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GS-16 Geology and structure of the Bird River Belt, southeastern Manitoba (NTS 52L5 and 6)

by M. Duguet, H.P. Gilbert, M.T. Corkery and S. Lin, p. 170-183.

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The caption for diagram b) in Fig. GS-16-3 has been changed to:

b) *Ta/Yb vs. Th/Yb discriminant diagram (Gorton and Schandl, 2000; abbreviations: ACM, active continental margin; WPVZ, within plate volcanic zones; WPB, within plate basalts; MORB, mid-ocean ridge basalt);*

GS-16

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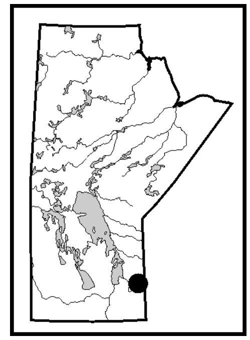
by M. Duguet[1], H.P. Gilbert, M.T. Corkery and S. Lin[1]



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Summary

The Bird River Belt (BRB) of the Superior craton is situated between the English River Domain to the north and the Winnipeg River Domain to the south. In 2005, the Manitoba Geological Survey initiated a multidisciplinary program of targeted bedrock mapping, structural analysis, lithogeochemistry and U-Pb geochronology in the BRB. The objective of this program is to further refine the stratigraphic, structural and tectonic framework of the belt.

During the summer of 2006, field investigations on the north flank of the BRB focused on the structural relationships between the Maskwa Lake Batholith and the different units of the BRB. These investigations highlighted the importance of the Peterson Creek Shear Zone (PCSZ) in the structural framework of this part of the belt; the last movements of the PCSZ are coeval with the emplacement of the 2631 Ma Marijane Lake pluton. Stratigraphic investigations have not significantly changed the number of subdivisions, but their definitions and structural inter-relationships were completely revised. These revisions include the reassignment of the sequence in the north part of the BRB, which was previously attributed to Bernic Lake Formation, to the Peterson Creek Formation. Another part of the section was assigned to a new sedimentary unit composed of turbidite, chert, argillite and conglomerate, which apparently represents a sedimentary cover sequence overlying the Lamprey Falls Formation.

Further fieldwork was also undertaken on the south flank of the BRB in the vicinity of the Winnipeg River and Eaglenest Lake. Two major shear zones with contrasting kinematics have been identified in that area.

The structural and kinematic data resulting from the mapping in 2005 and 2006 indicate the BRB is a pop-up structure that is the result of a complex, polyphase transpressive tectonic history.

Introduction

The BRB is located in southeastern Manitoba, about 150 km northeast of Winnipeg. The BRB of the Superior craton is situated between the English River Domain to the north and the Winnipeg River Domain to the south. It is a significant district for ore deposits (e.g., the Tanco rare-element pegmatite deposit, the Maskwa Fe-Ni-Cu–platinum group element (PGE) deposit and the Dumbarton Ni-Cu-Zn-PGE deposit). This area has been explored for ore deposits since the 1920s; however, few regional geological maps that include the BRB have been published (Davies, 1956; Trueman 1980; Cerny et al., 1981) and the available maps display numerous inconsistencies.

Three collaborative geological mapping projects were initiated in 2005 by the Manitoba Geological Survey and the University of Waterloo, with financial support from the following mining/exploration companies: Gossan Resources Limited (together with North American Palladium Ltd.), Mustang Minerals Corp and Tantalum Mining Corporation of Canada, Limited (Tanco). The objectives of these projects are to improve the understanding of the stratigraphic, structural and tectonic framework of the BRB and to establish the setting of the various mineral deposits that occur within the belt. This three-year, multidisciplinary project involves targeted bedrock mapping, structural analysis, lithogeochemistry and U-Pb geochronology. The preliminary results of fieldwork undertaken in 2005 were published in Duguet et al. (2005).

Field investigations in 2006 were focused both on the north flank of the BRB and on the south flank of the belt along the Winnipeg River. The objectives were to

- update the lithostratigraphy and the main stratigraphic subdivisions (the Peterson Creek, Bernic Lake and Lamprey Falls formations) and, in particular, establish the contact relationships between the Maskwa Lake Batholith and contiguous BRB supracrustal rocks to the south. Samples for geochemistry and geochronology were collected as part of this investigation.
- investigate the Peterson Creek Shear Zone, particularly in the vicinity of the contact with the Maskwa Lake Batholith. This major shear zone (200–300 m wide) is of potential economic interest since gold has been found in association with sulphide occurrences (Bernatchez, 1994; Murphy and Theyer, 2005).
- establish the regional tectonic setting of the BRB by integrating new geological data along the south flank

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of the BRB with kinematic and structural information. Geochemical and geochronological samples were collected in support of this investigation.

In this report, new data relating to the geology, structure, geochemistry and metamorphism of the Bernic Lake and Peterson Creek formations — as well as geochronological data on the Marijane Lake pluton — are integrated to provide an updated geological and structural framework for the BRB, help establish a revised tectonic history and enhance the understanding of the economic potential of the BRB.

Stratigraphy

Trueman (1980) provided the most comprehensive and detailed description of the lithological subdivisions of the BRB. Six formations were described as follows:

- The Eaglenest Lake Formation is composed of volcaniclastic sediments and minor mafic lavas.
- The Lamprey Falls Formation consists of pillowed basalt with intercalated tuff and iron formation and is in fault contact with the Eaglenest Lake Formation and the Bird River Sill.
- The Peterson Creek Formation contains rhyolite, andesitic and minor basaltic flows, pyroclastic breccia, lapillistone tuff and volcanic sandstone. This formation has been dated (by U-Pb zircon analysis) at 2740 ±4 Ma (Wang, 1993).
- The Bernic Lake Formation is composed predominantly of basalt with subordinate andesite, dacite, rhyolite, iron formation and volcanic sandstone. All of these rocks have been deformed and metamorphosed up to the middle-amphibolite-facies grade. The Bernic Lake Formation is widely intruded by granodiorite, diorite and gabbro plutons; the Tanco pegmatite (2640 ±7 Ma by U-Pb on tantalite; Baadsgaard and Cerny, 1993) occurs within one of the gabbroic plutons.
- The Booster Lake Formation is composed mainly of greywacke-mudstone turbidite. Interbedded conglomerate and iron formation have been observed on the western side of the BRB within this formation (Cerny et al., 1981). This sequence is strongly deformed and a synclinorial structure has been mapped at Booster Lake in the east part of the formation (Gilbert, 2005). This formation has undergone high-temperature–low-pressure metamorphism coeval with the emplacement of the Marijane Lake pluton and the associated pegmatitic granites.
- The Flanders Lake Formation is composed of polymictic conglomerate, which includes pebbles derived from the Bernic Lake Formation and metamorphosed lithic meta-arenite. The Flanders Lake Formation is intruded by the Marijane Lake pluton and is in fault contact with the Peterson Creek, Booster Lake and Bernic Lake formations.

The structural-stratigraphic regional interpretation of Trueman (1980) is based largely on the assumption that the BRB has been deformed in a major synform. The three volcano-sedimentary formations of the BRB (i.e., the Lamprey Falls, Peterson Creek and Bernic Lake formations) were recognized by Trueman on both the north and the south limbs of the major synform. Although the number of units has not been significantly changed, new mapping by the senior author has extensively revised the lithological identity of the stratigraphic subdivisions (Figure GS-16-1). For example, the map unit previously attributed to the Bernic Lake Formation on the north flank of the BRB has been reassigned. Thus, in the west part of the BRB, the Peterson Creek Formation is in direct contact with the Lamprey Falls Formation. South of the Page property (Bird River Sill), a new sedimentary unit has been described (Figure GS-16-1) that does not compare with any rocks previously assigned to the Bernic Lake Formation. The sedimentary subunit may represent a sedimentary cover sequence overlying the Lamprey Falls Formation and the Bird River Sill, with which it is closely associated. Based on this inferred stratigraphic association, the sedimentary subunit has been assigned to the Lamprey Falls Formation. The following descriptions are confined to the Peterson Creek and Lamprey Falls formations because these two formations have undergone the greatest changes as a result of new mapping in 2006.

Lamprey Falls Formation

Lamprey Falls Formation at the north margin of the BRB

The Lamprey Falls Formation at the north margin of the BRB consists mainly of massive to pillowed basalt flows. The formation is a monoclinal south-facing sequence and is pervasively intruded by diabase dikes and gabbro sills associated with sulphide mineralization (*see* Mealin, GS-19, this volume). These mafic dikes occur in both the basalt and the overlying sedimentary subunit as well as the Maskwa Lake Batholith. The northeast to east trend of this diabase-gabbro intrusive complex is parallel to the contacts between the Lamprey Falls Formation, the Peterson Creek Formation and the Bird River Sill. The Lamprey Falls Formation is weakly deformed and metamorphosed at greenschist-facies grade. The Lamprey Falls basalt is similar to a mid-ocean ridge basalt (MORB) and compositionally similar to a modern back-arc basin basalt (BABB; *see* Gilbert, 2005). Geological mapping in 2006 has resulted in extensions of the Lamprey Falls Formation east toward the Maskwa Lake Batholith to the area south of the Page property (Figure GS-16-1). These extensions are based on lithological criteria and are necessarily provisional until they can be confirmed by geochemical data.

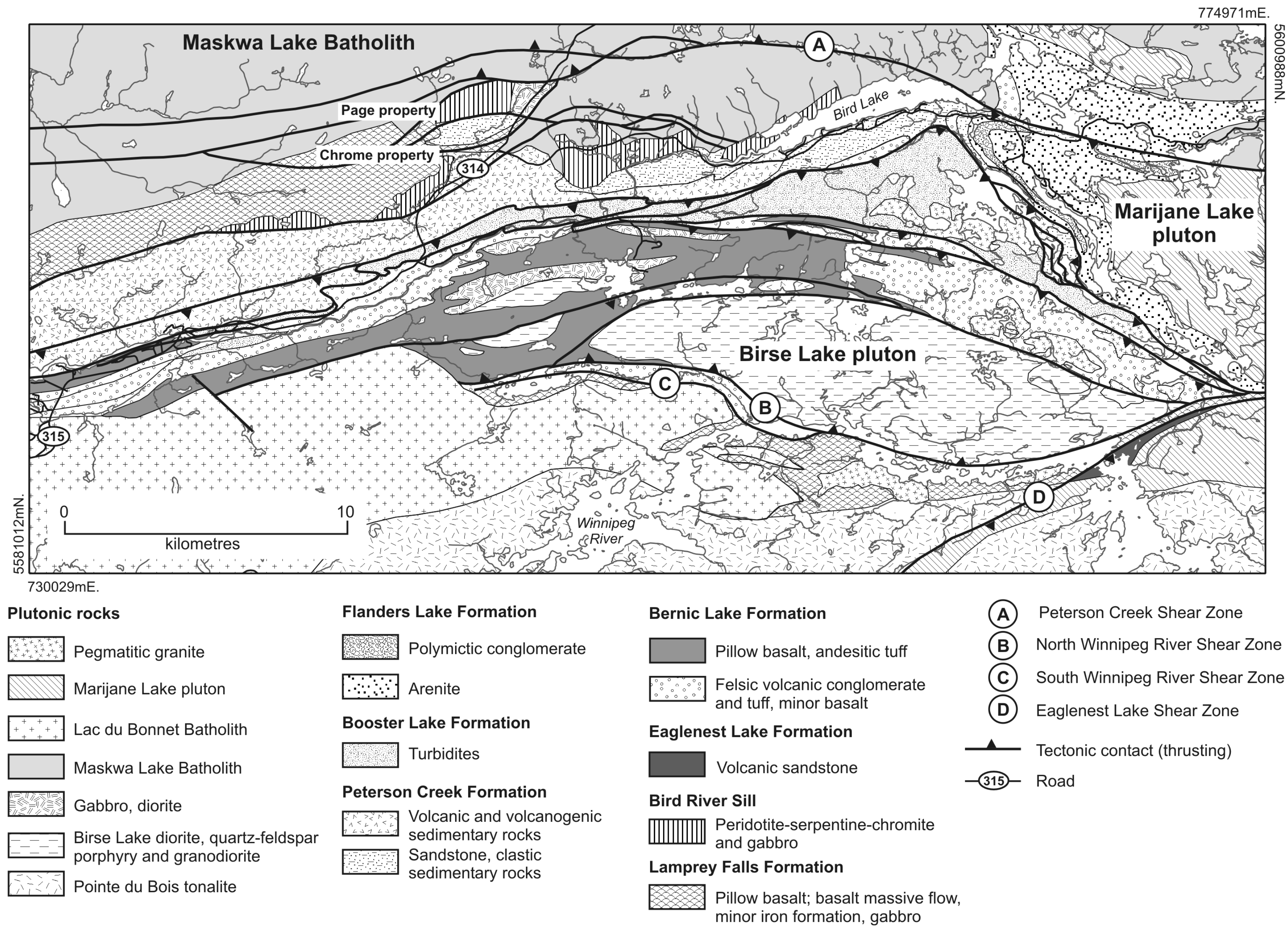

Figure GS-16-1: *Simplified geological and structural map of the BRB.*

Sedimentary subunit

The sedimentary subunit within the Lamprey Falls Formation, located in the area south of the Page property, is weakly deformed and folded by northeast- to east-trending upright folds. The folding is inferred from the reversal of stratigraphic-facing direction. No fold hinges were observed in the field. Due to poor exposure and inferred fold structures within the subunit, the following stratigraphic description is only provisional. The base of the sedimentary subunit consists of a heterolithic conglomerate that is discontinuous and appears to be closely associated with the Bird River Sill (*see* Mealin, GS-19, this volume; Gilbert, GS-17, this volume). The conglomerate is composed mainly of well-rounded clasts that constitute up to 90% of the rock (Figure GS-16-2). Clasts range from 0.1 to 1 m in size. The matrix is essentially mafic, composed chiefly of hornblende. Clast types include basalt and gabbro pebbles (predominantly derived from the Lamprey Falls Formation and the Bird River Sill), felsic volcanic rocks and quartz pebbles. The conglomerate appears to be locally interbedded with massive basalt. It is uncertain whether these rock units are conformable or structurally intercalated.

The basal conglomerate of the sedimentary subunit is overlain by a central siltstone-greywacke-conglomerate member. Graded bedding in the central member is abundant and locally indicates opposing top directions, which suggests the sequence is folded. The conglomerate contains well-rounded clasts that include centimetre-scale quartz, feldspar and possible rhyolite. Some parts of the central member consist of massive volcaniclastic sandstone with blue quartz grains. The sandstone could have been derived from resedimented felsic volcanic flows. In some respects, the central member of the sedimentary subunit is comparable to turbidites of the Booster Lake Formation.

The upper member of this sedimentary subunit consists of white laminated chert, approximately 20 to 30 m in width.

The sedimentary subunit is interpreted to be unconformable with the underlying Lamprey Falls basalt and the Bird River Sill. No contacts are exposed in the field and there is no angular unconformity evident between these map units. The basal contact of the conglomerate is interpreted as disconformable.

Lamprey Falls Formation at the south margin of the BRB (Winnipeg River area)

A thick sequence of basalt outcrops along the shores of the Winnipeg River in the area west of Eaglenest Lake. Pillows are widespread in the mafic flows and are reliable north-facing top indicators. Sporadic south-facing flows indicate that the mafic volcanic section is folded. Sulphide mineralization, locally associated with oxide-facies iron formation, occurs at two stratigraphic levels within the basaltic sequence (*see* Gilbert, GS-17, this volume). In contrast to the Lamprey Falls Formation at the north margin of the BRB, the basalt along the Winnipeg River is strongly deformed and metamorphosed at a relatively higher metamorphic grade, as indicated by garnet-bearing assemblages that are common within this basalt. The basalt is in fault contact with felsic volcanic rocks and the Birse Lake pluton to the north, as well as the sediments of the Eaglenest Lake Formation and Pointe du Bois tonalite pluton to the south. The basalt is intruded by the post-tectonic Lac du Bonnet Batholith that occurs immediately west of the Lamprey Falls Formation. The Lamprey Falls basalt is widely intruded by abundant gabbroic sills and quartz-feldspar porphyry intrusions associated with the Birse Lake pluton to the north. The gabbroic dikes are assumed to postdate the quartz-feldspar porphyry because the former are slightly boudinaged, whereas the latter is strongly mylonitized.

Figure GS-16-2: *Polymictic conglomerate composed of mafic and minor felsic cobbles (south of the Page property). The mafic pebbles are from the Lamprey Falls basalt and the Bird River Sill gabbro (hammer for scale).*

Peterson Creek Formation

Stratigraphy

The following stratigraphic description is based on the part of the Peterson Creek Formation north of the Booster Lake Formation, west of the former Maskwa-Dumbarton mines and east of Provincial Road 314. The bedrock exposure in this area is irregularly distributed and the rocks are commonly deformed. Thus, a detailed and comprehensive stratigraphic investigation has not been possible.

Within the mapped area, the Peterson Creek Formation consists of two members: lower and upper. The lower member is composed of basaltic to dacitic massive flows and their tuffaceous and pyroclastic equivalents. This member is well exposed in an anticlinal fold structure in the central part of the area. Massive flows in the southeastern part of the area are intercalated with tuffaceous equivalent units of similar composition and with minor rhyolitic layers. Crystal tuffs range from lapillistone tuff with decimetre-scale clasts to ash-flow tuff with millimetre-scale detritus. The matrix has dark grey to black weathering and contains abundant hornblende. A thick, 200 to 300 m layer of mafic lapillistone and flow breccia is intercalated with basalt in the central part of this member. The rocks have been metamorphosed at upper-greenschist- to lower-amphibolite-facies grade. The mineral assemblage in the andesite-dacite flows is garnet+hornblende+biotite+epidote+plagiclase ±carbonate and the assemblage in basaltic rock consists of hornblende+quartz+plagioclase±epidote. The metamorphic grade of these volcanic rocks is very similar to that of rocks in the Bernic Lake Formation south of the Booster Lake Formation (Figure GS-16-1).

The upper member of the Peterson Creek Formation in the area mapped consists of two subunits. The first subunit, interpreted as being older, consists of thinly bedded, aphyric to quartz-phyric rhyolite and tuff. A sericite-rich, white to grey weathering surface is characteristic of this subunit. The inferred younger subunit to the north consists of massive to weakly stratified, rhyolitic to dacitic lapilli tuff and rhyolite. The tuff contains plagioclase-phyric pumice clasts within a dark grey matrix. In the east part of the mapped area, well-rounded blue quartz is an additional component in the well-bedded, tuffaceous deposit, which also contains detrital plagioclase and is classified as volcaniclastic sandstone.

Geochemistry

Eight samples (six from the Peterson Creek Formation and two from the Bernic Lake Formation) were analysed for major, trace and rare earth elements. The samples range from andesitic basalt to rhyolite in composition.

Plots of felsic volcanic rocks (dacite to rhyolite) in the primitive-mantle–normalized incompatible elements diagram are characterized by strongly enriched light rare earth elements (LREE), strong negative Nb and moderate to strong negative Eu anomalies, as well as moderate to very prominent negative Ti anomalies. Heavy rare earth elements (HREE) are weakly fractionated and strongly enriched (sample 2321A; Figure GS-16-3).

Plots of mafic and intermediate volcanic rocks (47–65 wt. % SiO_2; 0.011–0.022 Zr/TiO_2) display profiles similar to those of felsic volcanic rocks in primitive-mantle–normalized extended diagrams. The mafic to intermediate rocks are characterized by enriched and fractionated LREE, moderate negative Nb anomalies and weakly fractionated and strongly enriched in HREE (Figure GS-16-3).

All eight samples plot in the arc or continental crust field in the Th/Yb vs. Ta/Yb diagram.

Structural geology and deformation history

Available data

Details of the structural geology in the north part of the BRB are described in Duguet et al. (2005). This section provides a brief update of the tectonic history and a reinterpretation of the kinematic and structural data.

The belt was affected at first by vertical movements with south-side-up shearing in the study area (Duguet et al., 2005). This D_1 event thrust the Bernic Lake Formation from the south onto Booster Lake Formation rocks to the north, which in turn was structurally superimposed on the Peterson Creek and Flanders Lake formations. An interesting feature of this tectonic event is the juxtaposition of units metamorphosed under amphibolite-facies conditions (i.e., the Bernic Lake Formation) upon units of a lower metamorphic grade (i.e., turbidites of the Booster Lake Formation). This characteristic strongly suggests an initial low-angle thrust-type event and the subsequent steepening of the units prior to strike-slip; moreover, this idea has been strengthened by some new geochronological data, which seem to show that the Booster Lake Formation is slightly older than the Flanders Lake Formation.

The D_1 tectonic event evolved from initial thrusting into a transpressive event with a significant strike-slip movement, although the principal component of the movement was vertical. This history is particularly well documented in the Booster Lake area, where dextral shearing is included in the same fabric in which the south-side-up movement is documented. The direction of strike-slip movement varies depending on the locality. Dextral shearing is clearly associated with a southeast- to east-trending fault in the Booster Lake area. On the other hand, sinistral strike-slip movements in the Booster Lake Formation west of the Tanco mine road, and also at the northeast edge of the Birse Lake pluton, are associated with northeast-trending faults. This strike-slip event is

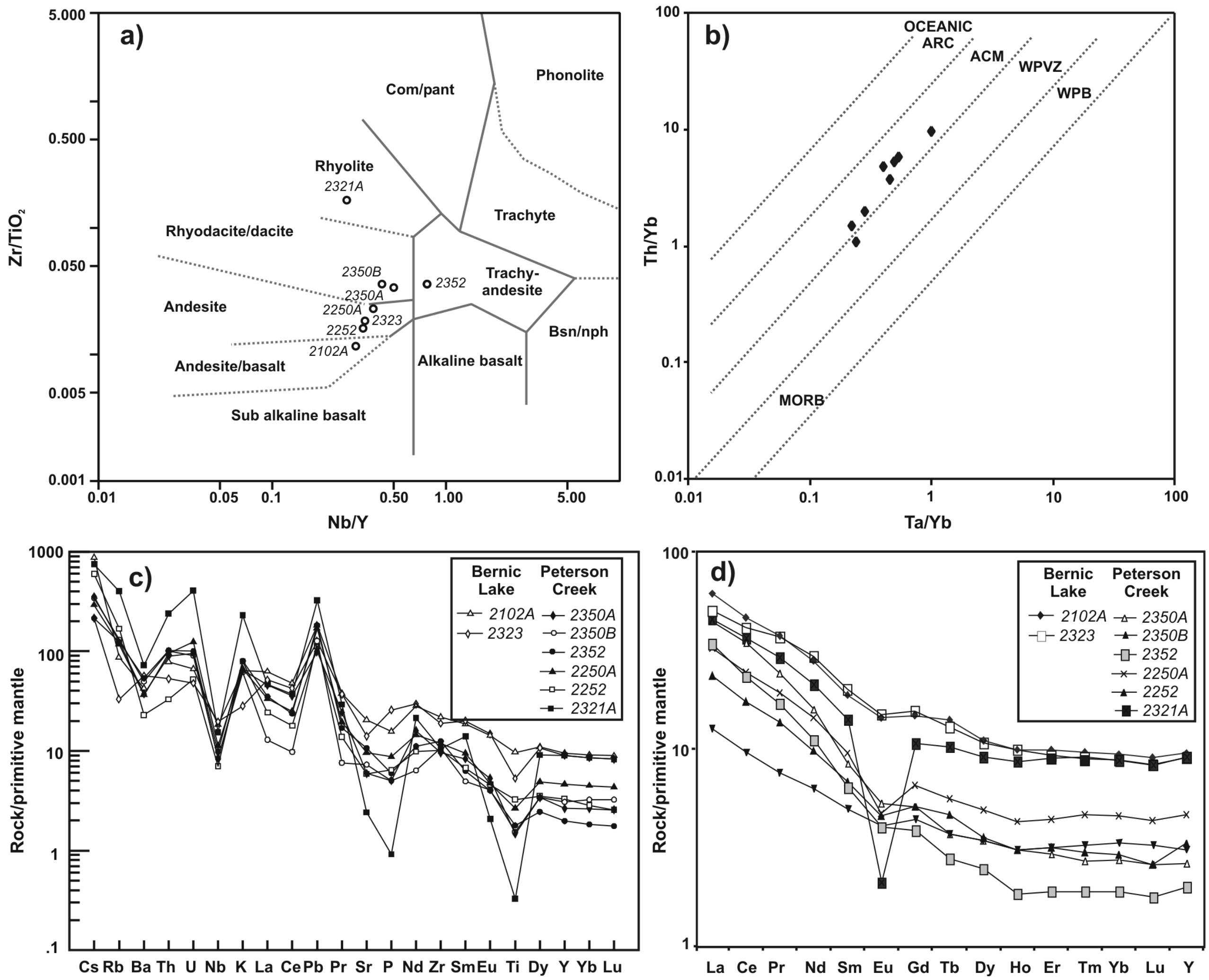

***Figure GS-16-3:** Geochemical discrimination diagrams for samples of felsic volcanic rock in the Peterson Creek and Bernic Lake formations: **a)** Nb/Y vs. Zr/TiO$_2$ (after Winchester and Floyd, 1977; abbreviations: Bsn, basanite; nph, nepheline); **b)** Ta/Yb vs. Th/Yb discriminant diagram (Gorton and Schandl, 2000; abbreviations: ACM, active continental margin; WPVZ, within plate volcanic zones; WPB, within plate basalts; MORB, mid-ocean ridge basalt); MORB, mid-ocean ridge basalt); **c)** primitive-mantle–normalized (Sun and McDonough, 1989) extended-element diagram for samples of mafic and felsic metavolcanic rocks in the Peterson Creek and Bernic Lake formations; **d)** primitive-mantle–normalized rare earth element diagram for samples of mafic and felsic metavolcanic rocks in the Peterson Creek and Bernic Lake formations.*

probably associated with the upright folding that affects all map units. The upright folds are well documented in the east part of the BRB in the Booster Lake and Flanders Lake formations (Gilbert, 2005; Duguet et al., 2005). The trend of major folds is variable from area to area (east in the central part, southeast in the eastern part and northeast in the western part) but these folds are invariably parallel to the tectonic contacts. During the D_1 event, the Marijane Lake pluton was emplaced in the Flanders Lake Formation. The synkinematic emplacement of this granite resulted in magmatic foliation folded by the southeast-trending upright folds in this area (Figure GS-16-1). Furthermore, some dikes associated with the granitoid pluton intrude the Peterson Creek Shear Zone in this area and display an asymmetric dextral boudinage with a vertical south-side-up component of movement. The Marijane Lake pluton has been dated at 2631 ±4 Ma by U-Pb on monazite (D. Davies, pers comm, 2006). The last tectonic movements resulted in upright folds and dragfolds that crosscut all rock types and reworked some tectonic contacts. These folds seem to be associated with the onset of some movements along major shear zones, which appear to postdate the folds. A good example is situated just west of the former Maskwa-Dumbarton mine, where a hectometre-scale northeast-trending fold deforms both the Peterson Creek and Booster Lake formations. West of Provincial Road 314, southeast-trending upright folds also deform the Peterson Creek and Booster Lake formations. These late structures are interpreted as en échelon folds during the last sinistral movement along the shear zone.

Peterson Creek Shear Zone (PCSZ)

The Peterson Creek Shear Zone (PCSZ) is a conspicuous structural feature that plays a major role in the tectonic history of the north part of the BRB. This shear zone crosscuts all the geological units of the area, namely the Lamprey Falls Formation, the Maskwa Lake Batholith, the Flanders Lake Formation and the Marijane Lake pluton. The greater part of the PCSZ trends east through the Maskwa Lake Batholith. Toward the east, the trend of the PCSZ changes to the southeast. Fieldwork this year focused on the west part of the shear zone where it intersects the Bird River Sill and the Lamprey Falls and Peterson Creek formations. The east-trending shear zone in this area is estimated to be 200 m wide. All the facies of Maskwa Lake Batholith are strongly deformed and locally altered to ultramylonite (Figure GS-16-4). This deformed facies has rarely been observed due to the relatively sparse outcrop. In contrast to the shearing in the east part of the PCSZ, kinematic criteria in the west part of the zone indicate a top-to-the-south shearing associated with a dextral component of movement.

Two sets of several other small ductile faults arise directly from the PCSZ. The first set is oriented southeast to east and is characterized by dextral displacement, whereas the second set, oriented northeast, is associated with sinistral shearing (Figures GS-16-5 and GS-16-6). Horizontal displacement along of these faults is invariably subordinate to the amount of vertical movement. Available shear criteria on the vertical X-Z planes indicate a north-side-up shearing. The principal characteristic of these shear zones is to present an important curvature (Figure GS-16-7). The same fault can have both previously described directions associated with their kinematics. Thus, these faults delineate kinematic domains or boudins almost free of internal deformation (Figures GS-16-4 and GS-16-7). Deformation takes place at the

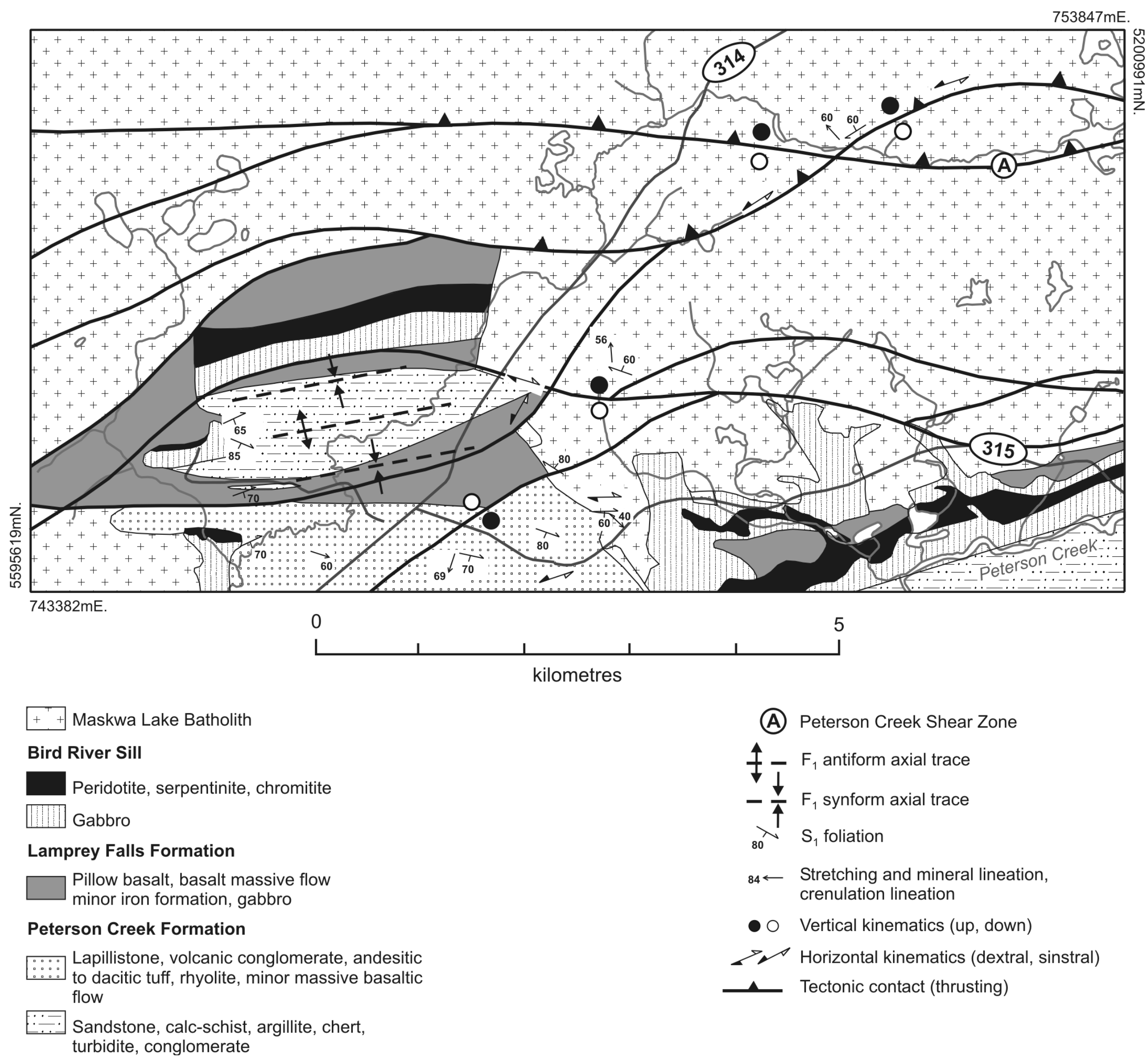

Figure GS-16-4: *Kinematic and structural map of the Maskwa-Page property area.*

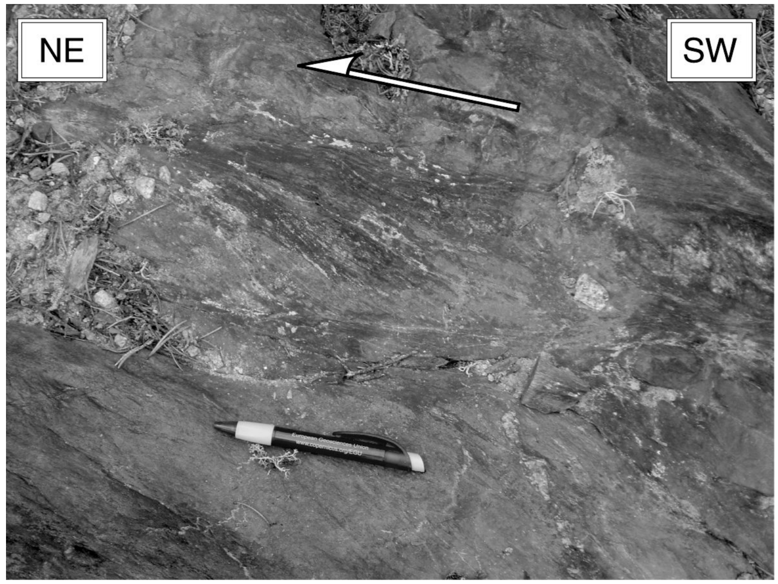

Figure GS-16-5: *Shear bands in tuff with a sinistral shear sense (Ore Fault deposit). The shear zone is oriented to the northeast (pencil for scale).*

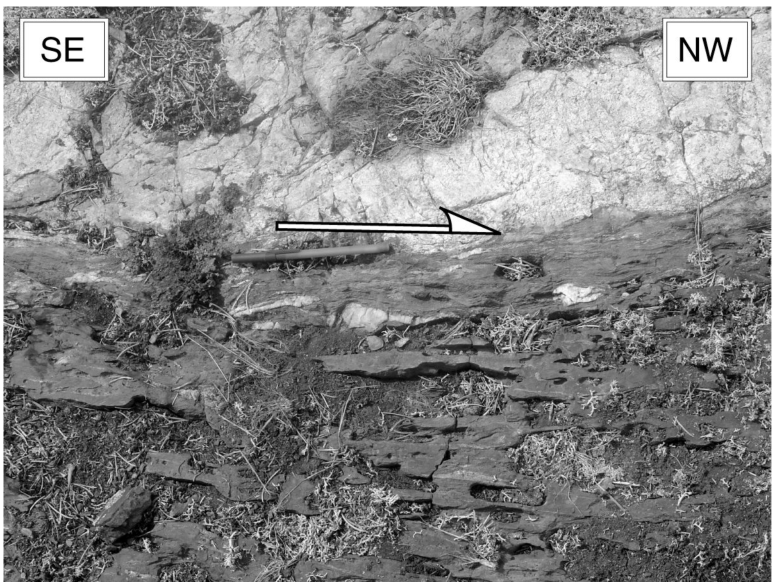

Figure GS-16-6: *Asymmetric boudin of quartz pod with a dextral shear sense (Ore Fault deposit). The shear zone is oriented southeast and affects only the mafic dike. The hostrock represented by the Maskwa Lake Batholith is free of deformation (pencil for scale).*

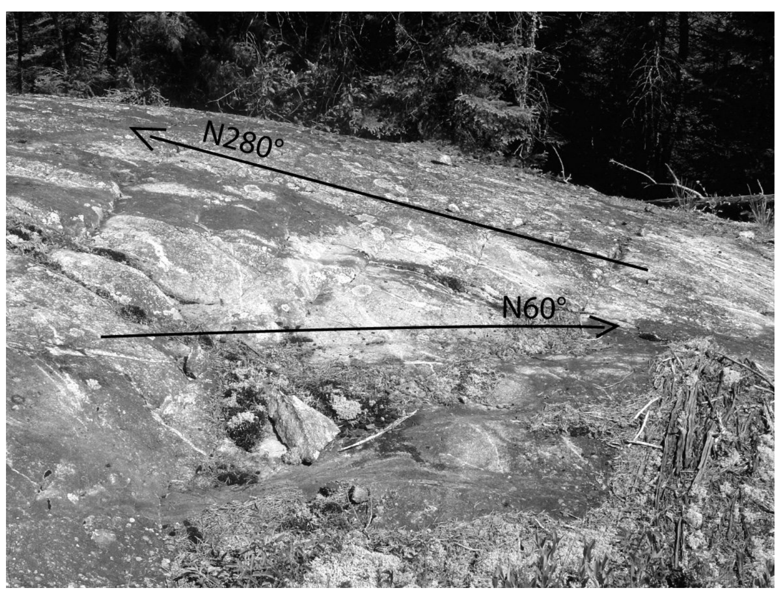

Figure GS-16-7: *Conjugate sets of ductile shear zones in the Maskwa Lake Batholith.*

boundary of the boudin and often at the contact between different rock types. For example, numerous mafic dikes within the Maskwa Lake Batholith are deformed, whereas the granite itself is almost free of deformation. This structural pattern is observed at both small (outcrop) and large (map) scales, and is particularly well defined in the Maskwa Lake Batholith; it is also applied to rocks of the Bird River Sill at the Page property and the Lamprey Falls Formation. Some of these faults apparently served as conduits for the distribution and dispersion of base-metal sulphide. Examples of such mineralization include the Ore Fault property (Murphy and Theyer, 2005) and a sulphide mineral occurrence located just south of the PCSZ and east of Provincial Road 314 (Bernatchez, 1994).

Winnipeg River area

In the Winnipeg River area, all geological units display a strong deformation fabric represented by a southeast- to east-trending foliation in the western and central parts and northeast-trending foliation in the eastern part (Figure GS-16-8). The subvertical- to vertical-dipping foliation is inclined alternatively north or south. This foliation commonly bears a prominent stretching and mineral lineation presenting a steep plunge. This foliation seems to be unique in the investigated area. The fabric is also parallel to the original stratigraphic bedding represented by pillowed mafic volcanic flows and sedimentary strata, and is locally folded by upright folds with axes plunging moderately westward.

The Winnipeg River area contains two major shear zones. Three geological units are delineated by faults in the north part of the Winnipeg River area: the Birse Lake pluton to the north, felsic volcanic rock (interpreted as a part of the Peterson Creek Formation) in the centre and basaltic flows assigned to the Lamprey Falls Formation to the south. The contact between the Birse Lake granite and the Lamprey Falls basalt is strongly deformed and shear criteria (such as sigma-type porphyroclasts and garnet porphyroblasts) as well as shear bands indicate

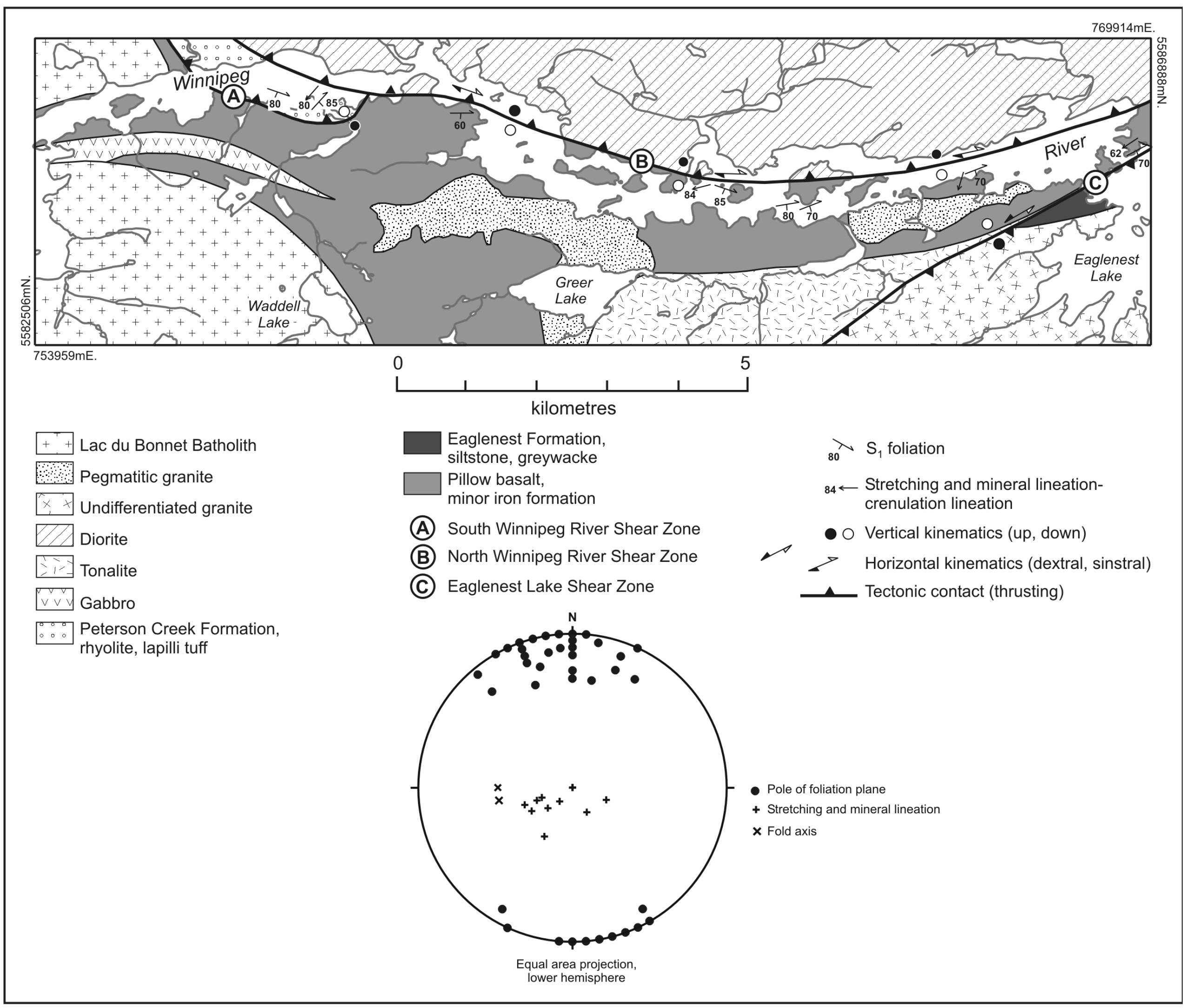

Figure GS-16-8: *Structural and kinematic map of the Winnipeg River area.*

a consistent north-side-up direction of shearing with a dextral component of movement along the contact (Figures GS-16-9 and -10). The contact between basalt and pegmatitic granite at the south shore of the Winnipeg River is also affected by this shearing event, which resulted in the formation of dextral shear bands. The fault zone at that locality is identified as the North Winnipeg River Shear Zone (NWRSH). Farther west, the contact between felsic and mafic volcanic rocks of the Peterson Creek and Lamprey Falls formations, respectively, is identified as the South Winnipeg River Shear Zone (SWRSH). This fault is strongly deflected at the junction with NWRSH and adopts a southeast to south trend. The deflection is probably due to folding at a relatively late stage in the deformation history. Shear criteria at one locality in this area indicate a south-side-up direction of shearing.

In the south part of the Winnipeg River area, a major northeast-trending shear zone occurs between the Lamprey Falls and Eaglenest Lake formations. This shear zone, identified as the Eaglenest Lake Shear Zone (ELSZ), is 300 to 400 m wide and associated with a conspicuous topographic lineament. The ELSZ is characterized by a sinistral horizontal offset associated with south-side-up shearing. Shear criteria within the zone consist of asymmetrically boudinaged granitic pods and dikes (Figures GS-16-11 and -12). The ELSZ is intruded to the south by pink-white granite that is petrographically similar to the Marijane Lake pluton. This granite displays a conspicuous magmatic foliation defined by the alignment of K-feldspar and by mafic enclaves, which are oriented parallel to the shear zone boundaries (Figure GS-16-13). These features suggest that the emplacement of the granite was coeval with the onset of shearing of the ELSZ.

Figure GS-16-9: *Asymmetric boudinage of basalt, giving a north-side-up shearing (hammer for scale).*

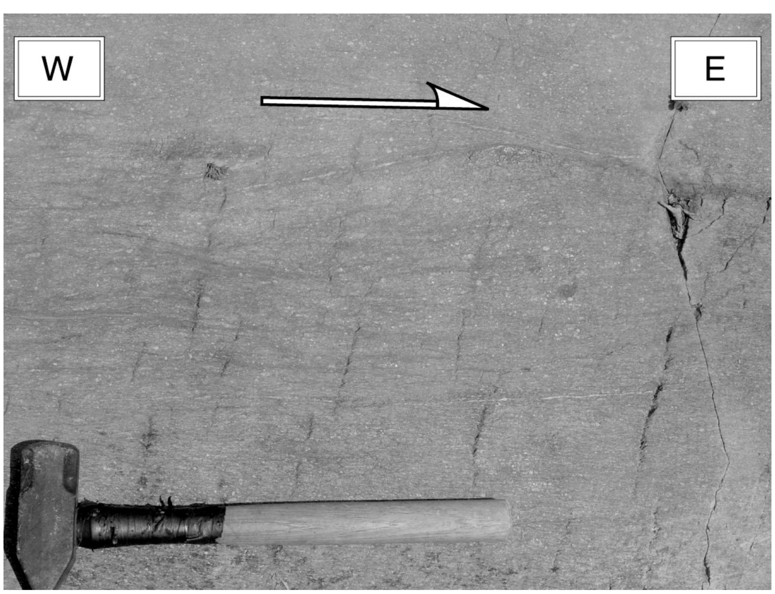

Figure GS-16-10: *Shear bands in the Birse Lake pluton showing dextral shearing (horizontal plane; hammer for scale).*

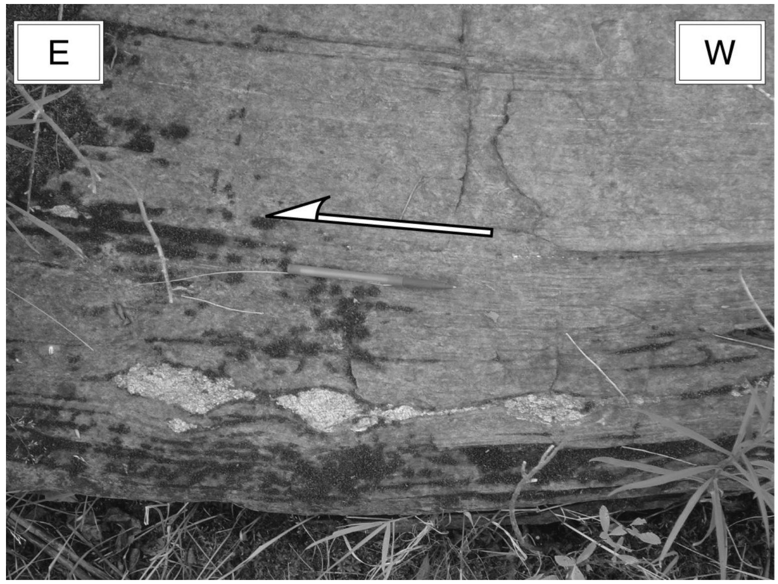

***Figure GS-16-11:** Asymmetric boudinage of granitic pods in Eaglenest Lake Formation, indicating sinistral shearing (horizontal plane; pencil for scale).*

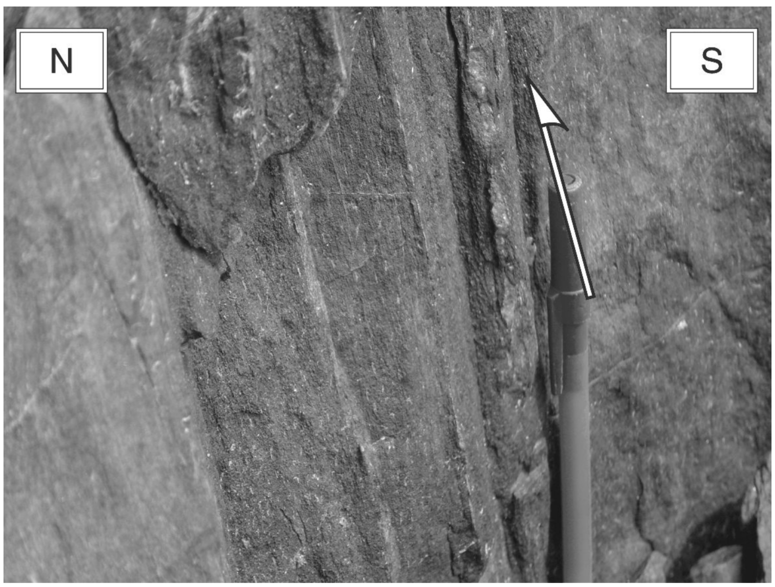

***Figure GS-16-12:** Asymmetric boudinage of granitic pods in Eaglenest Lake turbidite giving a south-side-up shearing (vertical plane, contact between the Lamprey Falls Formation and the Eaglenest Lake Formation; pencil for scale).*

***Figure GS-16-13:** Magmatic foliation in the granite intruding the Eaglenest Lake Shear Zone. Note the strong orientation of mafic enclaves.*

Discussion

Field investigations in 2005, complemented by data collected in 2006, have provided a basis for the following observations regarding the tectonic history of the BRB:

- All shear criteria that were observed have indicated that the central part of the BRB is tectonically uplifted relative to the margins. All documented faults are interpreted as high-angle reverse faults with only a horizontal offset.
- The BRB is sigmoidal in shape.
- Many of the shear zones that were mapped are part of a regional anastomosing network. The faults have various orientations in response to antithetic shearing in the horizontal plane.
- The same tectonic contact can change the orientation of its principal stress ellipsoid along strike.
- Two parallel faults can be characterized by opposite directions of offset. This feature is particularly well illustrated in the Winnipeg River area.
- These observations are consistent with the inferred model for the BRB as a pop-up structure assumed to have developed during a progressive single transpressive event. The last movements in the north part of the BRB are coeval with the emplacement of the 2631 Ma Marijane Lake pluton.

Preliminary results on metamorphic history

Two rock samples from the Peterson Creek Formation in the area south of Bird Lake and one rock sample from the Bernic Lake Formation close to the contact with the Booster Lake Formation were used to investigate metamorphic mineral assemblages. Electron microprobe analyses were undertaken on selected metamorphic minerals and examined for petrographic textures. The mineral assemblage of the two samples from the Peterson Creek Formation (2350A and 352) is as follows: garnet+blue-green amphibole+biotite+plagioclase +quartz±epidote. A third sample from the Bernic Lake Formation (2102A) consists of garnet biotite+green hornblende+ilmenite+plagioclase+quartz. Thermobarometric data (performed by the THERMOCALC™ software) are summarized in Table GS-16-1. The pressure-temperature conditions for the Peterson Creek Formation are estimated to be 550°C and 5 kbar. Data from sample 2102A indicate that the pressure for the Bernic Lake Formation is lower (3–4 kbar), assuming temperatures similar to those of the Peterson Creek Formation. The pressure of 3 kbar was calculated from analyses of rim minerals and 4 kbar was indicated by core mineral analysis. The estimated pressure conditions, together with petrographic data, indicate that garnet breakdown had been initiated. These features and the estimated 3 to 4 kbar pressure conditions are consistent with retrogressive metamorphism during the D_1 top-to-the-north event in the Bernic Lake Formation.

Economic considerations

The BRB has been extensively explored for ore deposits since 1920, when (Ni-Cu) sulphide deposits were discovered in the Cat Creek–Maskwa River area (McCann, 1921). At present, economic interest is focused on mineralization allied to three known ore deposits: the Tanco rare-element pegmatite, the Maskwa Fe-Ni-Cu-platinum group element (PGE) deposit and the Dumbarton Ni-Cu-Zn-PGE deposit.

The Tanco mine at Bernic Lake has produced tantalum, cesium and lithium since 1969. The Maskwa and Dumbarton deposits were mined from 1974 to 1976 and from 1969 to 1973, respectively; renewed production at Maskwa is planned as a result of the recent discovery of additional ore reserves (Mustang Minerals Corp., 2005). In the area north of Bernic Lake, Ni-Cu-PGE mineralization is spatially associated with the mafic-ultramafic Bird River Sill.

At the present time, the BRB is being extensively explored by the Tantalum Mining Corporation of Canada Limited (for rare element-bearing pegmatite deposits), and by Gossan Resources Limited and Mustang Minerals Corp. (for Ni-Cu-Zn-PGE). The geological setting of the different ore deposit types remains poorly understood. Mapping, structural and kinematic analyses, and geochronological investigations are necessary in order to better understand both the evolution of the BRB and the setting of the various ore deposit types, and will aid in supporting exploration programs that currently are underway in the area.

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Table GS-16-1: Thermobarometric data for samples 2102A, 2350A and 2352A, Peterson Creek Formation (abbreviations: ab, albite; alm, almandine; an, anorthite; ann, annite; cor, correlation factor; cz, clinozoisite; east, eastonite; ep, epidote; fact, ferroactinolite; fep, ferroepidote; gl, glaucophane; gr, grossular; P, pressure; parg, paragonite; phl, phlogopite; py, pyrite; q, quartz; sd, standard deviation; sigfit, significant fit; T, temperature; tr, tremolite; ts, tschermakite).

Sample 2102A:	**Sample 2350A:**
T = 520°C, sd = 43,	*T = 557°C, sd = 55,*
P = 3.2 kbar, sd = 1.2, cor = 0.594, sigfit = 1.05	*P = 5.1 kbar, sd = 1.1, cor = 0.610, sigfit = 0.76*
Independent set of reactions	Independent set of reactions
1) 2py + 4gr + 3ts + 12q = 3tr + 12an	1) 2py + 4gr + 3ts + 12q = 3tr + 12an
2) 6tr + 21an = 10py + 11gr + 27q + $6H_2O$	2) 6tr + 21an = 10py + 11gr + 27q + $6H_2O$
3) 6fact + 21an = 11gr + 10alm + 27q + $6H_2O$	3) 6fact + 21an = 11gr + 10alm + 27q + $6H_2O$
4) 3tr + 6parg + 18an = 4py + 8gr + 6ts + 3gl	4) 3tr + 6parg + 18an = 4py + 8gr + 6ts + 3gl
5) py + ann = alm + phl	5) py + ann = alm + phl
6) 3tr + 3ts + 6parg + 18ab = 4py + 8gr + 12gl	6) 3tr + 3ts + 6parg + 18ab = 4py + 8gr + 12gl
7) 6parg + 12phl + 18an = 4py + 8gr + 3tr + 3gl + 12east	7) 6parg + 12phl + 18an = 4py + 8gr + 3tr + 3gl + 12east
Sample 2102A (core minerals):	**Sample 2352A:**
T = 555°C, sd = 44,	*T = 500°C, sd = 38,*
P = 4.3 kbar, sd = 1.3, cor = 0.613, sigfit = 0.89	*P = 5.2 kbar, sd = 1.0, cor = 0.920, sigfit = 0.96*
Independent set of reactions	Independent set of reactions
1) 2py + 4gr + 3ts + 12q = 3tr + 12an	1) 10py + 3tr + 24cz = 4gr + 15ts + 12an
2) 6tr + 21an = 10py + 11gr + 27q + $6H_2O$	2) 2py + 4gr + 3ts + 12q = 3tr + 12an
3) 6fact + 21an = 11gr + 10alm + 27q + $6H_2O$	3) 19ts = 14py + 3tr + 16cz + $8H_2O$
4) 3tr + 6parg + 18an = 4py + 8gr + 6ts + 3gl	4) 4gr + 5alm + 6cz + 15q = 3fact + 18an
5) py + ann = alm + phl	5) 4gr + 5alm + 12ep + 15q = 3fact + 18an + 6fep
6) 3tr + 3ts + 6parg + 18ab = 4py + 8gr + 12gl	6) py + ann = alm + phl
7) 6parg + 12phl + 18an = 4py + 8gr + 3tr + 3gl + 12east	7) 4py + 8gr + 9ts + 6ab = 3tr + 6parg + 24an
	8) 5py + 15phl + 12cz = 2gr + 6tr + 15east + 6an

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