# GS-13 Structural geology and kinematic evolution of the Bird River greenstone belt, English River Subprovince, Manitoba (NTS 52L5, 6)

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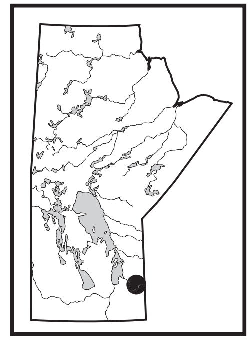
Duguet, M., Lin, S., Gilbert, H.P. and Corkery, M.T. 2007: Structural geology and kinematic evolution of the Bird River greenstone belt, English River Subprovince, Manitoba (NTS 52L5, 6); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p.144–154.



## Summary

This report synthesizes structural and kinematic data that relate to the tectonic evolution of the Bird River greenstone belt (BRGB). The structures of the BRGB reflect a long-lived transpressive regime during which at least two kinematic events are distinguished. A $D_1$ event is characterized by north-side-up shearing coeval with some backthrusting. This event is coeval with an episode of metamorphism that produced amphibolite-facies mineral assemblages. A $D_2$ event corresponds to a reworking of the previous structures. It is characterized by south-side-up shearing with a dextral strike-slip component in the eastern part of the belt. The $D_2$ event occurred during the emplacement of pegmatitic granite bodies and the Marijane Lake granite, with the latter dated by U-Pb zircon geochronology at 2645.6 ±1.3 Ma (U-Pb on monazite; D. Davis, pers. comm., 2006).

Further investigations in the English River Subprovince in the summer of 2007 have highlighted the kinematic pattern of a major shear zone separating the English River Subprovince (ERSP) from the BRGB. This 3–4 km wide, northwest-trending shear zone on the northern edge of the Maskwa Batholith displays conspicuous dextral shear sense coeval with a magmatic event in the metasedimentary rocks of the ERSP. This dextral event is similar to the dextral shearing that took place east of the BRGB at ca. 2645 Ma (Duguet et al., 2006).

New geochronological data on the Maskwa Batholith give a U-Pb zircon crystallization age of 2830 ±1 Ma (U-Pb on zircon; D. Davis, pers. comm., 2007). This age brings into perspective the role played by the Maskwa granite during the collision between the North Caribou Terrane and the Winnipeg River Subprovince. It suggests that the Maskwa Batholith acted as a small rigid microcontinent during this collision event and, as such, must be considered a distinct subprovince between the ERSP and the BRGB.

## Introduction

The Bird River Greenstone Belt (BRGB) is located in southeastern Manitoba, about 150 km northeast of Winnipeg (Figure GS-13-1). It is situated between the English River Subprovince to the north and the Winnipeg River Subprovince to the south. The BRGB is a significant district for ore deposits (e.g. the Tanco rare element pegmatite and the Maskwa [Fe-Ni-Cu-PGE] and Dumbarton [Ni-Cu-Zn-PGE] deposits). The area has been explored for ore deposits since the 1920s. Despite its obvious economic importance, few regional geological maps that include the BRGB have been published (Davies, 1952; Trueman 1980; Cerny et al., 1981). Furthermore, the available maps display numerous inconsistencies and are in need of updating.

A collaborative geological mapping project was initiated in 2005 by the Manitoba Geological Survey and the University of Waterloo, with financial support from the Natural Sciences and Engineering Research Council of Canada (NSERC) and the following mining and exploration companies: Gossan Resources Limited, North American Palladium Ltd., Marathon PGM Corporation, Mustang Minerals Corp. and Tantalum Mining Corporation of Canada Ltd. The objectives of the project are to improve the understanding of the stratigraphic, structural and tectonic framework of the BRGB and to establish the setting of the various mineral deposits that occur within it. This three-year, multidisciplinary project involves targeted bedrock mapping, structural analysis, lithogeochemistry and U-Pb geochronology. The preliminary results of fieldwork undertaken in 2005 and 2006 were published in Duguet et al. (2005) and Duguet et al. (2006).

Field investigations in 2007 were focused on the north flank of the Maskwa Batholith and the adjacent English River Subprovince (ERSP), and in some key areas of the BRGB. The objectives of the 2007 work were to

1) investigate the boundary between the BRGB and the ERSP in order to place the structural pattern of the BRGB into a regional geodynamic setting;
2) complete the mapping of the BRGB; and
3) sample for geochronology and geochemistry, especially in the northern part of the BRGB and the ERSP.

In this report, new data relating to the geology, structure, geochemistry and metamorphism of the northern margin of the Maskwa Batholith and ERSP metasedimentary rocks, as well as geochronological data, are integrated to provide an updated geological and regional structural framework for the BRGB. The objectives are to help establish a revised tectonic history

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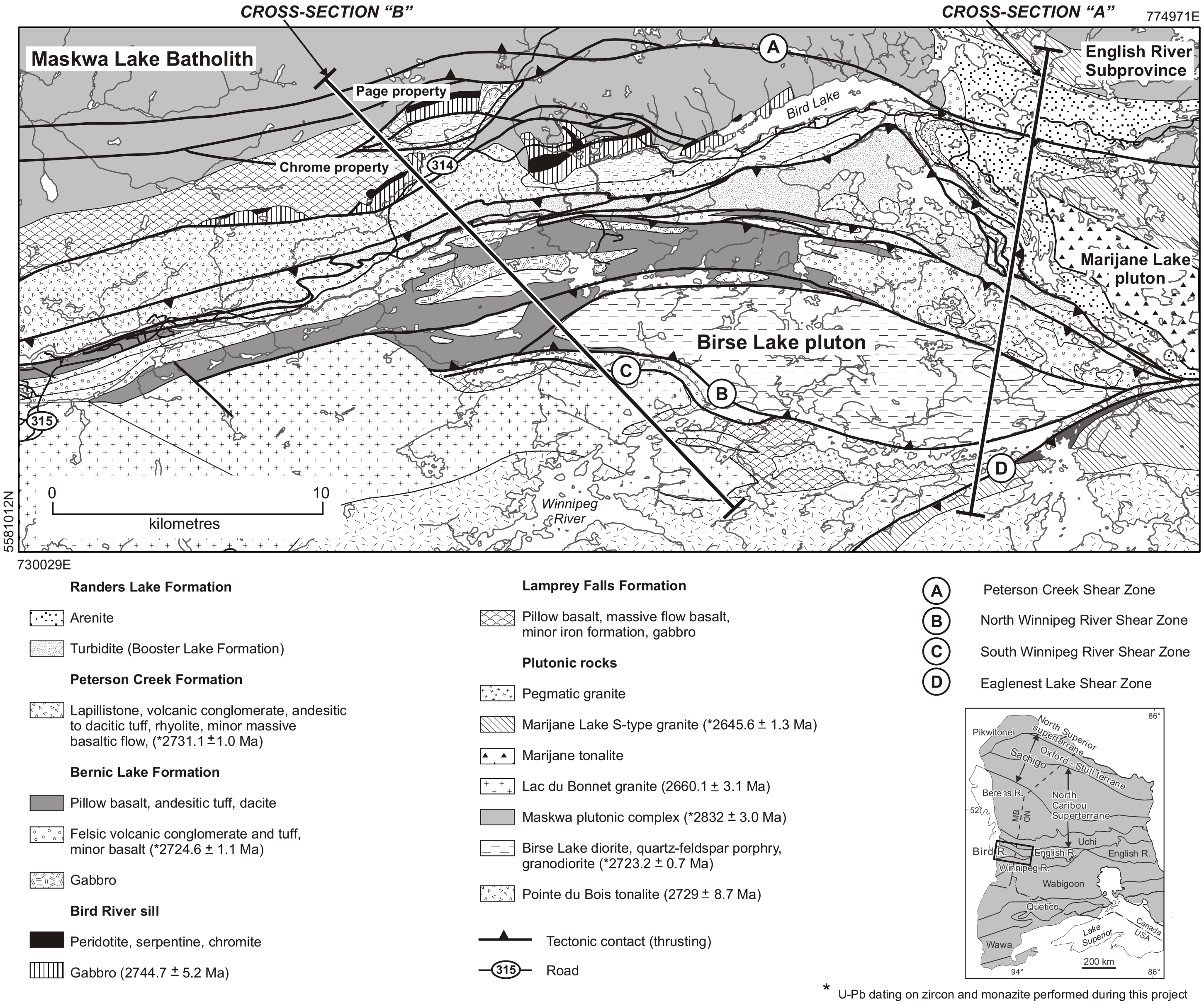


***Figure GS-13-1:*** *Simplified geological and structural map of the Bird River greenstone belt, southeastern Manitoba.*

and to provide geological context for mineral deposits in this economically important area.

## Stratigraphy

This report briefly describes the stratigraphy of the BRGB. Recent mapping by Gilbert has extensively revised the stratigraphy of the BRGB. Gilbert has defined six main units, which are briefly described below. The reader is referred to Gilbert (2006, GS-12, this volume) for further details.

- The Lamprey Falls Formation, which consists of pillowed basalt with intercalated tuff and iron formation, is in fault contact with the Eaglenest Lake Formation and the Peterson Creek Formation. It is considered to be the oldest unit of the BRGB (Trueman, 1980; Gilbert, 2006). This formation is present on both flanks of the BRGB and is chemically comparable to enriched mid-ocean-ridge basalt (E-MORB), which is typically emplaced in a back-arc setting (Gilbert, 2006, GS-12, this volume). On the south flank of the belt, the northern limit of this unit has been extended north of the Birse Lake Batholith on the basis of chemistry (Gilbert, GS-12, this volume) and is now interpreted to include basalt previously mapped as the Bernic Lake Formation. The two units are separated by an east-trending shear zone, exposed on the north shore of Bernic Lake (Kremer, 2005; Gilbert, GS-12, this volume). On the north flank of the belt, the Lamprey Falls Formation is intruded by an ultramafic–mafic intrusion known as the Bird River Sill. In reality, this sill corresponds to several discontinuous and separate small gabbroic and peridotitic intrusions hosting Cr–platinum group element (PGE) and minor base-metal sulphide mineralization (Mealin, 2006). The sill is dated at 2745 ±5 Ma (U-Pb on zircon, Timmins et al*.,* 1985) and provides a minimum age constraint on the Lamprey Falls Formation. The Birse Lake granodiorite, dated at 2723.2 ±0.7 Ma (U-Pb on zircon, D. Davis, pers. comm., 2007), also intrudes the Lamprey Fall Formation.
- The Eaglenest Lake Formation is composed of volcaniclastic sedimentary rocks and minor mafic lavas. This unit is located on the south flank of the BRGB along the Winnipeg River and crops out only in a limited area. The original stratigraphic position of the Eaglenest Lake Formation is uncertain as it is in fault contact with the Lamprey Falls Formation.
- The Peterson Creek Formation contains rhyolite, andesite and minor basaltic flows, pyroclastic breccia, lapillistone tuff and volcanic sandstone. A large percentage of this formation is composed of sedimentary rocks, including turbidite, calcschist, and chert interlayered with minor felsic volcanic rocks (Gilbert, GS-12, this volume). This subunit is well represented on the north side of the BRGB, where it is in fault contact with the Bird River Sill and the Lamprey Falls Formation. The Peterson Creek Formation falls within the north panel, in the terminology of Gilbert (2006). This formation was previously dated (U-Pb zircon analysis) at 2740 ±4 Ma (Wang, 1993). New dating (U-Pb on zircon) on a rhyolite has provided an age of 2731.1 ±1.0 Ma (D. Davis, pers. comm., 2007). The chemistry shows that the volcanic rocks of the Peterson Creek Formation were emplaced in an arc setting. Spider diagrams on rare earth elements (REE) display calcalkaline affinities (Gilbert, 2006; Duguet et al., 2006).
- The Bernic Lake Formation is composed predominantly of basalt with subordinate andesite, dacite, rhyolite, iron formation and minor volcanic sandstone. All of these rock types have been deformed and metamorphosed up to the middle-amphibolite facies. The 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. As mentioned above, the Bernic Lake Formation is now restricted to the area north of the fault along the north shore of Bernic Lake. The Bernic Lake Formation displays geochemistry akin to arc-tholeiite (Gilbert, 2006), indicating that it is distinct from the Peterson Creek Formation. In the terminology of Gilbert, the Bernic Lake Formation falls within the south panel. New dating on a dacite has given an age of 2724.6 ±1.1 Ma (U-Pb on zircon, D. Davis, pers. comm., 2007).
- 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 BRGB within this formation (Cerny et al., 1981). This sequence is strongly deformed and a synclinorial structure has been mapped at Booster Lake in the eastern part of the formation (Gilbert, 2005). This formation has undergone high temperature–low pressure metamorphism coeval with emplacement of the Marijane Lake pluton and the associated pegmatitic granite bodies. On the basis of dating of detrital zircons (U-Pb) by inductively coupled plasma–mass spectrometry (ICP-MS), the maximum age of deposition of this unit can be limited to 2712 ±17 Ma by the age of the youngest detrital zircon (Gilbert, 2006).
- The Flanders Lake Formation is composed of polymictic conglomerate, which includes tonalitic and mafic clasts 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. On the basis of the dating of detrital zircons (U-Pb) by ICP-MS, this unit is considered as

the youngest in the BRGB (<2697 ±18 Ma; Gilbert, 2006).

## Deformation structure and kinematics of the Bird River greenstone belt, regional framework

For detailed description of structure and shear zones, the reader is referred to Duguet et al. (2005) and Duguet et al. (2006). The following sections attempt to present a coherent tectonic model for the BRGB and the adjacent ERSP based on all data collected during the summers of 2005, 2006 and 2007.

### *Tectonic evolution of the Bird River greenstone belt*

The Bird River greenstone belt (BRGB) was first affected by apparent vertical movements with a minor strike-slip component. Along the north flank of the belt, the east-trending Peterson Creek Shear Zone (PCSZ) deforms the Maskwa granite with a north-side-up offset. The central part of the belt, consisting of supracrustal formations, was affected by a south-side-up shearing (Figure GS-13-2). This event led to tectonic thrusting of the Bernic Lake Formation from the south (present co-ordinates) over the Booster Lake and Peterson Creek formations to the north and the Flanders Lake Formation to the east. In the northern part of the belt, this event is coeval with an amphibolite facies metamorphism that reached peak conditions (550°C, 5kbar) after a pressure increase. This structural framework can be interpreted as an initial low-angle thrusting followed by steepening of all the formations. This interpretation is supported by new geochronological data, which indicate that the Booster Lake Formation is slightly older than the Flanders Lake Formation (Gilbert, 2006). The actual position of the Booster Lake Formation upon the Flanders Lake Formation can only be explained by overthrusting of the former upon the later.

The Birse Lake granite intrudes the Lamprey Falls Formation (Figure GS-13-1), with their contact modified to the south by the North Winnipeg River Shear Zone (NWRSZ). The North Winnipeg River Shear Zone, where it marks the contact between the two units, shows a dextral and north-side-up shear sense. Southward, the Lamprey Falls Formation is separated from the Winnipeg River Subprovince by a later northeast-trending shear zone with a sinistral and south-side-up shear sense. The sinistral south-side-up tectonic event in the northwestern part of the belt is characterized by northwest-trending upright folds in the east and a northeast-trending, south-side-up shear zone in the west. In the west, the deformation took place under metamorphic conditions that produced greenschist-facies mineral assemblages, retrogressing the previous amphibolite-facies assemblages. In the east, due to late magmatism, the formations experienced high temperature–low pressure metamorphism that produced amphibolite-facies mineral assemblages. The Marijane Lake granite, which has been dated at 2645.6 ±1.3 Ma (U-Pb on monazite; D. Davis, pers. comm., 2006), is coeval with this event.

### *Structural and kinematic relationships of the Bird River greenstone belt (BRGB) and the English River Subprovince (ERSP)*

During the summer of 2007, a survey was undertaken near the northern margin of the Maskwa Batholith in the ERSP. The objective was to characterize the kinematic evolution of the structural boundary between the ERSP and the BRGB.

#### Deformation and structures in the English River Subprovince

On aerial photographs of the ERSP, a strong, 3–4 km wide, northwest-trending lineament, which is present in the metasedimentary rocks, traces to the southeast where the Maskwa Batholith pinches out and the Flanders Formation of the BRGB and metasedimentary rocks of the ERSP are directly in contact (Figure GS-13-1). The metasedimentary rocks display a northwest-trending foliation that dips steeply to the south. This foliation locally exhibits a northwest-plunging stretching lineation (Figure GS-13-3). The metasedimentary rocks are extensively intruded by white, leucogranitic and pegmatitic dikes emplaced parallel to the regional foliation. The dikes are 2–50 cm wide and regularly spaced. In some zones, the sedimentary rocks are completely replaced by the granite. A marginally younger, pinkish pegmatitic phase of granite is also present and displays strong intermixing with the previous phase, such that it is sometimes difficult to distinguish between them. The pink phase is very similar to the S-type Marijane Lake granite, dated at 2645.6 ±1.3 Ma (U-Pb on monazite, D. Davis, pers. comm., 2006). These dikes display asymmetric boudinage coeval with a dextral shearing (Figure GS-13-4). The dextral shearing occurs during dike emplacement, as the magmatic texture is still preserved and the deformation takes place only on the margins of the dikes. Some dikes display clear plastic deformation at the solidus stage (Figure GS-13-5), which means that the dextral shearing continued after crystallization and cooling of this melt.

The age of the first generation of white granite is unknown. Even though, the pinkish granite seems a bit later, it displays the same structural relationships (especially during the dextral kinematic deformation) as the white granite. This suggests that the two granites may have been emplaced closely in time, ca. 2645 Ma.

#### Deformation and structures on the northern margin of the Maskwa Batholith

On its northern margin, the Maskwa Batholith is a tonalite that is intruded by numerous mafic dikes. Most of the mafic dikes are northeast-trending, but some display a northwest trend. Both the mafic dikes and the tonalite

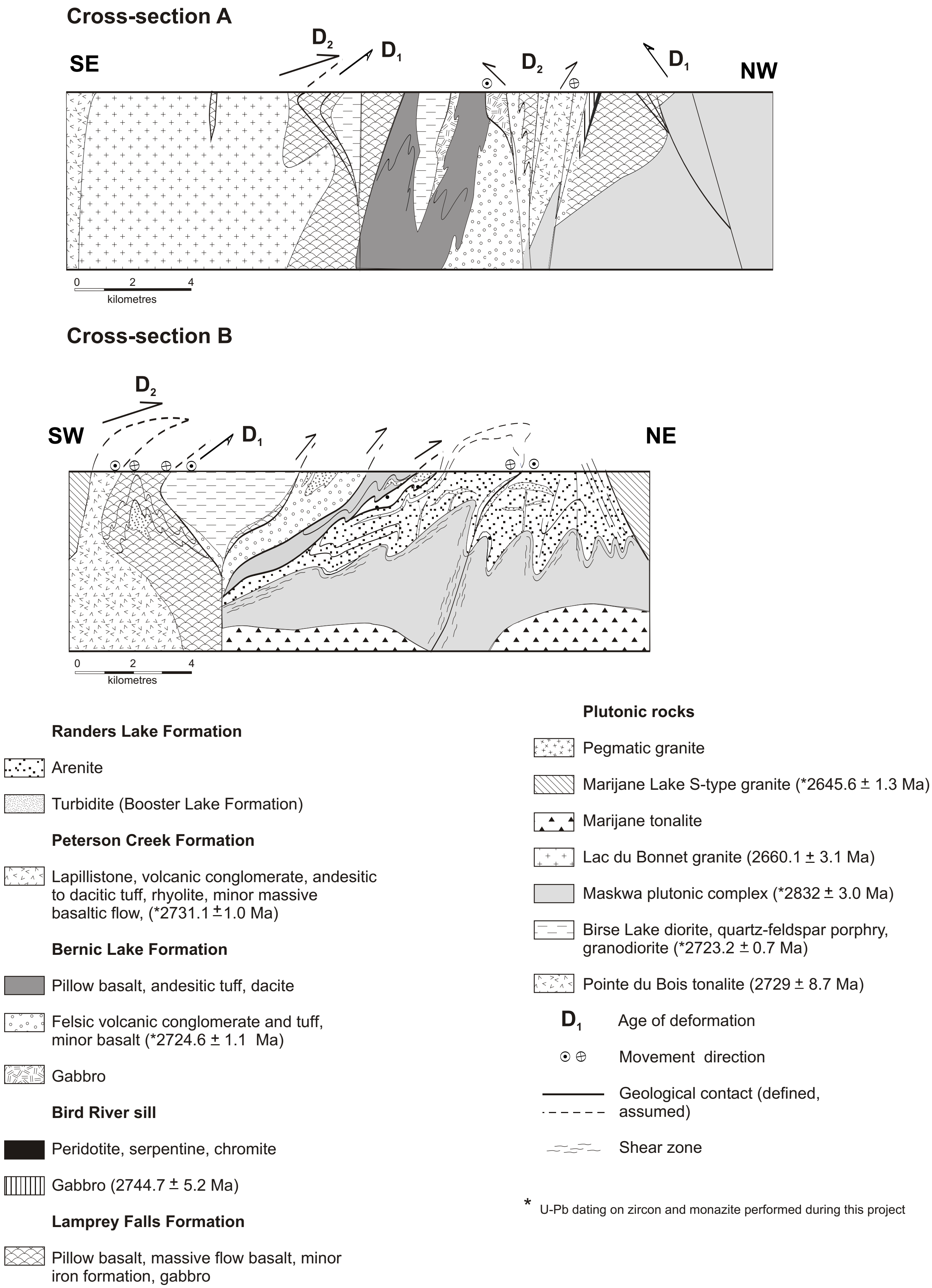


***Figure GS-13-2:*** *Cross-sections of the Bird River greenstone belt, southeastern Manitoba. See Figure GS-13-1) for locations of sections.*

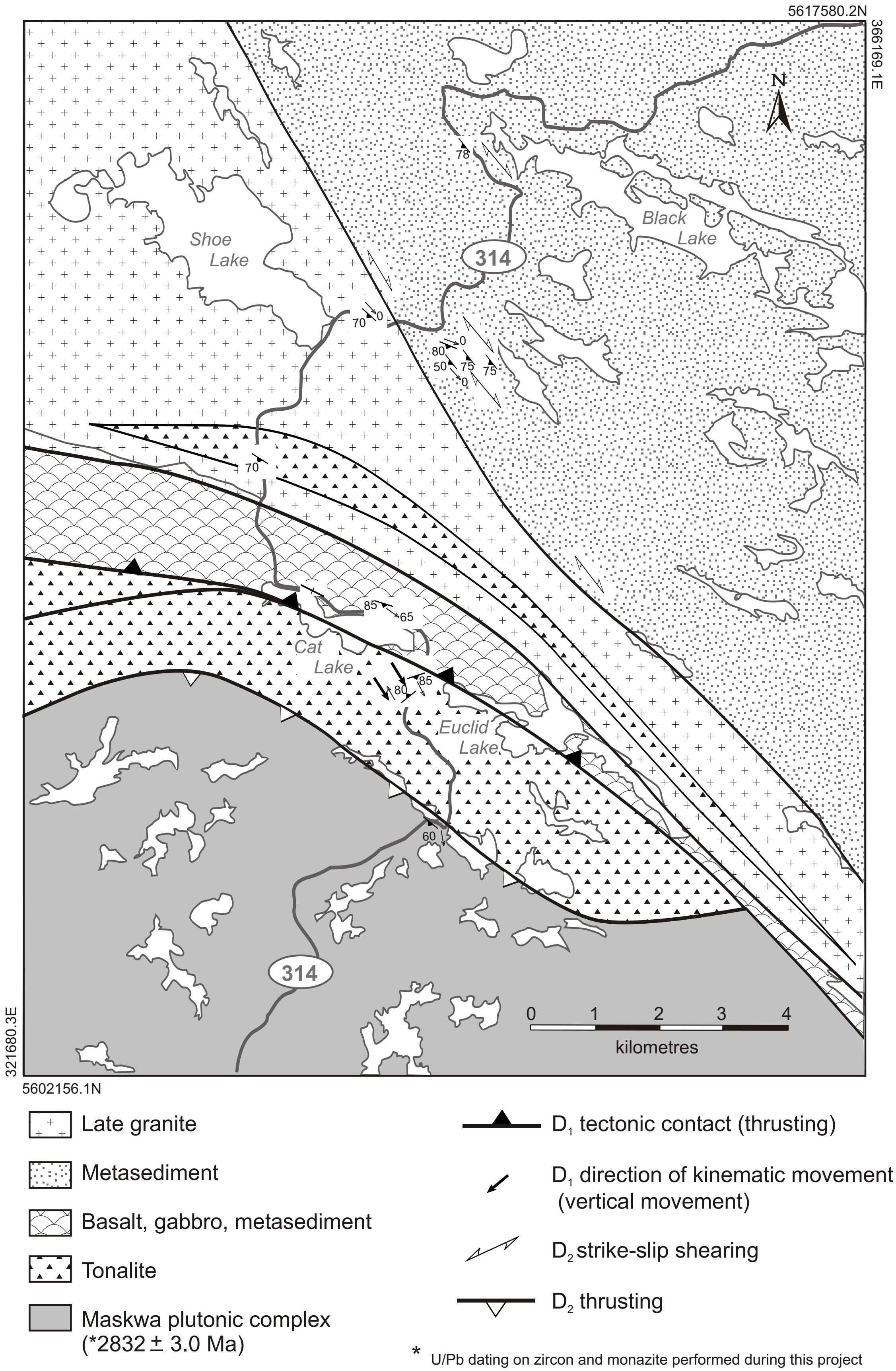


***Figure GS-13-3:*** *Simplified structural map of the Maskwa Batholith–English River Subprovince area.*

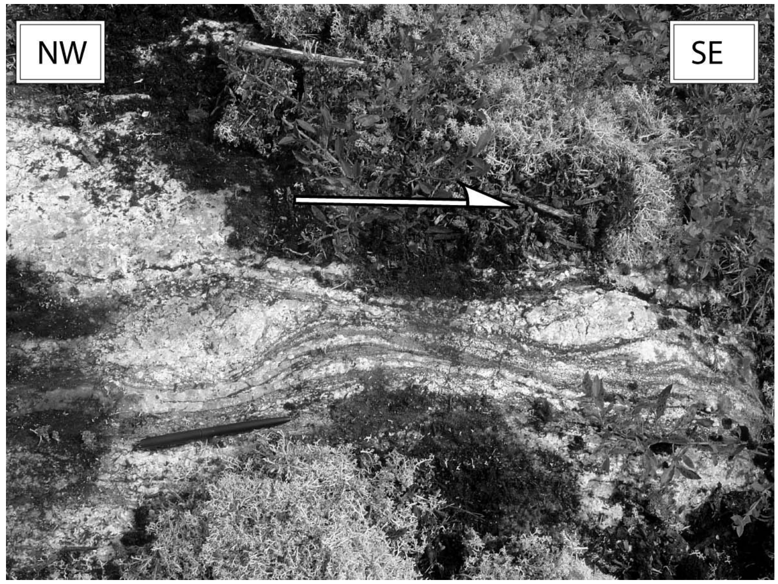


***Figure GS-13-4:*** *Asymmetric boudinage of granitic dikes, giving a dextral sense of shear in metasedimentary rocks of the English River Subprovince. Pen for scale.*


***Figure GS-13-5:*** *Late dextral shear bands affecting granitic dikes in metasedimentary rocks of the English River Subprovince. Pen for scale.*

are crosscut by late, pink pegmatitic dikes and late S-type granite.

Near the contact with metasedimentary rocks of the ERSP, both the tonalite and the mafic dikes display a strong non-coaxial deformation. The foliation has a northwest trend, dips steeply to the south and exhibits a steeply plunging stretching and mineral lineation. Fabric observed in hand-sample sections cut parallel to the lineation and perpendicular to the foliation display shear criteria (shear bands and asymmetric strain shadow around porphyroclasts), giving a north-side-up sense of shear (Figure GS-13-3). A similar shear sense was found to the southeast in a migmatite (Figure GS-13-4) that crops out inside the sedimentary unit of the ERSP northeast of Tulabi Lake and north of Davidson Lake. The relationships between the sedimentary rocks and migmatite are not clear, as the sedimentary rocks display a horizontal composite stretching and mineral lineation associated with dextral shear. It is difficult to determine if the migmatite corresponds to a tectonic slice or if it is derived by *in situ* melting of the metasedimentary rocks. Because the sedimentary rocks surrounding the migmatite don't display any partial melting, a tectonic emplacement of the migmatite seems more likely. Compared to the PCSZ, the authors interpret the north-side-up shearing in the migmatite to be earlier than the dextral shearing in the sedimentary rocks. The rarity of the north-side-up shearing could be interpreted to mean that this event is older. A lack of clear overprinting relationships, however, leaves the question unresolved.

To the south along Provincial Road 314, another shear zone affects the tonalite and a pink leucogranite that display a strong non-coaxial deformation. The foliation strikes northwest and dips moderately (50°) to the south (Figure GS-13-3). This foliation bears a steeply plunging stretching lineation. In hand-sample sections cut parallel to the lineation and perpendicular to the foliation, shear criteria (shear bands and asymmetric strain shadows around porphyroclasts) give a south-side-up sense of shear (Figures GS-13-6, -7). As this leucogranite seems to be petrographically similar to the Marijane Lake granite, the authors assume that this south-side-up event is a later deformation event coeval with the ca. 2645 Ma emplacement of the Marijane Lake granite.

### *Geodynamic significance of the Maskwa Batholith*

The Maskwa Batholith played a significant role in the tectonic history of both the BRGB and the ERSP because of its size and position between them. As described above, the northern margin of the Maskwa Batholith is occupied by a large-scale, dextral shear zone predominantly within the metasedimentary rocks of the ERSP. Only the northern margin of the Maskwa Batholith is affected by this deformation. The southern margin of the Maskwa Batholith is deformed as well. In contrast to the northern margin, defining a clear structural limit between the Maskwa Batholith and the supracrustal rocks of the BRGB is difficult. Indeed, the first order structures, such as the PCSZ, crosscut all the formations (Maskwa Batholith, Lamprey Falls Formation and Peterson Creek Formation). This feature is quite unusual in a greenstone belt. It is obvious that the Maskwa Batholith underwent a heterogeneous deformation, with shear zones delineating broad areas free of deformation in which the magmatic texture is still preserved. Three different ages have been reported for the Maskwa Batholith (2725.1 ±5.5 Ma, 2782 ±11 Ma, 2844 ±12 Ma from U-Pb on zircon; Wang, 1993). The first age is more or less coeval with those encountered in the BRGB supracrustal rocks, but the other two are significantly older. The Maskwa Batholith is clearly a polyphase pluton, composed of several generations of melt. The proportions of the different generations and their respective importance in the evolution of the BRGB

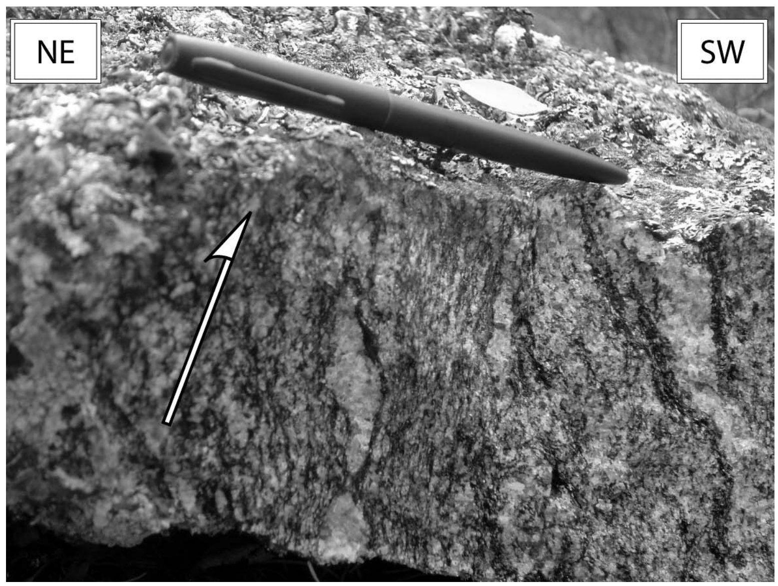


***Figure GS-13-6:*** *Asymmetric strain shadows around a K-feldspar porphyroclast, giving a north-side-up sense of shearing in migmatite of the English River Subprovince, northeast of Tulabi Lake.*

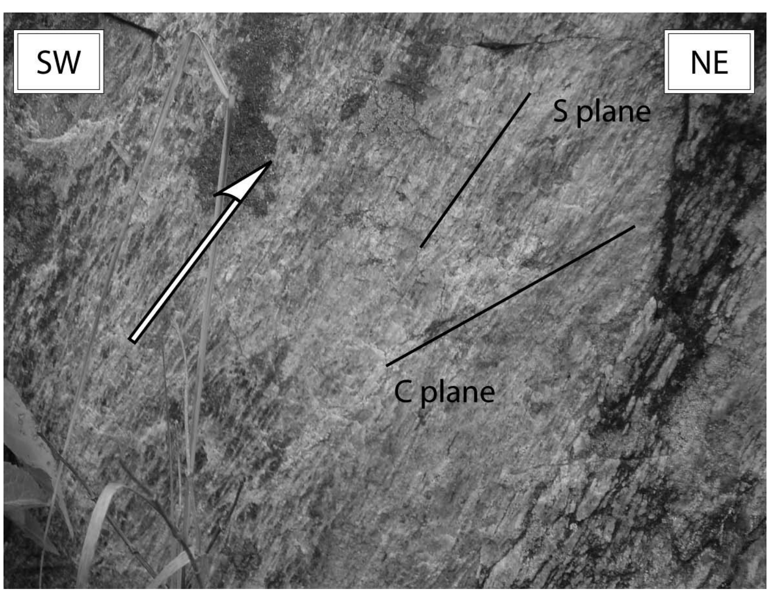


***Figure GS-13-7:*** *Shear bands, giving a south-side-up sense of shearing in the Maskwa Batholith and late pink granite. Arrow approximately 10 cm long.*

remain unknown. For example, is the Maskwa Batholith an older terrane or a younger granite with volumetrically minor older material?

In order to decide between the hypotheses of a young granite coeval with the supracrustal rocks or an older terrane that may form a basement to the adjacent rocks, new geochemical and geochronological data were needed. During the summer of 2006, a sample was collected from the dominant phase of the Maskwa Batholith. This sample was processed and gave an age of 2832 ±3 Ma (U-Pb on zircon; D. Davis, pers. comm., 2007), which is significantly older than any other ages in the BRGB and ERSP. In addition, geochemistry of a prominent set of dikes emplaced into southern margin of the Maskwa Batholith, has produced REE profiles identical to those for basalt of the Lamprey Falls Formation (Figure GS-13-8). One interpretation of these dikes is that they are synvolcanic feeders to the Lamprey Falls Formation (Peck et al., 1999). A corollary of this interpretation is that the volcanic rocks of the Lamprey Falls Formation were likely to have been deposited, at least in part, upon the Maskwa Batholith during back-arc spreading and creation of oceanic crust.

The new data provided by the geochemistry and the geochronology lead to the interpretation of the Maskwa Batholith as an older microcontinent split from a continental margin during back-arc spreading (Lamprey Falls Formation). After this first event, the Maskwa Batholith acted as a small rigid block during the collision between the BRGB and the ERSP. The Maskwa Batholith must therefore be considered a distinct subprovince between the ERSP and the BRGB.

## Economic considerations

The Bird River greenstone belt 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:

- Tanco rare-element pegmatite emplaced ca. 2640 Ma. Mapping has been interpreted to indicate that the Tanco pegmatite was emplaced in a still-active tectonic context (Kremer and Lin, 2006)

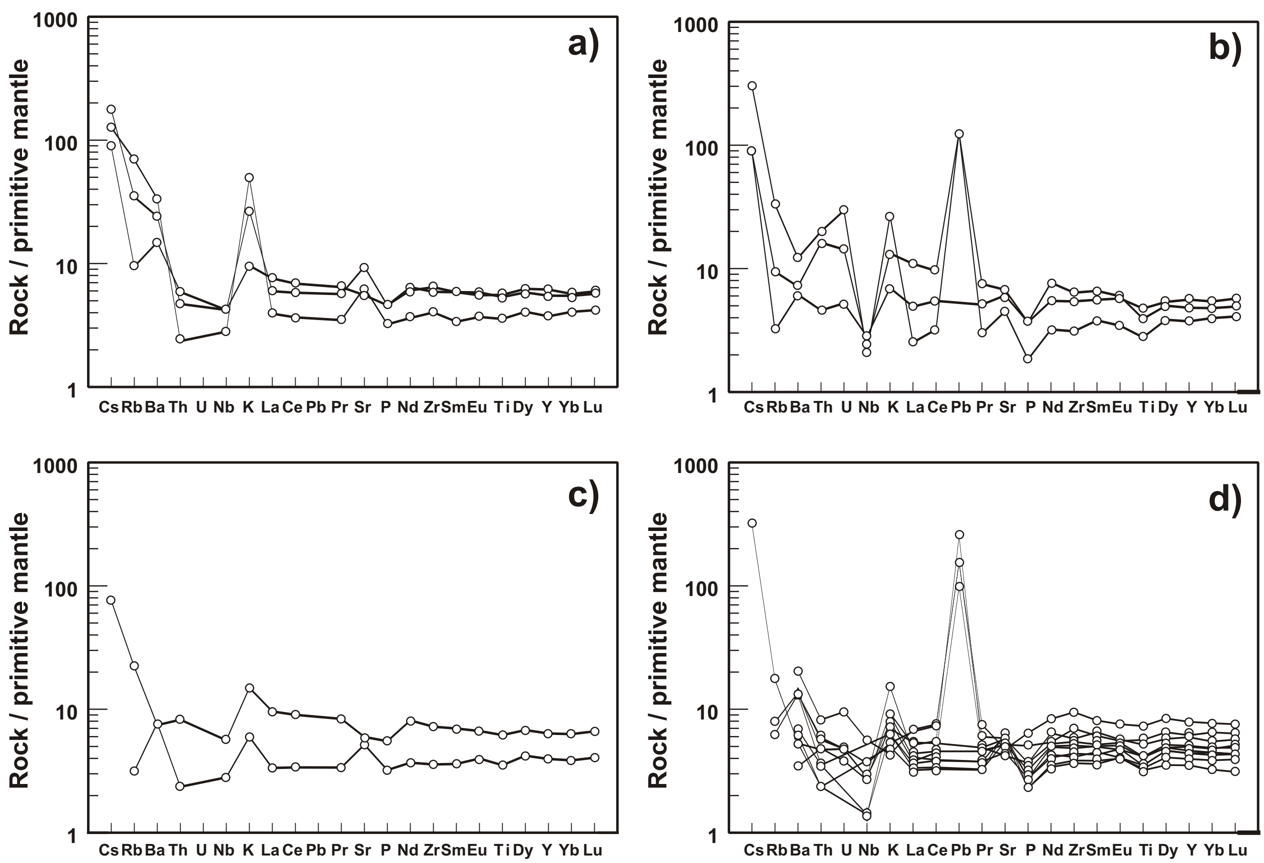


***Figure GS-13-8:*** *Geochemical discrimination diagrams for samples of mafic dikes intruded through the Maskwa Batholith:* ***a)*** *primitive mantle–normalized rare earth element diagram for samples of mafic dikes on the southern margin of the Maskwa Batholith;* ***b)*** *primitive mantle–normalized rare earth element diagram for samples of mafic dikes on the northern margin of the Maskwa Batholith;* ***c)*** *primitive mantle–normalized (Sun and McDonough, 1989) extended-element diagram for samples of basalt from the Lamprey Fall Formation for comparison;* ***d)*** *primitive mantle–normalized (Sun and McDonough, 1989) extended-element diagram for samples of basalt from the Mayville Formation for comparison.*

- Maskwa Fe-Ni-Cu-PGE deposit
- Dumbarton Ni-Cu-Zn-PGE deposit

The Tanco mine at Bernic Lake has produced Ta, Cs and Li 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 due to 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 Bird River greenstone belt is being extensively explored by Tanco for rare element-bearing pegmatite deposits, and by Gossan Resources Limited, Marathon PGM Corporation and Mustang Minerals Corp. for Ni-Cu-Zn-PGE mineralization.

The new geochronological data on the Maskwa Batholith support a new interpretation of its geodynamic significance. The age of 2830 Ma demonstrates that the Maskwa Batholith must now be considered an independent microcontinent that split off during a back-arc spreading event. It is worth noting that all Ni-Cu-Zn-PGE occurrences in mafic–ultramafic bodies are associated with this event and are found on the both sides of the Maskwa Batholith, in the Bird River Sill and Maskwa-Dumbarton mine to the south, and in the Mayville Formation to the north. One implication is that a rigid microcontinent, such as the Maskwa Batholith, may have played a significant role in the preservation of these deposits. In comparison, mafic and ultramafic rocks formed as remnants of oceanic crust, are more sensitive to destruction in subduction environments. The presence of low-density microcontinents intruded by mafic and ultramafic rocks can permit the preservation on their margins of some relics of oceanic crust. These microcratons, and especially their boundaries, should constitute new targets for future Ni-Cu-Zn-PGE exploration.

## Acknowledgments

The Manitoba Geological Survey, the University of Waterloo, Gossan Resources Limited, Marathon PGM Corporation and North American Palladium Ltd., Mustang Minerals Corp. and Tantalum Mining Corporation of Canada Ltd. have generously supplied funding for this project. P. Kremer and C. Mealin are gratefully acknowledged for sharing their ideas on the Bird River belt. Field assistant Ellen Reid provided voluntary assistance in the field throughout the summer. The manuscript was considerably improved by the thoughtful comments of A. Bailes. who also generously made available unpublished geochemical analyses of the Lamprey Falls and Mayville formations.

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