyolite are relatively minor components (e.g., Island Lake belt; Oxford-Gods-Knee lakes belt). The prominence of felsic rocks in the BRB may be related to the presence of continental lithosphere underplating the greenstone belt, which is suggested by lithoprobe deep crustal profiles based on seismic survey data. The mantle-derived source magma for the volcanic rocks may have interacted with the continental crust through which it rose; this crust may have been partially melted and then incorporated into the evolving magma, resulting in an increase in the volume of felsic magma.

Geochemical data such as Sm/Nd isotope analyses support such a continental-arc-type model for the BRB. The isotope data further suggest differences in the amount of crustal assimilation for the arc-type vs back-arc-type formations in the BRB (*Fig. 18*). Arc-type volcanic rocks are characterized by εNd values (at 2.7 Ga) between -2.4 to + 1.0, in contrast to the back-arc-type Lamprey Falls Formation, where Nd values range from +1.3 to +1.9. These data indicate the Lamprey Falls Formation was derived from a mantle source that was relatively more juvenile and less contaminated by continental crust, compared to the source of the younger arc-type rocks. The εNd values (at 2.7 Ga) of arc-type volcanic flows in the BRB north panel are +1 to -1.1, whereas the south panel (Bernic Lake Formation) values range from +0.7 to -2.4, thus suggesting slightly more crustal contamination and/or recycling of older crust than in the BRB north panel.

The various volcanic rock suites in the BRB are also characterized by contrasting Th/Ta ratios. This ratio is commonly used to identify the tectonic setting of modern volcanic rocks, because arc-generated magmas have higher Th/Ta than those in a within-plate volcanic setting. The Th/Ta vs Yb diagram of Gorton and Schandl (2000) (*Fig. 19*) shows BRB north panel rocks plot in the 'Active Continental Margin' field, whereas the slightly younger BRB south panel rocks plot in the 'Within-plate Volcanic Zone'. The implication is that BRB north panel rocks are relatively enriched in Th (resulting in higher Th/Ta ratios) due to their proximity to the subduction zone at the continental margin, whereas BRB south panel volcanic rocks are 'within-plate' and thus less influenced by Th enrichment.

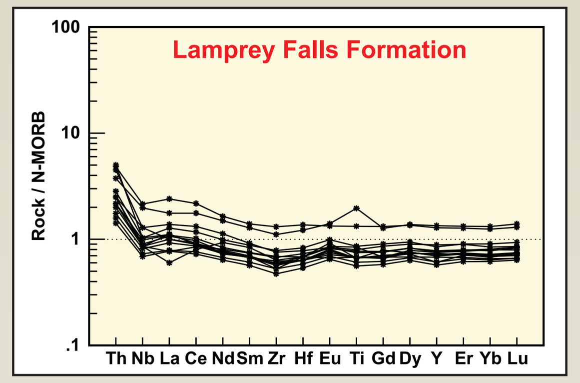

Figure 14. N-MORB-normalized extended element plots of Lamprey Falls Formation back-arc type basalt. Normalizing values are after Sun and McDonough (1989).

Economic considerations

The continental arc tectonic setting of the BRB has implications for the economic potential of the area and for targeting prospective terranes for mineral exploration. For example, surface showings of base-metal mineralization are not conspicuous in the voluminous felsic volcanic formations in the BRB, except where they contain sedimentary iron formations. This observation is in contrast to that in many VMS camps, where base-metal ore deposits are hosted by felsic volcanic rocks associated with bimodal volcanism in island arc settings. In the BRB, the most promising terranes for sulphide-type mineralization are:

- the mafic-ultramafic Bird River Sill and immediate mafic volcanic host rocks, which have yielded Cr, Ni, Cu, Zn and platinum group elements; and
- back-arc type mafic volcanic rocks of the Lamprey Falls Formation, which locally contain strata-bound, base-metal mineralization and sulphide-bearing iron formations. Sporadic mafic-ultramafic intrusions, lithologically similar and related to the Bird River Sill, occur in the Lamprey Falls Formation at the north margin of the BRB and represent potential exploration targets.

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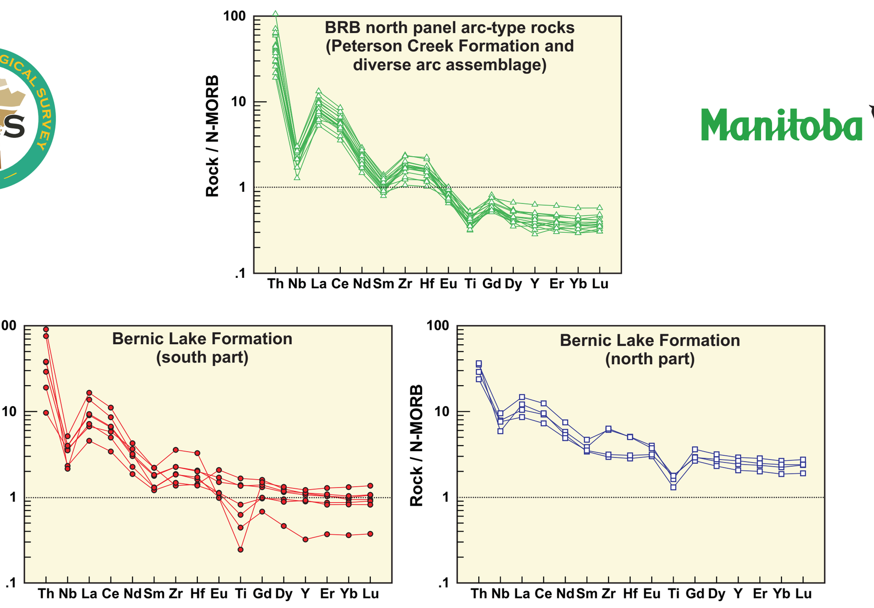

Figure 15. N-MORB-normalized extended element plots of mafic to intermediate volcanic rocks in a) Bird River Belt north panel arc-type rocks; b) Bernic Lake Formation, south part; and c) Bernic Lake Formation, north part.

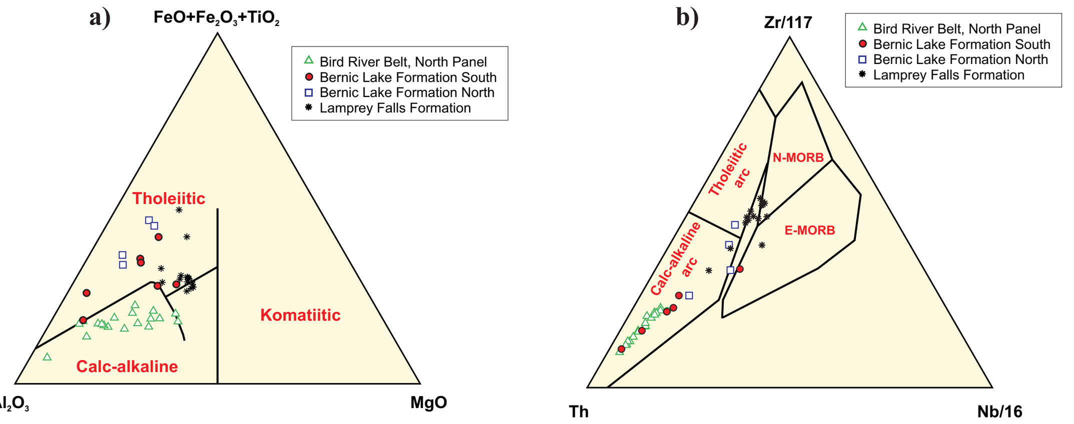

Figure 16. a) Jensen (1976) cation plot and b) Th-Zr-Nb ternary diagram (Wood, 1980) of volcanic rocks in Lamprey Falls Formation; BRB north panel arc-type rocks; Bernic Lake Formation, south part; and Bernic Lake Formation, north part.

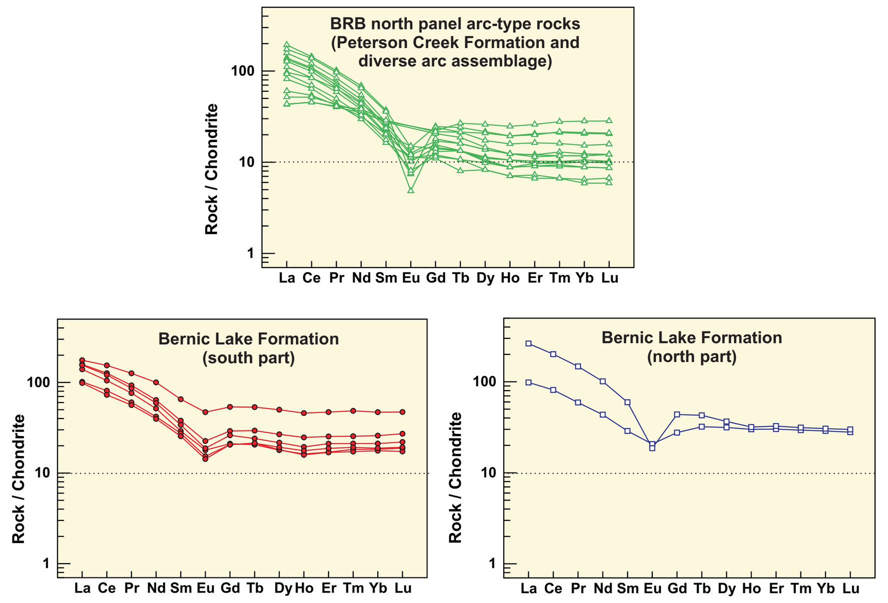

Figure 17. Chondrite-normalized extended element plots of rhyolitic rocks in a) Bird River Belt north panel arc-type rocks; b) Bernic Lake Formation, south part; and c) Bernic Lake Formation, north part. Normalizing values are after Sun and McDonough (1989).

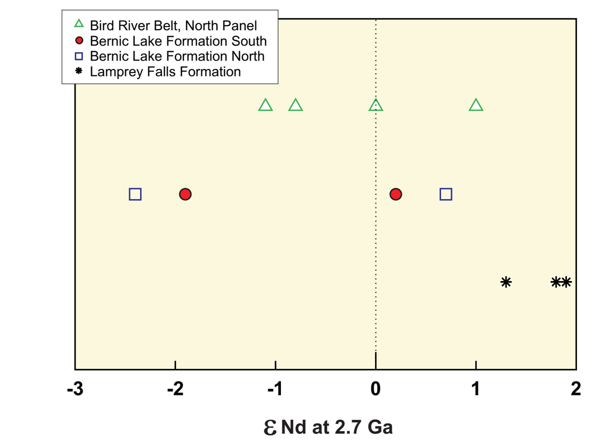

Figure 18. εNd values (at 2.7 Ga) of volcanic rocks in a) Bird River Belt north panel; b) Bernic Lake Formation, south part; c) Bernic Lake Formation, north part; and d) Lamprey Falls Formation.

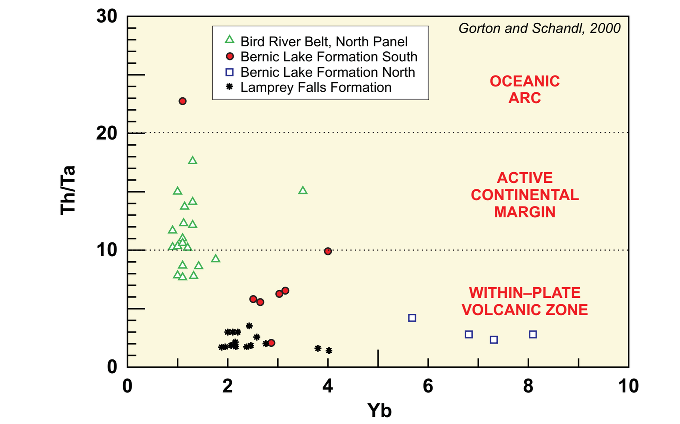

Figure 19. Th/Ta vs Yb plot (Gorton and Schandl, 2000) of volcanic rocks in a) Bird River Belt north panel; b) Bernic Lake Formation, south part; c) Bernic Lake Formation, north part; and d) Lamprey Falls Formation.