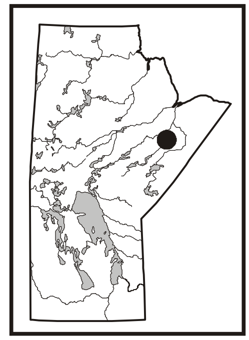
GEOLOGY AND MINERAL OCCURRENCES OF THE FOX RIVER SILL IN THE GREAT FALLS AREA, FOX RIVER BELT (PART OF NTS 53M/16)

by G. Desharnais[1], D.C. Peck[2], P. Theyer, L. Potter[2], M. Huminicki[3], R.F.J. Scoates[4], N.M. Halden[1] and G. Kohut[1]



Desharnais, G., Peck, D.C., Theyer, P., Potter, L., Huminicki, M., Scoates, R.F.J., Halden, N.M. and Kohut, G., 2000: Geology and mineral occurrences of the Fox River sill in the Great Falls area, Fox River Belt (part of NTS 53M/16); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 42-48.

SUMMARY

The Great Falls area provides the best known exposures of the Fox River sill within the Fox River Belt. Mapping completed in 2000 focused on outcrops of the Marginal zone and enabled completion of a 1:1000 scale geological map of the northern half of the Great Falls outcrop area. Mapping has shown that the lower part of the Fox River sill in this area is largely undeformed, with the exception of an orthogonal set of subvertical, brittle faults that have developed along and perpendicular to major petrological boundaries. These faults are believed to have developed contemporaneously with active rifting in the Fox River Belt (peak extension). In the Great Falls study area, the lower part of the Fox River sill has a chilled contact with older pyritic mudstone and siltstone of the Middle Sedimentary formation. These sedimentary rocks are typically hornfelsed within the several metre thick contact aureole that is developed adjacent to the southern margin of the sill. The Marginal zone of the Fox River sill comprises a lower, reverse differentiated, mafic to ultramafic unit (Basal Contact unit) and two normally differentiated ultramafic to mafic cyclic units.

Surface prospecting in 1999 and 2000 delineated disseminated Fe-Cu-Ni sulphide mineralization within the Marginal zone at three different stratigraphic levels: 1) in the Basal Contact unit, immediately north of the Middle Sedimentary formation; 2) in pyroxene-rich ultramafic rocks developed along the base of the second cyclic unit (KO zone); and 3) in the gabbroic upper part of the second cyclic unit. The KO zone is a stratabound zone of sulphide mineralization, enriched in Cu, Ni and platinum-group elements (PGE), that developed immediately above the irregular contact between the host ultramafic rocks of the second cyclic unit (UM2 subunit) and the upper, leucogabbroic part of the first cyclic unit (LG1 subunit). The irregular form of the LG1-UM2 contact is interpreted to have developed by erosion of the older UM1 subunit through current action associated with the emplacement of the second cyclic unit (UM2-LG2). Recent analytical results confirm the PGE-rich nature of the KO zone, which has a maximum grade of 5.4 g/t combined Pd+Pt+Au, 2.3% Cu and 1.1% Ni, based on a limited number of surface grab samples. Total sulphide abundance in the KO zone increases toward the base of the UM2 subunit, where the sulphide minerals occur within a pyroxenite layer that ranges from less than 1 to 3 m in thickness. The mineralization appears to reach its maximum abundance in the numerous, small, centimetre- to metre-wide troughs that are developed along the LG1-UM2 contact. However, disseminated sulphide mineralization of presently unknown grade also extends northward into overlying lherzolite and olivine pyroxenite, so that the total thickness of the KO zone is not presently known. Irregularly disseminated sulphide mineralization is also present in the gabbroic upper part of the second cyclic unit (LG2 subunit) but appears to have low base-metal and PGE contents. Poddy, metre-size leucogabbro-leucodiorite bodies are locally present within the UM2 subunit at a distance of 1 to 5 m above its base. These pods are also locally mineralized and are interpreted to represent melts derived from the LG1 subunit that entrained pre-existing sulphide minerals in the KO zone.

The KO zone is continuous along strike within the Great Falls area (approx. 1.5 km of strike length) and, given the lateral continuity of the Fox River sill stratigraphy on a regional scale, is likely to be present in other parts of the Fox River Belt. The host pyroxenite layer exhibits normal size and compositional grading of both sulphide and silicate components, indicating derivation through settling of immiscible sulphide liquid and pyroxene from a S-saturated ultramafic magma. Therefore, it is suggested that the KO zone represents a basal-segregation type of magmatic sulphide mineralization. If this is correct, then the high Cu:Ni ratios and Pd+Pt abundances in the KO zone are difficult to reconcile with the primitive composition of the host rocks. Accordingly, it is likely that more Ni-rich sulphide mineralization, which would be expected to develop in the Mg- and Ni-rich ultramafic parent magmas to the UM2 subunit, may be present in larger troughs/embayments along the LG1-UM2 contact. These preliminary findings, coupled with previous investigations of stratabound sulphide mineralization in the Upper Central Layered zone, demonstrate the significant potential for magmatic Ni-Cu-PGE sulphide deposits in the Fox River sill.

INTRODUCTION

The regional geology of the Fox River Belt (FRB) is discussed by Scoates (1981, 1990). Results obtained from previous mapping programs in the Great Falls area (Fig. GS-9-1) are given in Scoates (1981, 1990), Peck et al. (1999) and Syme et al. (1999). The FRB is an east-trending supracrustal belt, approximately 300 km long and 30 km wide, comprising abundant mafic and ultramafic intrusions (including the approx. 2 km thick Fox River sill), submarine flow sequences, and marine clastic and chemical sedimentary rocks. The FRB represents the best preserved (least deformed) part of the Superior Boundary Zone, which extends to the northeast through Hudson Bay into the Cape Smith Belt in northern Quebec, and to the southwest into the Thompson Nickel Belt in central Manitoba. The FRB is poorly exposed, but limited geological mapping, combined with detailed drill core studies described by Scoates (1981, 1990), has shown that it is a well preserved, Proterozoic, rifted continental-margin sequence. Heaman et al. (1986) have dated the Fox River sill (Marginal zone) at 1883 Ma using the U-Pb method. Results from the current program, which focused on the geology and mineral occurrences of the Marginal zone in the Great Falls area, are discussed below. Preliminary lithological sections for the Great Falls area are given in Figure GS-9-2. This year's mapping results are shown in detail in Peck et al. (2000).

The objectives of the 2000 field program in the Great Falls area were to:

1) complete a detailed 1:1000 scale geological map of the northern part of the Great Falls outcrop area; and
2) document the mineral occurrences throughout the study area, with an emphasis on the Marginal zone, in which a PGE-Cu-Ni occurrence (MZ1 showing) was identified in June of 1999 (Peck et al., 1999).

[1] Department of Geological Sciences, University of Manitoba, 125 Dysart Road, Winnipeg, Manitoba R3T 2N2
[2] Falconbridge Limited, 21-C Murray Park Road, Winnipeg, Manitoba R3J 3S2
[3] Department of Earth Sciences, Laurentian University, Ramsey Lake Road, Sudbury, Ontario P3E 2C6
[4] Consultant, 509 Windermere Avenue, Ottawa, Ontario K2A 2W3

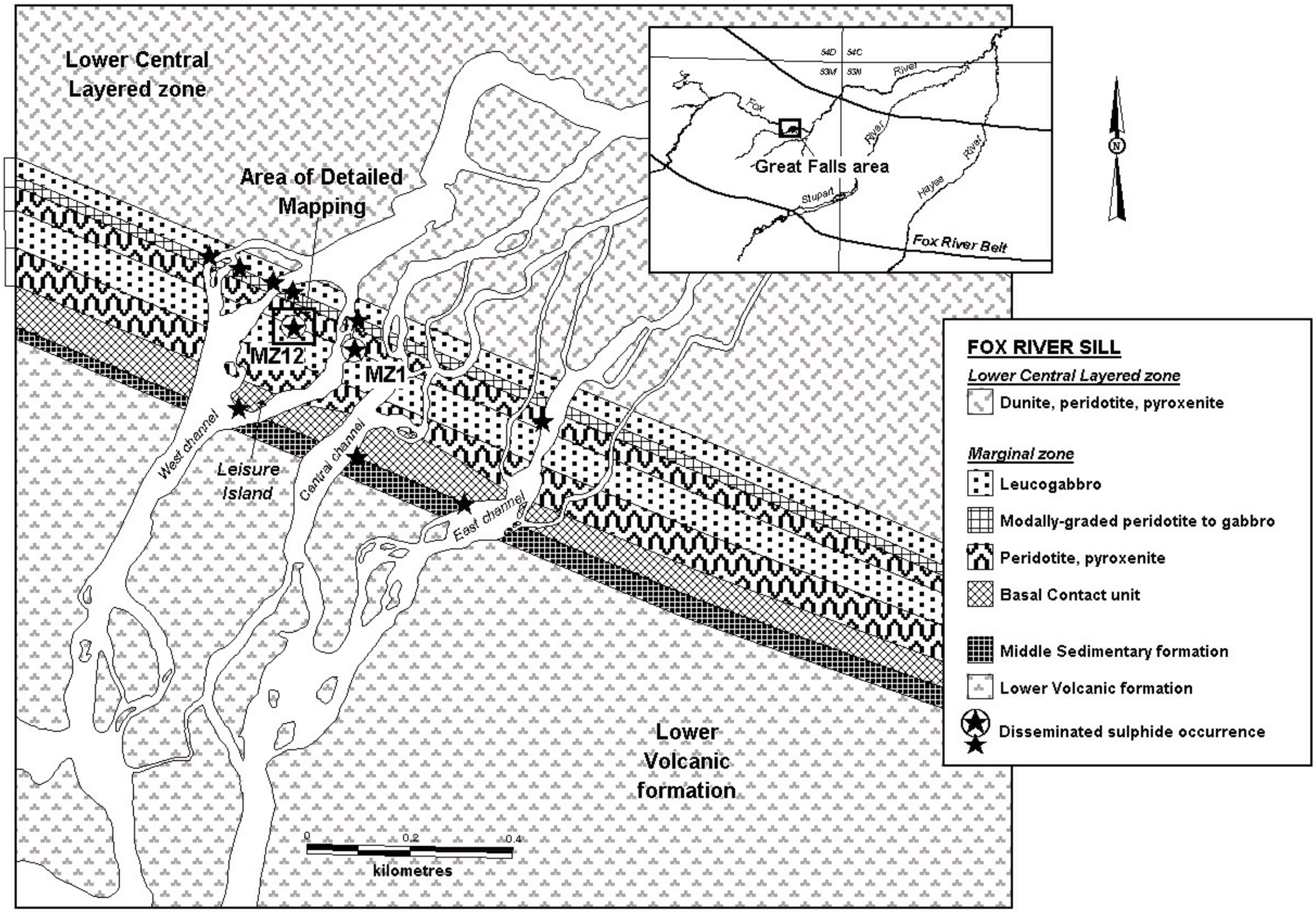


Figure GS-9-1: General geology of the Great Falls outcrop area, Fox River Belt. Inset map shows location of the study area in the western part of the Fox River Belt. Box outlines the Leisure island detailed mapping area.

GEOLOGY OF THE FOX RIVER SILL IN THE GREAT FALLS AREA

The Great Falls provides the best outcrop exposure of the Fox River sill in the FRB. It covers an area of about 2.1 by 2.8 km (Fig. GS-9-1) that is underlain by a homoclinal, north-facing, conformable, supracrustal and intrusive sequence comprising (from south to north) the upper part of the Lower Volcanic formation, the Middle Sedimentary formation, and the Marginal zone and lower part of the Lower Central Layered zone of the Fox River sill (Fig. GS-9-1). Peak metamorphism in the area is low grade, and varies between the prehnite-pumpellyite and lower greenschist facies (Scoates, 1990). Primary mineralogy is typically well preserved, particularly in the rocks of the Marginal zone (Huminicki, 2000). In this study, no attempt was made to distinguish between ortho- and clinopyroxene in the field, so the generic term ‘pyroxenite’ (which could represent clinopyroxenite, websterite or orthopyroxenite) is used. Similarly, the field term ‘gabbro’ may represent norite, gabbronorite or gabbro. The more precise terminology is advanced in the discussion of the geochemical results.

The study area is relatively undeformed, with the exception of an orthogonal pair of prominent fractures and/or brittle faults. One of these is coplanar with igneous layering (e.g. striking between 110 and 115º and having vertical or near-vertical dips), and the other cuts layering at approximately right angles, trending at approximately 020º (*see* Peck et al., 2000). The latter structures locally show north-northeast-directed lateral displacement of the stratigraphy. Within the study area, this north-northeast apparent horizontal displacement is largely taken up on a single major fault that has a dextral offset of layering of approximately 200 m (Peck et al., 2000). Some of the units in the Fox River sill appear to thicken across this major fault, suggesting that it could represent a synmagmatic structure, coincident with peak extension in the Fox River Belt during an active rifting stage. Locally, a south-side-up sense of vertical displacement is evident on the east-southeast-trending (layer-parallel) faults, suggesting that they are normal faults. The Lower Volcanic formation in the Great Falls area is composed of a layered sequence of pillowed and massive, compound flows of basaltic to komatiitic-basaltic composition (*see* Syme et al., 1999). In the study area, the Middle Sedimentary formation forms a thin (generally <100 m), poorly exposed, discontinuous package of laminated, pyritic mudstone and siltstone (Fig. GS-9-1). These sedimentary rocks are hornfelsed near the contact with the sill, where their primary bedding has been replaced by a massive, aphanitic texture.

At Great Falls, the Marginal zone comprises three main subunits, each approximately 100 m thick, including (from south to north) the Basal Contact unit, Cyclic unit 1 and Cyclic unit 2 (Fig. GS-9-1, -2). Most of the ultramafic and mafic rocks in the study area are cumulate rocks made up of variable proportions of cumulus olivine, clinopyroxene, chromite (minor) and postcumulus (poikilitic) orthopyroxene (ultramafic units), or cumulus clinopyroxene, orthopyroxene and plagioclase (mafic units). The sense of differentiation of the units is such that the stratigraphic younging direction is assumed to be to the north, in keeping with flow tops measured in the underlying Lower Volcanic formation. The Basal Contact unit locally contains hornfelsed xenoliths of the Middle Sedimentary formation and minor disseminated pyrrhotite±chalcopyrite at its base. The Basal Contact unit is overlain by Cyclic unit 1, which is normally differentiated and 100 to 150 m thick. Cyclic unit 1 grades abruptly from a lower lherzolite and olivine pyroxenite subunit (UM1 subunit) to a more leucocratic, melagabbro (minor) to gabbro to leucogabbro sequence (LG1 subunit). An anorthosite layer, less than 0.5 m thick, is locally present at the top of the LG1 subunit, and

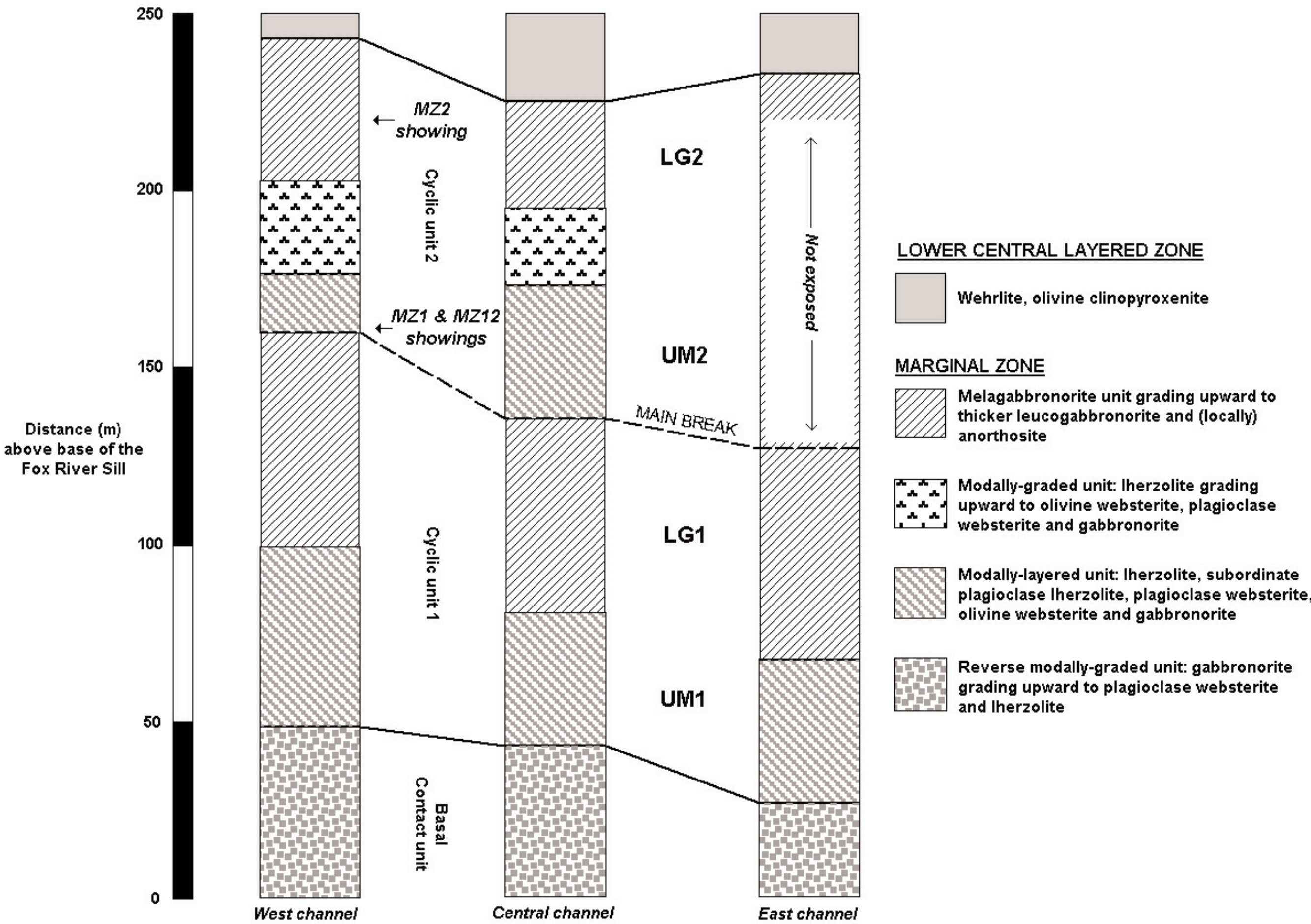


Figure GS-9-2: Preliminary lithological sections for the West, Central and East channels of the Fox River in the Great Falls area (modified from Scoates, 1990; Peck et al., 1999).

leucotonalite veins are commonly present in the upper 20 m of this subunit. Cyclic unit 1 and Cyclic unit 2 are separated by the Main break (Fig. GS-9-1, -2), a decimetre- to metre-wide break in outcrop that forms a prominent east-southeast-trending lineament on aerial photographs. The Main break locally appears to represent a vertical (normal) fault, but elsewhere is simply a narrow fracture represented by a 1 to 2 m wide break in the outcrop that reflects preferential weathering of the less resistant ultramafic rocks of the lower parts of the UM2 subunit relative to the more resistant gabbroic rocks of the LG1 subunit. Cyclic unit 2 is 100 to 150 m thick and interpreted to have formed from a single pulse of magma emplaced before the rocks in Cyclic unit 1 were completely solidified. Field observations, not yet corroborated by petrographic studies, indicate a crystallization order for Cyclic unit 2 of orthopyroxenefi olivinefi chromitefi clinopyroxenefi plagioclase, which is atypical for the Marginal zone and for the Fox River sill in general (olivinefi chromitefi clinopyroxenefi plagioclasefi orthopyroxene; Scoates, 1990). Cyclic unit 2 is further distinguished by the persistent development of disseminated pyrrhotite±chalcopyrite mineralization, which suggests that it, unlike Cyclic unit 1, crystallized from sulphur-saturated magma.

The lowermost 1 to 3 m of the UM2 subunit host several occurrences of chalcopyrite-dominant, disseminated sulphide mineralization (Fig. GS-9-1). In the Leisure island (unofficial name) detailed-mapping area (Fig. GS-9-1), these sulphide minerals are principally confined to a coarse-grained pyroxenite layer and appear to be best concentrated within decimetre- to metre-size troughs that are erratically developed along the LG1-UM2 contact (Fig. GS-9-3, -4). The sulphide mineralization at the base of the UM2 subunit is referred to as the KO zone. Chalcopyrite is the dominant sulphide mineral, and attains a maximum of 15% near the base of the troughs. The unit also contains lesser amounts of pyrrhotite (up to 8%) and pentlandite, whose presence has been inferred from chemistry. Generally, the sulphide minerals are segregated into a lowermost, coarse-grained, pyrrhotite-rich horizon (approx. 10 cm), which grades upward into a wider, finer grained, chalcopyrite-dominant layer (up to 3 m thick but typically <1 m). The total sulphide content generally decreases upward.

At the original discovery outcrop (MZ1 showing, Fig. GS-9-1; *see also* Peck et al., 1999), the pyroxenite layer is absent but the mineralization persists and is contained within a pod-shaped body of leucogabbro that becomes more pyroxene rich and coarser grained toward its base. Where present, the pyroxenite layer varies from very coarse grained (crystals up to 3 cm long) to medium grained (crystals <0.5 cm long). The local absence of the pyroxenite layer is considered to represent preferential erosion of talc-amphibole–altered parts of the layer, rather than lateral thickness variations in the layer. The basal UM2 pyroxenite grades abruptly upward into lherzolite and olivine pyroxenite. The lherzolite is a fine-grained olivine cumulate that also contains coarse-grained orthopyroxene oikocrysts and finer grained, subequant clinopyroxene. At Leisure island (Fig. GS-9-1), no mineralization was observed in the olivine cumulates overlying the mineralized pyroxenite layer, but the olivine cumulates are not well exposed. Elsewhere, such as at the MZ1 showing (Fig. GS-9-1), centimetre-thick bands of disseminated sulphide-bearing lherzolite are recognized within 1 to 3 m of the Main break, in areas where the basal pyroxenite layer is not observed. At the MZ1 showing, chalcopyrite-rich disseminated sulphide mineralization occurs in a pod-shaped, variably textured, and differentiated body of gabbro to leucogabbro that is interpreted to represent melts derived from the underlying LG1 subunit. Similar gabbroic pods, lacking abundant

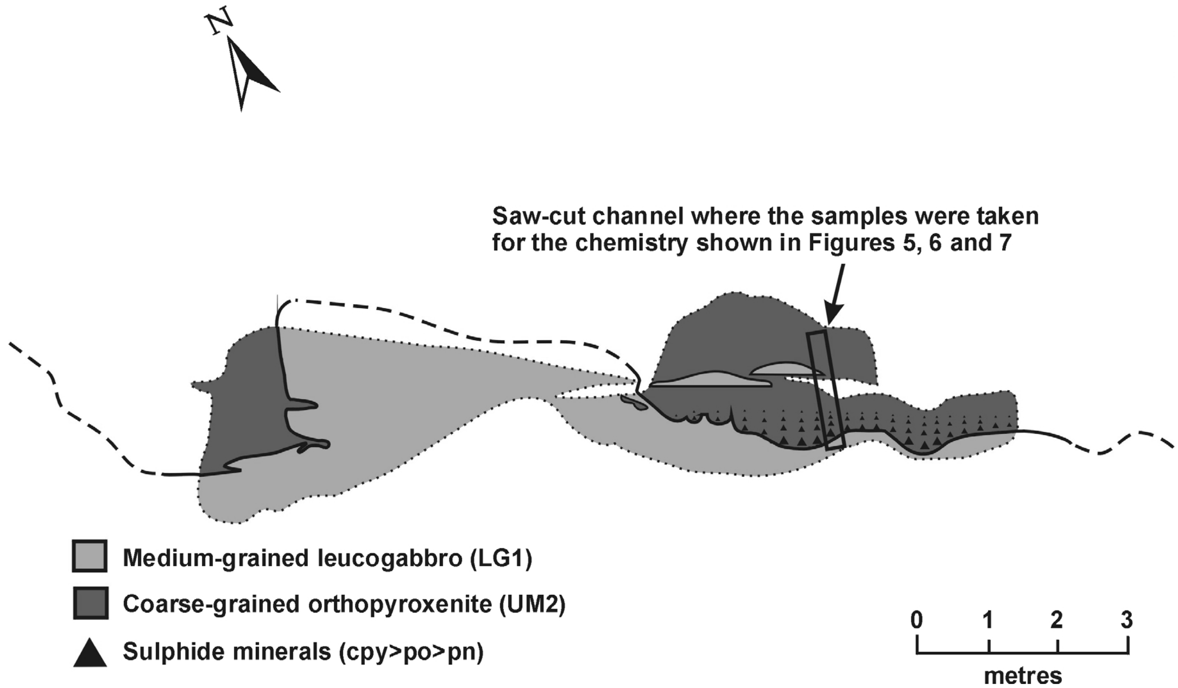


Figure GS-9-3: Geology and sample locations for the MZ12 sulphide showing outcrop (Leisure island, Great Falls; Fig. GS-9-1), illustrating the irregular, scalloped contact between the LG1 and UM2 subunits of the Marginal zone, Fox River sill.

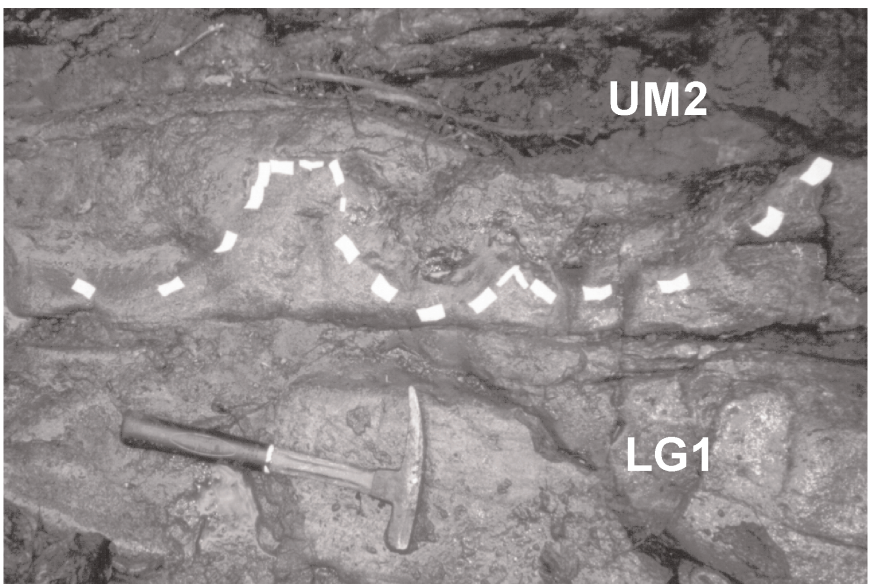


Figure GS-9-4: Photograph of the scalloped contact between LG1 and UM2 units; the contact has been outlined with pieces of white tape.

sulphide minerals, are present along most of the exposed parts of the lower UM2 subunit. The UM2 subunit grades upward into a melagabbro layer, several metres thick, that in turn grades upward into the LG2 subunit (gabbro and leucogabbro). Trace to 15% disseminated, pyrrhotite-rich sulphide mineralization is erratically distributed throughout both the transitional melagabbro layer and the LG2 subunit. Cyclic unit 2 is overlain by a pyroxenite layer representing the base of the approximately 1 km thick Lower Central Layered zone (Scoates, 1990).

THE KO ZONE: A NEW CU-NI-PGE TARGET IN THE MARGINAL ZONE OF THE FOX RIVER SILL

Mapping and surface prospecting in the Marginal zone of the Fox River sill, completed during the 1999 and 2000 field programs, delineated several new sulphide showings in the lower part of the UM2 subunit. The initial discovery (MZ1 showing) was made by K. Olshefsky of Falconbridge Ltd. in July of 1999. In recognition of this, the Cu-Ni-PGE-enriched parts of the UM2 subunit, comprising the basal pyroxenite layer and the sulphide-bearing parts of the overlying lherzolite–olivine pyroxenite sequence, are herein referred to as the KO zone.

Geological Characteristics and Genetic Constraints of KO Zone Mineralization

The KO zone mineralization, typically restricted to the lowermost 1 to 3 m of the UM2 subunit, comprises medium- to coarse-grained, disseminated pyrrhotite and chalcopyrite (the presence of pentlandite has not been visually confirmed but is inferred from assays; Fig. GS-9-3, -4). The sulphide minerals display a range of textures, including interstitial-irregular, net-textured and blebby. The following is a summary of the principal geological attributes of the KO zone, based on field observations made during the 1999 and 2000 field programs and research conducted by Huminicki (2000). In addition, preliminary genetic interpretations are provided where constrained by the field data. A graduate thesis study, recently initiated by the senior author at the University of

Manitoba, will further consider the metallogeny of the KO zone.

1) The KO zone mineralization always occurs on or immediately above the LG1-UM2 contact, and is clearly stratabound and locally stratiform in nature, as reflected by the presence of thin sulphide-rich layers at the MZ1 showing. These layers are conformable with igneous layering in the host lherzolite–olivine pyroxenite sequence.
2) The mineralization is concentrated within small-scale basin structures that are interpreted as representing primary topographic features caused by scouring of the LG1 subunit by the UM2 magma.
3) The development of small-scale basin structures in the Great Falls outcrop area, where the Marginal zone internal subunit contacts are extremely planar on the scale of the map area, indicates that larger, second-order (e.g. decimetre-scale) and first-order (kilometre-scale) structures could exist along strike to the west and east.
4) Where most concentrated, the KO zone sulphide mineralization displays textural and compositional features reflecting effective separation of immiscible, magmatic sulphide liquid from a S-saturated ultramafic parent magma, including normal size and compositional grading of both sulphide and silicate components. Accordingly, the mineralization may be better concentrated in larger basin structures that, to date, have not been seen in outcrop or drill core.
5) The KO zone is principally hosted by an isomodal, pyroxene-rich layer, but is also locally present in overlying lherzolite and olivine pyroxenite that make up most of the approximately 50 m thick UM2 subunit. Additional surface prospecting and, ultimately, drilling will be required to determine the dimensions of the zone.
6) Leucogabbroic pods, up to 10 m long and 5 m thick, occur within several metres of the LG1-UM2 contact in the UM2 subunit. The pods display variable textures (fine grained to pegmatitic) and compositions (melagabbro to leucodiorite) and, like the pod at the MZ1 showing (Peck et al., 1999; Huminicki, 2000), are locally mineralized and normally differentiated with respect to their grain size (fining upward) and mineralogy (increase in plagioclase content upward). Based on the existing mapping, the pods are believed to represent small volumes of buoyant, evolved gabbroic magma that originated in the underlying LG1 subunit. These gabbroic melts could have been generated by reheating and melting of the top of the LG1 subunit due to heat transfer from the overlying UM2 magma. No pods have been recognized in the middle or upper parts of the UM2 subunit, and it is not known why the pods failed to ascend farther above the UM2 contact. Their origins will be investigated in more detail by the senior author as part of the previously mentioned graduate thesis project.

Preliminary Geochemical Results

Assay and whole-rock analytical data have been obtained for 40 samples collected during the 2000 field season from the Leisure island exposures of the KO zone mineralization (Table GS-9-1). Analytical work was carried out by Activation Laboratories, Ancaster, Ontario; QA/QC data are available on request. Additional data, acquired during the 1999 field season from other outcrops of the UM2 and LG2 subunits in the Great Falls area, are discussed in Peck et al. (1999) and Huminicki (2000). Collectively, these data provide additional constraints on the genesis of the mineralization, including the following critical features:

1) Collectively, the UM1-LG1 subunits represent a normally differentiated sequence of lherzolite→websterite→melagabbronorite→gabbronorite→leucogabbronorite→anorthosite, in which Al content increases and Mg content decreases up section (Huminicki, 2000).Note that both geochemical and petrographic data are used here to support further subdivision of the various gabbroic and ultramafic rocks, based on the relative abundances of clino- and orthopyroxene.
2) The UM2 subunit is very different in chemical composition compared to most of the other ultramafic intrusive and volcanic units in the Fox River Belt. This reflects the atypically high orthopyroxene and sulphide mineral content in the UM2 subunit.
3) The base of the UM2 subunit shows the first significant increase in S and chalcophile metal content in the Fox River sill, with the notable exception of the disseminated sulphide mineralization recognized in

Table GS-9-1: Geochemistry of selected samples collected from MZ12 showing. Oxides expressed in per cent, trace elements in ppm.

Sample No.	M1B-A	M1B-B	M1B-C	M1B-D	M1B-E	M1B-F	M1B-G	M1B-H	M1B-I	M1B-J	M1B-K	M1B-L	M1B-M	M2EA
SiO_2	49.69	46.10	44.77	46.54	44.54	45.35	45.94	49.62	47.16	46.70	44.97	47.10	46.28	49.36
Al_2O_3	16.16	8.67	9.41	7.91	9.42	8.58	7.77	6.08	7.22	7.85	9.66	7.72	8.08	4.42
Fe_2O_3	7.99	14.90	15.22	14.28	15.00	14.44	14.96	11.36	12.97	12.80	14.12	12.90	13.07	15.47
MnO	0.14	0.18	0.18	0.18	0.18	0.17	0.17	0.18	0.18	0.15	0.19	0.18	0.18	0.15
MgO	11.49	20.57	21.81	21.40	22.18	21.70	21.25	21.17	21.59	22.57	22.14	22.17	22.03	20.22
CaO	12.83	9.15	8.38	9.18	8.26	9.10	9.11	10.85	10.27	9.43	8.45	9.50	9.89	9.70
Na_2O_3	1.08	0.22	0.11	0.13	0.13	0.22	0.24	0.28	0.24	0.17	0.17	0.19	0.18	0.16
K_2O	0.37	-0.01	0.06	0.07	0.02	0.07	0.07	0.08	0.09	0.04	0.03	0.02	0.04	0.07
TiO_2	0.25	0.19	0.24	0.29	0.25	0.33	0.45	0.36	0.26	0.25	0.28	0.21	0.24	0.43
Cr	145	211	846	866	1040	991	1030	564	732	899	143	662	866	315
Co	37	103	123	122	137	120	116	107	83	87	50	45	69	225
Ni	215	2040	1980	1830	1880	1690	1730	1520	895	663	311	461	635	9350
Cu	52	3400	3760	6980	3910	6590	11800	302	176	283	42	119	143	20700
Zn	64	65	62	57	84	62	72	41	82	52	53	48	66	78

M1B-A: gabbro at southern end of saw cut shown on Figure GS-9-3 (subunit LG1)
M1B-B: orthopyroxenite above M1B-A (UM2)
M1B-C: orthopyroxenite above M1B-B (subunit UM2)
M1B-D: orthopyroxenite above M1B-C (subunit UM2)
M1B-E: orthopyroxenite above M1B-D (subunit UM2)
M1B-F: orthopyroxenite above M1B-E (subunit UM2)
M1B-G: orthopyroxenite above M1B-F (subunit UM2)
M1B-H: orthopyroxenite above M1B-G (subunit UM2)
M1B-I: orthopyroxenite above M1B-H (subunit UM2)
M1B-J: orthopyroxenite above M1B-I (subunit UM2)
M1B-K: orthopyroxenite above M1B-J (subunit UM2)
M1B-L: orthopyroxenite above M1B-K (subunit UM2)
M1B-M: orthopyroxenite above M1B-L (subunit UM2)
M2EA: orthopyroxenite sample collected 15 m east of M1B samples (subunit UM2)

1999 at the base of the reverse-differentiated Basal Contact subunit. To date, S-bearing samples from the KO zone contain up to 5.4 g/t combined Pd+Pt+Au (Pd>>Pt>>Au), 2.3% Cu and 1.1% Ni (Peck et al., 1999). All samples analyzed to date contain disseminated sulphide mineralization and no massive sulphide mineralization has been assayed, although a 2 cm thick massive sulphide band occurs at the base of the MZ1 showing. Geochemical analyses obtained for samples from the recently discovered Leisure island showing (MZ12, discovered by M. Huminicki, L. Potter and G. Desharnais) contain up to 1.9 g/t combined Pd+Pt+Au, 2.1% Cu and 0.9% Ni (Table GS-9-1). At the time this report was written, PGE data were not available for most of the samples collected during the current program.

4) The available data indicate that the samples from the MZ12 showing have lower Pd/Pt ratios (average of 1.5 for five samples) than those from the MZ1 showing (generally >3). Also, most of the available samples from the KO zone are Cu-rich (average Cu:Ni ratio of approx. 2.1, although this ratio is quite variable, ranging from <0.1 to 8).
5) The large range in Cu:Ni ratios reflects variations in the chalcopyrite:pentlandite ratio.
6) The Cu and Ni concentrations generally decrease with increasing stratigraphic height (Fig. GS-9-5). This is in agreement with a simple density segregation process, whereby sulphide liquid droplets accumulate toward the base of a magma body.

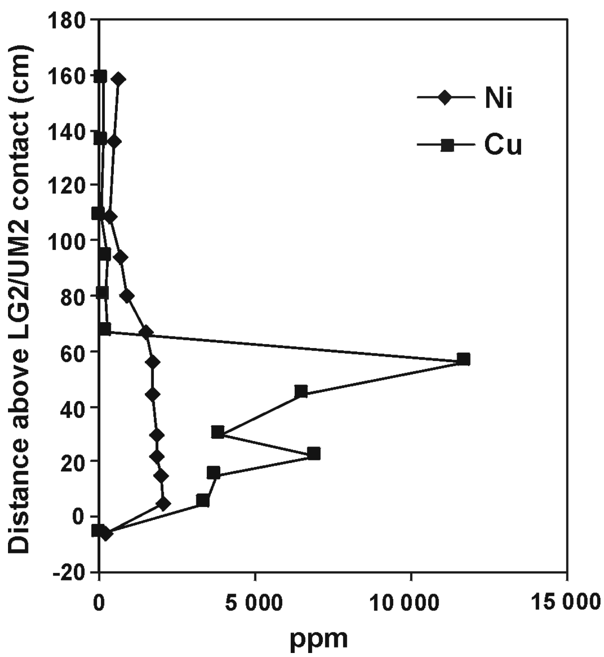


Figure GS-9-5: Variations in whole-rock Cu and Ni abundances with distance from the contact between the LG1 and UM2 subunits. Refer to Figure GS-9-3 for sample locations.

7) A plot of four major elements (oxides of Fe, Ca, Al and Mg) shows that Al and Fe vary similarly with stratigraphic height. In contrast, there is an antipathetic relationship between Al or Fe and Ca (Fig. GS-9-6). These trends are consistent with a pyroxene±plagioclase control on this part of the UM2, in contrast to the more typical olivine±pyroxene control evident in the overlying lherzolite sequence.
8) There is a very significant positive correlation ($r^2 = 0.97$) between Cu and Se contents in all KO zone samples collected from Leisure island. This suggests a strong sulphide control on the Cu content in this zone. The correlation between Ni and Se, although still significant, is weaker than that between Cu and Se. This may reflect a minor silicate control on Ni abundances in the KO zone (e.g. olivine).
9) Mantle-normalized multi-element plots for representative samples from the KO zone at Leisure island (Fig. GS-9-7) illustrate that most of the mineralized rocks have mantle-like trace-element compositions with prominent, negative Eu anomalies. These samples also display a positive Zr anomaly (Fig. GS-9-7). None of the samples analyzed to date show any significant enrichment in incompatible trace elements (e.g. La) that might be expected had the parent magmas assimilated significant amounts (bulk or partial melts) of country rock. This suggests that the magma was saturated in S prior to intrusion and that wall-rock assimilation may have been localized within the Basal Contact unit.

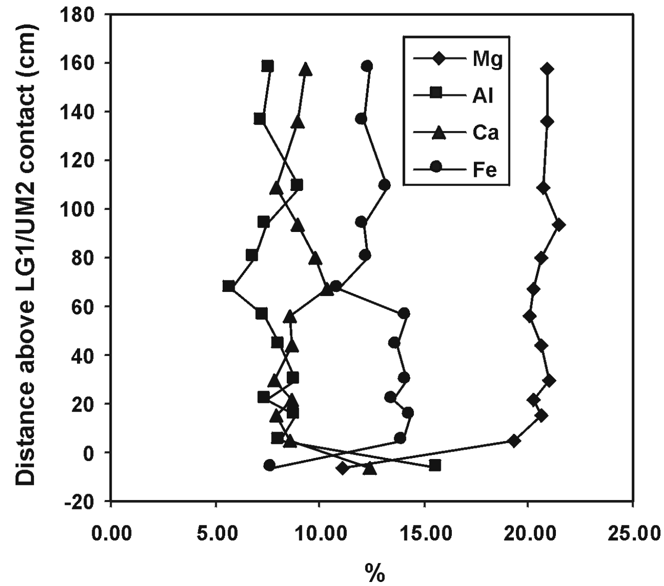


Figure GS-9-6: Variations in whole-rock MgO, CaO, Al_2O_3 and Fe_2O_3 contents with distance from the contact between the LG1 and UM2 subunits. Refer to Figure GS-9-3 for sample locations.

DISCUSSION: PRELIMINARY GENETIC MODEL FOR THE KO ZONE

A preliminary emplacement model is proposed that is generally consistent with both field observations and geochemical data:

1) Stage 1: Emplacement and crystallization of the reverse-differentiated Basal Contact unit, representing the first pulse of magma into the Fox River sill and effectively representing a broad chilled margin that locally grades into a petrologically complex magmatic breccia.
2) Stage 2: Emplacement of Cyclic unit 1, the first normally differentiated cyclic unit of the Marginal zone and the second major influx of magma into the proto-chamber of the Fox River sill. The Basal Contact unit and Cyclic unit 1 may, in fact, have formed from a single pulse of magma, but field relationships are presently inconclusive. Cyclic unit 2 magma differentiated through (?)flow-enhanced segregation of cumulus olivine to produce the observed ultramafic base (UM1) and leucogabbroic upper part (LG1). Late-stage leucotonalite liquid may have evolved at the temporary roof of the chamber or may reflect contact-related melting of the LG1 subunit during emplacement of Cyclic unit 2.
3) Stage 3: Sulphur-saturated ultramafic magma responsible for Cyclic unit 2 is injected between the anorthositic upper part of the LG2 subunit and the actual roof of the chamber (possibly underlain by leucotonalite from Cyclic unit 1), scouring the top of the UM1 subunit and creating local troughs within which dense S-liquid droplets are collected by flow-enhanced gravitational settling. The sulphide minerals concentrate along the lowermost part of the UM2 subunit, regardless of the presence of trough structures or late-stage mafic pods.
4) Stage 4: Conductive and/or convective heat loss across the solid anorthositic top of the LG1 layer helps advance crystallization of pyroxene in lieu of olivine. Early-formed pyroxene collects with the sulphide liquid in a mush zone at the base of the UM2 subunit. This

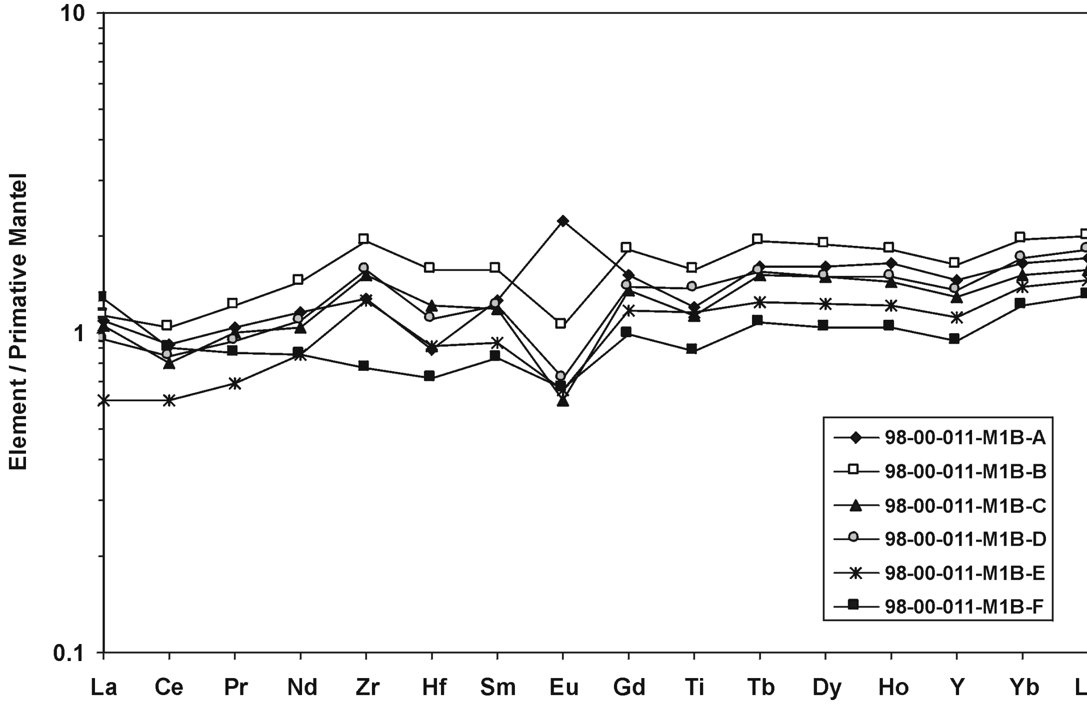


Figure GS-9-7: Condensed, mantle-normalized, multi-element plot for selected, representative samples from the contact between the LG1 and UM2 subunits. Refer to Figure GS-9-3 for sample locations. Sample 9800-011-M1B-A was collected from the northernmost part of the LG1 subunit. The remaining samples are from the lowermost part of the UM2 subunit.

heating may have promoted partial melting of the leucogabbroic rocks beneath the refractory, anorthositic top of the UM1 subunit, which then ascended across the LG1-UM2 contact and invaded the mushy base of the UM1 subunit. These pod-like injections entrained sulphide minerals and UM2 'mush', and crystallized as melagabbronorite-gabbronorite-leucogabbronorite-leucodiorite pods that have normal modal gradation and are locally mineralized (e.g. MZ1 pod). Several of these pods are variably textured, suggesting that the release of deuteric vapours from Cyclic unit 1 may have enhanced migration of the pod parent liquids upward into the UM2 subunit.

Ongoing research of the Marginal zone geology and mineralization is being carried out by the senior author (University of Manitoba). This research will provide new geological, mineralogical and geochemical observations that will allow the development of rigorous genetic models for the emplacement and mineralization of the KO zone. On a more regional scale, ongoing detailed investigations of the Fox River sill will continue to provide constraints on its emplacement and crystallization. One hypothesis currently being tested, which is consistent with many recent field and geochemical observations, is that the Fox River sill was emplaced on a subvertical, syn-rift, axial fault system and is therefore a major dyke.

REFERENCES

Heaman, L.M., Machado, N., Krogh, T.E. and Weber, W. 1986: U-Pb zircon ages for the Molson dyke swarm and the Fox River sill: constraints for Early Proterozoic crustal evolution in northeastern Manitoba, Canada; Contributions to Mineralogy and Petrology, v. 94, p. 82–89.

Huminicki, M. 2000: A mineralogical, petrological and geochemical evaluation of the Cu-Ni–platinum-group element mineralization in the Marginal Zone of the Fox River sill, northeastern Manitoba; B.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 95 p.

Peck, D.C., Desharnais, G., Theyer, P., Huminicki, M., Potter, L., Wegleitner, C. and Kohut, G. 2000: Geology and mineral occurrences of the Fox River sill in the Great Falls area, Fox River Belt, northeastern Manitoba (part of NTS 53M/16); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Map 2000 T-1, 1:1000 scale.

Peck, D.C., Huminicki, M., Wegleitner, C., Theyer, P., Olshefsky, K., Potter, L. and Scoates, R.F.J. 1999: Lithostratigraphic framework for platinum-group element–copper-nickel sulphide mineralization in the Marginal Zone of the Fox River sill (parts of NTS 53M/16 and 53N/13); *in* Report of Activities 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 46–50.

Scoates, R.F.J. 1981: Volcanic rocks of the Fox River Belt, northeastern Manitoba; Manitoba Energy and Mines, Geological Services, Geological Report GR81-1, 109 p.

Scoates, R.F.J. 1990: The Fox River sill: a major stratiform intrusion; Manitoba Energy and Mines, Geological Services, Geological Report GR82-3, 192 p.

Syme, E.C., Peck, D.C. and Huminicki, M., 1999: Volcanic stratigraphy of selected sections on the Fox and Stupart rivers, Fox River Belt (parts of NTS 53M/16 and 53N/13); *in* Report of Activities, 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 51–60.