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Targeted Geoscience Initiative 4: Canadian Nickel-Copper-Platinum Group Elements-Chromium Ore Systems — Fertility, Pathfinders, New and Revised Models

Regional characterization of mafic-ultramafic intrusions in the Oxford-Stull and Uchi domains, Superior Province, Ontario

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Contribution to the Geological Survey of Canada's Targeted Geoscience Initiative 4 (TGI-4) Program (2010–2015)

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ABSTRACT

The mafic-dominated Big Mac, Fishtrap Lake, Highbank Lake, and Oxtoby Lake, the ultramafic-dominated Max, and the mafic-ultramafic Wabassi Main intrusions in the Oxford-Stull and Uchi domains of the Superior Province show significant potential for Fe-Ti-V-(P), Ni-Cu-(PGE), and/or Cr-(PGE) mineralization. The broadly layered Big Mac intrusion appears to have crystallized from an evolved high Fe-Ti basaltic parental magma that was injected from a feeder conduit below the northern part of the intrusion. The Fishtrap Lake and Highbank Lake intrusions represent parts of a large layered mafic-dominated igneous complex that formed from the injection of several pulses of basaltic magma. The genetically associated Max and Wabassi Main intrusions have crystallized from more primitive, basaltic parental magmas that were injected from a feeder conduit below the northwestern part of the Wabassi Main layered intrusion. In this magmatic system, the Max intrusion represents a magmatic conduit. The Oxtoby Lake intrusion appears to have crystallized from a differentiated basaltic parental magma and may represent an isolated intrusion.

INTRODUCTION

The eastern part of the Oxford-Stull and Uchi domains (Superior Province) hosts numerous mafic and ultramafic intrusions with great potential to host orthomagmatic mineralization, as attested by the occurrence of world-class Cr deposits (e.g. Black Thor), significant Ni-Cu-(platinum-group element (PGE)) deposits (e.g. Eagle's Nest), and Fe-Ti-V-(P) occurrences (e.g. Thunderbird).

This study is part of the high-magnesium ultramafic to mafic systems subproject under the Targeted Geoscience Initiative 4 (TGI-4; Houlé et al., 2012; Houlé and Metsaranta, 2013) of the Geological Survey of Canada (GSC). The main purpose of this research is to characterize mafic and ultramafic intrusions within the McFaulds Lake and Miminiska-Fort Hope greenstone belts (Fig. 1) in order to assess their economic potential and identify the most prospective intrusions. In this contribution, we present the main petrological, geochemical, mineralogical, and geochronological characteristics of some of these intrusions and discuss their internal structure, the nature of their parental magmas, the sulphide and oxide saturation history, their emplacement processes, and the implications for exploration.

RESULTS

Methodology

The studied intrusions are mostly covered by surficial deposits and are exposed only in scarce outcrops. For each intrusion, several representative samples were selected from diamond-drilled cores and rare outcrops for detailed petrographic, geochemical, and mineralogical studies (Table 1). The main characteristics for each intrusion are presented in Table 2.

All samples from the Big Mac intrusion and a few samples from the Fishtrap Lake, Oxtoby Lake (formerly Wabassi North), and Wabassi Main intrusions were analyzed for whole-rock geochemistry at the Ontario Geoscience Laboratories (Sudbury, Canada); the bulk of the samples from Fishtrap Lake, Highbank Lake, Max, Oxtoby Lake, and Wabassi Main intrusions were analyzed at ALS Minerals (Vancouver, Canada). Major elements have been recalculated to a 100% volatile-free basis and full analytical details are provided in Sappin et al. (in prep.).

Major element contents of silicates and Fe-Ti oxides, and minor and trace element contents of Fe-Ti oxides were determined using a CAMECA SX-100 five-spectrometer electron microprobe at Université

Sappin, A.-A., Houlé, M.G., Lesher, C.M., Metsaranta, R.T., and McNicoll, V.J., 2015. Regional characterization of mafic-ultramafic intrusions in the Oxford-Stull and Uchi domains, Superior Province, Ontario, *In:* Targeted Geoscience Initiative 4: Canadian Nickel-Copper-Platinum Group Elements-Chromium Ore Systems — Fertility, Pathfinders, New and Revised Models, (ed.) D.E. Ames and M.G. Houlé; Geological Survey of Canada, Open File 7856, p. 75–85.

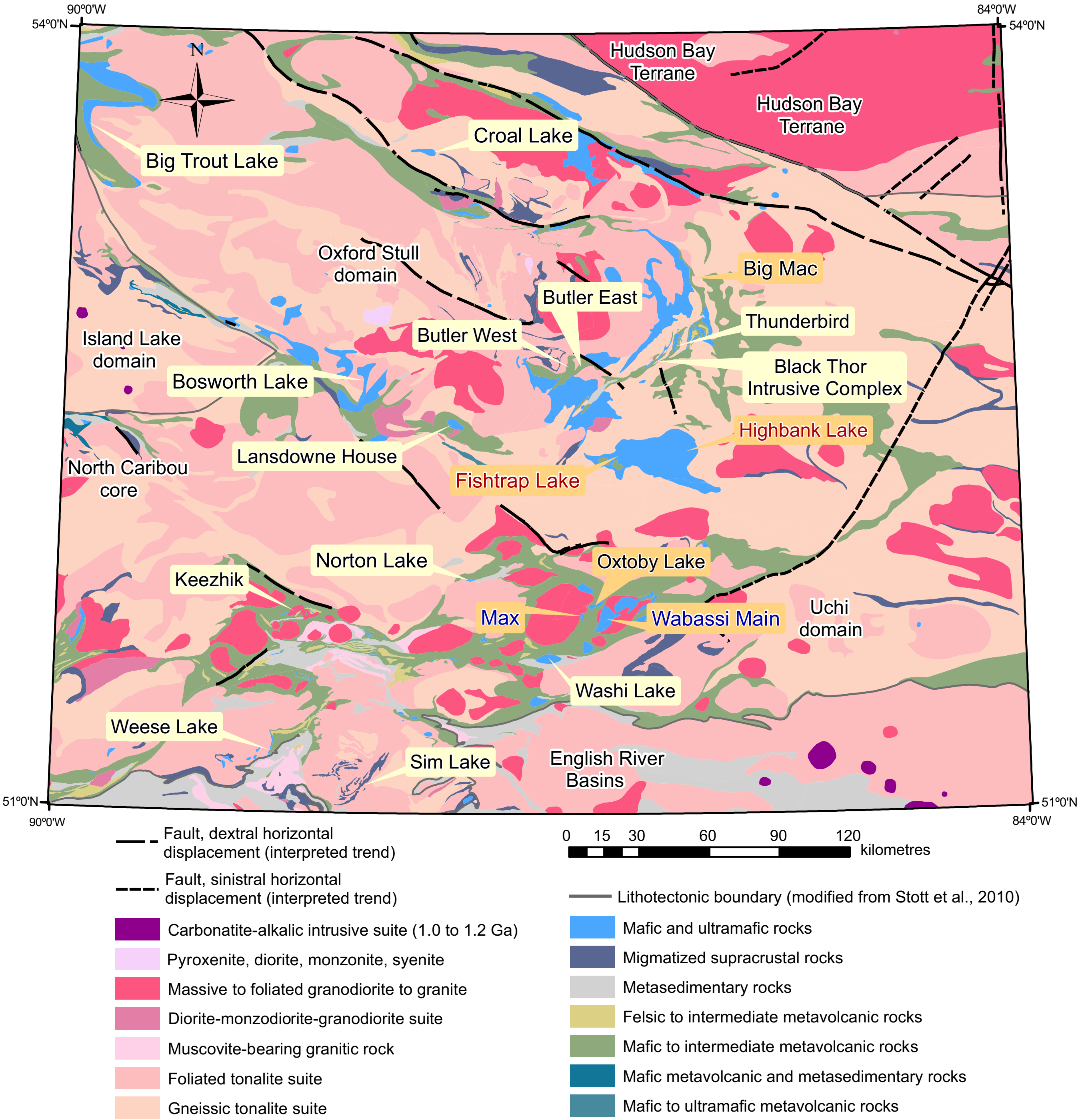

Figure. 1. Simplified geological map of the eastern Oxford-Stull and Uchi domains and general location of the main mafic and ultramafic intrusions in the area, including the studied (orange) intrusions (modified from Houlé and Metsaranta, 2013). The intrusions with their name in red and those with their name in blue are, respectively, genetically related. Geology modified from Stott and Josey (2009).

Laval (Québec, Canada). Analytical conditions are provided in Sappin et al. (in prep.).

Petrography

All mafic and ultramafic rocks have been metamorphosed to greenschist-amphibolite facies (Metsaranta and Houlé, 2012), but igneous textures are often preserved and igneous minerals are sometimes preserved, so the prefix “meta” has been omitted for simplicity.

Big Mac Intrusion

The 120 km^2 Big Mac intrusion is composed of gabbroic rocks (Fig. 2a), minor anorthosite, and rare pyroxenite. It also contains a few decimetre- to metre-thick semi-massive to massive magnetite-ilmenite layers (Fig. 2b). The pyroxenite and the oxide layers are

Table 1. Type and number of samples from each intrusion that were characterized through this study.

		Big Mac	Fishtrap Lake	Highbank Lake	Max	Oxtoby Lake	Wabassi Main
Petrographic study							
	Core	40 (5 ddhs)	-	113 (14 ddhs)	29 (7 ddhs)	6 (1 ddh)	75 (15 ddhs)
	Surface	-	9	3	-	-	29
Geochemistry							
Whole rock	*Core*	57	-	83	23	6	50
	Surface	-	6	1	-	-	22
Mineral	*Core*	20	-	40	8	3	13
	Surface	-	6	1	-	-	6

Note:40 (5 ddhs) = 40 samples from 5 diamond drillholes

restricted to the northern part of the intrusion. The gabbroic rocks, anorthosite, and pyroxenite mostly contain plagioclase and amphibole, with rare preserved clinopyroxene and up to 35% Fe-Ti oxides. They display relict cumulate textures with cumulus plagioclase. Semi-massive oxides (40–80% Fe-Ti oxides) and massive oxides (>80% Fe-Ti oxides) mostly contain large magnetite crystals with ilmenite exsolutions, rare silicate phases, and up to 20% disseminated to net-textured Fe-Ni-Cu sulphides.

Fishtrap Lake and Highbank Lake Intrusions

The 270 km^2 Fishtrap Lake intrusion is composed of layers of gabbroic rocks interbedded with layers of anorthosite (Fig. 2c). They mostly contain plagioclase and amphibole. The gabbroic rocks and anorthosite are likely former plagioclase cumulates.

The 420 km^2 Highbank Lake intrusion is composed of layers of gabbroic rocks interlayered with layers of anorthosite and pyroxenite (Fig. 2d) and a few decimetre-thick semi-massive magnetite-ilmenite layers restricted to the north-central part of the intrusion. The gabbroic rocks, anorthosite, and pyroxenite commonly contain plagioclase and amphibole, with up to 40% Fe-Ti oxides and up to 40% disseminated to net-textured Fe-Cu-Ni sulphides. The gabbroic rocks and pyroxenite are likely former pyroxene-plagioclase cumulates. The anorthosite is likely former plagioclase cumulates. Semi-massive oxides (60–75% Fe-Ti oxides) mostly contain large magnetite crystals with ilmenite exsolutions and rare silicate phases.

Max, Oxtoby Lake, and Wabassi Main Intrusions

The 4 km^2 Max intrusion is composed of peridotite (Fig. 2e), minor olivine pyroxenite, pyroxenite, plagioclase-bearing pyroxenite, and rare gabbroic rocks. The peridotite and olivine pyroxenite mostly contain olivine and pyroxene, with up to 15% disseminated to net-textured Fe-Ni-Cu sulphides. They display cumulate textures with cumulus olivine-plagioclase± chromite and poikilitic pyroxene. The pyroxenite, plagioclase-bearing pyroxenite, and gabbroic rocks primarily contain amphibole and plagioclase.

The 12 km^2 Oxtoby Lake intrusion is composed of gabbroic rocks (Fig. 2f). They mostly contain plagioclase and amphibole.

The 42 km^2 Wabassi Main intrusion is composed of gabbroic rocks, olivine gabbroic rocks, local anorthosite, minor feldspathic peridotite (Fig. 2g) and Fe-Ti oxide-rich ferrogabbroic rocks, and subordinate hornblende-bearing gabbroic rocks (Fig. 2h). The olivine gabbroic rocks and the peridotite are mainly restricted to the western and northern parts of the intrusion, the ferrogabbroic rocks to the southeastern part, and the hornblende-bearing gabbroic rocks near the western margin and in the central and the southeastern parts. The gabbroic rocks, olivine gabbroic rocks, anorthosite, and peridotite mostly comprise pyroxene, plagioclase, olivine, and a few centimetre- to decimetre-thick intervals with up to 75% pyrrhotite-dominated disseminated, net-textured, and semi-massive Fe-Cu-Ni sulphides. The gabbroic rocks, olivine gabbroic rocks, and anorthosite display cumulate textures with cumulus pyroxene-plagioclase±olivine±Fe-Ti oxides and, locally, poikilitic pyroxene; the peridotite displays cumulate textures with with cumulus olivine-plagioclase±chromite and poikilitic pyroxene. The hornblende-bearing gabbroic rocks mainly contain amphibole, plagioclase, and quartz.

Whole-Rock Chemistry

Big Mac Intrusion

Big Mac mafic and ultramafic rocks commonly have low to intermediate SiO_2 contents, low MgO contents, and locally high FeO_t contents (Fig. 3, Table 2).

Big Mac mafic rocks are enriched in highly incompatible lithophile elements (HILE) relative to moderately incompatible lithophile elements (MILE) but enriched to depleted in Nb-Ta relative to HILE of similar compatibility, enriched to depleted in Hf-Zr relative to MILE of similar compatibility, and enriched in Ti relative to MILE of similar compatibility (Table 2). Big Mac pyroxenite is depleted in HILE relative to MILE but their profiles show weak negative anomalies in Zr and Hf and pronounced positive anomalies in Ti compared with the rare earth elements (Table 2).

Fishtrap Lake and Highbank Lake Intrusions

Fishtrap Lake mafic rocks have intermediate SiO_2 contents and low MgO and FeO_t contents (Fig. 3, Table 2). Highbank Lake mafic and ultramafic rocks have generally low to intermediate SiO_2 contents, low to high MgO contents, and locally high FeO_t contents (Fig. 3, Table 2). Overall, the composition of the mafic rocks from the Fishtrap Lake intrusion follows the same compositional trends defined by the mafic and ultramafic rocks of the Highbank Lake intrusion (Fig. 3).

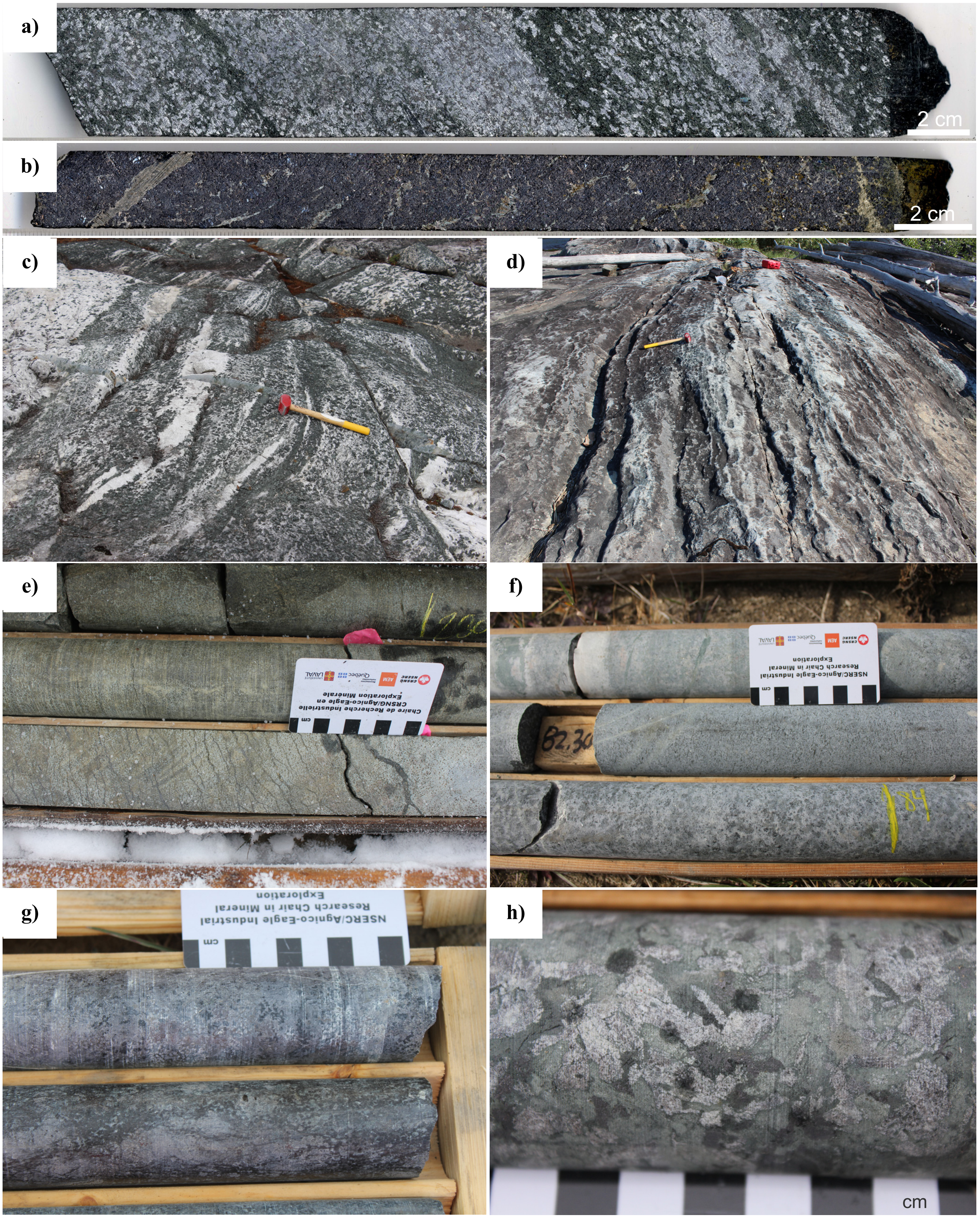

Figure 2. Photographs of outcrop and drill core. **a)** Gabbroic rocks from the Big Mac intrusion (BM09-04, 43.28 m). **b)** Massive Fe-Ti oxides from the Big Mac intrusion (BM09-04, 23.70 m). **c and d)** Modal magmatic layering in the Fishtrap Lake and Highbank Lake intrusions. The hammer is ~38 cm long. **e)** Peridotite from the Max intrusion (08MX-02, 282.84 m). **f)** Hornblende-bearing gabbroic rocks from the Oxtoby Lake intrusion (08WA-02, 82.30 m). **g)** Peridotite from the Wabassi Main intrusion (10WA-05, 240.48 m). **h)** Hornblende-bearing gabbroic rocks from the Wabassi Main intrusion (11WA-18, 30.71 m).

Table 2. Summary of the main petrological, geochemical, and mineralogical characteristics of the studied intrusions.

	Big Mac		**Fishtrap Lake**	**Highbank Lake**		**Max**		**Oxtoby Lake**	**Wabassi Main**	
Location	McFaulds Lake greenstone belt					Miminiska-Fort Hope greenstone belt				
Mafic/Um ratio	Mafic >>> Um		Mafic	Mafic > Um		Um >>> Mafic		Mafic	Mafic > Um	
Internal structure	Broadly layered		Layered	Layered		-		-	Layered	
Size	1–4 km x 60 km 120 km^2		27 km x 16 km 270 km^2	21 km x 35 km 420 km^2		1.5 km x 3 km 4 km^2		7 km x 2 km 12 km^2	9 km x 11 km 42 km^2	
Lithology	Gabbroic rocks, minor anorthosite, pyroxenite, and semi-massive to massive Fe-Ti oxides		Gabbroic rocks, anorthosite	Gabbroic rocks, anorthosite, pyroxenite, and minor semi-massive Fe-Ti oxides		Peridotite, minor olivine pyroxenite, pyroxenite, plagioclase-bearing pyroxenite, and gabbroic rocks		Gabbroic rocks	Gabbroic rocks (± olivine), anorthosite, minor peridotite	
Igneous mineralogy	Pl, Cpx, Opx?, Mag, Ilm, Ap		Pl, Opx, Cpx?, Ilm, Ap	Pl, Px?, Ilm, Mag, Ap		Ol, Opx, Cpx?, Pl, Chr		Pl, Px?, Mag, Ilm, Ap	Cpx, Opx, Pl, Ol, Ilm, Mag, Chr, Ap	
Mineralization	Fe-Ti-V-(P) 76% FeO$_t$, 19% TiO$_2$, 0.58% V$_2$O$_5$		- -	Fe-Ti-V, Cr-(PGE) 64% FeO$_t$, 17% TiO$_2$, 0.98% V$_2$O$_5$ (www.northernshield.com/properties/highbank)		Ni-Cu-(PGE) 0.31% Ni, 0.18% Cu, 0.32 ppm Pt+Pd (Vaillancourt and Bliss, 2010)		- -	Ni-Cu-(PGE) 3.5% Cu, 0.24% Ni (Vaillancourt et al., 2011)	
Geochemistry	**Mafic**	**Um**	**Mafic**	**Mafic**	**Um**	**Mafic**	**Um**	**Mafic**	**Mafic**	**Um**
Major elements										
SiO$_2$ (wt.%)	32–55	38	50–52	28–52	40–53	51–52	41–49	47–50	44–59	44–49
MgO (wt.%)	0–11	10	0–7	1–12	6–24	9–12	23–38	4–6	2–16	24–28
FeO$_t$ (wt.%)	2–36	35	1–8	3–37	11–27	6	10–18	9–13	4–20	13–16
Trace Elements										
HILE/MILE ratio	HILE>MILE	HILE<MILE	HILE<MILE to HILE>MILE	HILE<MILE to HILE>MILE	HILE<MILE to HILE>MILE	HILE>MILE	HILE>MILE	HILE>MILE	HILE≈MILE to HILE>MILE	HILE≈MILE to HILE>MILE
Nb/Th	0.9–60.8	14.68	6.3–7.3	0.5–61.4	0.4–6.7	3.4–3.8	2.3–7.5	2.3–7.1	0.7–158.3	1.8–5.5
Ta/Th	0.1–4.5	1.0	nd	0.0–6.7	0.0–0.6	0.3–0.5	0.2–0.8	0.1–0.3	0.1–10.0	0.1–0.5
Hf/Y	0.0–0.5	0.0	0.1–0.2	0.0–0.3	0.1–2.0	0.1	0.1–0.2	0.1–0.2	0.0–0.4	0.1–0.2
Zr/Y	0.8–13.4	1.5	1.5–6.0	0.3–15.0	2.0–81.9	2.8–6.3	3.6–6.2	2.9–6.9	0.8–15.0	5.3–9.5
Ti/Y	138–26834	2209	397–1093	219–19709	143–4914	321–404	197–612	470–949	52–5965	276–660
Mineral Composition	**Mafic**	**Um**	**Mafic**	**Mafic**	**Um**	**Mafic**	**Um**	**Mafic**	**Mafic**	**Um**
Olivine	-		-	-		-	Mg#$_{80–67}$	-	Mg#$_{78–19}$	Mg#$_{78–73}$
Orthopyroxene	-		Mg#$_{53}$	-		-	Mg#$_{84-82}$	-	Mg#$_{84–44}$	Mg#$_{84–77}$
Clinopyroxene	-	Mg#$_{68-60}$	-	-		-		-	Mg#$_{80–56}$	Mg#$_{95–91}$
Plagioclase	An$_{90–20}$	-	An$_{71–31}$	An$_{99–24}$	An$_{86–36}$	-		An$_{68–47}$	An$_{96–31}$	An$_{100–61}$
Magnetite	V ≤ 9319 Ni ≤ 230 Cr ≤ 11077 Ti ≤ 14090	V ≤ 2830 Ni ≤ 100 Cr ≤ 9530 Ti ≤ 1190	-	V ≤ 10726 Ni ≤ 731 Cr ≤ 21900 Ti ≤ 65330	V ≤ 7749 Ni ≤ 786 Cr ≤ 13869 Ti ≤ 28790	-	No primary Mag	V ≤ 3380 Ni ≤ 1290 Cr ≤ 2020 Ti ≤ 53938	V ≤ 12380 Ni ≤ 1713 Cr ≤ 30714 Ti ≤ 123685	No primary Mag
Ilmenite	V ≤ 5308 Ni ≤ 130 Cr ≤ 766 Mn ≤ 22304	V = 0 Ni ≤ 134 Cr ≤ 360 Mn ≤ 16040	V = nd Ni ≤ 120 Cr ≤ 1530 Mn ≤ 20090	V ≤ 3881 Ni ≤ 180 Cr ≤ 2853 Mn ≤ 30498	V = 0 Ni ≤ 100 Cr ≤ 790 Mn ≤ 38610	-	No primary Ilm	V ≤ 3710 Ni = 0 Cr ≤ 710 Mn ≤ 12990	V ≤ 5 290 Ni ≤ 680 Cr ≤ 4 190 Mn ≤ 14610	No primary Ilm
Mag/Ilm ratio	Mag > Ilm	Mag > Ilm	Ilm >>> Mag	Ilm > Mag	Ilm > Mag	-	-	Mag > Ilm	Ilm > Mag	-
Parental magma	Basaltic with high-Fe and Ti contents		Basaltic	Basaltic with high-Fe and Ti contents		Basaltic		Basaltic	Basaltic	

Abbreviations: Ap = appatite, Chr = chromite, Cpx = clinopyroxene, HILE = highly incompatible lithophile elements (e.g. Th, Nb, Ta, light rare earth elements), Ilm = ilmenite, Mag = magnetite, MILE = moderately incompatible lithophile elements (e.g. Zr, Hf, Ti, middle rare earth elements, Y), nd = not determined, Ol = olivine, Opx = orthopyroxene, PGE = platinum-group element, Pl = plagioclase, Px = pyroxene, Um = ultramafic

Note: Mg# (Mg number) = 100×Mg/(Mg+Fe^{2+}) in atomic proportions, An (anorthite content) = 100×Ca/(Na+K+Ca) in atomic proportions.
V, Ni, Cr, Ti, Mn concentrations in magnetite and ilmenite are in ppm.

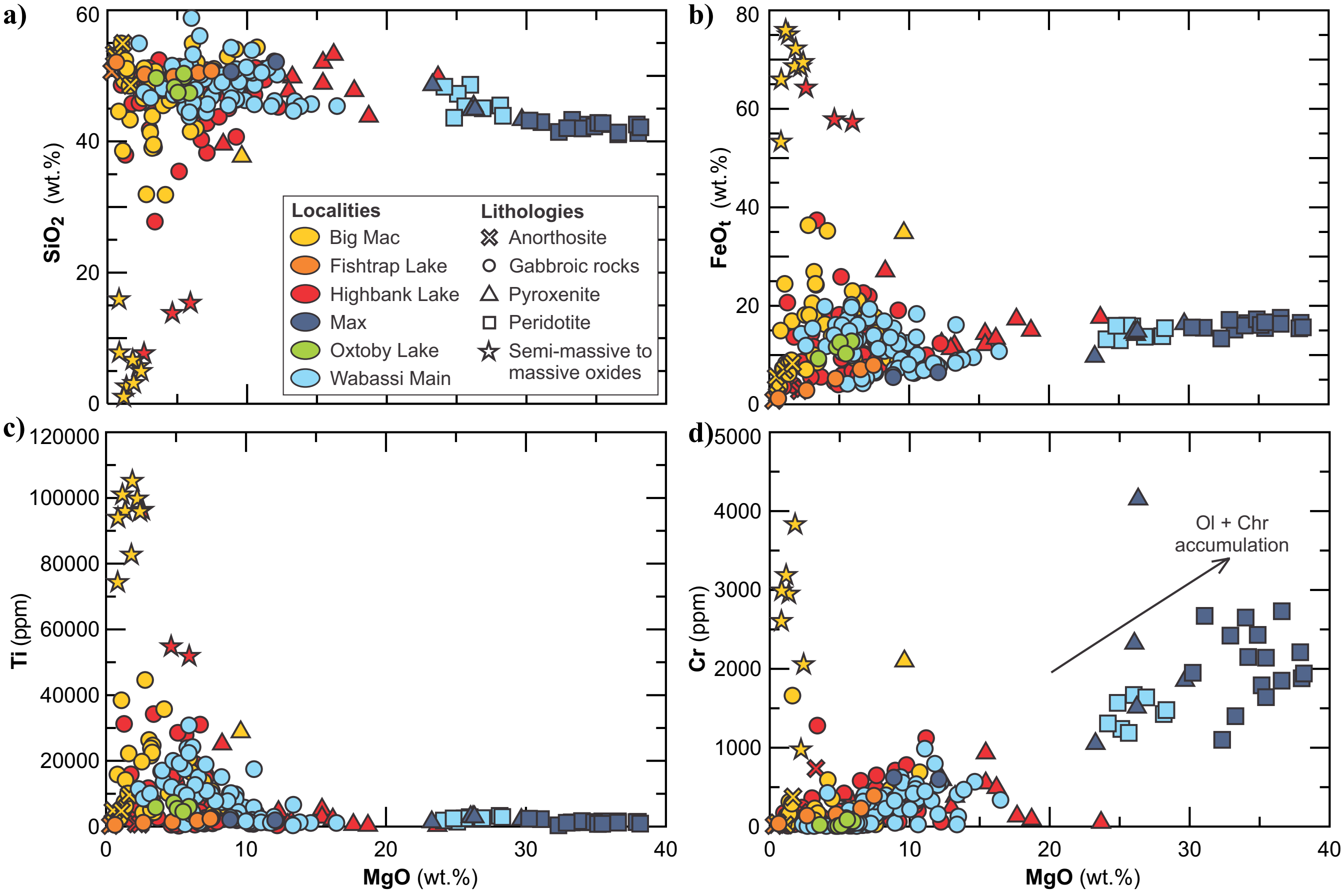

Figure 3. Binary plots showing **(a)** SiO_2 versus MgO, **(b)** FeO_t versus MgO, **(c)** Ti versus MgO, and **(d)** Cr versus MgO. Abbreviations: Chr = chromite, Ol = olivine.

Fishtrap Lake and Highbank Lake mafic and ultramafic rocks are slightly depleted to enriched in HILE relative to MILE but less enriched in Nb relative to HILE of similar compatibility, and depleted in Hf-Zr relative to MILE of similar compatibility (Table 2). Highbank Lake mafic and ultramafic rocks may also be enriched to depleted in Ta relative to Nb and in Hf-Zr-Ti relative to MILE of similar compatibility (Table 2).

Max, Oxtoby Lake, and Wabassi Main Intrusions

Max mafic and ultramafic rocks have intermediate SiO_2 contents, low to high MgO contents, and low to intermediate FeO_t contents (Fig. 3, Table 2). Oxtoby Lake mafic rocks have intermediate SiO_2 and FeO_t contents and low MgO contents (Fig. 3, Table 2). Wabassi Main mafic and ultramafic rocks have intermediate SiO_2 contents, low to high MgO contents, and low to intermediate FeO_t contents (Fig. 3, Table 2). The composition of the intrusive rocks of the three intrusions shows well correlated trends (Fig. 3).

Max mafic and ultramafic rocks are enriched in HILE relative to MILE but less enriched in Nb and, locally, Ta relative to HILE of similar compatibility (Table 2). Oxtoby Lake mafic rocks are enriched in HILE relative to MILE but less enriched in Nb-Ta relative to HILE of similar compatibility and less enriched in Zr-Hf relative to MILE of similar compatibility (Table 2). Wabassi Main mafic and ultramafic rocks are unenriched to enriched in HILE relative to MILE but less enriched in Nb relative to HILE of similar compatibility and enriched to depleted in Ta relative to Nb and, locally, in Hf-Zr-Ti relative to MILE of similar compatibility (Table 2).

Mineral Chemistry

Big Mac Intrusion

Big Mac intrusive rocks contain plagioclase (An_{90-20}, where An=100×Ca/(Na+K+Ca)) and rare clinopyroxene ($Mg\#_{68-60}$, where Mg#=100×Mg/(Mg+Fe^{2+})) with mostly evolved compositions (Table 2). Big Mac intrusive rocks contain magnetite and ilmenite with wide compositional variations (Table 2).

Composition of the Big Mac intrusive rocks varies with location. To the north, plagioclase has the most primitive composition (up to An_{84}) and magnetite and ilmenite are richest in compatible elements in mafic magmas such Al-Mg-V-Ni-Cr. To the south, plagioclase has the most evolved composition (up to An_{49})

and magnetite and ilmenite are poor in Al-Mg-V-Ni-Cr and locally rich in Ti-Mn-Zn.

Fishtrap Lake and Highbank Lake Intrusions

Fishtrap Lake intrusive rocks contain plagioclase ($An_{71\text{-}31}$) and rare relicts of orthopyroxene ($Mg_{\#53}$) with relatively evolved compositions (Table 2). Highbank Lake intrusive rocks contain plagioclase ($An_{99\text{-}24}$) with wide compositional variations (Table 2). Fishtrap Lake and Highbank Lake intrusive rocks contain magnetite and ilmenite with wide compositional variations (Table 2).

Max, Oxtoby Lake, and Wabassi Main Intrusions

Max ultramafic cumulates contain olivine ($Mg\#_{80–67}$) and orthopyroxene ($Mg\#_{84–82}$) with intermediate compositions (Table 2). Oxtoby Lake hornblende-bearing gabbroic rocks contain plagioclase ($An_{68–47}$) with evolved compositions (Table 2). Wabassi Main ultramafic cumulates contain olivine ($Mg\#_{78–73}$), orthopyroxene ($Mg\#_{84–77}$), clinopyroxene ($Mg\#_{95–91}$), and plagioclase ($An_{100–61}$) with intermediate compositions. Wabassi Main gabbroic rocks (± olivine) and anorthosite contain olivine ($Mg\#_{78–19}$), orthopyroxene ($Mg\#_{84–44}$), clinopyroxene ($Mg\#_{80–56}$), and plagioclase ($An_{96–37}$) with evolved to intermediate compositions. Wabassi Main hornblende-bearing gabbroic rocks contain plagioclase ($An_{66–31}$) with evolved compositions.

Composition of the Wabassi Main intrusive rocks varies with location. Near the western contact, olivine (up to $Mg\#_{78}$), orthopyroxene (up to $Mg\#_{84}$), clinopyroxene (up to $Mg\#_{95}$), and plagioclase (up to An_{100}) have the most primitive composition. In the southeastern area, olivine is absent and orthopyroxene (up to $Mg\#_{57}$), clinopyroxene (up to $Mg\#_{73}$), and plagioclase (up to An_{71}) have more evolved composition.

Geochronology

The Highbank Lake intrusion has a U-Pb zircon age of ca. 2808 Ma (Stott, 2008). Preliminary U-Pb isotope dilution thermal ionization mass spectrometry (ID-TIMS) zircon data from hornblende-plagioclase-bearing gabbroic rock suggest crystallization ages of 2810 Ma, 2717 Ma, and 2727 Ma (McNicoll, unpublished data) for the Fishtrap Lake, Oxtoby Lake, and Wabassi Main intrusions, respectively.

DISCUSSION

Internal Structure

The internal structure of the broadly layered Big Mac intrusion is not well constrained. Based on the presence of more primitive whole-rock and mineral chemical signatures in the northern part and more evolved signatures in the southern part, and assuming that it fractionated upwards, the intrusion appears to young to the south.

The Fishtrap Lake and Highbank Lake intrusions are layered, but their internal structure is thus far poorly constrained. Preliminary mineral chemical data suggest that these intrusions are not systematically fractionated and therefore formed from multiple magma replenishments.

The Max and Oxtoby Lake intrusions do not exhibit any internal structural variations. The Max intrusion is composed primarily of cumulate rocks, which suggests that it represents a magmatic conduit in which cumulus olivine ± pyroxenes accumulated. The Oxtoby Lake intrusion is composed primarily of gabbroic rocks and likely represents an undifferentiated intrusion.

The Wabassi Main intrusion is layered with an interpreted stratigraphic top to the southeast based on geochemistry and mineral chemistry.

Parental Magmas

The whole-rock major element, whole-rock trace element, and mineral chemical characteristics of the studied intrusions (Table 2) suggest that they are mantle-derived rather than crustally derived magmas. The $Mg\#_{80}$ and $Mg\#_{78}$ maximum Mg numbers of olivine and $Mg\#_{84}$ maximum Mg numbers of orthopyroxene in the Max and Wabassi Main intrusions suggest that they crystallized from basaltic rather than picritic or komatiitic parental magmas. The Big Mac, Fishtrap Lake, Highbank Lake, and Oxtoby Lake intrusions do not contain any relict igneous olivine but the composition of the whole rocks, orthopyroxene, clinopyroxene, and plagioclase suggests they are more evolved. This suggests that they are part of a larger magmatic system, the lower parts in which crystal fractionation occurred.

Sulphide and Oxide Saturation History

Platinum group element data are needed to better constrain the sulphide saturation history of the intrusions, but the higher Ni contents of olivine in peridotite of the Wabassi Main intrusion suggest that the parental magma did not segregate significant amounts of sulphide and was therefore fertile; the lower Ni contents of olivine in other lithologies of the Wabassi Main intrusion and in the Max intrusion suggest that those rocks formed from magmas that had segregated sulphides. The variations from undepleted to depleted suggest that this occurred at higher levels (perhaps locally) rather than at lower levels (which would have left all of the rocks depleted).

All of cumulate rocks in the Max and Wabassi Main intrusions are enriched in Cr relative to the non-cumulate rocks, suggesting that all of the magmas were saturated in chromite (Fig. 3d). This is consistent with the relatively evolved inferred compositions of the parental magmas.

Form and Emplacement

The Big Mac intrusion appears to have the form of a subconcordant sill. The rocks in the northern part of the intrusion are more primitive and may represent a more vent-proximal facies, whereas the rocks in the southern part are more evolved and may represent a more distal facies.

The Fishtrap Lake and Highbank Lake intrusions are interpreted to be genetically related because of their geographic proximity and their petrographic, mineralogical, geochemical, and geochronological similarities. They represent the largest known mafic intrusive complex in the McFaulds Lake area, which we have called the Highbank-Fishtrap intrusive complex (HFIC).

The Max and Wabassi Main intrusions appear to be genetically related based on similarities in ultramafic cumulate textures, geochemical signatures, and silicate mineral compositions. However, the smaller Max intrusion contains primarily olivine-rich cumulate rocks and cumulate rocks have higher olivine contents, suggesting that it represents a magmatic conduit in which more olivine accumulated and less fractionation occurred. In contrast, the larger Wabassi Main intrusion contains a wider range of cumulate and non-cumulate rocks and the cumulate rocks contain less olivine, suggesting that it represents a magma chamber in which less olivine accumulated and more fractionation occurred.

Despite its proximity to the Max and Wabassi Main intrusions, the Oxtoby Lake intrusion is different in terms of petrography, whole-rock chemistry, mineral chemistry, and geochronology. Its homogeneous non-cumulate composition is consistent with a magmatic conduit that did not experience any olivine accumulation or fractional crystallization.

IMPLICATIONS FOR EXPLORATION

The intrusions studied in the eastern part of the Oxford-Stull and Uchi domains, with the exception perhaps of the Oxtoby Lake intrusion, exhibit some prospectivity to host Fe-Ti-V-(P), Cr-(PGE), and/or Ni-Cu-(PGE) mineralization.

The presence of semi-massive to massive oxide layers with high Fe-Ti-V-P contents within the Big Mac intrusion and the HFIC clearly demonstrates their potential to host those styles of mineralization, but it is not yet clear if these represent closed-system fractional crystallization products or whether the systems were open enough for long enough to contain large amounts of mineralization.

The potential for Cr-(PGE) mineralization in these intrusions is less clear. However, as noted above, the magmas that formed the Max and Wabassi Main intrusions were saturated in chromite, and the occurrence of chromite-rich boulders in the vicinity of the HFIC highlights the potential for this type of mineralization within their ultramafic parts.

The potential for Ni-Cu-(PGE) mineralization is uncertain. The Max intrusion contains some Ni-Cu-(PGE) mineralization and most likely represents an open and dynamic magmatic system that has interacted with the surrounding rocks (Sappin et al., 2013). However, the Oxtoby Lake intrusion appears to have been a closed system and the Wabassi Main intrusion also appears to have been relatively closed, so are much less prospective.

Work in progress will further evaluate the economic potential of these intrusions.

FORTHCOMING PRODUCTS

The preliminary results and interpretations presented in this contribution will be used in three upcoming referred journal publications. Each paper will focus on understanding the formation of one of these three magmatic systems — such as the Big Mac intrusion, the HFIC, and the Max, Oxtoby Lake, and Wabassi Main intrusions — and also to evaluate their potential for orthomagmatic mineralization.

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