Classification of Mafic–Ultramafic Intrusions in Ontario and Implications for Platinum-Group Element Mineralization

C. Vaillancourt[1], **R.A. Sproule**[2], **C.A. MacDonald**[1], **C.M. Lesher**[2], and **L.J. Hulbert**[3]
[1]Ontario Geological Survey, Sudbury, Ontario, Canada
[2]Mineral Exploration Research Centre and Department of Earth Sciences, Laurentian University, Sudbury, Ontario, Canada
[3]Geological Survey of Canada, Ottawa, Ontario, Canada
e-mail: christine.vaillancourt@ndm.gov.on.ca

A study of platinum group elements (PGE) potential of mafic–ultramafic intrusions in Ontario was initiated in January 2001 to follow up on multiple new discoveries of PGE occurrences in the province. This initiative represents a collaborate effort between the Ontario Geological Survey (OGS), the Geological Survey of Canada (GSC), and the Mineral Exploration Research Centre (MERC) at Laurentian University. The first phase of the study was funded by Operation Treasure Hunt, an aggressive government geoscience program designed to stimulate exploration activities and attract mineral investment in the province of Ontario. It will result in the development of a comprehensive database outlining critical geological information on mafic–ultramafic intrusions and PGE mineralization in Ontario and new lithogeochemical data for mafic–ultramafic intrusions across the province. This database will provide a key framework to increase our understanding of PGE mineralization in mafic–ultramafic intrusions in Ontario, which can hopefully be extended to the Superior, Grenville, and Southern provinces.

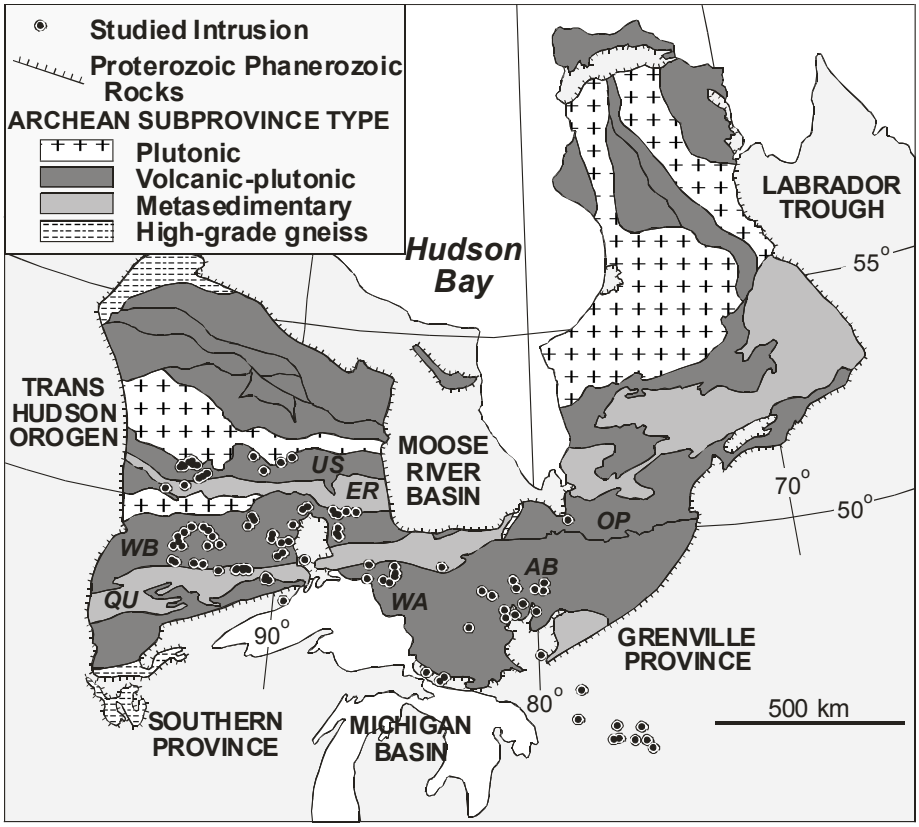

Figure 1. *Locations of mafic-ultramafic intrusions sampled in this study with major geological subdivisions. Geological Subprovinces: AB=Abitibi, ER=English River, OP=Opatica, QU=Quetico, UC=Uchi, WA=Wawa, WB=Wabigoon.*

Table 1. *Mineralization types, locations, tectonic settings, geochemical affinities, ages, and mineral associations of representative PGE mineralized intrusions in Ontario.*

Mineralization Type	Subtype	Examples	Tectonic Subdivision	Tectonic Setting	Composition	Chemical Affinity	Age (Ga)	Mineral Association
Type I (stratiform contact)		East Bull Lake, River Valley intrusion	SP	CR	M > UM	High-Al-TH	2.5	SUL
		Nipissing Diabase		Large dyke swarm	M >> UM	TH	2.2	SUL
		Coldwell Complex	MCR	CR	F-I >> M	ALK	1.1	SUL
		Seagull intrusion/ Wolf Mountain	MCR	CR	UM > M	TH	1.1?	SUL
Type II (stratabound disseminated)		Entwine Lake	WBG	RA?	I >> M	CAL	2.7	SUL
Type III (stratiform reef)	Lowermost zone	Coldwell Complex	MCR	CR	F-I >> M	ALK	1.1	MAG+ SUL
	Ultramafic zone	Chrome-Puddy Lake	WBG	Alpine intrusion?	UM >> M	TH?	2.7	CHR
		Nordica	AGB	RA	UM ~ M	TH	2.7	CHR
		Mann intrusion	AGB	RA	UM > M	TH - KOM	2.7	SIL
	Ultramafic-mafic transition zone	Centre Hill Complex	AGB	RA	M ~ UM	TH	2.7	SUL
	Mafic zone	Crystal Lake Gabbro	MCR	CR	M	TH?	1.1	CHR+SUL
Type IV (hydrothermally mobilized magmatic)		Lac des Iles	WBG	RA	M >> UM	TH	2.7	SUL?
Type V (tectonically /metamorphically mobilized)		Rathburn Lake		CR	M	TH?	~2.5?	SUL
Other		Otto Stock	AGB	RA	F-I > M	ALK	2.7	SIL+SUL?

Tectonic subdivision: WBG = Wabigoon, SP = Southern Province, AGB = Abitibi greenstone belt, MCR = Mid continental rift; Tectonic setting: CR = continental rift, RA = rifted arc; Composition: F = felsic, I = intermediate, M= mafic, UM = ultramafic; Geochemical affinity: TH = tholeiitic, ALK = alkaline, CAL = calc-alkaline, KOM = komatiitic; Mineralogical association: SUL = sulphide, MAG = magnetite, CHR = chromitite, SIL = silicate.

The province of Ontario comprises a diverse range of tectonic settings and contains a very large number of mafic–ultramafic and intermediate intrusions. The high potential for PGE deposits in Ontario is already proven by the Lac des Iles mine, one of three presently-operating PGE mines in the world. The purpose of this study is to develop a classification framework for mafic-ultramafic intrusions and PGE occurrences based on geochemistry of the host intrusion, mineralization styles, and tectonic setting, which may be used to help delineate areas where exploration should be focussed. To achieve these aims, we have sampled over 100 mafic to ultramafic and intermediate intrusions. This project is in the early stages, so this contribution includes only initial observations and interpretations.

Sampling was undertaken with the strategy of:

1. obtaining a good stratigraphic section through an intrusion, particularly for intrusions that have well-defined layering such as the Centre Hill Complex in the Abitibi greenstone belt (Theriault and Fowler, 1996);

2. obtaining samples from each of the known rock types within an intrusion, particularly for heterogeneous, multiphase intrusions such as the Entwine Lake intrusion in the Wabigoon Subprovince (Arnold et al., 2000; Stone, 2000);

3. focussing on phases within an intrusion known to be associated with PGE mineralization in other mineralized hosts, for example, areas of repeated magmatic stratigraphy, mafic–ultramafic contacts, varitextured and pegmatoidal zones, and highly altered zones.

A large diversity of PGE mineralization styles is observed in Ontario. Using a subdivision analogous to the scheme developed for Ni-Cu-PGE deposits by Lesher and Keays (in press), we have identified 5 major mineralization types: (1) **Type I** stratiform contact mineralization (e.g., Agnew, East Bull Lake, River Valley: Peck et al., 2001); (2) **Type II** stratabound disseminated mineralization (e.g., Entwine Lake: Arnold et al., 2000); 3) **Type III** stratiform reef-style mineralization (e.g., Centre Hill: this study), (4) **Type IV** hydrothermally-

mobilized magmatic mineralization (e.g., Lac des Iles: Brügmann et al., 1989); and (5) **Type V** tectonically mobilized mineralization (e.g., Rathburn Lake: Rowell and Edgar, 1986).

Determination of geochemical affinities is complicated in many cases by the effects of mineral accumulation. It is also possible that the mineralized portions of composite intrusions (e.g., mafic phases of intermediate suites) may differ in affinity from that of the host intrusion. However, preliminary observations indicate that (1) Type I stratiform contact mineralization is associated with a wide range of magma types, including komatiitic, tholeiitic, and alkalic magmas, (2) Type II stratabound disseminated mineralization is associated with calc-alkalic magmas, and (3) Type III stratiform reef-style mineralization is associated with tholeiitic and alkalic magmas. Thus, primary PGE mineralization is associated with a diversity of magma types.

Determination of the tectonic setting of many regions in Ontario is controversial. Type I stratiform contact mineralization is associated with continental rifts, rifted arcs, and dyke swarms. Type II stratabound disseminated mineralization is associated with rifted arcs. Type III stratiform reef-style mineralization is associated with continental rifts and rifted arcs. Thus, the tectonic setting does not appear to be an important parameter controlling PGE mineralization in Ontario. What is more important is that large volumes of high-MgO magmas must be generated.

In summary, PGE mineralization in Ontario:

(1) occurs in mafic to ultramafic rocks cumulate rocks, typically in layered intrusions or layered flows;
(2) is associated with a wide range of parental magma types, including komatiitic, tholeiitic, and alkaline magmas;
(3) occurs in a wide variety of rift-related settings; and
(4) appears to be most significant in the largest intrusions.

References

Arnold, J., Beakhouse, G., and James, R.S., 2000. The Entwine Lake intrusion: a Neoarchean Cu-Ni-PGE bearing intermediate to mafic complex in the western Wabigoon Subprovince, northwestern Ontario; Summary of Field Work and Other Activities, Ontario Geological Survey, Open File Report 2000, p.21-1 to 21-5.

Brügmann, G.E., Naldrett, A.J., and Macdonald, A.J., 1989. Magma mixing and constitution zone refining in the Lac des Iles Complex, Ontario; genesis of platinum-group element mineralization. Economic Geology, v. 84, p. 1557-1573.

Lesher, C.M., and Keays, R.R., in press, Komatiite-Associated Ni-Cu-(PGE) Deposits: Mineralogy, Geochemistry, and Genesis, in L.J. Cabri (Editor), The Geology, Geochemistry, Mineralogy, and Mineral Beneficiation of the Platinum-Group Elements, Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 54.

Peck, D.C., Keays, R.R., James, R.S., Chubb, P.T., and Reeves, S.J., 2001. Controls on the formation of contact-type platinum-group element mineralization in the East Bull Lake Intrusion. Economic Geology, v.96, p.559-581.

Rowell, W.F., and Edgar, A.D., 1976. Platinum-group element mineralization in a hydrothermal Cu-Ni sulfide occurrence, Rathburn Lake, northeastern Ontario. Economic Geology, v. 81, p. 1272-1277.

Stone, D., 2000. Geology, mineral chemistry and thermobarometry of the Entwine Stock, northwest Ontario: base metal, platinum group element and gold mineralization; Ontario Geological Survey, Open File Report 6021, p.1-8.

Theriault, R.D., and Fowler, A.D., 1996. Gravity driven and in situ fractional crystallization processes in the Centre Hill Complex, Abitibi Subprovince, Canada; evidence from bilaterally-paired cyclic units. Lithos, vol.39, no.1-2, p.41-55.