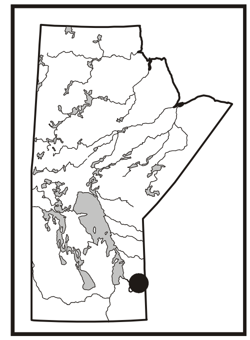
GS-24

FIELD AND LITHOGEOCHEMICAL INVESTIGATIONS OF MAFIC AND ULTRAMAFIC ROCKS AND ASSOCIATED Cu-Ni-PGE MINERALIZATION IN THE BIRD RIVER GREENSTONE BELT (PARTS OF NTS 52L)

by D.C. Peck, P. Theyer, A.H. Bailes and J. Chornoby[1]



Peck, D.C., Theyer, P., Bailes, A.H., and Chornoby, J. 1999: Field and lithogeochemical investigations of mafic and ultramafic rocks and associated Cu-Ni-PGE mineralization in the Bird River greenstone belt (parts of NTS 52L); *in* Report of Activities, 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 106-110.

SUMMARY

Mineral potential studies were conducted in the Mayville intrusion and the Bird River Sill. The Mayville intrusion hosts disseminated to semi-massive Cu-rich sulphide mineralization ("contact-type" mineralization) near its base. Maximum PGE abundances of 3 ppm were obtained from the lower part of the mineralized zone. The rock types and sulphide mineralization in the Mayville intrusion are very similar to those developed in the lower parts of ca. 2.48 Ga anorthositic intrusions in central Ontario (East Bull Lake intrusive suite). Several of these intrusions contain broad zones of contact-type, PGE-rich sulphide mineralization that are currently the focus of significant exploration programs. Field observations suggest that the Mayville intrusion represents a dynamic magma chamber in which large-scale convection promoted the migration of dense components (immiscible magmatic sulphides and residual Mg- and Fe-rich magma) toward the base of the chamber. The development of large convection cells is believed to be a critical stage in the formation of PGE-rich "contact-type" sulphide mineralization in anorthositic intrusions.

In the southern part of the Bird River Belt, field work began on a potential feeder structure to the Bird River Sill north of the Maskwa and Dumbarton nickel mines. Ongoing research will address the geochemistry of the mafic and ultramafic intrusive rocks exposed in the feeder structure and the potential role of an exposed iron formation as a source of external sulphur. In addition, other parts of the Bird River Sill warrant additional investigation for reef-type PGE deposits based on favourable geology and the existence of several PGE-rich sulphide zones (Chrome Property).

Geochemical data are being acquired for volcanic sequences and associated mafic-ultramafic intrusions in the Bird River Belt. This data will be compared to data for the adjacent Rice Lake greenstone belt to help develop regional tectonic, petrogenetic and metallogenetic models for the Bird River belt.

INTRODUCTION

Relevant, published investigations into the geology and mineral occurrences of the Bird River greenstone belt (BRGB) include government mapping projects (e.g., Theyer, 1985, 1986; Macek, 1985; Scoates et al., 1989; Trueman and Macek, 1971; Davies, 1952, 1955, 1956, 1957; Springer, 1949, 1950) and graduate research projects (Trueman, 1971, 1980; Juhas, 1973). Previous mineral exploration in the Bird River greenstone belt (BRGB) has focussed on rare-earth element enriched granitic pegmatites (Cerny et al., 1981) and magmatic Ni-Cu sulphide deposits (Juhas, 1973; Karup-Moller and Brummer, 1971) and chromite mineralization in both the Bird River Sill and the Mayville intrusion (Bateman, 1943; Theyer, 1985).

The objectives of the current investigation are:

(1) Assess the potential for PGE-Cu-Ni sulphide deposits in the BRGB; and

(2) Develop a lithogeochemical database augmented by new, detailed field mapping, in order to construct regional tectonic, petrogenetic and metallogenetic models for the belt.

Field work was completed in September, 1999, and focussed on detailed mapping and lithogeochemical sampling of the Mayville intrusion in the northern part of the BRGB and reconnaissance studies and lithogeochemical sampling of selected sections through volcanic sequences in both the northern and southern parts of the belt. Prior to this current program, in February, 1999, logging and systematic lithogeochemical sampling was completed on core from five drill holes that intersected the mineralized base of the Mayville intrusion and a mineralized, finer-grained gabbroic intrusion to the south (Copper Contact body). In addition, saw cut samples from the Chrome Property of the Bird River Sill (Fig. GS-24-1; Theyer, 1985) were re-sampled for a lithogeochemical study that will investigate the genesis of the Bird River Sill and several, contained PGE-rich sulphide-bearing zones (Theyer, 1985; Peck and Theyer, 1998).

LITHOSTRATIGRAPHIC AND MINERAL POTENTIAL STUDIES OF THE MAYVILLE INTRUSION

Mapping at a scale of 1:1000 was carried out with the aid of flagged gridlines and digital orthophotographs. The study benefited from existing geological mapping of the Mayville intrusion (Macek, 1985). A type section approximately 1100 m long (south to north) was generated based on mapping in the well exposed central part of the intrusion along the Mayville property road. Additional mapping was completed on a series of exploration trenches that were recently established in the southernmost exposed part of the Mayville intrusion by Exploratus Elementis Diversis.

The intrusion is principally composed of metamorphosed, coarse-grained leucogabbro that grades to anorthosite and gabbro. Rare younging criteria such as modal and size graded layering, indicate that the intrusion is consistently north-facing. Planar, centimetre- and metre-scale modal layering is rarely developed and, where present, typically displays variable strikes (060°-100°), vertical to moderate, southward dips and limited lateral continuity (e.g., several metres). In the lowermost, exposed 150 m of the southern part of the intrusion, irregular, inclusion-rich pyroxenite and melagabbro zones are developed (see below).

The major lithostratigraphic units identified are (from base to top, with estimated true thickness shown in parenthesis - based on the type section for the central part of the Mayville intrusion, Fig. GS-24-2):

(1) Heterolithic Breccia zone (>120 m; based not exposed), comprises irregular pods, veins and layers, <1 to 100 m thick, of melagabbro and pyroxenite that have intruded, eroded and entrained fragments of pre-existing, semi-consolidated poikilitic and plagioclase megaphyric leucogabbro. The breccia unit also contains veins of fine-grained gabbro and pods and veins of varitextured, medium-grained to pegmatitic gabbro and quartz diorite. Basalt xenoliths are rarely observed. Sulphide mineralization is erratically developed throughout the breccia zone (see below);

(2) Lower Megacrystic zone (320 m), comprises alternating, decametre-thick, very-coarse-grained poikilitic and megacrystic leucogabbro subunits;

(3) Central Layered zone (220 m), comprises centimetre- and metre-scale modal and grain size layering in megacrystic anorthosite and leucogabbro, coarse-grained, poikilitic gabbro and massive, medium- to coarse-grained leucogabbro;

(4) Upper Megacrystic zone (110 m), similar to the Lower Megacrystic zone, but contains minor, centimetre-size partially digested, epidotized, granitic xenoliths;

(5) Upper Massive zone (350 m), including a lower, coarse-grained poikilitic leucogabbro that grades upward into massive, medium-grained leucogabbro with increasing proportions of granitic xenoliths;

(6) Gabbro zone (>20 m; top not exposed), comprises medium-grained gabbro with up to 15% centimetre- to metre-size granitic xenoliths and derived, interstitial granophyre (xenomelt).

The arrangement of rock types within the intrusion is typical of megacrystic anorthosite bodies that are described from other Archean granite-greenstone belts (e.g., Peck et al., GS-21, this volume) and to the basal, anorthositic parts of younger, ca. 2.48 Ga layered mafic intrusions in central Ontario (e.g., Peck et al., 1993). The geology of the intrusion can

[1] Exploratus Elementis Diversis, Box 235, Dugald, Manitoba R0E 0K0

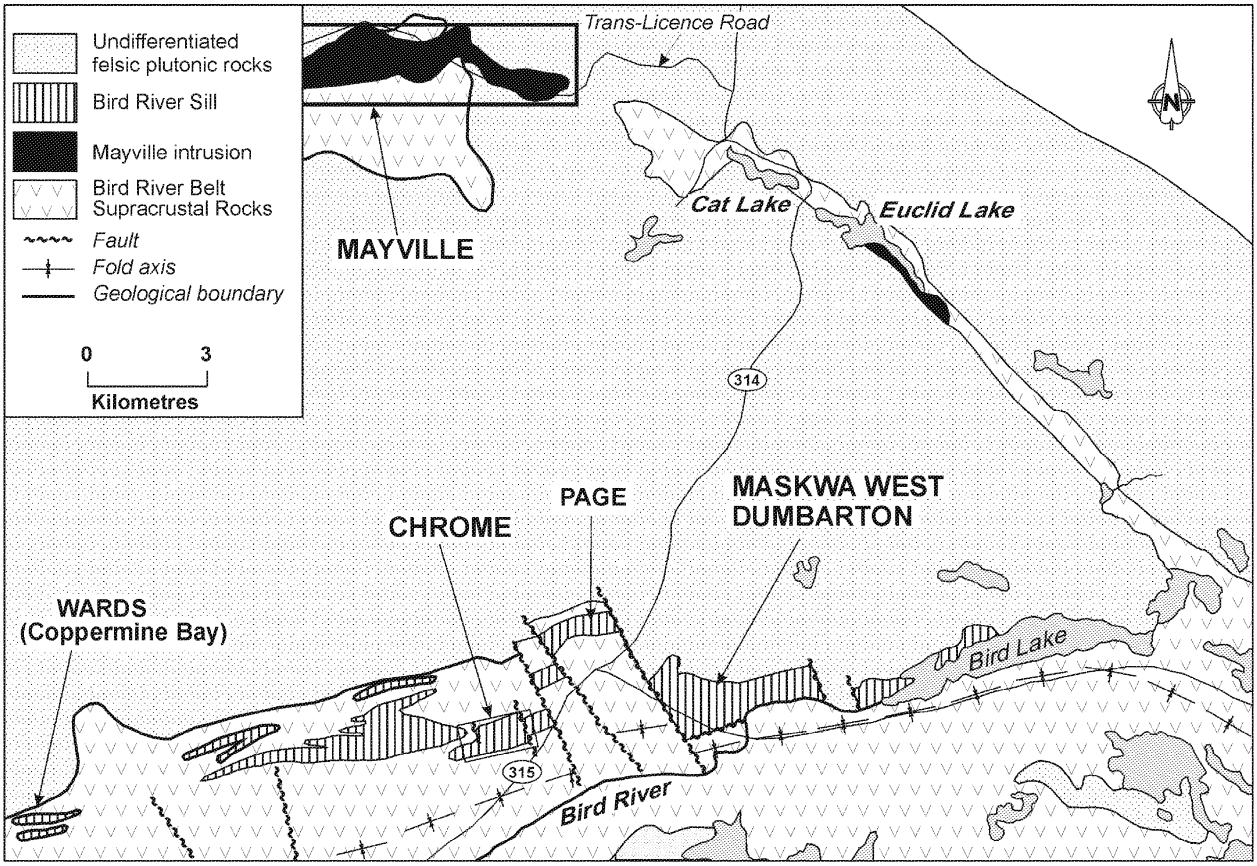


Figure GS-24-1: Location of study areas in the Bird River greenstone belt.

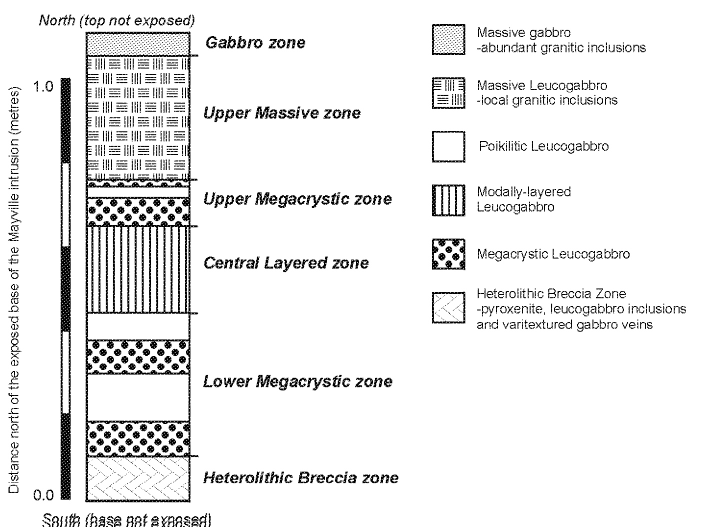


Figure GS-24-2: Partial lithostratigraphic section for the Mayville intrusion. The section is based on a 150 to 300 m wide, north-south oriented mapping corridor across the central part of the intrusion. Based on average igneous layering orientations striking ca. 080° and dipping >80° to the south, the section is believed to estimate, within 15%, the maximum true thickness of the exposed parts of the Mayville intrusion. Neither the upper nor the lower contacts of the intrusion are exposed. Based on drill hole information, the Heterolithic Breccia zone and its disseminated sulphide mineralization likely extend an additional 100 m to the south of the southernmost exposure in the study area. The upper contact appears to be 100 to 200 metres to the north of the northernmost exposure. Accordingly, the observed north-south dimension of the intrusion is believed to be at least 200 metres greater than the 1.1 km of measured section shown in this figure.

be explained by one or more pulses of Al-rich (hyperfeldspathic) basaltic magma that initially crystallized only plagioclase. Plagioclase crystallization led to enrichment of Mg and Fe in residual, interstitial magma that became denser than both the parental magma and the early-formed plagioclase crystals (primocrysts). The concentration of mafic rocks in the base of the intrusion and the presence of leucogabbro clasts in both pyroxenite and melagabbro in the Heterolithic Breccia zone may reflect ponding of dense, residual mafic liquid at the base of the intrusion.

The abundance of plagioclase megacrysts in the lower and central parts of the intrusion attest to slow cooling, whereas the presence of finer-grained rocks and ubiquitous granitic xenoliths in the upper part of the intrusion suggest higher cooling rates near the roof. Accordingly, the magma(s) that filled the intrusion probably experienced thermal - and density-driven convection until sufficient heat was lost to allow crystallization to advance to the point at which convection was impeded. Evidence for convection in the Mayville intrusion also includes: (1) The absence of planar, regular centimetre- and metre-scale rhythmic layering, such as that seen in the petrologically similar Pipestone Lake anorthosite complex (Jobin-Bevans et al., 1998), which would be expected to form if the magma stagnated at an early stage of crystallization. Convection would keep the magma compositionally homogeneous by promoting mixing of early and late pulses; and (2) The presence of granitic xenoliths throughout the middle and upper parts of the intrusion. In a stagnant magma, the low density granitic xenoliths would remain near the roof.

Sulphide mineralization in the Mayville intrusion

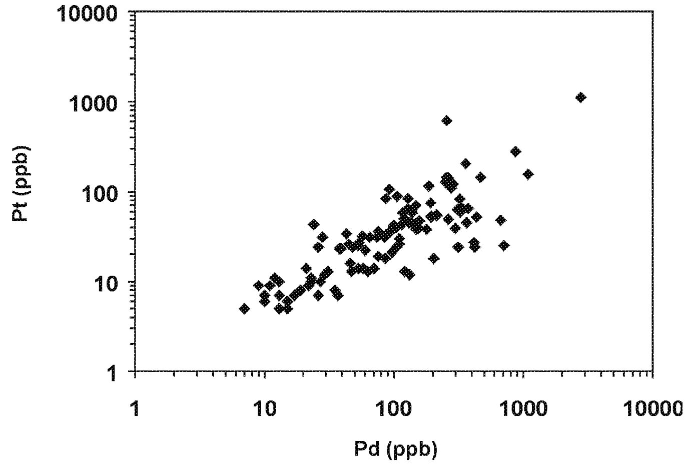
Disseminated pyrrhotite and subordinate chalcopyrite occur throughout the lowermost 300 m of the intrusion. The sulphides are not evenly distributed, and range in abundance from trace amounts to solid sulphide bands in hand specimens. The average sulphide abundance appears to be as high as 3-5% in drill core from the base of the intrusion; it decreases to <1% in outcrops in the upper part of the mineralized zone. The sulphides commonly form blebs in which pyrrhotite is the dominant mineral and chalcopyrite occurs at the bleb margins.

Sulphides are present in all of the rock types in the mineralized parts of the intrusion; in the Heterolithic Breccia zone, pyrrhotite and chalcopyrite occur in pyroxenite, melagabbro, gabbro, varitextured gabbro and leucogabbro. The mineralization gradually disappears over a distance of 100 m above the top of the Heterolithic Breccia zone and sulphides are rarely seen in the middle and upper parts of the intrusion. The sulphide mineralization in the lower part of the intrusion is believed to represent high-temperature, immiscible sulphide liquids. Given the geological evidence for convection previously discussed, it is likely that some of the mineralization could be enriched in PGE, particularly finer-grained sulphides that may have been kept in suspension for long periods of time, enabling effective scavenging of PGE.

The geology of the Mayville intrusion is very similar to the lower, mineralized parts of ca. 2.48 Ga mafic layered intrusions in central Ontario, including the East Bull Lake and River Valley intrusive complexes. Both of these complexes contain PGE-rich, contact-type sulphide mineralization (e.g., Peck et al., 1993) that is currently the target of major exploration programs.

To investigate the PGE potential of the sulphide-bearing zone within the Mayville intrusion, Exploratus Elementis Diversis and Manitoba Energy and Mines completed a petrological and geochemical study of ca. 200 drill core samples. The core was obtained from 5 drill holes (Falconbridge Ltd. and Exploratus Elementis Diversis drilling) that intersected the unexposed, basal part of the Mayville intrusion and a second sulphide-bearing gabbroic intrusion (Copper Contact intrusion) that occurs ca. 1 km to the south of the Mayville intrusion. Unfortunately, none of the available core comes from drill holes that intersect the entire mineralized zone and most were exclusively cored in the lowermost 100 m of the intrusion, which is characterized by abundant, several metre-wide shear zones and extensive remobilization of the magmatic sulphide mineralization. Nevertheless, the assay data indicate that: (1) the mineralized zones contain anomalously high average combined Au, Pt and Pd abundances, including 690 ppb over 100 feet and 470 ppb over 66 feet in drill holes M16 and M15, respectively (Fig. GS-24-3,4); (2) Pd tends to be the most abundant precious metal and Pd:Pt ratios are typically in excess of 3:1; (3) Pd abundance shows a moderate, positive correlation with total sulphide abundance, but the highest Pd tenors do not always occur in sulphide-rich samples; and (4) the maximum combined Au + Pt + Pd abundance obtained for the drill core samples is 4.2 ppm, and 17% of the samples contain >200 ppb of Pd (see Fig. GS-24-3). A petrologically similar, broad zone of disseminated sulphide mineralization in the East Bull Lake intrusion, Ontario, hosts high-grade PGE mineralization (Peck et al., 1993).

Ongoing petrological and geochemical studies of the Mayville intrusion will focus on better documenting the abundances of PGE and sulphides in the lower part of the intrusion. Surface grab samples were collected for geochemical analysis from two locations within the exposed, mineralized part of the intrusion. Also, new stratigraphic information is being gained from 1:100 scale mapping in a series of trenches recently established by Exploratus Elementis Diversis in the unexplored section of the basal, mineralized part of the intrusion.



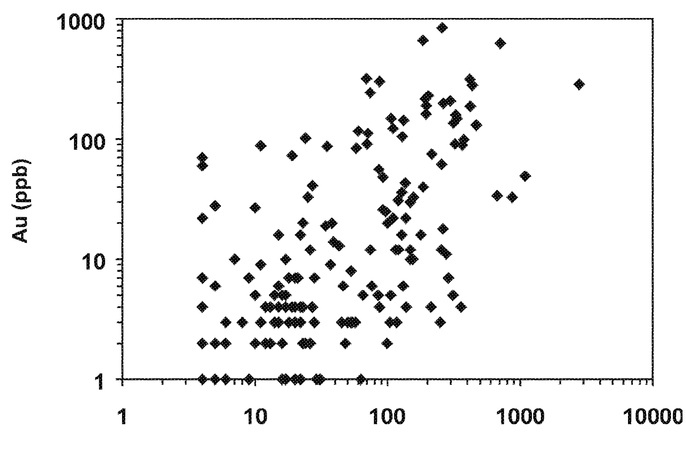


Figure GS-24-3: Simple log-normalized scatter plots of Au, Pt and Pd analyses of 165 core samples from 4 drill holes (M96-1, M96-2, M15 and M16) into the lower, mineralized part of the Mayville intrusion. The data are presented here with permission from Exploratus Elementis Diversis.

METALLOGENETIC AND PETROGENETIC STUDIES IN THE BIRD RIVER SILL

Maskwa and Dumbarton mines

A reconnaissance mapping and lithogeochemical sampling program was conducted in gabbroic rocks that appear to feed the Bird River Sill in the vicinity of the Maskwa and Dumbarton Ni mines (Fig. GS-24-1). The study, conducted with the cooperation and support of Canmine Resources Ltd., will continue this fall and winter with: (1) geochemical analyses of the surface samples and logging; and (2) sampling of core from a fence of drill holes that extend from the potential feeder zone in the north, through Bird River Sill to the south, including its mineralized base and both the ultramafic and overlying mafic series rocks. The feeder zone is at least 1 km wide and extends for a minimum of 1 km to the north of the base of the Bird River Sill. It consists of relatively uniform, medium-grained gabbro and melagabbro that locally host disseminated sulphide mineralization. An enigmatic feature of the feeder zone is that it appears to truncate a mineralized, sulphide-rich banded iron formation (the Dumbarton Mine horizon; Karup-Moller and Brummer, 1971). We are investigating the possibility that the absence of the iron formation reflects its assimilation by ascending gabbroic magmas in the feeder zone, possibly causing sulphur saturation in the first magmas to enter the Bird River Sill.

Chrome Property

Preliminary evaluation of the PGE abundances in the Bird River Sill (Theyer, 1985) indicated the presence of several PGE-rich layers in the ultramafic part of the intrusion. In 1998, a follow up investigation was initiated involving major and trace element geochemistry of selected surface samples and limited, precision ICP-MS analyses (Geoscience Laboratories, Ontario Geological Survey) for all six PGE and Au. In 1999, this work has expanded to include a systematic lithogeochemical investigation of nearly continuous channel samples obtained by Theyer (1985) from the Chrome Property (Fig. GS-24-1). The analytical work is in progress and the results will be used to develop predictive models for PGE mineralization in the Bird River Sill. The favourable geology (e.g., stratiform ultramafic-mafic intrusion with chromitite layers), numerous PGE-rich sulphide occurrences (e.g., Peck and Theyer, 1998) and lack of any significant exploration for PGE in the Bird River Sill make it an attractive exploration target for reef-type PGE deposits.

LITHOGEOCHEMICAL STUDIES OF VOLCANIC ROCKS

Lithogeochemical studies of the Bird River Sill and Mayville intrusion were augmented in 1999 by systematic sampling of basalt flows stratigraphically underlying both intrusions, and by brief examination and sampling of the more diverse volcanic sequence that overlies the Bird River Sill. The main objectives of this study are to: (1) provide constraints for the tectonic setting of the Bird River Sill and Mayville intrusion,

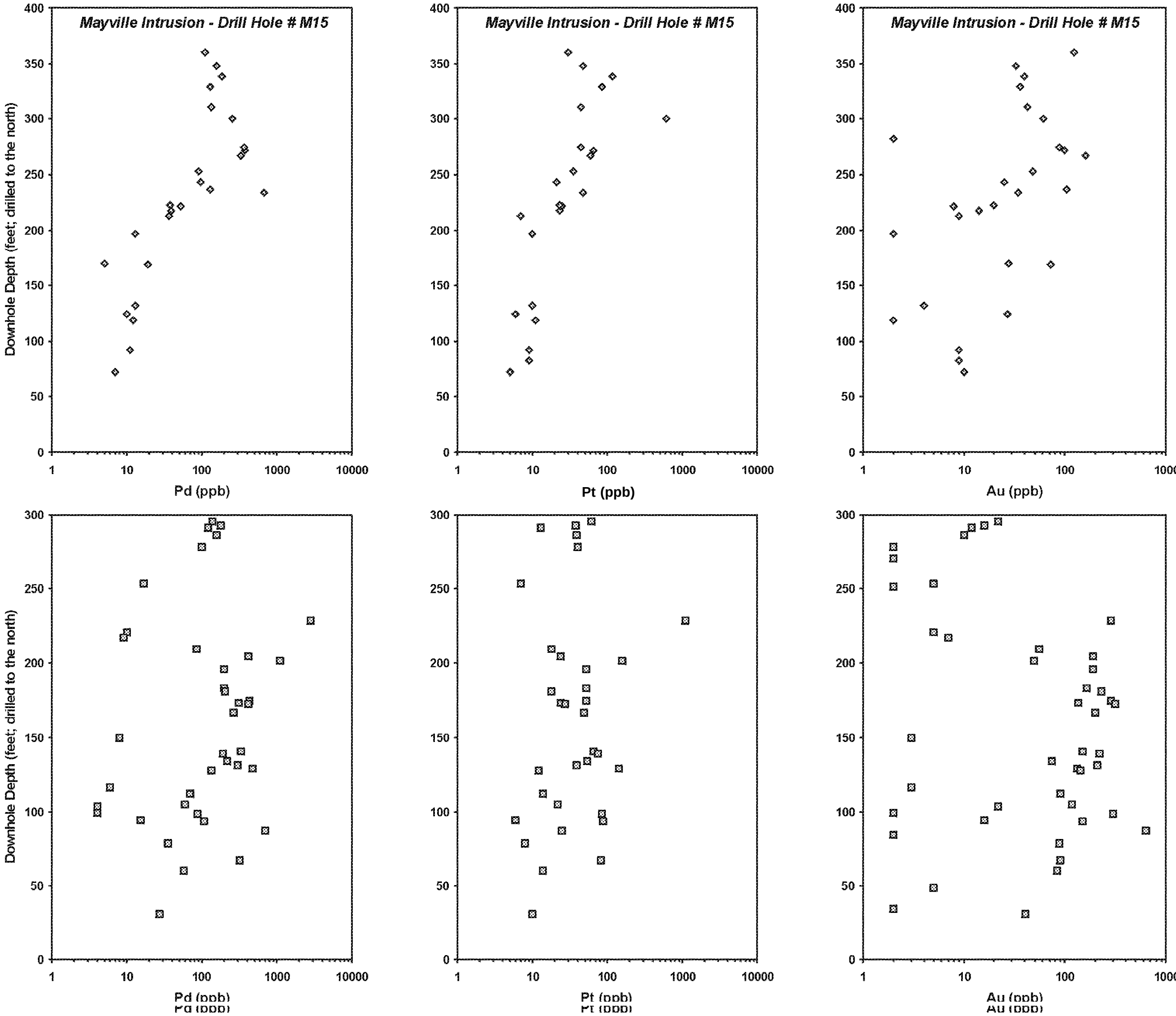


Figure GS-24-4: Variation in Pd, Pt and Au abundances with stratigraphic position in drill holes M15 and M16, both of which appear to have intersected the southernmost part of the Heterolithic Breccia zone, Mayville intrusion. The data are presented here with permission from Exploratus Elementis Diversis.

(2) compare volcanic suites from the northern and southern portions of the Bird River Belt to test their stratigraphic equivalence, and (3) compare the Bird River volcanic suites to those in the Rice Lake belt to help develop regional tectonic and metallogenetic models for both belts.

The southern and northern portions of the BRGB, respective hosts to the Bird River Sill and Mayville intrusion, have been suggested to be equivalent and to have been repeated by a large anticlinal structure centered on the Great Falls pluton (e.g., Davies et al., 1962). Our examination of the basalt flows that underlie the Bird River Sill and the Mayville Intrusion, respectively, indicate them to be identical in appearance, texture, and morphology. Both sequences are characterized by dark grey-green-weathering, aphyric to rarely plagioclase phyric, massive to pillowed flows with local amoeboid pillow breccia. Pillows in both are distinguished by low to negligible vesicle content, narrow to negligible pillow selvages, and <0.5 cm up to 2 cm of interpillow hyaloclastite. Alteration of these basalt flows is only minor and usually restricted to minor epidote and quartz veinlets introduced during deformation. Trueman and Turnock (1982) report flows underlying the Bird River Sill to contain minor intercalated iron formation. Although we did not observe iron formation in the outcrops below the Bird River and Mayville intrusions, with the exception of the banded iron formation at the Maskwa-Dumbarton property, our observations are restricted to two narrow stratigraphic sections. Pillow younging directions in basalts underlying the Bird River Sill and Mayville intrusion give south-southeast- and the north-facing directions, respectively, the same as top determinations on igneous layering in the associated intrusions. The potential equivalency of these two opposite-facing basalt sections and their possible repetition by folding (Davies et al., 1962) will be tested by geochemistry of samples collected from both suites in 1999.

The Bird River Sill and stratigraphically underlying basalts are structurally overlain to the south by a diverse suite of volcanic rocks (Bernic Lake and Peterson Lake formations of Trueman, 1980). According to Trueman and Turnock (1982) the contact between Bird River Sill and the Bernic Lake and Peterson Lake formations is everywhere delimited by a fault. Although the exact relationship between these suites of rocks is not known, the Bernic Lake and Peterson Lake formations are clearly younger than the Bird River Sill and its underlying basalts. This conclusion is supported by the observation that a heterolithologic debris flow deposit at the base of the Bernic Lake formation, directly adjacent to the Bird River Sill, contains cobbles and boulders of anorthosite (2-150cm in diameter) that were apparently derived by unroofing of the Bird River Sill. Some of the cobbles of anorthosite are subrounded, so the unroofing likely occurred in a subaerial or shallow marine environment. Unroofing of the Bird River Sill occurred within a short time frame because anorthosites in the sill have a U-Pb zircon age of 2745±5 Ma and a rhyolite in the overlying Peterson Lake formation has a U-Pb age of 2741 Ma (Timmins et al., 1985).

The Bernic Lake and Peterson Lake formations include a diverse suite of volcanic rocks that include: (1) heterolithologic debris flow deposits, (2) plagioclase-amphibole porphyritic andesite flows that locally contain large 1-2 cm quartz amygdales, (3) aphyric and porphyritic rhyolite flows, tuff, lapilli tuff, and derived felsic volcaniclastic rocks, and (4) highly deformed basalt and amphibolite at Bernic Lake that locally contains recognizable pillows. North facing directions in pillowed flows at Bernic Lake suggest isoclinal folding of the Bernic Lake and Peterson Lake formations.

Older components within granitic terranes south of the BRGB (3180-2700 Ma, Winnipeg River Subprovince, Cruden et al., 1998) and between the south and north segments of the BRGB (2779±35 Ma, Great Falls pluton, Timmins et al., 1985) suggest that the ca. 2.74 Ga rocks (Timmins et al., 1985) of the Bird River Belt may have been deposited upon older crust. Geochemistry of basalts that underlie the Bird River Sill and the Mayville intrusion will permit this hypothesis to be evaluated. Geochemistry of mafic, intermediate and felsic flows in the Bernic Lake and Peterson Lake formations will provide information on the regional tectonic setting of the upper BRGB and place constraints on the tectonic setting of the Bird River Sill.

RECOMMENDATIONS

Given the current, strong interest in finding new sources of PGE in Canada, focused exploration of both the Mayville intrusion and the Bird River Sill is warranted. Concurrent detailed mapping projects, focussing on lithostratigraphy, and lithogeochemical investigations, focussing on the distribution of sulphides and chalcophile metals, will be invaluable to any PGE and Cu-Ni exploration program in these intrusions. The dearth of good quality exposure in the BRGB precludes new mapping of the supracrustal sequences at this time. Lithogeochemical studies (ongoing) and additional high precision U-Pb geochronology of selected volcanic units and intrusions should be used in the interim as a framework from which regional tectonic models can be developed.

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