Geochemical characteristics of the Mayville mafic-ultramafic intrusion and associated PGE-Cu-Ni-(Cr) mineralization in the Neoarchean Bird River greenstone belt, Manitoba (part of NTS 52L12)

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Summary

The Mayville mafic–ultramafic intrusion, consisting of anorthosite, leucogabbro, gabbro, melagabbro and pyroxenite, is located in the Neoarchean Bird River greenstone belt (BRGB), approximately 145 km northeast of Winnipeg. The intrusion contains a significant amount of platinum group element (PGE), Cu, Ni and locally Cr minerals, as indicated by recent mineral exploration. Mustang Minerals Corp (2011) reported that the Mayville property (M2 deposit), a part of the Mayville intrusion, has an NI 43–101 open-pit mineral resource (indicated category) consisting of 9.2 million tonnes averaging 0.61% Cu, 0.23% Ni and 0.43 g/t combined precious metals (Pd+Pt+Au). The Mayville deposit appears to be open along strike and to depth, but requires more diamond drilling and detailed geological and geochemical investigations to identify the full extent of the mineral resource, and to improve the understanding of the metallogeny of the Mayville intrusion. An exploration target such as that within the Mayville intrusion (i.e., stratabound PGE-enriched sulphide- and chromite-bearing layers; see Hoatson, 1998) although attractive, is difficult to delineate. Questions that need to be addressed include the following:

1) What are the main controls on mineralization?

2) Where is the mineralization located within the stratigraphic sequence of the intrusion?

3) What are the diagnostic features of PGE mineralization within sections of drill core?

This poster presents preliminary results of reconnaissance geological mapping and lithogeochemical sampling conducted in the summer of 2011, together with a review of previous geochemical data compiled by the Manitoba Geological Survey. The aim is to address a fundamental question relating to the economic potential of the Mayville intrusion: Is the intrusion derived from appropriate magma(s) and emplaced in a geological setting favourable for the formation of a base- and precious-metal ore deposit? In order to address this question, it is necessary to investigate the temporal, spatial and petrogenetic relationships among the various intrusive phases within the Mayville intrusion by means of geological mapping, geochronological determinations and evaluation of the geochemical characteristics.

A petrogenetic model is presented that suggests the Mayville intrusion may have formed by the injection of multiple batches of magma from a fractionating magma chamber, in which assimilation and fractional crystallization of tholeiitic magma(s) derived from a high degree of partial melting of a depleted mantle source beneath thin (approximately 21 km) lithospheric crust. During emplacement of each batch of magma, assimilation and fractional crystallization may have taken place to some extent. Sulphide saturation, segregation and accumulation may have resulted in PGE-Ni-Cu concentration and mineralization of the mafic–ultramafic rocks, particularly in the basal part of the Mayville intrusion and/or in the contact and transitional zones between different phases in the lower parts of the intrusion. Although differentiation and crustal contamination may result in sulphide saturation in the residual magmas, an external sulphur source would be required to trigger sulphide saturation to produce metal mineralization; the identity of such a source remains, so far, problematic. Redox conditions during the evolution of the magma may have varied from reduced to relatively oxidized conditions, which facilitated crystallization and accumulation of the chromite that is locally concentrated in chromitiferous bands or zones within the intrusion. Based on this model, the most likely settings for PGE-Ni-Cu-(Cr) mineralization in the Mayville intrusion appear to be 1) the basal part of the intrusion; 2) transitional zones between different intrusive phases; 3) at contacts between the different phases; and 4) at the basal contact of the Mayville intrusion, where sulphide minerals may have accumulated if they were not remobilized by later geological events.

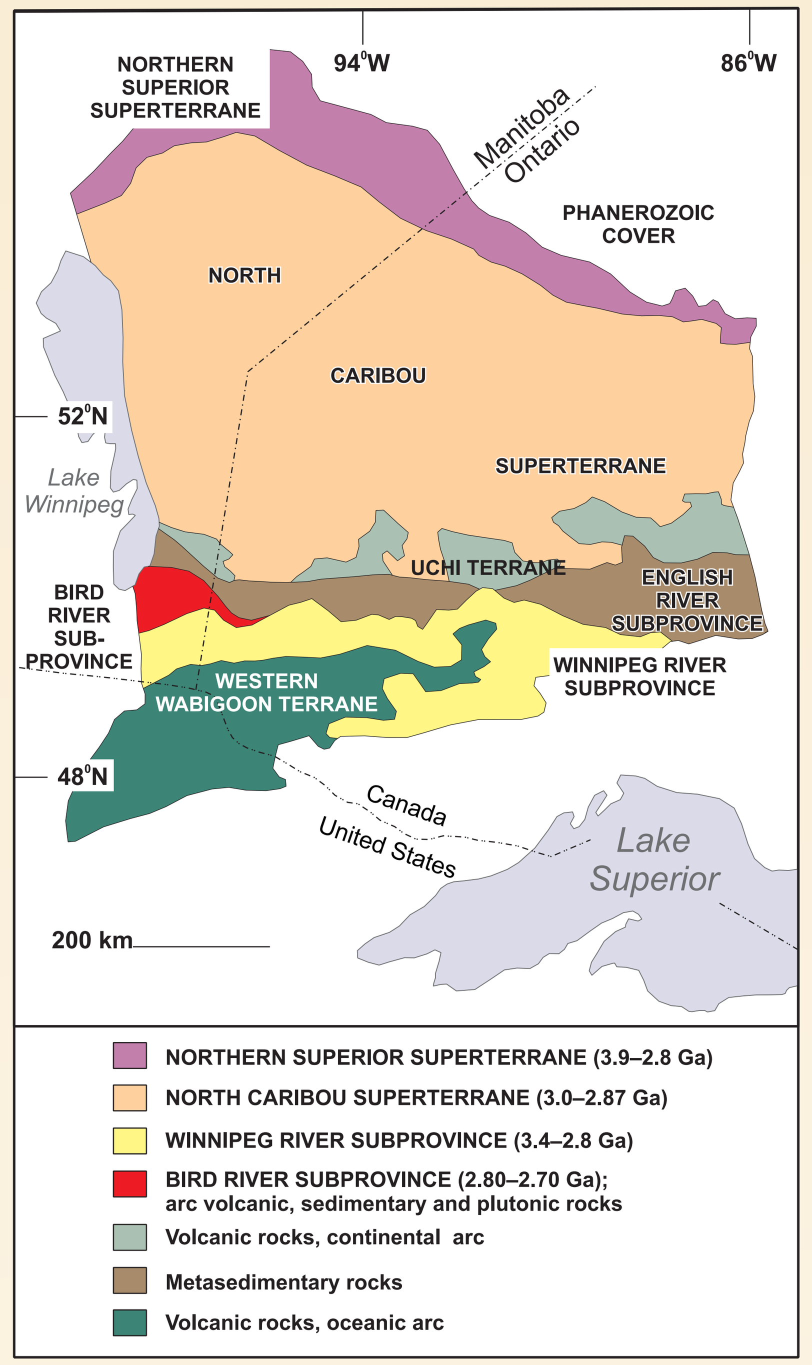

Fig. 1 Simplified geology of the western Superior Province, showing the location of the Neoarchean Bird River greenstone belt (BRGB; after Gilbert, 2007).

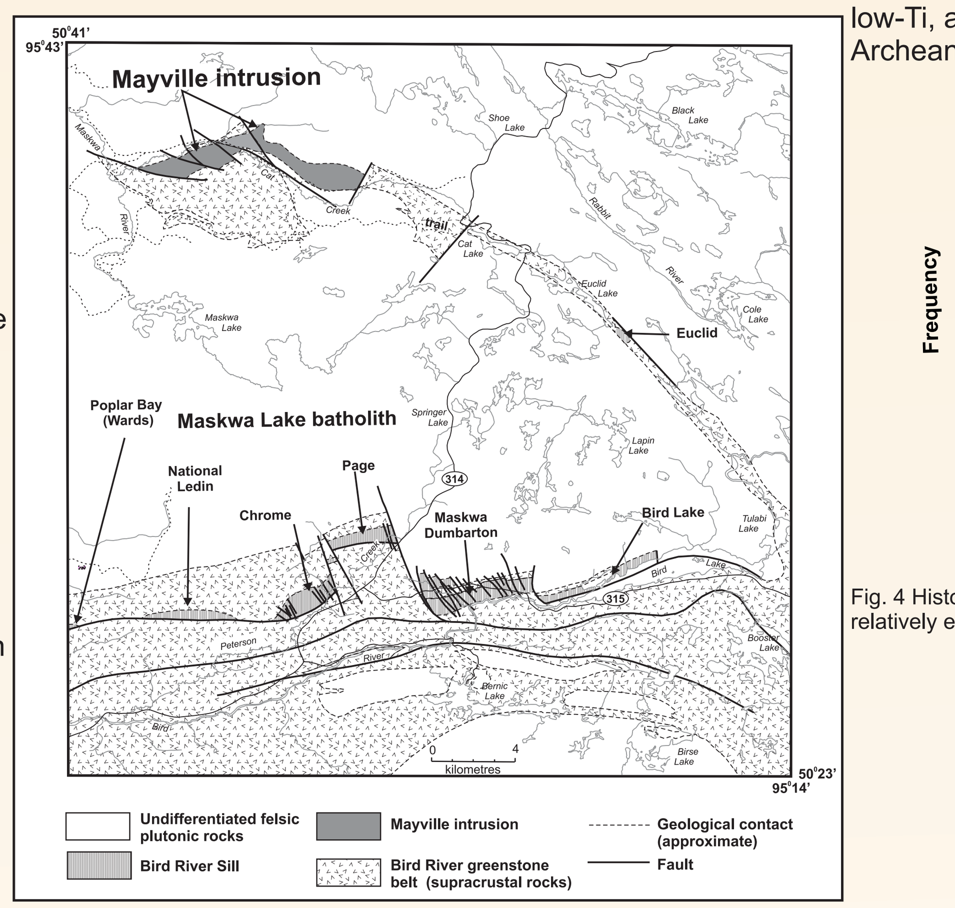

Fig.2 Simplified geology of the Neoarchean Bird River greenstone belt, showing the location of the Mayville mafic–ultramafic intrusion and the Bird River Sill (after Peck et al., 2002).

Introduction

The Mayville mafic-ultramafic intrusion hosts significant Ni-Cu-PGE-(Cr) mineralization, but its nature of magmas, relation to the Bird River Sill, and tectonic setting are poorly understood. Preliminary results of a reconnaissance mapping program and evaluation of existing geochemical data (Peck et al. 2000) are presented to address the questions and to provide assistance in planning detailed geological mapping for next field season.

Geological setting

The Mayville intrusion is a layered mafic–ultramafic body, 1.1 km wide, 10 km long, situating in the northern arm of the Neoarchean Bird River greenstone belt. Based on Peck et al. (2002), the Mayville intrusion is subdivided into two zones, i.e., a Heterolithic Breccia Zone (HBZ), and an upper anothositic to Leucoggabbro Zone (ALZ). Various rock types displaying varied textures occur in the HBZ that contains disseminated sulphide minerals (pyrrhotite, pentlandite, chalcopyrite ±pyrite) and locally semimassive to massive sulphide mineralization, particularly at the base contact. Chromitite bands locally occur. The ALZ rarely contains disseminated sulphide. Although metamorphosed to greenschist to amphobolite facies, igneous textures are well preserved.

Based on field relationships and internal textural variations, the Mayville intrusion is an overturned Neoarchean intrusion. An investigation of lithogeochemical data and petrography of 17 samples taken in the 2011 summer is being undertaken, which will enhance the results of evaluation of previous geochemical data acquired by the Manitoba Geological Survey. A geochronology sample was collected from differentiated phase present in the HBZ, which will be dated using U-Pb zircon and/or baddeleyite technique by the Geological Survey of Canada funded by a TGI 4 program.

Geochemical characteristics

The Mayville mafic-ultramafic rocks display tholeiitic, low-Ti, and high-Al characteristics, comparable to Archean megacrystic anorthosite suite (Ashwal,1993).

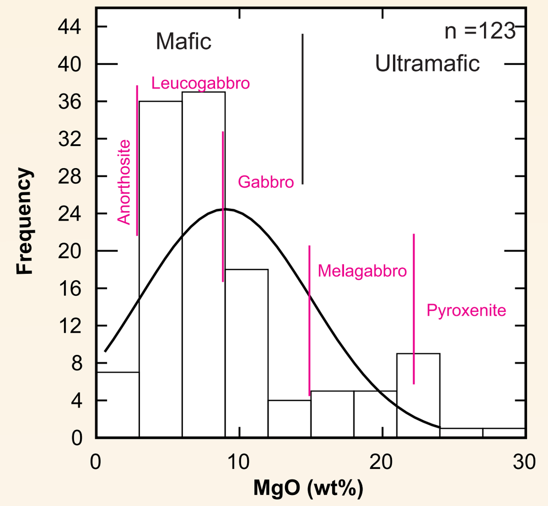

Fig. 4 Histogram of MgO contents (wt%) for the Mayville intrusion, showing a relatively evolved mafic–ultramafic intrusion. Date from Peck et al. (2000).

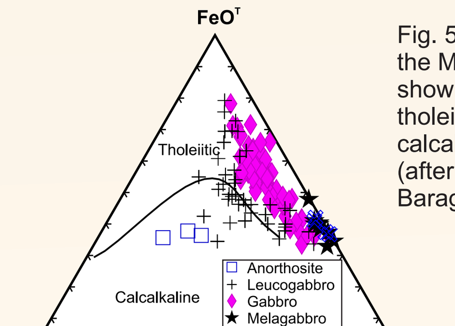

Fig. 5 AFM diagram for the Mayville intrusion, showing the division of tholeiitic and calcalkaline magmas (after Irvine and Baragar, 1971).

Fig. 3 Field photographs showing lithological features and details of mineralization in the Mayville mafic–ultramafic intrusion and associated country rock: a) pillowed basalt of the Northern MORB-type formation, with north-facing pillows discernible in centre and upper left (UTM Zone 15N, 316570E, 5611880N, NAD83); b) heterolithic breccia zone containing leucogabbro to anorthosite fragments and disseminated sulphide mineralization (UTM 314064E, 5612456N); c) anorthosite to leucogabbro, characterized by subrounded, stretched to irregular aggregates of glomeroporphyritic plagioclase (UTM 315426E, 5612597N); d) pyroxenite (left) in sharp contact (fault?) with very coarse grained leucogabbro (right) that is gradational to anorthosite (UTM 314666E, 5612593N); e) megacrystic leucogabbro (UTM 315037E, 5612797N); f) fine-grained gabbro dike with chilled margin, cutting pyroxenite and gabbro in the heterolithic breccia zone (UTM 314465E, 5612457N); g) medium-grained melagabbro with disseminated pyrrhotite and minor chalcopyrite (UTM 316612E, 5611924N); h) massive-sulphide layer (pyrrhotite with minor pentlandite and chalcopyrite) in Mustang Minerals Corp. diamond-drill hole May05-04 (drillcore photo courtesy of Mustang Minerals Corp.).

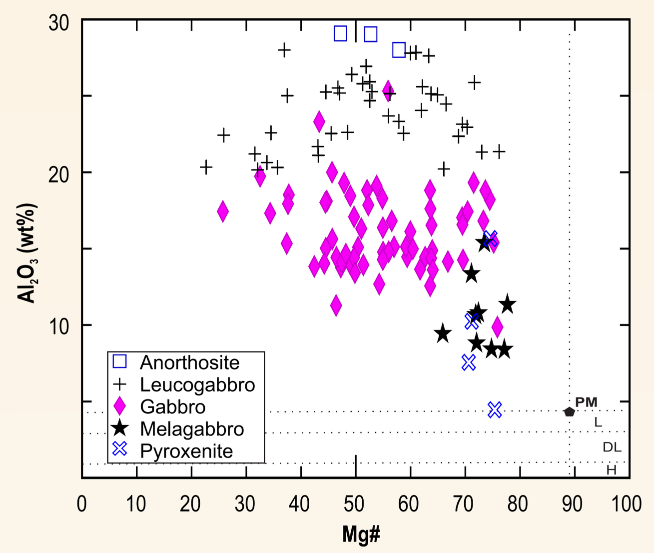

Fig. 6 Plot of Mg# vs. Al_2O_3 for mafic–ultramafic rocks in the Mayville intrusion. The boundaries of residual mantle peridotite, taken from Peltonen et al. (1998), are based on Al_2O_3 contents: harzburgite (H) < 1%; 1% < depleted lherzolite (DL) < 3%; and 3% < lherzolite (L) < 4.45%. The Mg# of the residual mantle rocks should be higher than that of primitive mantle (89.3). The Al_2O_3 contents of cumulate ultramafic rocks should be higher than the primitive mantle (4.45%), but with lower Mg# (<89.3). It should be noted that PM position is approximate, and can vary as a result of alteration. APM, primitive mantle (McDonough and Sun, 1995).

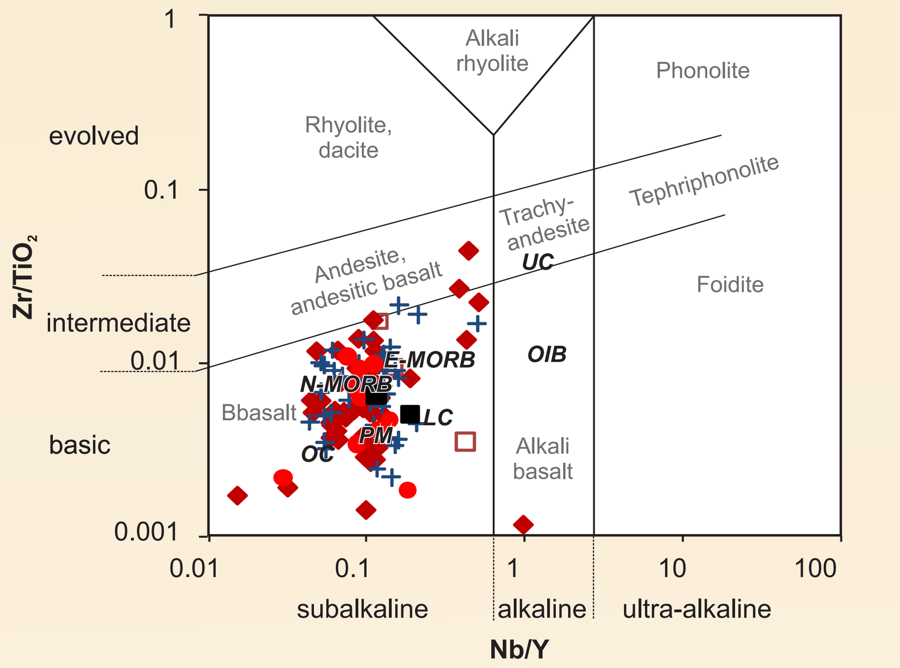

Fig.7 Plot of Zr/TiO_2 vs. Nb/Y (Pearce, 1996) for the Mayville intrusion. The TiO_2 values are quoted in ppm when calculating Zr/TiO_2 ratios. Rock type abbreviations (Sun and McDonough, 1989): PM, primitive mantle; N-MORB, normal mid-ocean-ridge basalt; E-MORB, enriched mid-ocean-ridge basalt; OIB, oceanic-island basalt. Crust abbreviations (Taylor and McLennan, 1985): UC, upper continental crust; LC, lower continental crust; OC, oceanic crust.

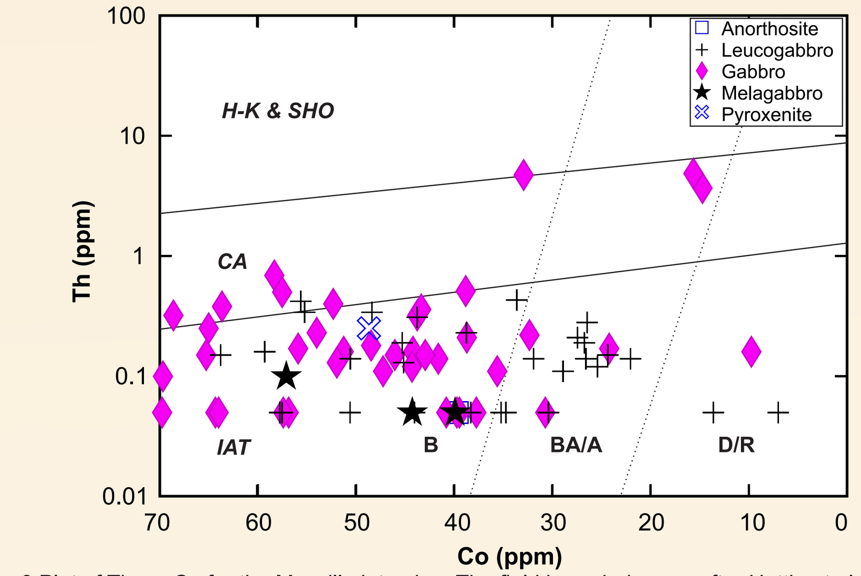

Fig. 8 Plot of Th vs. Co for the Mayville intrusion. The field boundaries are after Hattie et al. (2007). Rock series abbreviations: H-K & SHO, high-K calcalkaline and shoshonite; CA, calcalkaline; IAT, island-arc tholeiite. Rock type abbreviations: B, basalt; BA, basaltic andesite; A, andesite; D, dacite; R, rhyolite.

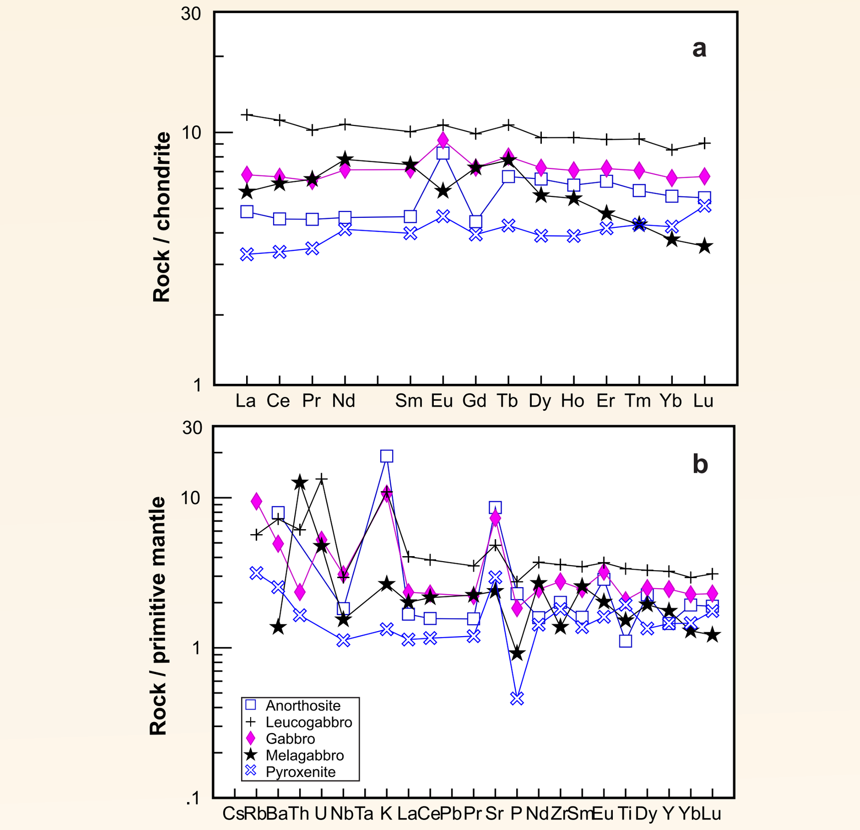

Fig. 9 Chondrite-normalized REE diagram (a) and primitive mantle–normalized extended element diagram (b) for the various rock types (Table GS-12-1) in the Mayville intrusion. Normalizing values from Sun and McDonough (1989).

Discussion

Based on discrimination diagrams, the magma source for the Mayville intrusion is subalkaline and exhibits a tholeiitic affinity, typical of a magmatic-arc or island-arc setting. On the TiO_2/MnO versus Mg# plot, most Mayville intrusion rocks plot exclusively in the volcanic-arc field. In the Zr/Y versus Zr discrimination diagram, however, these samples plot in both the oceanic- and continental-arc fields, consistent with a transition from oceanic/arc to continental-arc environment, as suggested by Gilbert (2007) and Gilbert et al. (2008).

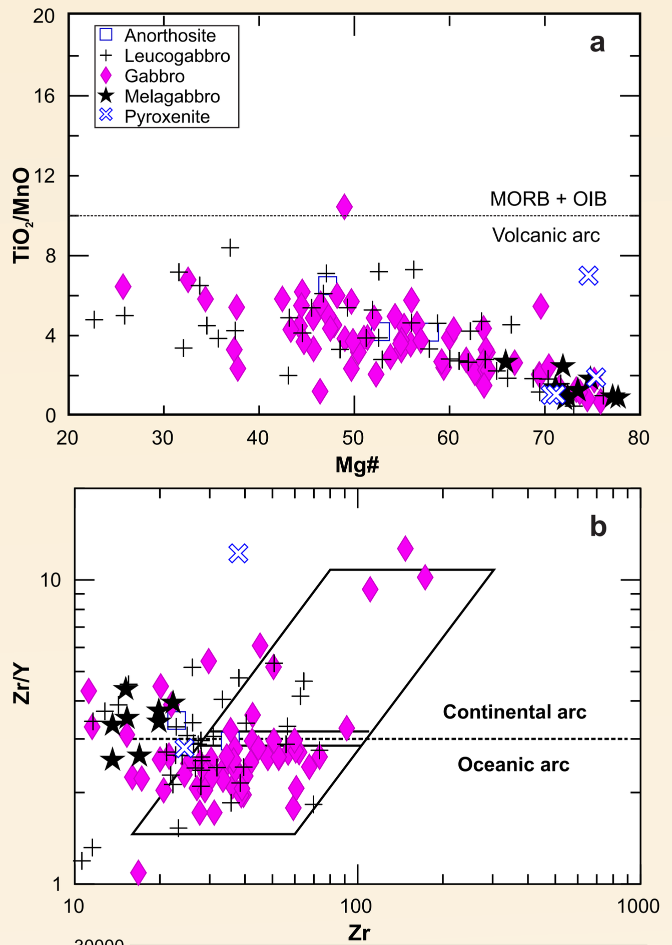

Fig.10 Plots for the Mayville intrusion of a) TiO_2/MnO ratio vs. Mg# (approximate line separating volcanic-arc from MORB and OIB fields from Mullen, 1983), and b) Zr/Y vs. Zr diagram (division between continental arc and oceanic arc from Pearce, 1983). Abbreviations: Mg# = MgO / (MgO + FeOT); MORB, mid-ocean-ridge basalt;

The maximum Ce/Y ratio in subalkaline basalt of the Northern MORB-type formation (footwall of the Mayville intrusion) is 0.98 (Gilbert, unpub. data, 2011), corresponding to a Moho depth of 21.3 km according to the model [D (±3 km) = 18.1 × ln(Ce/Y)max + 21.6] of Mantle and Collins (2008). This is consistent with a thinner crust (relative to that beneath the volcanic front of the BRGB arc), possibly related to an extensional setting such as incipient arc rifting in a back-arc environment, as pointed out by Gilbert et al. (2008).

Geochemical signatures of the Mayville intrusion, coupled with field relationships such as the chaotic nature of the heterolithic breccia zone and the presence of fragments of leucogabbro and anorthosite from the overlying ALZ that contains xenoliths of granitoid rocks and related gneiss, suggest that the Mayville intrusion may have been formed by multiple injections of tholeiitic magma that underwent fractional crystallization and some assimilation of the country rocks. A similar scenario was proposed by Mackie (2003). The magma generated beneath a relatively thin (<25 km) lithosphere may have begun to crystallize calcic plagioclase, which then rose and segregated to form one or more anorthosite layers.

These layers may subsequently have been broken up due to gravity instabilities or tectonic setting and, in part, became entrained within batches of late, turbulent magma at or close to the top of the magma chamber.Fractional crystallization and assimilation of the country rocks concurrent with magmatic emplacement would be an important requirement for segregating magmatic Ni-Cu-PGE sulphide mineralization (Lightfoot and Naldrett, 1999; Lesher et al., 2001; Peck et al., 2001). Plots of the Mayville intrusion rocks on the Ni versus Cu/Zr diagram display a trend consistent with sulphide segregation and fractional crystallization, suggesting that the intrusion was saturated with sulphide minerals. This hypothesis is supported by the presence of sulphide minerals as inclusions in early products of fractionation, such as pyroxene (amphibole) and chromite (Hiebert, 2003). Saturation, segregation and accumulation of sulphide minerals may have resulted in PGE-Ni-Cu concentration and mineralization, particularly in the basal part of the intrusion, and in the contact and transitional zones between different phases in the lower part of the intrusion. Although differentiation and crustal contamination may result in sulphide saturation in the residual magmas, an external source of sulphur appears necessary to trigger and segregate significant amounts of sulphide mineralization. Although early sulphide saturation in magmas is evident (Hiebert, 2003), an external source for sulphur has not yet been identified.

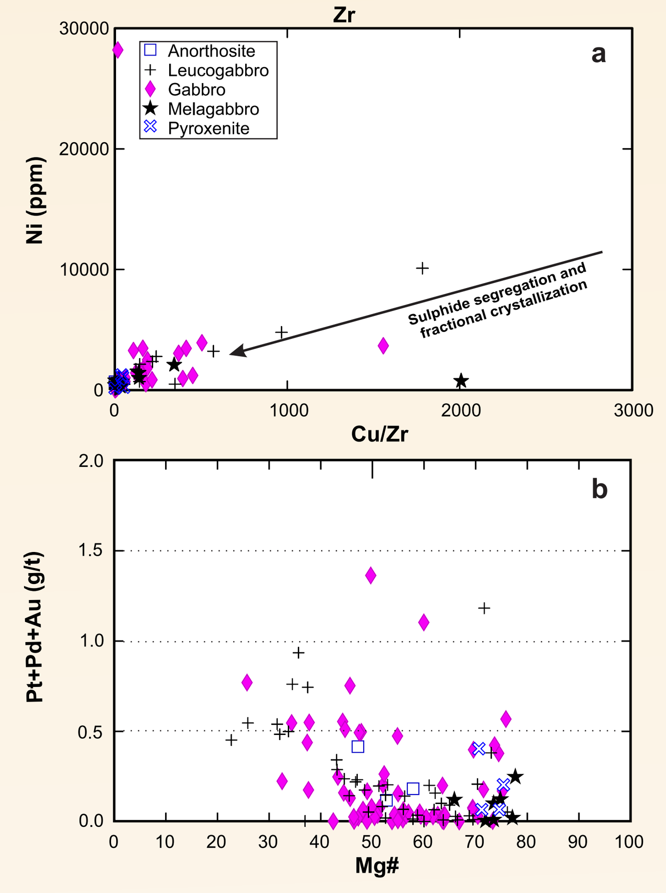

Fig. 11 Plots of Ni (ppm) vs. Cu/Zr (a) and noble metals (Pt+Pd+Au in g/t) vs. Mg# (b) for the Mayville intrusion.

Conclusions and future work

In summary, the Mayville intrusion is one of the major layered mafic–ultramafic intrusions in the BRGB. The dominant mafic part is subdivided into two zones: the heterolithic breccia zone and the anorthosite–leucogabbro zone. Based on preliminary analytical results, it is interpreted as an evolved mafic intrusion of tholeiitic affinity that evolved from a depleted mantle source. Preliminary assessment of its geochemical characteristics using tectonic discrimination diagrams suggests a magmatic-arc system as the tectonic setting, consistent with that proposed by Gilbert et al. (2008) for the BRGB. The Mayville intrusion hosts one Ni-Cu-(PGE) deposit within the heterolithic breccia zone (M2 deposit) and significant PGE and chromite mineralization.

Detailed geological mapping, together with geochemical and geochronological investigations in the course of this project, are expected to yield new insights into the intrusion's metallogeny. and the potential for base- and precious-metal mineralization associated with mafic–ultramafic intrusions in the BRGB in general and the Mayville intrusion in particular. The study will also address the relationship between Cr and Ni-Cu-PGE sulphide mineralization in these intrusions, as well as the potential to host Fe-Ti-V oxide mineralization. Finally, the study is expected to improve our overall understanding of the geological and tectonic evolution of the BRGB within the Superior Province.

Acknowledgments

We thank Mustang Minerals Corp. for providing access to their property and drill core, in particular C. Galeschuk, A. Dietz and R. Shegelski for their generous help in the field and constructive discussion.

References

Ashwal, L.D. 1993: Anorthosites; Springer-Verlag, Berlin, Germany, 422 p.
Gilbert, H.P. 2007: Stratigraphic investigations in the Bird River greenstone belt, Manitoba (part of NTS 52L5, 6); in Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 129–143.
Gilbert, H.P., Davis, D.W., Duguet, M., Kremer, P., Mealin, C.A. and MacDonald, J. 2008: Geology of the Bird River Belt, southeastern Manitoba (parts of NTS 52L5, 6); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Geoscientific Map MAP2008-1, scale 1:20000.
Hattie, A.R., Kerr, A.C., Pearce, J.A. and Mitchell, S.F. 2007: Classification of altered volcanic island arc rocks using immobile trace elements: development of the Th-Co discrimination diagram; Journal of Petrology, v. 48, p. 2341–2357.
Hoatson, D.H. 1998: Platinum-group element mineralisation in Australian Precambrian layered mafic-ultramafic intrusions; AGSO Journal of Australian Geology & Geophysics, v. 17, p. 139–151.
Irvine, T.N. and Baragar, W.R.A. 1971: A guide to the chemical classification of the common volcanic rocks; Canadian Journal of Earth Sciences, v. 8, p. 523–548.
Lesher, C.M., Burnham, O.M., Keays, R.R., Barnes S.J. and Hulbert, L. 2001: Trace-element geochemistry and ore-associated komatiites; Canadian Mineralogist, v. 39, p. 673–696.
Lightfoot, P.C. and Naldrett, A.J. 1999: Geological and geochemical relationships in the Voisey's Bay intrusion, Nain Plutonic Suite, Labrador, Canada; in Dynamic Processes in Magmatic Ore Deposits and their Application to Mineral Exploration, R.R. Keays, C.M. Lesher, P.C. Lightfoot and C.E.G. Farrow (ed.), Geological Association of Canada, Short Course Notes 13, p. 1–30.
Lightfoot, P.C., Hawesworth, C.J., Olshefsky, K., Green, T., Doherty, W. and Keays, R.R. 1997: Geochemistry of Tertiary tholeiites and picrites from Qeqertarssuaq (Disko Island) and Nuussuaq, West Greenland, with implications for mineral potential of comagmatic intrusions; Contributions to Mineralogy and Petrology, v. 128, p. 139–163.
Mackie, R.A. 2003: Emplacement history and PGE-enriched sulphide mineralization of the heterolithic breccia zone in the Mayville intrusion; B.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 135 p.
Mantle, G.W. and Collins, W.J. 2008: Quantifying crustal thickness variations in evolving orogens: correlation between arc basalt composition and Moho depth; Geology, v. 36, p. 87–90.
McDonough, W.F. and Sun, S.-s. 1995: The composition of the Earth; Chemical Geology, v. 120, p. 223–253.
Mullen, E.D. 1983: MnO/TiO2/P2O5: a minor element discriminant for basaltic rocks of oceanic environments and its implications for petrogenesis; Earth and Planetary Science Letters, v. 62, p. 53–62.
Mustang Minerals Corp. 2011: Annual Report 2010; Mustang Minerals Corp., 40 p.
Pearce, J.A. 1983: Role of the sub-continental lithosphere in magma genesis at active continental margins; in Continental Basalts and Mantle Xenoliths, C.J. Hawkesworth and M.J. Norry (ed.), Shiva Publishing Limited, Nantwich, United Kingdom, p. 230–249.
Pearce, J.A. 1996: A user's guide to basalt discrimination diagrams; in Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration, D.A. Wyman (ed.), Geological Association of Canada, Short Course Notes 12, p. 79–113.
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. Cabri (ed.), Canadian Institute of Mining and Metallurgy, Special Volume 54, p. 367–387.
Peck, D.C., Theyer, P., Hulbert, L., Xiong, J., Fedikow, M.A.F. and Cameron, H.D.M. 2000: Preliminary exploration database for platinum-group elements in Manitoba; Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Open File OF2000-5, CD-ROM.
Peltonen, P., Kontinen, A. and Huhma, H. 1998: Petrogenesis of the mantle sequence of the Jormua Ophiolite (Finland): melt migration in the upper mantle during Palaeoproterozoic continental break-up; Journal of Petrology, v. 39, p. 297–329.
Sun, S.-s. and McDonough, W.F. 1989: Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes; in Magmatism in the Ocean Basins, A.D. Saunders and M.J. Norry (ed.), Geological Society, Special Publication 42, p. 313–345.