GS-7 Euclid Lake intrusion: a revisited cross-section through a historical chrome deposit of the Bird River greenstone belt, southeastern Manitoba

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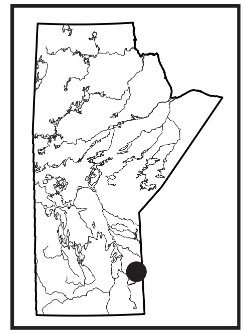

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Summary

The Euclid Lake intrusion[2] is located in the eastern part of the northern arm of the Bird River greenstone belt in southeastern Manitoba, approximately 145 km northeast of Winnipeg. The intrusion is interpreted as an extension of the Bird River sill. This paper examines the geological architecture and apparent stratigraphy of the Euclid Lake intrusion, based on an examination of recent drillholes in comparison with available historical data. The study has revealed that the Euclid Lake intrusion rests on mafic volcanic units interpreted as possible equivalent to the Northern mid-ocean-ridge-basalt–type formation of the Bird River greenstone belt. The intrusion consists of an ultramafic zone sandwiched between two mafic zones that are identified as the lower and upper gabbroic zones of the Euclid Lake intrusion. This apparent internal stratigraphy of the intrusion differs from the ultramafic to mafic succession typical of layered intrusions elsewhere, such as the Bird River sill. Various hypotheses, including structural delamination and multiple magmatic injections, are under consideration to explain the observed zonation, while petrological and geochemical investigations are in progress.

Introduction

In 2011, the Geological Survey of Canada (GSC), through the Targeted Geoscience Initiative Phase 4 (TGI-4) program and in collaboration with the Manitoba Geological Survey (MGS), initiated a multi-year project to characterize mafic and ultramafic intrusions and associated Cr–platinum-group-element (PGE), Ni-Cu-(PGE) orthomagmatic mineralization within the Neoarchean Bird River greenstone belt (BRGB) of southeastern Manitoba (Yang et al., 2011, 2012, 2013, GS-6, this volume; Houlé et al., 2012, 2013; Bécu et al., 2013). The geological investigations conducted within the BRGB are part of a broader study that is focused on various high-Mg ultramafic and mafic magmatic ore systems across the Oxford-Stull and Uchi domains (Ontario), and the La Grande and the Eastmain domains (Quebec) of the Superior province. These investigations also seek to identify possible correlations between the various mafic and ultramafic intrusions.

Mafic and ultramafic intrusions are widely distributed within the southern and northern arms of the BRGB in southeastern Manitoba. The nine main intrusions occur over a strike length of approximately 75 km and host significant Ni-Cu-(PGE) magmatic sulphide and chromite deposits and occurrences (Figure GS-7-1). Several of these intrusions, in both the northern and southern arms, are interpreted as part of the Bird River magmatic event (Houlé et al., 2013), historically identified as the Bird River sill (BRS) and more recently as the Bird River intrusive complex by Mealin (2008). This paper examines the geological architecture of the Euclid Lake intrusion (ELI), located in the eastern part of the northern arm of the BRGB (Figure GS-7-1), based on examination of recent drillholes and comparison of these observations with available historical data.

Previous work

The first record of geological investigations in the BRGB is attributed to Tyrell (1900). Discovery of nickel and copper sulphides in the Maskwa area focused attention on the Bird River sill (BRS), located in the southern arm of the belt. Regional mapping followed, and the discovery of chromite deposits on the Page and Chrome claims in 1942 led to extensive investigations of mafic–ultramafic rocks elsewhere in the area that could potentially be related to the BRS (Bateman, 1942, 1943, 1945; Brownell, 1942).

Chromite was first discovered in the ELI in the fall of 1942 on a small island surrounded by a swamp, which covers the rest of the intrusion. The property was staked and after some preliminary trenching, in 1942–1943, Gunnar Gold Mines Ltd. drilled 11 diamond-drill holes totalling 1185 m, followed in 1952 by a magnetic survey and the drilling of 10 additional holes for a total of 1861 m. In the 1980s, several ore resource estimates were made for chromite in the ELI (e.g., Robertson and Associates Ltd., 1981; Bannatyne and Trueman, 1982; Watson, 1985). The most recent evaluation was done by Ilam and Associates Ltd. ('Ilam') who calculated a 4.69 Mt ore tonnage resource at a grade of 6.42% Cr_2O_3, based exclusively on the compilation of 1942–1943 and

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[2] For the sake of consistency, the Manitoba Geological Survey has opted to make a universal change from capitalized to noncapitalized for the generic part of lithostructural feature names (formal stratigraphic and biostratigraphic nomenclature being the exceptions).

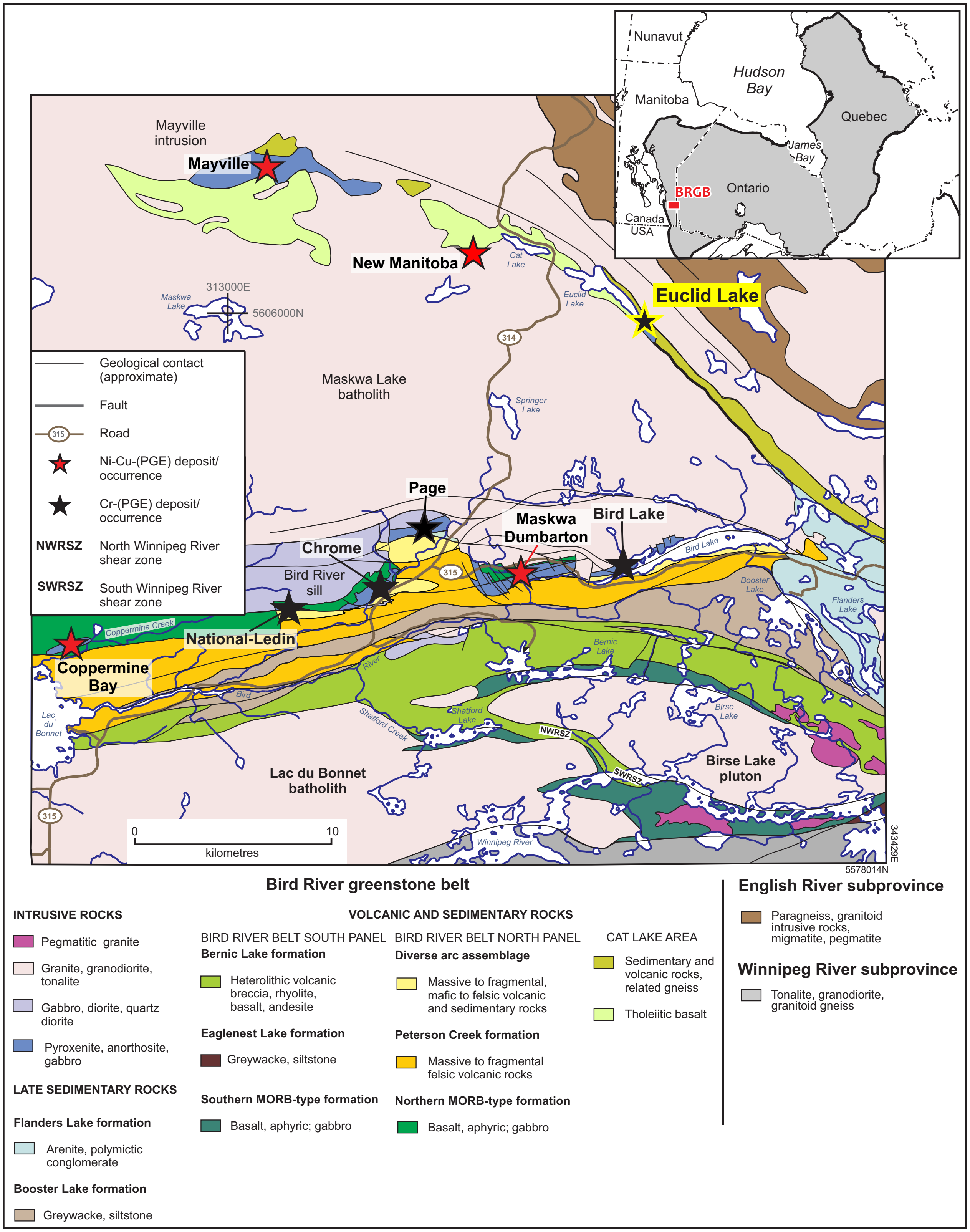

Figure GS-7-1: *Simplified geology of the southern and northern arms of the Bird River greenstone belt, showing the location of the Euclid Lake intrusion and other significant mafic and ultramafic igneous bodies and their associated Ni-Cu-(PGE) and Cr-(PGE) deposits/occurrences (modified from Bailes et al., 2003; Gilbert et al., 2008). Abbreviations: BRGB, Bird River greenstone belt; MORB, mid-ocean-ridge basalt.*

1952 diamond drill records of Gunnar Gold Mines Ltd (Assessment File 74747, Manitoba Mineral Resources, Winnipeg). Unfortunately, neither Ilam—nor, it seems, their predecessors—were able to re-examine the drillcore (Assessment File 74747). Very little work had been done on the ELI until 1997, when line-cutting and total-field and vertical-gradient magnetic surveys were carried out by Exploratus Elementis Diversis Ltd. ('Exploratus'). In 1999, Exploratus conducted preliminary geological mapping and prospecting on the Cat Lake–Euclid Lake property, aiming to investigate unexplained electromagnetic anomalies. More recently, Mustang Minerals Corporation ('Mustang') carried out an airborne versatile time-domain electromagnetic survey (VTEM) and a magnetic survey in the vicinity of the ELI in 2005, which were followed by selective geological mapping and sampling in 2008. In 2010, Mustang completed an airborne geophysical survey over the ELI and followed up with three diamond-drill holes in 2011, for a total of 527.6 m, to test VTEM anomalies.

Geological setting

The Euclid Lake intrusion is a mafic–ultramafic intrusion that has been interpreted as an extension of the BRS, assuming the model of a regional, east-plunging anticline (Bateman, 1942; Springer, 1950; Davis et al., 1962; Trueman and Macek, 1971; Trueman, 1980; Černý et al., 1981). The south limb of the inferred major fold structure ('Bird River Sill structure' of Macek [1985a, b]) is occupied by intrusions of the BRS, which comprises intrusions between the Coppermine Bay and the Bird Lake intrusions, whereas the north limb contains the ELI and Mayville intrusions (Figure GS-7-1). The ELI is bounded on the northeast side by metasedimentary rocks that, according to Assessment File 73385 (Manitoba Mineral Resources, Winnipeg), could be assigned to the Bernic Lake, Flanders Lake or Booster Lake formations. These metasediments are themselves bounded to the northeast by granitic rocks belonging to the English River subprovince. On surface, the ELI is bounded on the southwest side by granitic rocks of the Maskwa Lake batholith, with no evidence of the presence of supracrustal rocks. Springer (1950) reported that the lower part of the intrusion appeared to have been destroyed by granite to the south. The reader is referred to Yang et al. (GS-6, this volume) for more details on the regional geology of the Cat Lake–Euclid Lake area.

Euclid Lake intrusion (ELI)

According to the previous drilling conducted by Gunnar Gold Mines Ltd., the ELI is interpreted as a layered mafic–ultramafic intrusion composed essentially of a thick peridotite body that contains several chromite-rich zones overlain by gabbroic rocks. The chromite-rich rocks are characterized by thinly interlayered chromitite and peridotite; disseminated chromite occurs within the upper 100 m of the peridotite, below the gabbro contact (Robertson and Associates Ltd., 1981). Two principal chromitite horizons have been intersected: the Main zone and the South zone. The Main zone consists of a 9–46 m thick interval of thinly layered chromitite and chromite-bearing peridotite situated a few metres below the peridotite-gabbro contact. The South zone, located stratigraphically below the Main zone, is narrower and more discontinuous (Figure GS-7-2). Both zones have a very steep to vertical

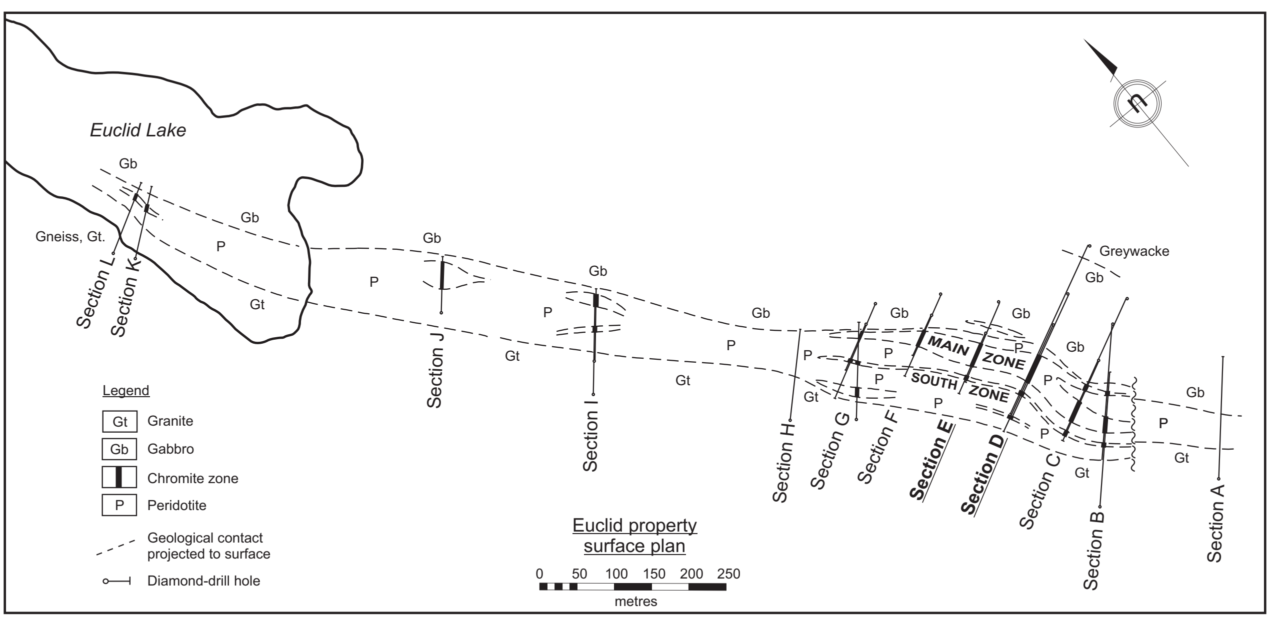

Figure GS-7-2: *Surface plan of the Euclid Lake intrusion (after Robertson and Associates Ltd., 1981), presenting the projection of geological units as intersected in the 1942–1943 and 1952 drillholes. The locations of the 12 drill sections (A–L) compiled by Robertson and Associates Ltd. (1981) are also shown.*

dip and are thought to be truncated by faulting at the southeastern end of the property. Below the South zone, a possible third chromite-rich zone was intersected in a few drillholes, but could not be fully delineated based on the available data (Robertson and Associates Ltd., 1981). In their resource calculations, Assessment File 74747 interpreted a bifurcation of the Main zone in its thickest portion, possibly reflecting an eastward thinning of the Main zone, corresponding to a thickening of the South zone. The deposit is thought to be open at depth (below 250 m). Robertson and Associates Ltd. (1981) noted the existence of an excellent correlation between the Main and South zones and a distinctive ground magnetic anomaly. This observation, combined with significant chromite mineralization in drillholes intersecting magnetic anomalies at the northwestern end of the property, might indicate the extension along strike of the ELI under Euclid Lake.

Field observations

The ELI is poorly exposed with limited outcrop exposures due to heavy overburden and swamp. Bateman (1943) and Springer (1950) reported the presence of a few surface exposures of peridotite, containing thin layers of disseminated and dense chromite over 15 m, whereas Assessment File 73385 reported that a small chromite-bearing outcrop (approximately 950 m southeast of the south end of Euclid Lake) was visited in 1997 by Exploratus geologists. Unfortunately, these exposures could not be found during fieldwork in 2012, but several outcrops of leucocratic to anorthositic gabbro were identified at the southeastern end of the lake. Furthermore, re-examination and resampling for geochemical analysis of recent cores in the Euclid Lake area in 2012 have provided a new perspective on the stratigraphy of the ELI as outlined below.

Drillhole ZEE-11-03 appears to intersect the ELI in what was reported as the thickest part of the main chromite zone of the Euclid Lake chromite deposit (Robertson and Associates Ltd., 1981), between drill sections D and E (Figure GS-7-2). This interval coincides with the inferred bifurcation of the main chromite zone by Assessment File 74747. A schematic cross-section of drillhole ZEE-11-03 (Figure GS-7-3) can be subdivided stratigraphically (from base to top) as follows: mafic volcanic rocks, lower gabbroic zone (LGZ), ultramafic zone (UZ) and upper gabbroic zone (UGZ).

Petrography and geochemistry

For simplicity, the prefix ‘meta’ will not be used in the following section with the understanding that all rocks in the ELI have undergone greenschist- to probably amphibolite-facies metamorphism. Primary minerals have been extensively replaced, but original textures and crystal forms are usually preserved, thus pseudomorphs (e.g., of pyroxene) were often used to determine the primary mineralogy.

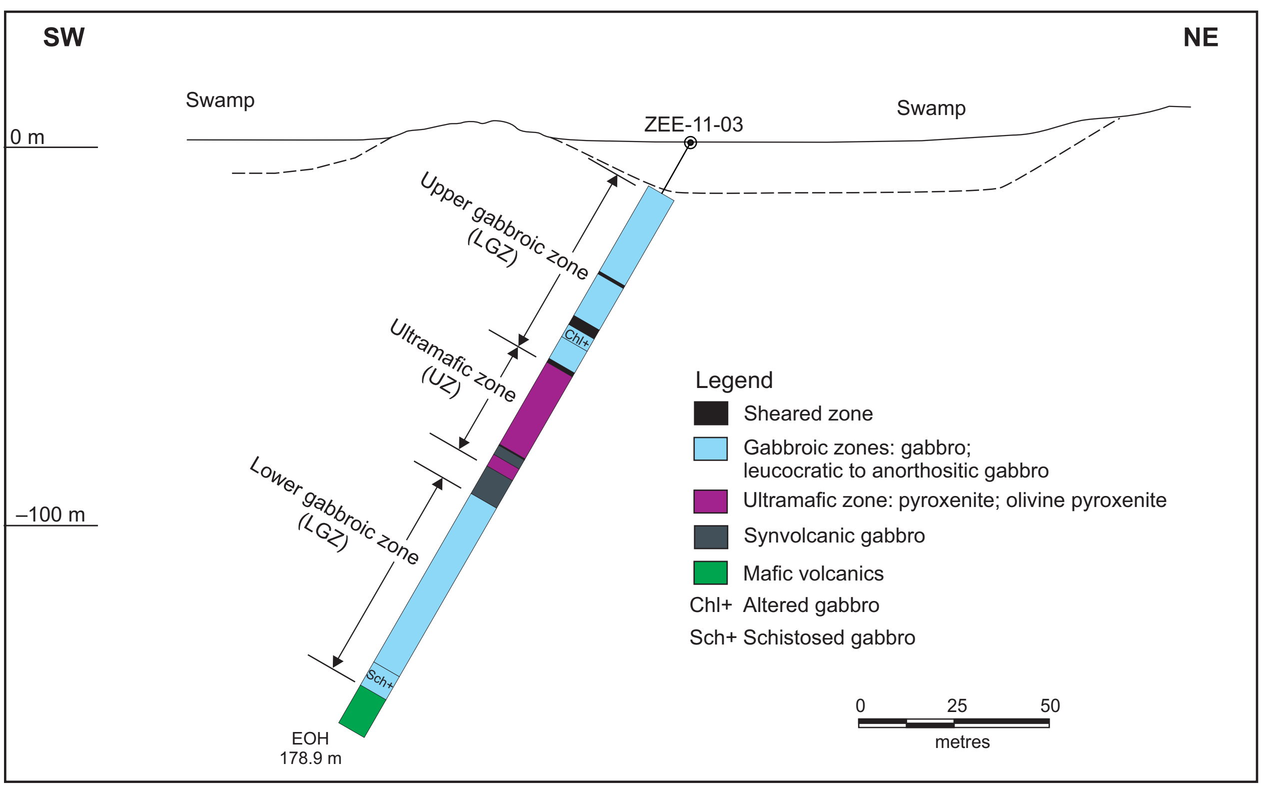

***Figure GS-7-3:** Schematic southwest–northeast geological cross-section of the Euclid Lake intrusion, illustrating the main geological units intersected in hole ZEE-11-03, drilled in 2011 by Mustang Minerals Corporation.*

For the first time, mafic volcanic rocks and subordinate synvolcanic gabbro are recognized here as hostrocks at the basal (footwall) contact of the ELI. The mafic volcanic rocks are dark grey, aphanitic to fine grained, but locally coarser grained (Figure GS-7-4a). The synvolcanic gabbro is fine to medium grained and exhibits a salt-and-pepper texture in drillcore, in which light-coloured plagioclase contrasts with darker magnesiohornblende (Figure GS-7-4b); traces of apatite and ilmenite are also present. This mineral assemblage is identical to that observed in the mafic volcanic rocks; the distinction between the volcanic and gabbroic rocks is based solely on grain size and megascopic texture. Both the mafic volcanic rocks and synvolcanic gabbro have very similar MgO, SiO_2, FeO^T, TiO_2 and Zr contents, as well as rare-earth-element (REE) patterns (Figure GS-7-5); their composition is also very similar to that of the Northern and Southern mid-ocean-ridge-basalt (MORB)–type formations within the BRGB (Gilbert et al., 2008). The contacts between the pyroxenitic and gabbroic units of the LGZ that flank the synvolcanic gabbro are sheared.

The lower contact of the LGZ with mafic volcanic rocks is marked by an approximately 0.4 m thick interval

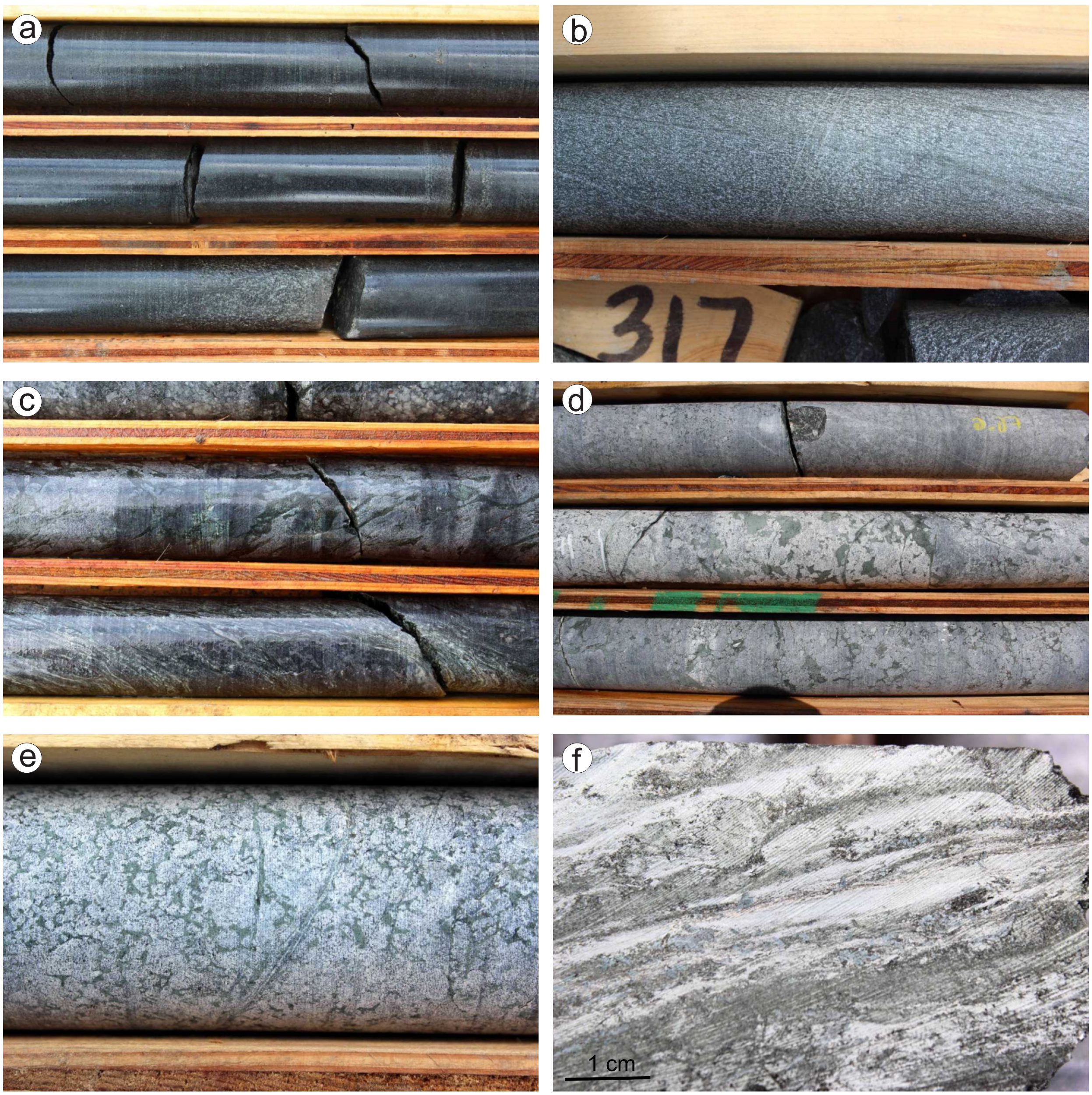

Figure GS-7-4: *Drillcore from the main geological units intersected in drillhole ZEE-11-03:* ***a)*** *aphanitic to fine-grained mafic volcanic rocks, locally medium grained;* ***b)*** *fine- to medium-grained, synvolcanic gabbro exhibiting a salt-and-pepper texture;* ***c)*** *altered and schistose gabbro marking the contact between Euclid Lake intrusion gabbroic units and mafic volcanic rocks;* ***d)*** *medium-grained gabbro;* ***e)*** *medium- to coarse-grained leucogabbro, gradational along strike to anorthositic gabbro;* ***f)*** *altered and sheared olivine pyroxenite, intruded by talc–Mg-rich-chlorite±serpentine veinlets.*

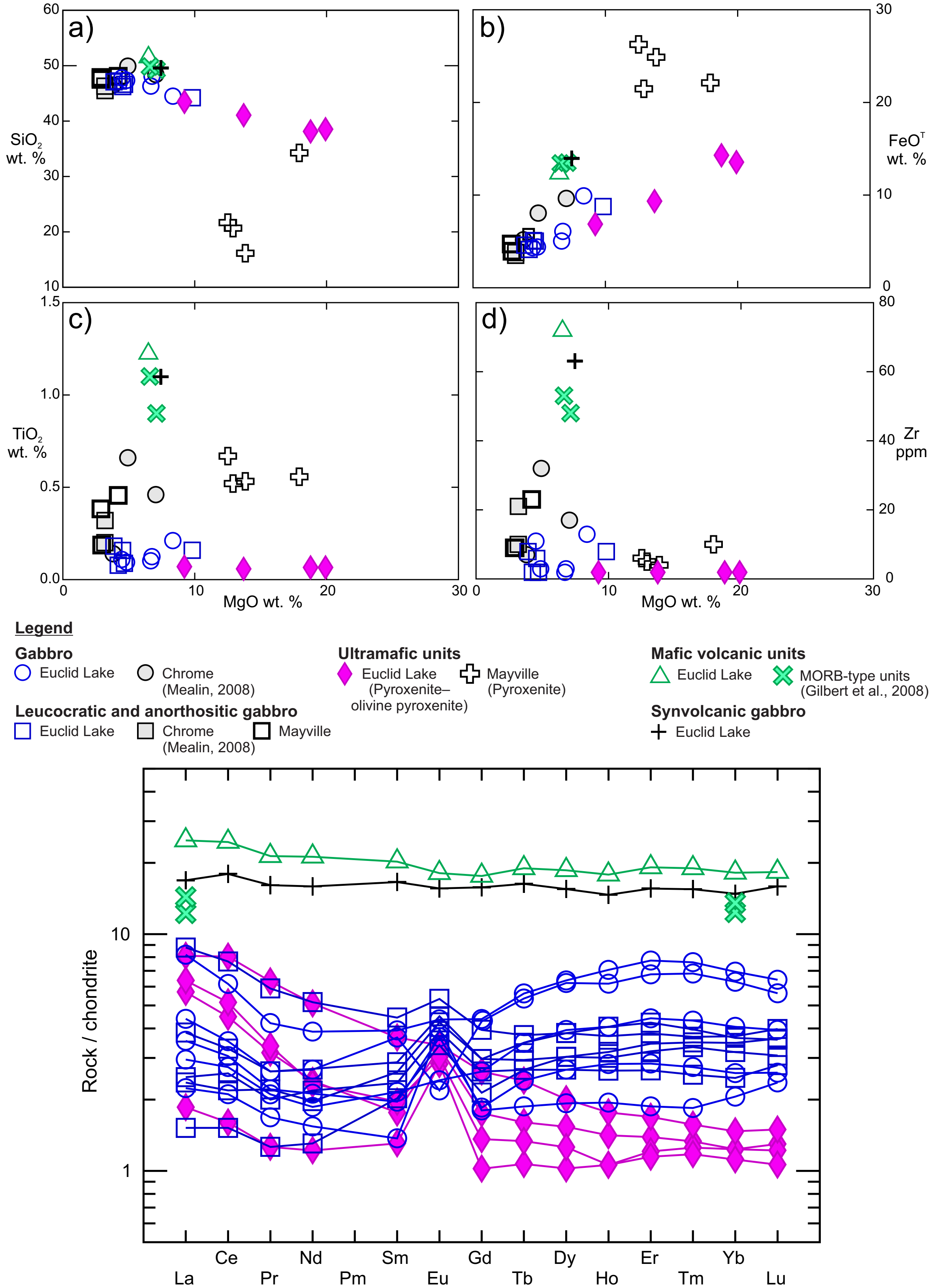

Figure GS-7-5: *Whole-rock geochemistry and chondrite-normalized rare-earth-element diagram for the main geological units in the Euclid Lake intrusion. Normalizing values are from Sun and McDonough (1989). Whole-rock geochemistry for the Chrome property (Mealin, 2008) and the Mayville intrusion (ongoing study; Bécu et al., 2013), together with the mean values of Northern mid-ocean-ridge-basalt (MORB)– and Southern MORB-type units from Gilbert et al. (2008), are also shown for comparison.*

of altered and schistose gabbro (Figure GS-7-4c). The LGZ consists of alternating intersections that vary in thickness of medium- to coarse-grained gabbro, leucogabbro and anorthositic gabbro. The distinction between these three gabbroic facies is mainly accomplished by megascopic observation, based on variations of the magnesiohornblende to plagioclase ratio (Figure GS-7-4d, e). Traces of chlorite and ilmenite are also present within the various gabbroic rocks. The MgO, SiO_2, FeO^T, TiO_2 and Zr concentrations of the three gabbroic facies are quite similar and comparable to the values obtained for gabbroic rocks from the Chrome property and the Mayville intrusion (Figure GS-7-5). The REE patterns show relatively similar patterns to those observed for the ultramafic units, but are characterized by higher heavy rare-earth-element (HREE) contents, reflecting the mafic nature of these units. Positive Eu anomalies are conspicuous for three of the four samples.

The UZ is represented by an approximately 30 m thick pyroxenite unit (Figure GS-7-3) that occupies the central part of the drill section. This unit consists of various types of altered and sheared pyroxenite to olivine pyroxenite (Figure GS-7-4f). The large range of MgO content (9.48–19.96 wt. %) within the UZ suggests that gabbroic units are also present within the zone. The MgO values obtained for ELI rocks are similar to those of pyroxenitic rocks in the Mayville intrusion, which is also located within the northern arm of the BRGB (Figure GS-7-1). On the other hand, SiO_2 and TiO_2 values are higher and the FeO^T is lower in ELI rocks compared with rocks in the Mayville intrusion. The range of Zr content of ELI rocks is similar to that of Mayville rocks. Rare-earth-element patterns of UZ pyroxenitic rocks show relative HREE depletion when compared to rocks from the lower and upper gabbroic zones, consistent with a more ultramafic composition inferred for the UZ rocks. Light REE patterns of the UZ rocks show variable degrees of depletion that could be due to the substantial alteration inferred for these rocks. One rock sample with an MgO content of 9.48 wt. % displays the most depleted REE pattern, and further petrographic and microprobe work is required to explain the decoupling between the major- and trace-element variation for this particular sample.

The contact between the UZ pyroxenitic rocks and overlying gabbroic rocks of the UGZ is marked by a 0.6 m thick interval of what is interpreted as a 'mélange' of pyroxenite and gabbro that could correspond to a transition zone, similar to that described on the Chrome property of the BRS by Scoates (1983). The UGZ is characterized by alternating intersections of variable thickness that consist of medium- to coarse-grained gabbro, leucogabbro and anorthositic gabbro; these are geochemically similar and petrographically identical to analogous intersections within the LGZ. Based on these similarities, gabbroic units from both the LGZ and UGZ are interpreted to be part of the ELI. Furthermore, the geochemical signatures of these gabbroic rocks are comparable to analogous rocks in the BRS Chrome property and the Mayville intrusion, thus supporting the interpretation that the latter intrusions and the ELI are genetically linked and part of the same magmatic event.

Discussion

Despite the fact that numerous uncertainties remain, this investigation sheds new light on several aspects of the ELI. In the compilation of Robertson and Associates Ltd. (1981), and in other investigations (e.g., Assessment Files 73385, 74747), neither ELI mafic intrusive rocks nor mafic volcanic rocks were reported beneath the ELI ultramafic series, either in surface exposures or in section plans (Figures GS-7-3, -6). As reported earlier, the general understanding was that the lower part of the intrusion had been destroyed by younger granite intrusions to the south (Springer, 1950; Robertson and Associates Ltd., 1981), thus veiling the nature of the original footwall contact of the ELI. The mafic volcanic rocks intersected in drillhole ZEE-11-03 exhibit a similar geochemical signature to that of the Northern MORB-type formation within the southern arm of the BRGB, suggesting that these two supracrustal rock units are correlative, and served as basement to the ELI and BRS, respectively. Following this model, the synvolcanic gabbro/coarse-grained mafic volcanic rocks at the lower contact of the UZ could be interpreted as a raft of basement rock within the pyroxenite.

New observations from drillhole ZEE-11-03 have highlighted the presence of gabbroic rocks stratigraphically below the ELI pyroxenite unit. This relationship differs from that of other intrusions in the Bird River area, where the typical upward stratigraphic succession is from ultramafic to mafic units. Several hypotheses may be considered to explain the reverse sequence in the ELI, such as structural delamination of the base of the intrusion, a thrust repetition, a very tight isoclinal fold or complex primary igneous stratigraphy. None of these models can be ruled out. A structural explanation should be considered because the ELI displays a general northwest orientation parallel to the main structural trend in the area, its thickness is relatively small compared to other BRS-related intrusions (e.g., Chrome and Mayville), and it is located near the contact zone between two Archean terranes (Yang et al., GS-6, this volume). However, the hypothesis evoking complex magmatic activity cannot be overlooked because multiple magmatic injections have been proposed as a model of emplacement for the BRS and other related intrusions (e.g., Bateman, 1943; Osborne, 1949; Theyer, 1985; Peck et al., 2002; Mackie, 2003; Mealin, 2008).

In addition to the above observations, the lack of chromite horizons or noteworthy Cr_2O_3 anomalies in drillhole ZEE-11-03 is at odds with the compiled assay results and drill logs of the 1942–1943 and 1952 drillholes. Some discrepancies are also noted in the geological section

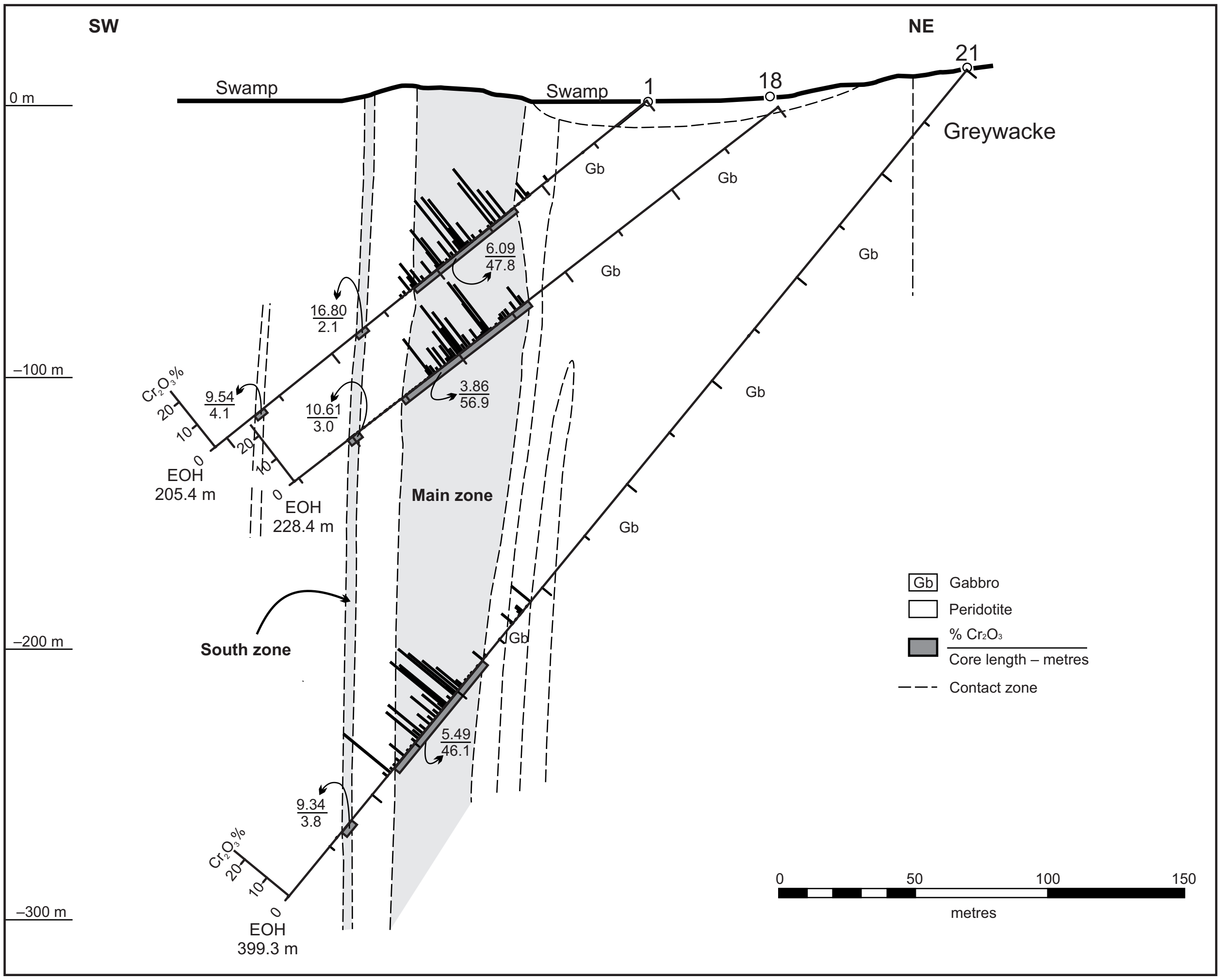

Figure GS-7-6: *Schematic geological cross-section of the Euclid Lake intrusion showing the main lithological units and average Cr_2O_3 contents calculated from data in section D of Robertson and Associates Ltd. (1981), compared with individual Cr_2O_3 values (wt. %) from assay compilation of original 1942–1943 and 1952 drillhole data (Assessment File 73385).*

presented in Figure GS-7-6, namely between the calculated Cr_2O_3 intersections of Robertson and Associates Ltd. (1981) and individual Cr_2O_3 intersections plotted from the Assessment File 73385 compilation of original drill logs. Considering that the drill logs are from 1942–1952, when surveying methods were far less accurate compared to those of today, imprecise drillhole locations could explain the apparent discrepancy between the ZEE-11-03 geological section and the compiled section of Robertson and Associates Ltd. (1981). In that sense, Assessment File 73385 reported that no traces of the original grid at Euclid Lake were visible in the field, thus no control was available to accurately locate the 1942–1952 diamond-drill hole collars.

Economic considerations

The BRGB is known to host significant Ni-Cu-(PGE) magmatic sulphide and chromite deposits and occurrences associated with several mafic and ultramafic intrusions. Whereas the majority of these intrusions are located in the southern arm of the belt, the historical resource of the ELI and the recently calculated Ni-Cu resource of the Mayville intrusion indicate that the northern arm of the belt also has significant potential for economic mineralization. The current investigation of the internal stratigraphy and geological setting of the ELI, combined with similar ongoing studies of other BRS-related intrusions (Yang et al., 2011; Houlé et al., 2012, 2013; Bécu et al., 2013) and regional mapping initiatives (Yang et al., 2012, 2013, GS-6, this volume), will help constrain the extent of each intrusive body, as well as the mechanism and timing of their emplacement. These studies also aim to provide geological and geochemical signatures typical of fertile intrusions in general, thus supporting exploration for Ni-Cu-Cr-(PGE) deposits beyond traditionally explored areas within the BRGB.

Future work

Ongoing petrological and geochemical work, in combination with a thorough compilation of all pertinent available data, will help to better define the internal architecture of the ELI, and may resolve any location issues between historical and more recent datasets. These initiatives, together with recent mapping results in the Cat Lake–Euclid Lake area (Yang et al., GS-6, this volume), should help to delineate the ELI extension under Euclid Lake, as well as advance our understanding of the distribution and stratigraphy of Bird River magmatic events in the northern arm of the BRGB.

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References

Bailes, A.H., Percival, J.A., Corkery, M.T., McNicoll, V.J., Tomlinson, K.Y., Sasseville, C., Rogers, N., Whalen, J.B. and Stone, D. 2003: Geology and tectonostratigraphic assemblages, West Uchi map area, Manitoba and Ontario; Manitoba Geological Survey, Open File OF2003-1 and Geological Survey of Canada, Open File 1522, Ontario Geological Survey, Preliminary Map P.3461, 1:250 000 scale, with marginal notes.

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. 1942: Chromite: Manitoba's gift to war industry; extent of deposits and their value in warfare; Precambrian Magazine, v. 15, no. 12, p. 2, 5–7, 23.

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

Bateman, J.D. 1945: Composition of the Bird River chromite, Manitoba; American Mineralogist, v. 30, p. 596–600.

Bécu, V., Houlé, M.G., McNicoll, V.J., Yang, X.M. and Gilbert, H.P. 2013: New insights from textural, petrographic and geochemical investigation of the gabbroic rocks of the Bird River intrusive event within the Bird River greenstone belt, southeastern Manitoba; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting 2013, Winnipeg, Manitoba, Program with Abstracts, p. 68.

Brownell, G.M. 1942: Chromite: Manitoba's gift to war industry; geology and character of a discovery deposit; Precambrian Magazine, v. 15, no. 12, p. 3–5.

Černý P., Trueman, D.L., Ziehlke, D.V., Goad, B.E. and Paul, 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.

Davis, J.F., Bannatyne, B.B., Barry, G.S. and McCabe, H.R. 1962: Geology and mineral resources of Manitoba; Manitoba Mines Branch, 190 p.

Gilbert, H.P., Davis, D.W., Duguet, M., Kremer, P.D., 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 1:50 000 (plus notes and appendix).

Houlé, M.G., Bécu, V., McNicoll, V., Yang, X.M. and Gilbert, H.P. 2012: Field investigations of mafic and ultramafic intrusions in the Bird River greenstone belt, southeastern Manitoba (part of NTS 52L11 and 52L12): implications for Ni-Cu-Cr-PGE mineralization; Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, poster presented at the Manitoba Mining and Minerals Convention 2012, Winnipeg, Manitoba, November 15–17.

Houlé, M.G., McNicoll, V.J., Bécu, V., Yang, X.M. and Gilbert, H.P. 2013: New age for the Mayville intrusion: implication for a large mafic-ultramafic event in the Bird River greenstone belt, southeastern Manitoba: Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting 2013, Winnipeg, Manitoba, Program with Abstracts, p. 115.

Macek, J.J. 1985a: Cat Creek project (parts of 52L/1, 8); *in* Report of Activities 1985, Manitoba Energy and Mines, Geological Services, Mines Branch, p. 122–129.

Macek, J.J. 1985b: Cat Creek; Manitoba Energy and Mines, Preliminary Map 1985C-1, scale 1:10 000.

Mackie, R. 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, 131 p.

Mealin, C.A. 2008: Geology, geochemistry and Cr-Ni-Cu-PGE mineralization of the Bird River sill: evidence for a multiple intrusion model; M.Sc. thesis, University of Waterloo, Waterloo, Ontario, 155 p.

Osborne, T.C. 1949: Petrography and petrogenesis of the Bird River chromite bearing sill; M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 66 p.

Peck, D.C., Scoates, R.F.J., Theyer, P., Desharnais, G., Hulbert, L.J. and Huminicki, M.A.E. 2002: Stratiform and contact-style 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.

Robertson and Associates Ltd. 1981: Report on the Chrome and Euclid properties of Dynamic Mining Exploration Ltd.; unpublished report, 89 p.

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.

Springer, G.D. 1950: Geology of the Cat Lake–Winnipeg River area, Manitoba; Manitoba Mines and Natural Resources, Mines Branch, Publication 49-7, 14 p.

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.

Theyer, P. 1985: Platinum-palladium distribution in ultramafic rocks of the Bird River complex, southeastern Manitoba; Manitoba Energy and Mines, Geological Services, Open File Report OF85-4, 64 p.

Trueman, D.L. and Macek, J.J. 1971: Ultramafic project: geology of the Bird River sill; Manitoba Department of Mines, Resources and Environmental Management, Mines Branch, Preliminary Map 1971-A1.

Trueman, D.L. 1980: Stratigraphy, structure and metamorphic petrology of the Archean greenstone belt at Bird River, Manitoba; Ph.D. thesis, University of Manitoba, Winnipeg, Manitoba, 150 p.

Tyrel, J.B. 1900: East shore, Lake Winnipeg; Geological Survey of Canada Annual Report, v. 11, Part G, p. 64–67, 72–77.

Watson, D.M. 1985: Chromite reserves of the Bird River sill; Manitoba Energy and Mines, Geological Services, Open File Report OF85-8, 22 p.

Yang, X.M., Gilbert, H.P., Corkery, M.T. and Houlé, M.G. 2011: The Mayville mafic–ultramafic intrusion in the Neoarchean Bird River greenstone belt, southeastern Manitoba (part of NTS 52L12): preliminary geochemical investigation and implication for PGE-Ni-Cu-(Cr) mineralization; *in* Report of Activities 2011, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 127–142.

Yang, X.M., Gilbert, H.P., Corkery, M.T. and Houlé, M.G. 2012: Geological investigations of the Cat Creek area in the Neoarchean Bird River greenstone belt, southeastern Manitoba (part of NTS 52L12): new insight into PGE-Ni-Cu-Cr mineralization; *in* Report of Activities 2012, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 32–53.

Yang, X.M., Gilbert, H.P., Houlé, M.G., Bécu, V., McColl, V.J. and Corkery, M.T. 2013: The Neoarchean Mayville mafic-ultramafic intrusion in the Bird River greenstone belt, southeastern Manitoba: geological setting, geochemical variation and the implications for Cu-Ni-PGE-Cr mineral exploration; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting 2013, Winnipeg, Manitoba, Program with Abstracts, p. 200.