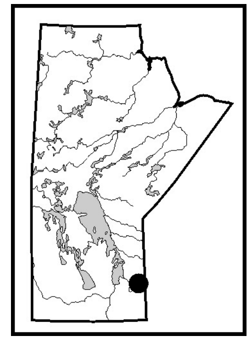
GS-19

Geological investigations in the Bird River Sill, southeastern Manitoba (part of NTS 52L5): geology and preliminary geochemical results

by C.A. Mealin[1]



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Summary

In 2005, this study was initiated to examine the Bird River Sill (BRS), a mafic-ultramafic layered intrusion located in the Bird River greenstone belt in southeastern Manitoba. The BRS is currently an exploration target for Ni-Cu–platinum group element (PGE) deposits and, in the past, hosted two Ni-Cu mines (Maskwa West and Dumbarton mines).

Nickel-copper mineralization on the western half of the BRS consists primarily of disseminated to blebby pyrrhotite+chalcopyrite and is present in the ultramafic series of the Chrome and Page properties and the mafic series of the Wards property. During this study, several new sulphide-bearing localities in both the ultramafic and mafic units of the sill have been identified. In addition, the geological contacts of the sill have been further constrained and the structural setting of the sill is being redefined (this study and Duguet et al., GS-16, this volume).

This report includes new geological data for the BRS and preliminary geochemical results.

Introduction

The Bird River sill (BRS) is a mafic-ultramafic intrusion located in the southern part of the Bird River Domain, approximately 120 km northeast of Winnipeg in southeastern Manitoba. Since the 1920s, the sill has been known to contain Ni, Cu and Cr mineralization, and has hosted two Ni-Cu mines, the Dumbarton mine (from 1969 to 1974) and the Maskwa West mine (from 1974 to 1976). The presence of platinum group elements (PGE) was discovered in the early 1980s by Theyer (1985).

Numerous studies have produced different theories over the years on the emplacement of the BRS and its inherent Ni-Cu-PGE and Cr mineralization. The sill was considered by Bateman (1943) to be the result of two different magma pulses: the first being of ultramafic composition and the second of mafic composition. Osborne (1949), the first to describe the magmatic lithology of the sill in detail, proposed a complex multi-injection theory. Juhas (1973), Trueman (1971) and Scoates (1983) all suggested a single magmatic injection where the layering was formed by subsequent crystal fractionation and gravitational differentiation. Theyer (1985) identified unusual cooling conditions requiring several magma pulses and cast doubt on a single magmatic intrusion theory.

In 2005, this study was initiated to examine the controls on Ni-Cu-PGE mineralization and test the single versus multiple injection hypothesis to establish the relationship between mineralization and the magmatic history. Specific objectives include

- detailed mapping of the Chrome, Page, Peterson Block and National-Ledin properties (Figure GS-19-1);
- determination of the sulphur source for the Ni-Cu-PGE mineralization;
- delineation of the sill's sulphur saturation history;
- examination of the sill's magmatic history; and
- examination of the influence of crustal contamination/assimilation on the sill.

This report presents the geology of the western half of the sill and preliminary geochemical results.

Previous work

Between 1982 and 1984, P. Theyer and assistants sawed three semicontinuous sampling sections (western, central and eastern cuts) across the Chrome property in the BRS. The western and eastern cuts crosscut the ultramafic portion and the central cut the gabbroic portion of the sill. These provide a nearly continuous channel sample and cross-section of the sill. Detailed geochemical analyses led to the identification of two PGE- and sulphide-enriched layers within the ultramafic unit (Theyer, 1985). Additional PGE-bearing layers were identified in the following years (Scoates et al., 1989).

Theyer (1985) defined several distinct igneous cycles based on remnant crystal morphology of olivine within the eastern and western cuts. The base of an idealized magmatic cycle is defined as a layer of fine-grained, tightly packed, lensoid-stage olivine that exhibits an abrupt lower contact with skeletal olivine. The remnant olivine textures exhibit a repeated progression from simple, ovoid crystal habits to increasingly complex dendritic crystals (Theyer, 1985).

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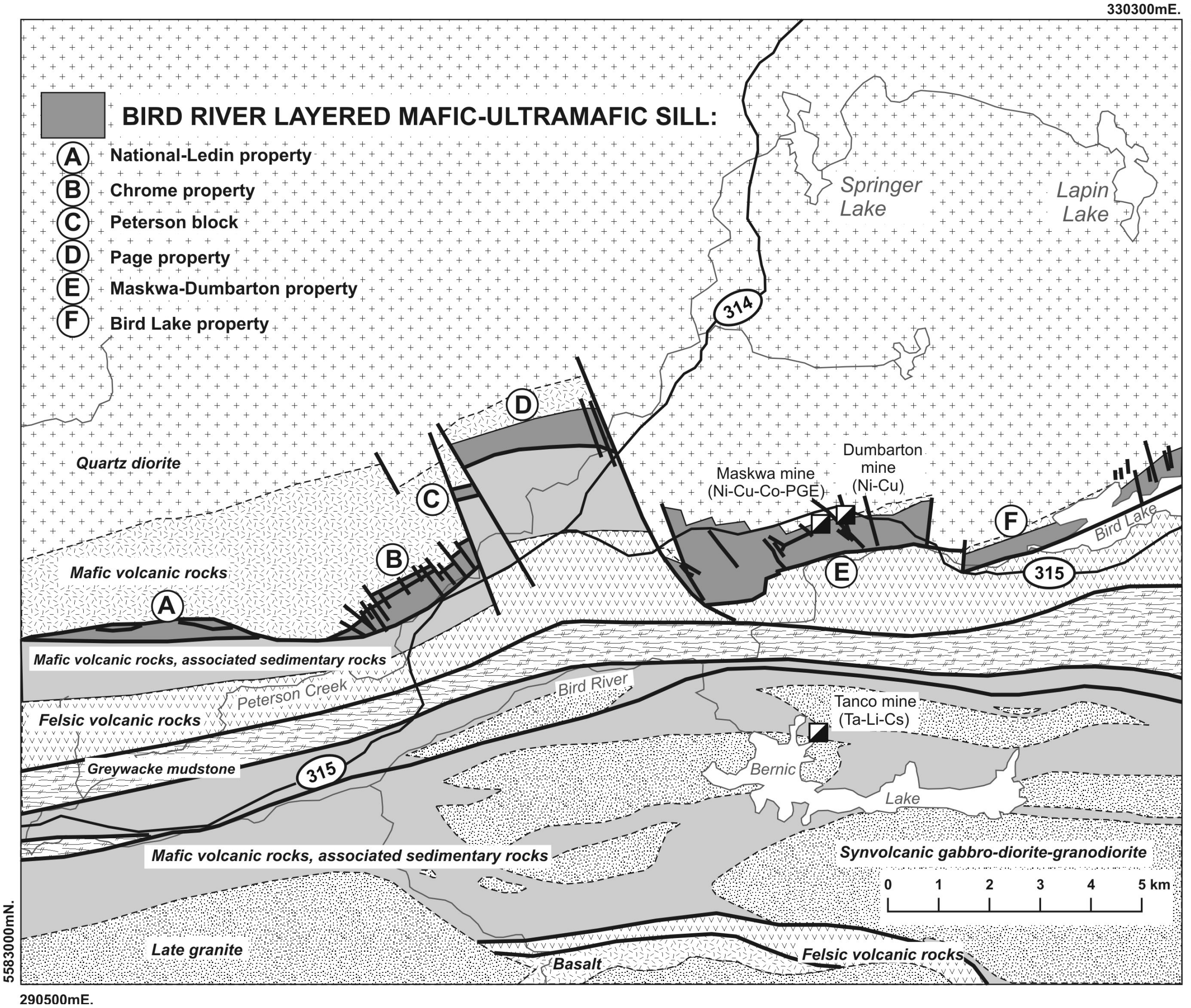

Figure GS-19-1: *Location of the Bird River Sill (*after *Theyer et al., 2001).*

Talkington et al. (1983) completed a study on platinum group mineral (PGM) inclusions in chromite from the Chrome property of the BRS. Platinum group mineral inclusions in chromite occur as discrete grains of laurite (Ru, Os, Ir)S_2, rutheniridosmine (Os, Ir, Ru alloy) and one PGE alloy containing 0.96 wt. % Rh (Talkington et al., 1983). Laurite grains contained up to 2.99 wt. % Pd, but no Pt was detected. All the chromite specimens collected contained inclusions of silicate minerals and hematite, but only samples from chromite seams contained PGM inclusions. Increasing oxygen fugacity by wallrock assimilation or new magma injection is thought to be the trigger for the chromite precipitation (Talkington et al., 1983).

Regional geology

The BRS intrudes the east-trending Bird River greenstone belt (BRGB), located in the southern portion of the Bird River Domain. The BRGB is in the Archean Superior Province of the Canadian Shield and is located in southeastern Manitoba. It is bounded to the north by the English River Domain and to the south by the Winnipeg River Domain.

The supracrustal rocks of the BRGB have been subdivided into six formations (Trueman, 1971; Cerny et al., 1981):

Eaglenest Lake Formation: volcaniclastic sedimentary rocks and mafic lavas

Lamprey Falls Formation: pillowed basalt with intercalated tuff and iron formation

Peterson Creek Formation: rhyolite flows, pyroclastic breccia, lapilli tuff, tuff and volcanic sandstone

Bernic Lake Formation: basalt, andesite, dacite, rhyolite, iron formation, conglomerate and sandstone

Flanders Lake Formation: polymictic conglomerate and metamorphosed lithic arenite

Booster Lake Formation: greywacke-mudstone turbidite, interbedded conglomerate and iron formation

Further descriptions can be found in Duguet et al. (GS-16, this volume).

Geology of the Bird River Sill

The BRS is a differentiated, layered, mafic-ultramafic sill that intrudes the Lamprey Falls Formation and is overlain by the Peterson Creek Formation. It trends easterly and is reported to be 2744.7 ±5.2 Ma (Wang, 1993). The sill has been metamorphosed to greenschist facies, and locally by contact metamorphism to lower amphibolite facies adjacent to granitic intrusions (Juhas, 1973). Primary textures are generally well preserved, although metamorphic minerals replace most of the original minerals (Theyer, 2002).

Mapping the western half of the BRS and immediate surrounding formations of the BRGB at a scale of 1:5000 was completed over the 2005 and 2006 summer field seasons. The final map (Mealin, 2006) is a compilation of this author's preliminary BRS map, Davies' (1952) BRGB map, Williamson's (1990) Chrome property maps, Duguet et al.'s (GS-16, this volume) BRGB map and interpretations from total field magnetic data (made available by Gossan Resources Ltd. and North American Palladium Ltd.).

Relationships between the Bird River Sill and country rock types

Lamprey Falls Formation

The BRS is hosted by the Lamprey Falls Formation. The intrusive contact is exposed in outcrops on the Chrome, Peterson Block and National-Ledin properties (Figure GS-19-2b). The formation comprises massive to pillowed basalt that ranges from aphyric to megacrystic. The pillowed basalt is generally moderately deformed and locally brecciated. Gilbert (2005) demonstrated that the basalt is geochemically akin to modern back-arc-basin basalt: the extended-element plot is almost flat, with rare earth element values similar to mid-ocean-ridge basalt (MORB; Gilbert, 2005).

Several gossanous shear zones are present north of the Chrome, Page and Peterson Block properties. The shear zones are mineralized with remobilized chalcopyrite, pyrite and pyrrhotite. Further petrographic study is ongoing and geochemical analyses are pending.

Davies (1952) mapped numerous east-trending gabbroic intrusions and one granitic intrusion in the Lamprey Falls Formation north of the BRS. The gabbro is massive and relatively undeformed. These intrusions were mapped by Juhas (1973) as being part of the BRS, but they have since been treated as separate from the sill and are completely omitted from later compilations (Cerny et al., 1981). The nature of the gabbroic intrusions, their age and their relation to the sill are currently unknown, but they have been sampled for further investigation.

Peterson Creek Formation

The BRS is overlain by the Peterson Creek Formation. The formation overlying the BRS has historically been interpreted to be part of the Bernic Lake Formation, but recent work by Duguet et al. (GS-16, this volume) has redefined the formations in this part of the belt.

The Peterson Creek Formation comprises metavolcanic and metasedimentary sequences. The volcanic rocks include rhyolite, lapilli tuff and tuff. The sedimentary rocks comprise greywacke turbidite, chert, mafic clast conglomerate and a polymictic conglomerate. The polymictic conglomerate was identified overlying the sill south of the Chrome, Peterson block and National-Ledin properties. This conglomerate contains gabbroic clasts that are believed to be from the mafic unit of the BRS. Therefore, the contact between the Peterson Creek Formation and the BRS likely represents an unconformity.

Maskwa Lake Batholith

The Maskwa Lake batholith is a large granitoid intrusion that intrudes the northern margin of the BRGB and is observed to intrude the BRS at the eastern edge of

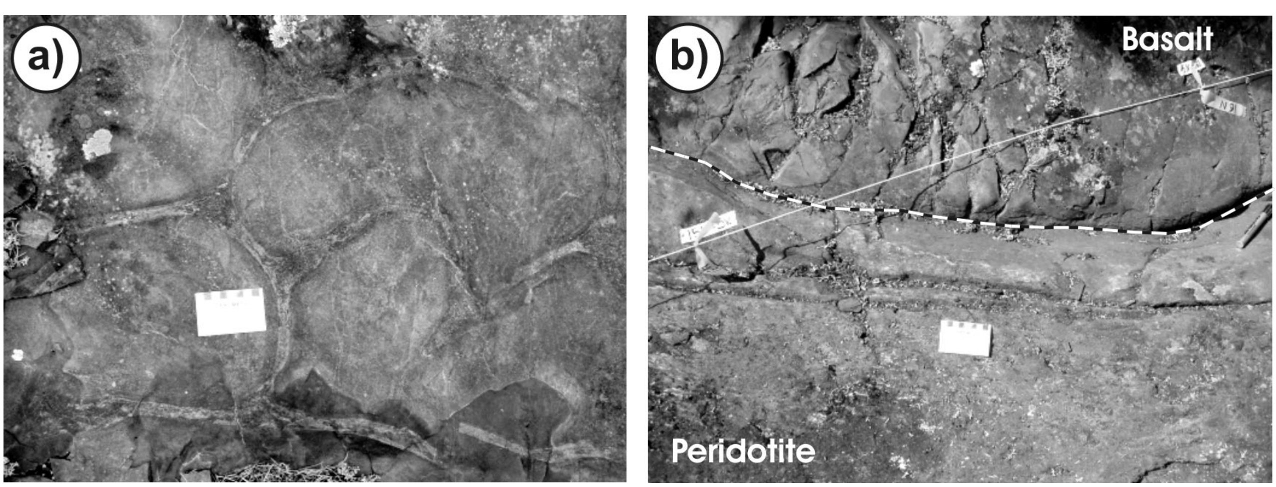

Figure GS-19-2: a) *Pillowed basalt, and* ***b)*** *intrusive contact of the Bird River Sill.*

the Page property. It comprises massive, coarse-grained granite, diorite and quartz diorite. The dominant rock type is quartz diorite. Contacts between the BRS and the Maskwa Batholith are not exposed. Further descriptions can be found in Cerny et al. (1981) and Duguet et al. (GS-16, this volume).

Bird River Sill

Stratigraphy

The BRS was originally subdivided into three magmatic series by Trueman (1971), based on the stratigraphy exposed at the Chrome property. The subdivisions, starting at the base, are the ultramafic series, the transition series, and the mafic series. The ultramafic series is absent on the Wards property but generally ranges from a few metres to 200 m thick on the Chrome, Page, Peterson Block and National-Ledin properties (Figure GS-19-3). The transition series was either absent or ranges from 1 to 5 m thick, and the mafic series ranges from 50 to 600 m thick.

Trueman's subdivision has since been expanded upon by Williamson (1990) and Scoates (1983), and is presented in column B of Figure GS-19-4 (Peck et al., 2002). The stratigraphy is based on extensive detailed mapping of the exposed central portion of the Chrome property. The current study observed and confirmed the previously defined stratigraphy and therefore focused on constraining the geological contacts of the BRS, the contact of the mafic and ultramafic units, and the location and full extent of chromite mineralization, as well as exploring for additional sulphide-bearing locations. The pegmatitic gabbro of the mafic series from the Chrome property was sampled this past summer for geochronological work.

The contact zone, reported by Trueman (1971) to contain plagioclase-bearing peridotite, also contains zones of pyroxenite that exhibit a rough, skeletal weathering. The chromitiferous zone on the Chrome property in general contains numerous straight, continuous, massive chromitite (>85% chromite) seams (Figure GS-19-5a), chromitiferous peridotite (<85% chromite) and 'disrupted' chromitite layers (Figure GS-19-5b). The chromite mineralization ranges from millimetres to metres in thickness.

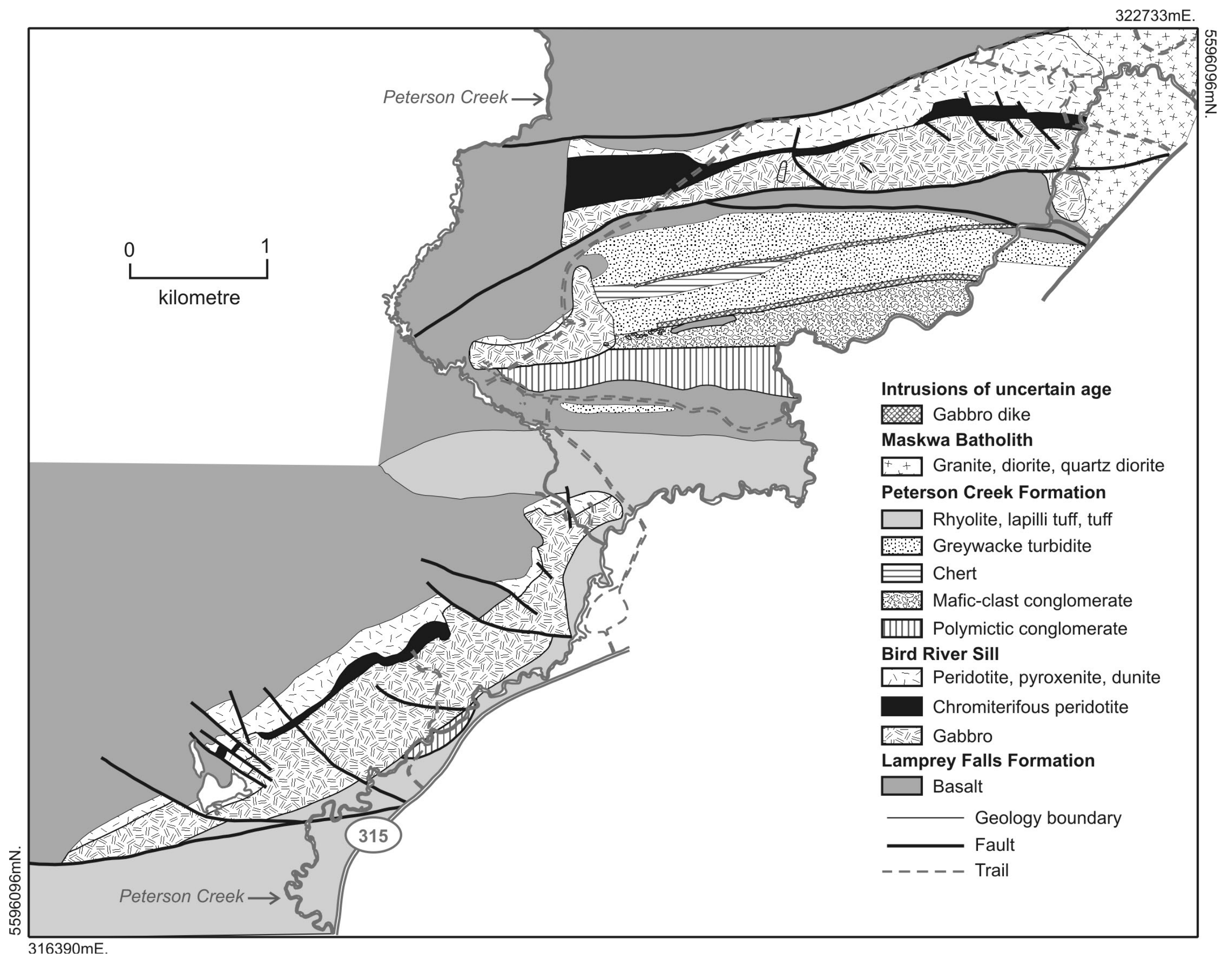

***Figure GS-19-3:** Geology of the Chrome, Page and Peterson Block properties, Bird River Sill.*

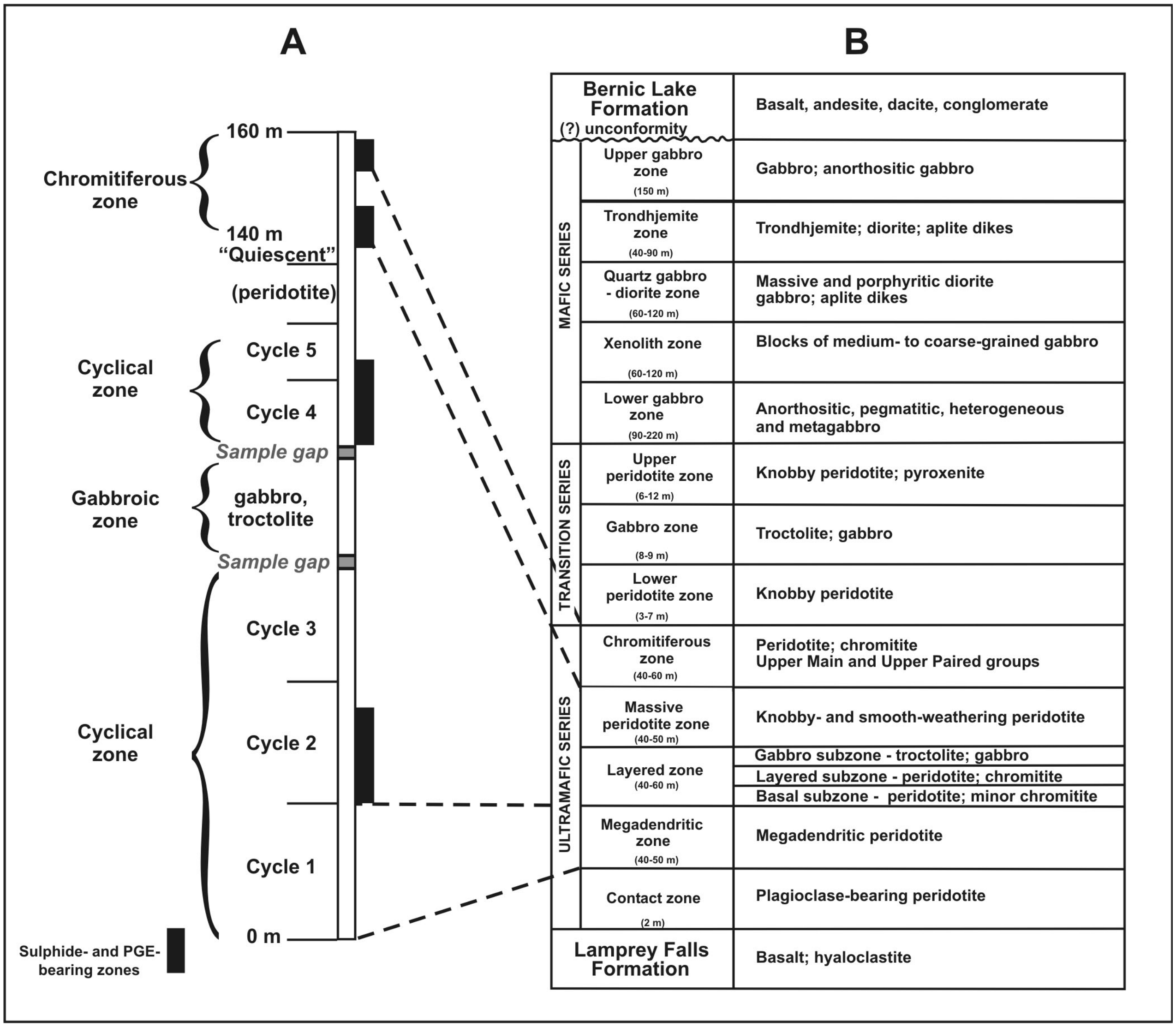

***Figure GS-19-4**: Stratigraphy of the Bird River Sill (Peck et al., 2002).*

Mineralization on the Page property is similar to that of the Chrome property but also contains chromitite and chromitiferous peridotite pebbles (Figure GS-19-5c). The pebbles increase in size (from a few millimetres to several centimetres), range from chromitite to chromitiferous peridotite and became increasing angular from the east end of the Page property towards the west. The pebbles and chromitite seams extend across the entire length of the Page property.

Massive chromite layers, up to 1 m wide, have also been identified at the Wards property (commonly referred to as the Coppermine Bay intrusion) by Theyer (1986) and, in contrast to other properties, are hosted in variably textured gabbro (Peck and Theyer, 1998). The BRS at the Wards property comprises a gabbroic intrusion with no ultramafic component.

A detailed 1:200 scale map of the chromite seams in the central portion of the Chrome property and a 1:100 scale sketch of the eastern exposure of the Page property chromitite, are presented by Williamson (1990) and Theyer et al. (2001), respectively.

Peck et al., (2002) proposed an alternative stratigraphy for the ultramafic series, incorporating five distinct igneous cycles and an upper quiescent zone (Figure GS-19-4, column A). The five cyclical layers coincide with the lower four subzones, and the quiescent zone corresponds to the chromitiferous zone.

It is important to note that the sill has been affected by greenschist-facies metamorphism and is intensely altered. In the ultramafic series, pyroxene is metamorphosed to amphibole (original amount is inferred to be proportional to the amphibole content; Theyer, 1990). Olivine is completely replaced, but original textures are preserved, as evidenced by pseudomorphs after olivine consisting of serpentine-tremolite-talc-carbonate±chlorite (Theyer, 1990). Accessory minerals include magnetite and ilmenite. The mafic series metamorphic assemblage consists of tremolite-clinoamphibole±clinozoisite±chlorite. Primary

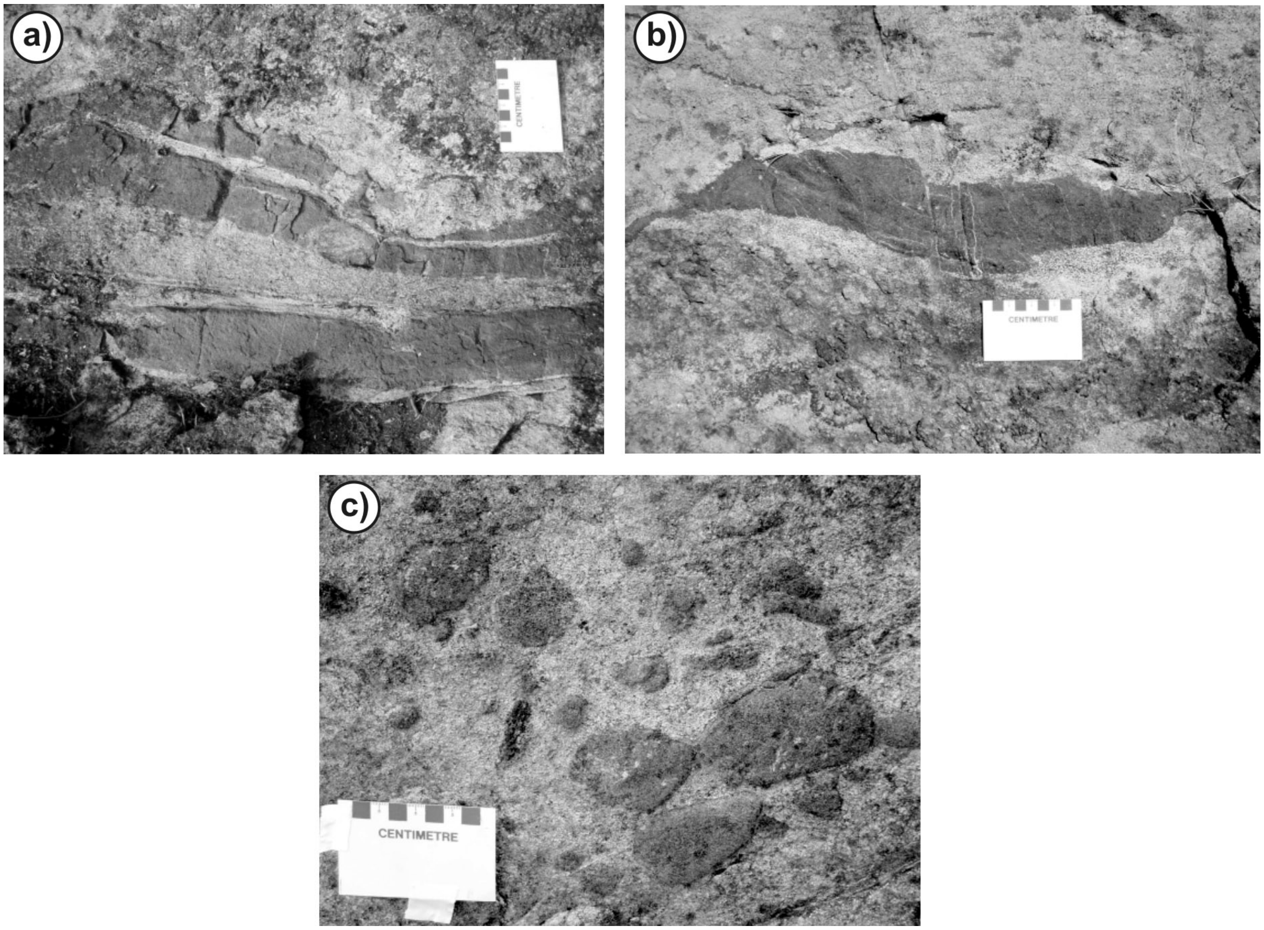

***Figure GS-19-5**: Three styles of chromite mineralization in the Bird River Sill: **a)** massive, continuous seams; **b)** disrupted seams, and **c)** chromitite pebbles.*

plagioclase has undergone varying degrees of sericite alteration throughout the Chrome property.

Mineralization

The BRS contains numerous sulphide-bearing zones enriched in Ni-Cu-PGE. The two most common sulphide minerals are pyrrhotite and chalcopyrite, which generally occur in the ultramafic unit of the BRS as fine disseminations. Sulphides are also present in the mafic unit of the BRS and underlying basalt of the Lamprey Falls Formation as remobilized material along shear zones.

As previously mentioned, four sulphide-bearing zones, enriched in Ni-Cu-PGE, were identified in the lower ultramafic series of the Chrome property (Figure GS-19-4) by Theyer (1985) and Scoates et al. (1989). The sulphides are associated with both the chromitiferous and massive peridotite zones and consist mainly of pyrrhotite-chalcopyrite ranging from fine disseminations to blebby disseminations to fracture coatings. In addition to the known four sulphide horizons, a possible fifth zone was identified this summer while channel sampling: millimetre-sized blebs of pyrrhotite and chalcopyrite were identified at the base of the Chrome property, approximately 1 m stratigraphically above the intrusive contact with the Lamprey Falls Formation. Assay results are pending.

Sulphide-bearing zones have also been identified on the Page property near the base of the chromitiferous zone by Theyer et al. (2001) and in drillholes penetrating the base of the sill. Styles of mineralization include massive pyrrhotite, semimassive net-textured pyrrhotite with minor chalcopyrite, millimetre- to centimetre-sized blebby disseminated pyrrhotite-chalcopyrite±millerite, disseminated pyrrhotite-chalcopyrite and pyrrhotite-chalcopyrite along fractures (Figure GS-19-6). The Page property mineralization is hosted in peridotite, pyroxenite and remobilized along fractures and quartz veins within the basalt of the Lamprey Falls Formation. Mineralization was also observed in quartz-feldspar porphyritic dykes; this occurrence is restricted to drillcore and was not observed on surface. Samples have been collected for further geochemical and petrographic study.

In contrast to the mineralized ultramafic series of the Chrome and Page properties, Peck and Theyer (1998) identified disseminated pyrrhotite and chalcopyrite sulphide mineralization in gabbro on the Wards property.

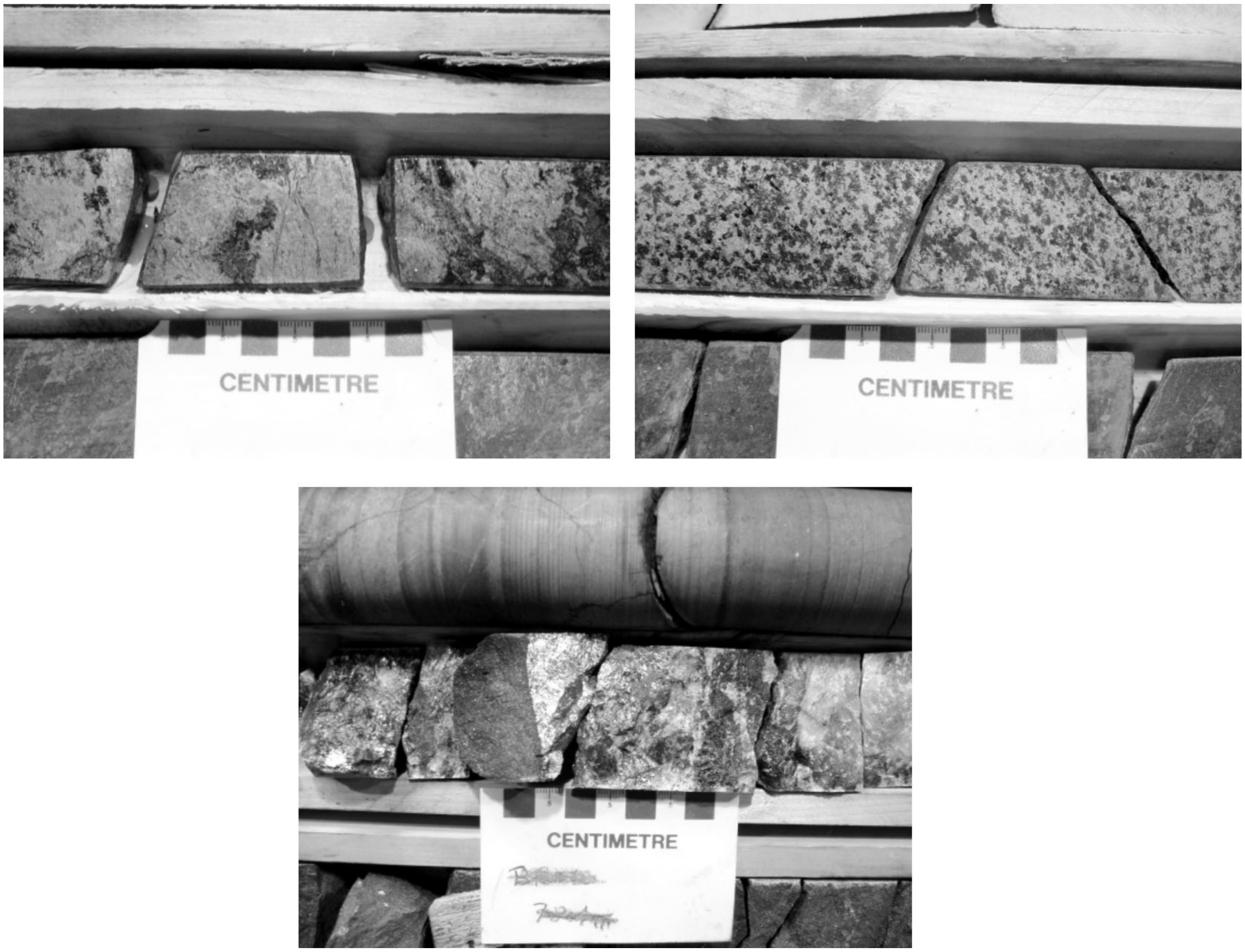

Figure GS-19-6*: Styles of mineralization in the sulphide-bearing zones on the Page property, Bird River Sill.*

The sulphides, which occur within an anorthositic layer overlying a chromitiferous gabbroic layer, are reported to contain up to 1.3 ppm combined Pd+Pt (Theyer, 1986).

During the summer of 2005, sulphides were discovered associated with shear zones in the mafic series on the Chrome property. Specifically, disseminated chalcopyrite, pyrite and pyrrhotite, ranging from trace amounts to up to 5%, were observed. Twelve samples were collected whose assay results and locations are shown on Table GS-19-1 and Figure GS-19-7, respectively. Two of the samples collected from the upper portion of the mafic series, approximately 300 m stratigraphically above the ultramafic-mafic contact, contained significant PGE: 831 ppb Pt+Pd and 338 ppb Pt+Pd. This could imply that significant remobilization of PGE along shear zones has occurred in the BRS. Further geochemical analyses of samples from the mafic series of the Page property are pending.

Structure

Previous studies have treated the BRS as a continuous intrusion that was block faulted due to tectonism and granitoid intrusions (Davies, 1952). Displacements were believed to follow north-northwest-trending, steeply dipping faults that produced offsets of up to 1525 m (Bannatyne and Trueman, 1982). This summer's mapping, in conjunction with that of Duguet et al. (GS-16, this volume) and total field magnetics, failed to find any evidence to support the existence of these faults. Therefore, an alternative theory is proposed here for the segmentation of the BRS.

The properties of the BRS are best explained if there were initially separate magmatic intrusions, possibly from the same magma chamber (i.e., the BRS does not represent a single, continuous intrusion; Figure GS-19-1). Three east-west fault zones, each several kilometres long, have been recognized from exposed shear fabrics occurring south of the Chrome property as well as north and south of the Page property. These are believed to have produced the north-northwest-trending faults and displacements observed on the Chrome and Page properties. The Chrome property has undergone relatively extensive faulting and displacement (up to several metres) compared to the other properties. This is likely the result of its being aligned obliquely to the east-west fault zones. This may have induced more stress on the Chrome property than

Table GS-19-1: Assay results for mineralized gabbro from the Chrome property, Bird River Sill.

Sample	Pd (ppb)	Pt (ppb)	Au (ppb)	Cu (%)	Ni (%)
1	661	170	25	0.041	0.015
2	1.3	4.0	3	0.015	0.006
3	1.6	0.2	-1	-0.001	-0.003
4	0.9	-0.1	-1	-0.001	-0.003
5	1.8	3.8	-1	-0.001	0.003
6	216	122	33	0.097	0.024
7	43.9	31.0	-1	0.003	0.009
8	4.5	4.0	1	0.006	0.018
9	11.9	6.5	6	0.002	0.004
10	13.3	7.0	2	0.002	0.013
11	20.6	18.8	4	0.014	0.013

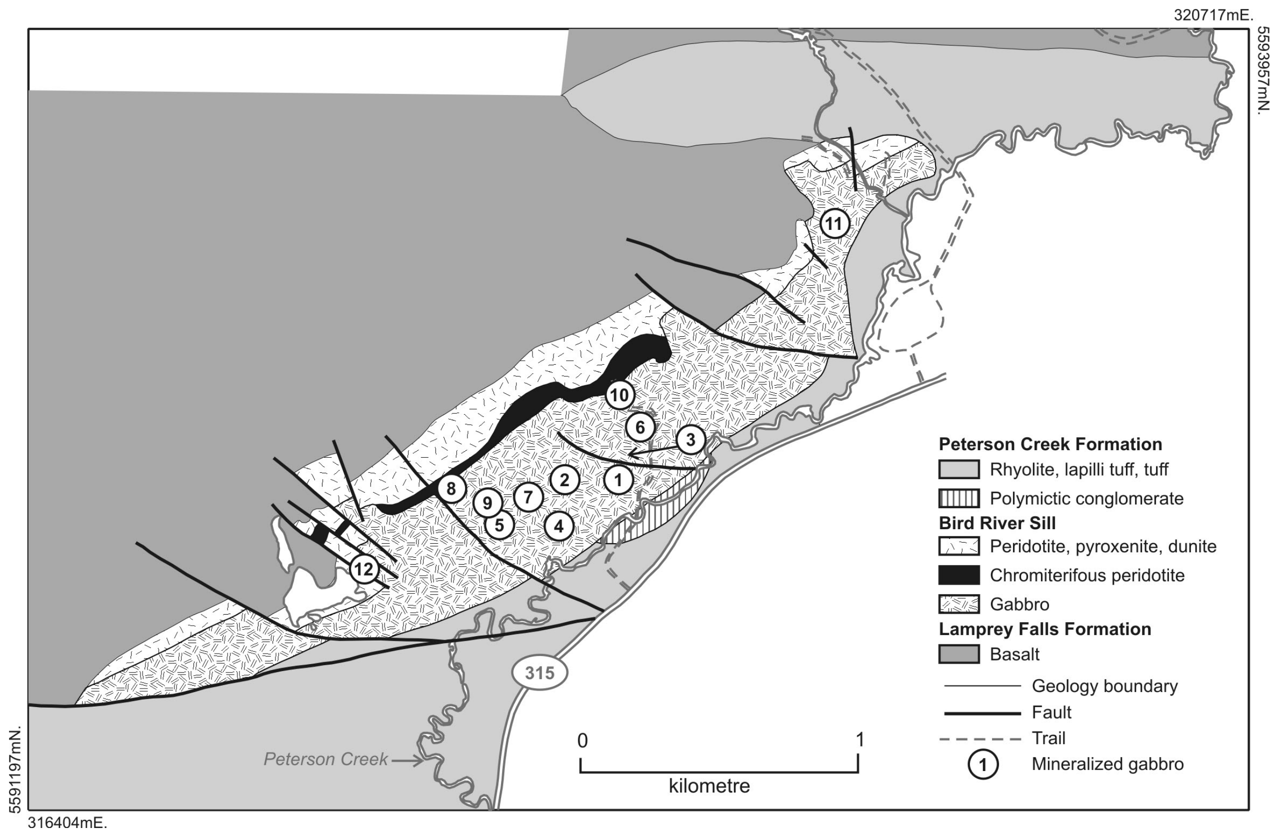

***Figure GS-19-7**: Locations of the mineralized gabbro samples on the Chrome property, Bird River Sill.*

on other locations that are parallel to the major structures (i.e., Page property). There is little structural information for the properties west of the Chrome property due to lack of exposure, but the Page and Chrome properties are very well exposed. Further details on the setting of the BRS within the BRGB are provided by Duguet et al. (GS-16, this volume).

Geochemistry

Forty-nine chip samples, 0.5 m in length and collected at 1.5 m intervals from the western channel-sample cut on the Chrome property, were analyzed for whole-rock trace element and sulphur content using inductively coupled plasma mass spectrometry (ICP-MS) and combustion infrared (LECO® carbon-sulphur) analyses, respectively. It is important to note that the sampling section at the current time is incomplete and geochemical analyses of the missing intervals (parts of cycles 1, 3 and 4) are pending.

Preliminary geochemical analysis of the ultramafic rocks indicates a primitive-mantle source. Figure GS-19-8 shows the abundances of immobile trace elements, including rare earth (RE) and high field strength elements. The spider diagram displays a flat pattern which is typical of primitive mantle. Low field strength elements and select transition elements were not included on the spider diagram because they are mobile in greenschist-facies metamorphic conditions. One more important characteristic of the spider diagram is the lack of a negative Nd anomaly. The lack of an Nd anomaly indicates there was no crustal contamination of the Chrome property intrusion.

If the sill was the result of a single magmatic pulse, with subsequent crystal fractionation, it is reasonable to expect that the concentrations of incompatible trace elements such as La and Nd would gradually increase in the residual liquid (i.e. with stratigraphic height; Cawthorn and McCarthy, 1985). By contrast, addition of a new magma can cause increases of trace elements at specific locations (Cawthorn and McCarthy, 1985). Figures GS-19-9a and -9b show an irregular increase of La and Nd stratigraphically upward. The degree of random scatter is inevitable due to variations in the trapped liquid proportion from sample to sample; therefore, to eliminate this effect, a trace element ratio plot is also used (Figure GS-19-9c). The Sm/Nd ratio is fairly constant throughout the ultramafic series. If there had been any magma mixing events or crustal assimilation, there should be either a gradual or an abrupt change in the element ratios. For example, Sm/Yb ratios throughout the stratigraphy of the volcanic pile at the Noril'sk–Talnakh deposit are constant in the lower and middle series but increase abruptly in the upper series, more than doubling in value, indicating mixing of two different magma series (Arndt et al., 2003). A constant ratio throughout the ultramafic rocks of the BRS and gradually increasing trace elements towards the mafic contact both suggest that the sill crystallized from a single magmatic injection.

Conclusions

In summary, it is proposed that the segmented properties of the BRS (i.e., Page, Chrome, Wards) are separate intrusions, possibly fed from the same magma chamber, which were deformed and faulted by late east-trending fault zones, rather than being block-faulted segments of a once-continuous sill. Preliminary geochemical analysis indicates a primitive-mantle source with no evidence of crustal contamination or magma mixing, thus suggesting the Chrome property crystallized from a single magmatic injection. Sulphide and PGE mineralization occur in several horizons in the ultramafic series of the sill but are not solely restricted to the ultramafic portion of the sill, as mineralization has also been identified in the mafic series of the Chrome property, associated with shear zones, likely remobilized, and is known to be present on the Wards property.

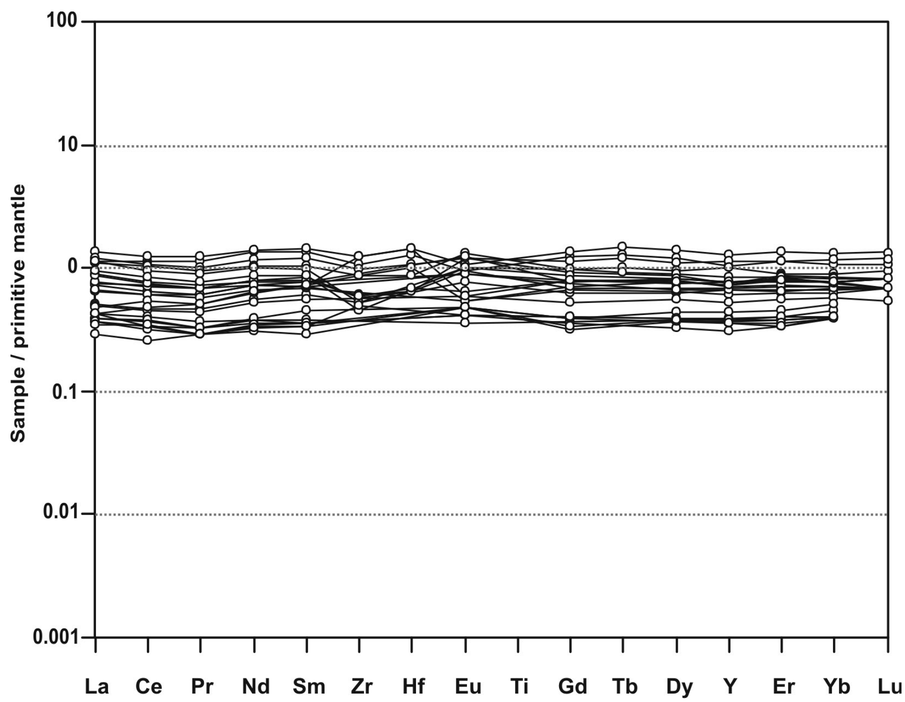

Figure GS-19-8: *Spider diagrams of immobile trace elements and rare earth elements, western channel-sample cut, Chrome property, Bird River Sill.*

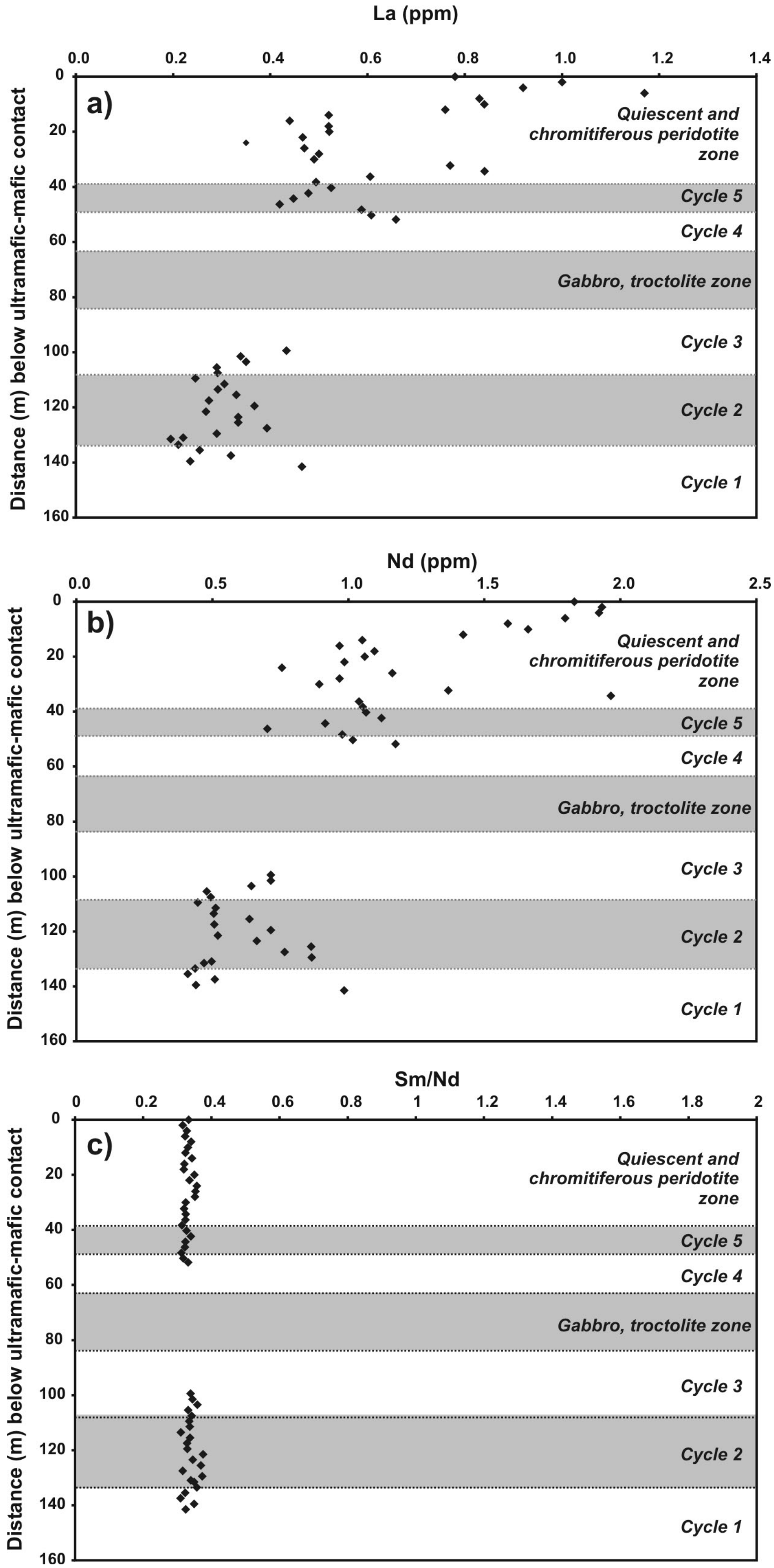

Figure GS-19-9: *Diagrams of incompatible trace elements versus stratigraphy, western channel-sample cut, Chrome property, Bird River Sill.*

Future work

Future work will focus on the following areas:

- Geochemical analysis of the remainder of the western and central channel cuts from the Chrome property and grab samples from the Page property for continued examination of sill petrogenesis
- Petrographic examination of grab samples from the ultramafic and mafic series of the Chrome, Page, Peterson Block and National-Ledin properties to determine the grade of metamorphism and to distinguish alteration from metamorphism
- PGE study emphasizing:
  - PGE mineralogy and habit in the mafic series versus ultramafic series
  - PGE mineralogy and habit in chromitiferous zones versus massive peridotite zones
  - differences and similarities between PGE mineralogy of the separate BRS properties
- Examination of the relationship between the sampled gabbroic intrusions of the Lamprey Falls Formation and the sill
- Sulphur isotope study comparing the Page property, Chrome property, Maskwa-Dumbarton property and sulphide-bearing iron formations local to the Maskwa-Dumbarton property.

Economic considerations

The Bird River Sill (BRS) is an excellent Ni-Cu-PGE exploration target because it 1) hosted two mines on the Maskwa-Dumbarton property, and 2) contains known significant zones of Ni-Cu-PGE mineralization that have not been fully delineated. Within the last two years, drilling by North American Palladium Ltd. has intersected massive sulphide zones containing up to 4 g/t Pd at the base of the sill on the Page property. Sulphide-bearing localities have been identified by this author at the basal contact of the Chrome property and in the gabbro unit on the Chrome property, which was previously believed to be barren but contains up to 861 ppb Pt+Pd, suggesting significant remobilization of the sulphides. The remobilization is also not confined to the limits of the BRS, as sulphides have been identified in the Lamprey Falls Formation, close to the BRS contact and along shear zones and quartz veins.

The relationship between the gabbroic intrusions of the Lamprey Falls Formation and the sill is a very interesting question, especially in light of the Wards property being a gabbroic intrusion into the Lamprey Falls Formation and containing significant PGE and chromite mineralization. The gabbroic intrusions will be a major focus of continued work to delineate any relationship to the known BRS. Further exploration of these intrusions is strongly recommended.

Acknowledgments

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References

Arndt, N.T., Czamanske, G.K., Walker, R.J., Chauvel, C. and Fedorenko, V.A. 2003: Geochemistry and origin of the intrusive hosts of the Noril'sk–Talnakh Cu-Ni-PGE sulphide deposits; Economic Geology, v. 98, p. 495–515.

Bannatyne, B.B. and Trueman, D.L. 1982: Chromite reserves and geology of the Bird River Sill, Manitoba; Manitoba Department of Energy and Mines, Mineral Resources Division, Open File Report OF82-1, 73 p.

Bateman, J.D. 1943: Bird River chromite deposits, Manitoba; Transactions of the Canadian Institute of Mining and Metallurgy, v. 46, p. 154–183.

Cawthorn, R.G. and McCarthy, T.S. 1985: Incompatible trace element behavior in the Bushveld Complex; Economic Geology, v. 80, p. 1016–1026.

Cerny, P., Trueman, D.L., Ziehlke, D.V., Goad, B.E. and Paul, B.J. 1981: The Cat Lake–Winnipeg River and the Wekusko Lake pegmatite fields, Manitoba; Manitoba Department of Energy and Mines, Mineral Resources Division, Economic Geology Report ER80-1, 215 p.

Davies, J.F. 1952: Geology of the Oiseau (Bird) River area; Manitoba Mines and Natural Resources, Mines Branch, Publication 51-3, 24 p.

Gilbert, H.P. 2005: Geological investigations in the Bird River area, southeastern Manitoba (parts of NTS 52L5N and 6N); *in* Report of Activities 2005, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 125–139.

Juhas, A.P. 1973: Geology and origin of copper-nickel sulphide deposits of the Bird River area of Manitoba; Ph.D. thesis, University of Manitoba, Winnipeg, Manitoba, 285 p.

Mealin, C.A. 2006: Geology of the Bird River Sill, southeastern Manitoba (part of NTS 52L5); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Preliminary Map PMAP2006-10, scale 1:5000.

Osborne, T.C. 1949: Petrography and petrogenesis of the Bird River chromite bearing sill; M.Sc. thesis, University of Manitoba Winnipeg, Manitoba.

Peck, D.C. and Theyer, P. 1998: PGE-copper-nickel potential of mafic-ultramafic intrusions in the Bird River greenstone belt (parts of NTS 52L); *in* Report of Activities 1998, Manitoba Energy and Mines, Manitoba Geological Survey, p. 151–160.

Peck, D.C., Scoates, R.F.J., Theyer, P., Desharnais, G., Hulbert, L.J. and Huminicki, M.A.E. 2002: Stratiform and contact-type PGE-Cu-Ni mineralization in the Fox River Sill and the Bird River Belt, Manitoba; *in* The Geology, Geochemistry, Mineralogy and Mineral Beneficiation of Platinum-Group Elements, L.J. Carbri (ed.), Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 54, p. 367–387.

Scoates, R.F.J. 1983: A preliminary stratigraphic examination of the ultramafic zone of the Bird River sill (part of 52L/5NE); *in* Report of Activities 1983, Manitoba Department of Energy and Mines, Mineral Resources Division, p. 70–83.

Scoates, R.F.J., Williamson, B.L., Eckstrand, O.R. and Duke, J.M. 1989: Stratigraphy of the Bird River Sill and its chromitiferous zone, and preliminary geochemistry of the chromitite layers and PGE-bearing units, Chrome property, Manitoba; *in* Investigations by the Geological Survey of Canada in Manitoba and Saskatchewan during the 1984–1989 Mineral Development Agreements, A.G. Galley (ed.), Geological Survey of Canada, Open File 2133, p. 69–82.

Talkington, W., Watkinson, D.H., Whittaker, P.J. and Jones, P.C 1983: Platinum-group-mineral inclusions in chromite from the Bird River Sill, Manitoba; Mineralium Deposita, v. 18, p. 245–255.

Theyer, P. 1985: Platinum-palladium distribution in ultramafic rocks of the Bird River complex, southeastern Manitoba; Manitoba Energy and Mines, Open File Report OF85-4, 46 p.

Theyer, P. 1986: Platinum group elements in southeastern Manitoba; *in* Report of Activities 1986, Manitoba Energy and Mines, Minerals Division, p. 70–83.

Theyer, P. 1990: Petrography, chemistry and distribution of platinum and palladium in ultramafic rocks of the Bird River Sill, SE Manitoba, Canada; Mineralium Deposita, v. 26, p. 165–174.

Theyer, P. 2002: Platinum group element investigations in the Peterson Block of the Bird River Sill (NTS 52L5NE), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 250–254.

Theyer, P., Bruni, E. and Sundell, C. 2001: Stratigraphy, geology and mineralization of selected parts of the Page property, Bird River Sill (part of NTS 52L/5); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 126–132.

Trueman, D.L. 1971: Petrological, structural and magnetic studies of a layered basic intrusion, Bird River Sill, Manitoba; M.Sc. thesis, University of Manitoba Winnipeg, Manitoba.

Wang, X. 1993: U-Pb zircon geochronology study of the Bird River greenstone belt, southeastern Manitoba; M.Sc. thesis, University of Windsor, Windsor, Ontario, 96 p.

Williamson, B.L. 1990: Geology of the Bird River Sill at the Chrome property, southeastern Manitoba; Geological Survey of Canada, Open File 2067, 44 p.