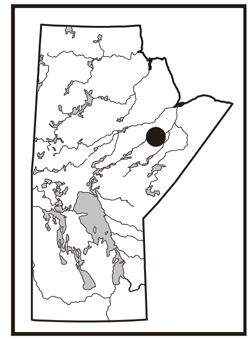
GS-13 LITHOSTRATIGRAPHIC FRAMEWORK FOR PLATINUM-GROUP ELEMENT-COPPER-NICKEL SULPHIDE MINERALIZATION IN THE MARGINAL ZONE OF THE FOX RIVER SILL (PARTS OF NTS 53M/16 AND 53N/13)



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Peck, D.C., Huminicki, M., Wegleitner, C., Theyer, P., Olshefsky, K., Potter, L., Hulbert, 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.

SUMMARY

Mapping in the Great Falls area of the Fox River Sill delineated disseminated magmatic pyrrhotite and chalcopyrite mineralization in the upper part of the Marginal Zone and along the base of the uppermost of two cyclic units that occur in this zone. Preliminary surface grab samples contain up to 4 g/t Pd, 2% Cu and 1% Ni (MZ1 showing; data courtesy of Falconbridge Limited). Later work revealed that trace to minor quantities of disseminated sulphides locally occur at the same stratigraphic position as the MZ1 showing and persistently occur in the overlying, leucogabbroic part of this cyclic unit (MZ2 showing). Lithogeochemical analyses of gabbroic and ultramafic rocks from the Marginal Zone, including sulphide-bearing rocks from the uppermost cyclic unit, returned low Pd and base metal abundances, typically less than 50 ppb and 0.2% combined Cu+Ni, respectively. The Pd-rich sulphide mineralization contained in the MZ1 showing resembles classic PGE reef-type mineralization in terms of its stratigraphic position (e.g., near a major petrological boundary), morphology (pothole structures) and the low PGE tenor of both the underlying and overlying units. However, the MZ1 showing contains higher Pd:Pt ratios and total sulphide abundances and lacks the high chromite abundances that characterize reef-type PGE deposits. Despite these uncertainties, the large dimensions and lateral continuity of the Fox River Sill and the known presence of PGE-rich magmatic sulphides in the Marginal Zone provides sufficient impetus for more detailed investigations of its PGE-Cu-Ni mineralization.

Field work also revealed that: (1) the Marginal Zone is made up of one reverse modally graded unit (basal contact zone) and two normally modally graded cyclic units; (2) the Marginal Zone is north facing and not structurally repeated; (3) the base of the Marginal Zone crystallized from the first magmas to enter the protochamber of the Fox River Sill. A thermal aureole extends outward from the basal contact zone into pyritic mudstone and siltstone of the Middle sedimentary formation. In the basal contact zone, the presence of siliceous xenomelt derived by contact melting of the sedimentary rocks and varitextured hornblende-bearing gabbroic rocks are evidence of both physical and chemical interaction between the country rock and the Fox River Sill parent magmas. This interaction may have promoted the development of the disseminated sulphides recognized in the basal contact zone. Based on these observations, we recommend that the potential for the development of massive Ni-Cu-PGE sulphide deposits in the Marginal Zone of the Fox River Sill be re-examined.

INTRODUCTION

The lower and middle parts of the Fox River Sill are well exposed in the Great Falls area (Fig. GS-13-1). Low water levels in 1999 provided excellent exposures in the many channels of the Fox River at Great Falls (Fig. GS-13-2). To capitalize on these excellent exposures, a two week

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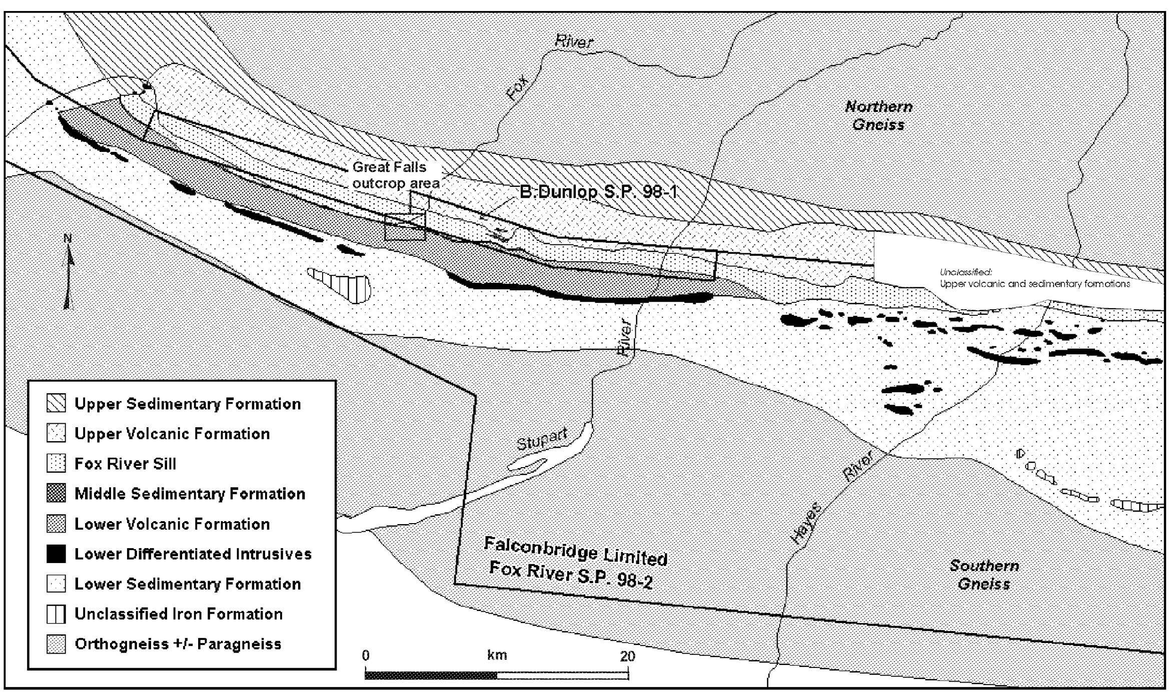

Figure GS-13-1: Simplified geology of the Fox River Belt showing the location of the Great Falls study area. Adapted from Scoates (1990) by Falconbridge Limited.

Figure GS-13-2: Several of the authors examining some of the excellent bedrock exposure in the Great Falls area. Rapids and falls typically develop at resistant pyroxenite layers, as seen here in the western channel area.

field program was undertaken with two major objectives, viz.:

(1) provide detailed stratigraphic information for the Marginal Zone of the Fox River Sill in the Great Falls area; and

(2) collect surface grab samples for a systematic lithogeochemical study of the mineral potential (Cu-Ni-PGE) and petrogenesis of the Marginal Zone of the Fox River Sill.

Previous exploration for Cu-Ni-PGE sulphides in the Fox River Sill focused on the search for massive Ni-rich sulphide deposits along the base of the sill (INCO Limited) and for Cu- and PGE-rich stratiform sulphide mineralization near the contact between the Lower Central Layered Zone and the Upper Central Layered Zone (B.P. Minerals, Open Assessment File reports; Schwann, 1989; Naldrett et al., 1994). Westminer Limited explored the Fox River belt in the early 1990s, focusing on the potential for Kambalda-style magmatic Ni sulphide mineralization at the base of the Lower volcanic formation.

A reconnaissance field program (July, 1999) in the western part of the Fox River Belt led to identification of disseminated Cu-rich sulphide mineralization in the upper part of the Marginal Zone in the western channel system, Great Falls area (Fig. GS-13-3). Assays completed by Falconbridge Limited for one of these occurrences (MZ1 showing, Fig. GS-13-3) returned highly anomalous platinum-group element (PGE) contents, including one grab sample with 4.3 ppm Pd, 0.4 ppm Pt, 0.7 ppm Au, 1.9% Cu and 0.7% Ni. A second sample from the same occurrence contains 4 ppm Pd, 0.4 ppm Pt, 0.3 ppm Au, 2.3% Cu and 1.1% Ni. These results prompted a follow up investigation of the distribution of disseminated sulphide mineralization in the Marginal Zone. Field work involved detailed lithostratigraphic mapping in the Great Falls area combined with systematic surface sampling for an ongoing lithogeochemical investigation (Fig. GS-13-4).

LITHOSTRATIGRAPHY OF THE MARGINAL SERIES, GREAT FALLS AREA

A summary of the geology of the Fox River Belt and the Fox River Sill is given in Peck et al. (GS-12, this volume) and is based on previous mapping and drill core studies (Scoates, 1981, 1990). Most of the mapping was concentrated in the western channel of the Great Falls braided stream complex (Fig. GS-13-3), which provides the most complete section through the Marginal Zone. In this report we present a modified version of Scoates' (1990) geological map of the Great Falls area based on the new field observations (Fig. GS-13-3).

According to Scoates (1990), the Marginal Zone forms a ca. 300 m thick layered sequence comprising a lower mafic unit that is overlain by three cyclic units. The layering strikes at ca. 110°, is generally vertical to sub-vertical, and is interpreted to face northward. Each cyclic unit comprises a lowermost 30-50 m thick peridotite layer, a central, 10-20 m thick pyroxenite layer and an upper, 20-40 m thick gabbroic layer. The Marginal Zone is underlain by a thin sequence of pyritic siltstone and mudstone (Middle sedimentary formation) that in turn is underlain by pillowed and massive komatiitic basalt flows belonging to the Lower volcanic formation (Scoates, 1981; 1990). The Marginal Zone is overlain by a ca. 50 m thick wehrlite layer that constitutes the base of the Lower Central Layered Zone (Scoates, 1990).

The results of our lithostratigraphic studies are summarized on three geological sections for the west, central and east channels of the Fox River (Fig. GS-13-4). We have opted to use the I.U.G.S. classification scheme (Le Matire, 1989) for rock nomenclature. The application of cumulus nomenclature will be deferred until the primary paragenesis for the Marginal Zone rocks can be established from petrographic analysis of the ca. 200 surface samples collected in 1999.

The contact between the underlying sedimentary rocks of the Middle sedimentary formation and the base of the Fox River Sill (e.g., base of the Marginal Zone) is only exposed in the east channel area (Fig. GS-13-3). Here, the contact is deformed in a >50 m wide high strain zone that represents the only known major zone of ductile deformation within the Fox River Sill. Despite asymmetric folding and schistosity development in this area, we determined that the predeformation contact was abrupt, but irregular, and involves a fine-grained gabbro (base of the Fox River Sill) and aphanitic, equigranular metasedimentary rocks. The metasedimentary rocks appear to be recrystallized and, possibly, melted equivalents of the Middle sedimentary formation. The protolith, as observed in the eastern channel, is thinly bedded pyritic siltstone and mudstone that contains alternating cherty or arkosic beds and pyrite laminae. However, within 20 m of the contact with the Fox River Sill, the bedding becomes obliterated by a pervasive hornfelsic texture that is attributed to contact metamorphism of the Middle sedimentary formation within the thermal aureole of the Fox River Sill (see also Scoates, 1990). The original pyrite laminae within the sedimentary rocks appear to have been reconstituted as blebby immiscible sulphide (pyrrhotite, pyrite) in massive siliceous hornfels. Mapping of the Marginal Zone in 1999 indicates that only two of the three cyclic units described by Scoates (1990) are exposed in the Great Falls area. Brittle faults were recognized in several parts of the west channel area and may account for the differences in the Great Falls lithostratigraphy from Scoates' Marginal Zone stratigraphy. One of these faults is developed at the contact between ultramafic rocks at the base of the second cyclic unit and a thin anorthosite layer at the top of the first cyclic unit. This fault, informally referred to here as the "main break", appears to extend across the entire Great Falls area, and locally displays evidence of south-side up vertical displacement. Despite the presence of local, brittle faults, mapping suggests the Marginal Zone in the Great Falls is not structurally repeated. All stratigraphic facing indicators (e.g., size graded and modally graded layering) are to the north.

Basal Contact Unit

The base of the Marginal Zone is a predominantly gabbroic, reverse modally graded layer that is referred to here as the basal contact unit. The average thickness of the basal contact zone is ca. 30 m. In both the east and central channels, the zone is observed to grade upward from hornblende gabbronorite near the contact with the Middle sedimentary formation to increasingly more pyroxene-rich rock types, culminating in an olivine melagabbronorite at the top of the unit. The boundary between the

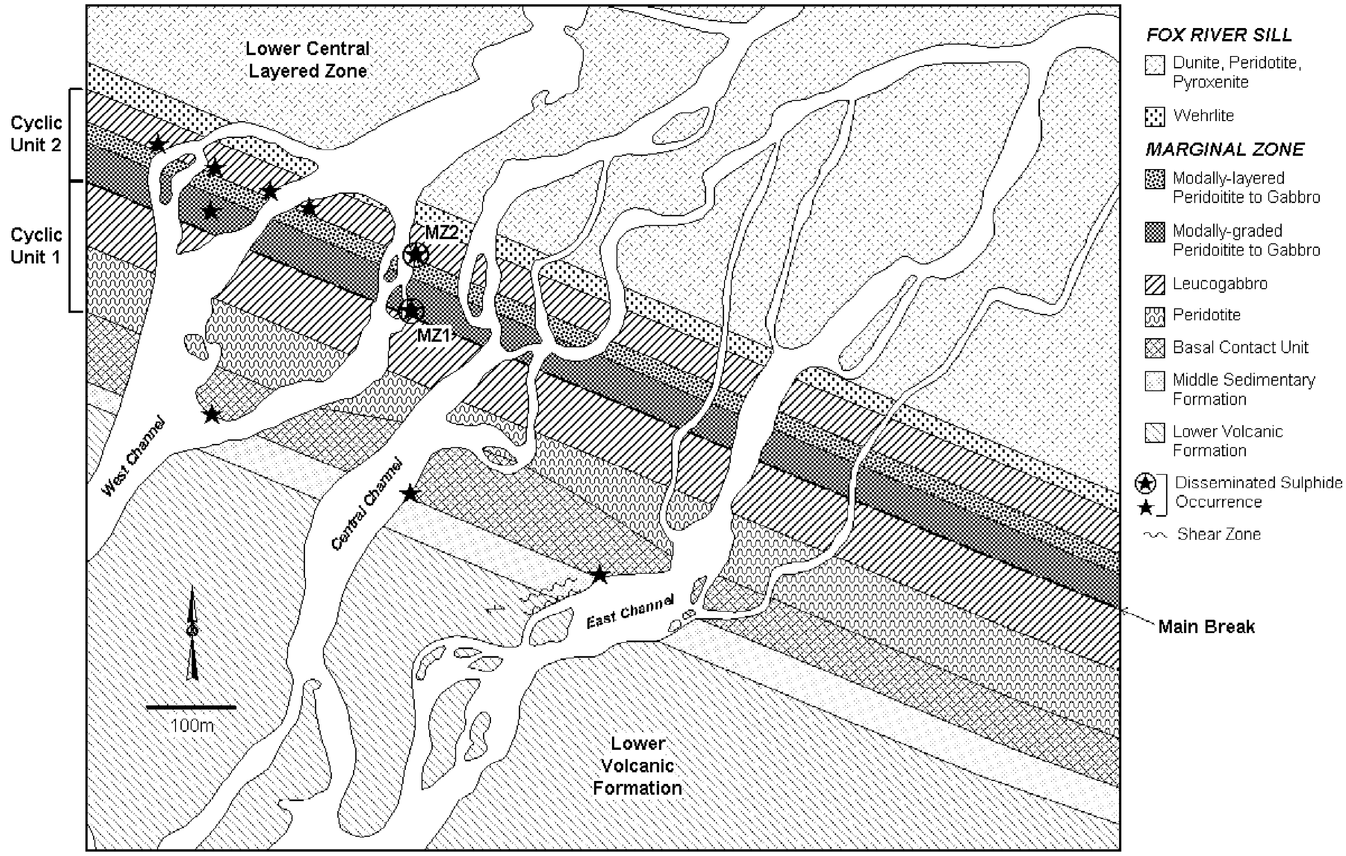

Figure GS-13-3: Geology of the Great Falls area. Mapping by Scoates (1990) and the current authors. Location of sulphide mineral occurrences are also shown.

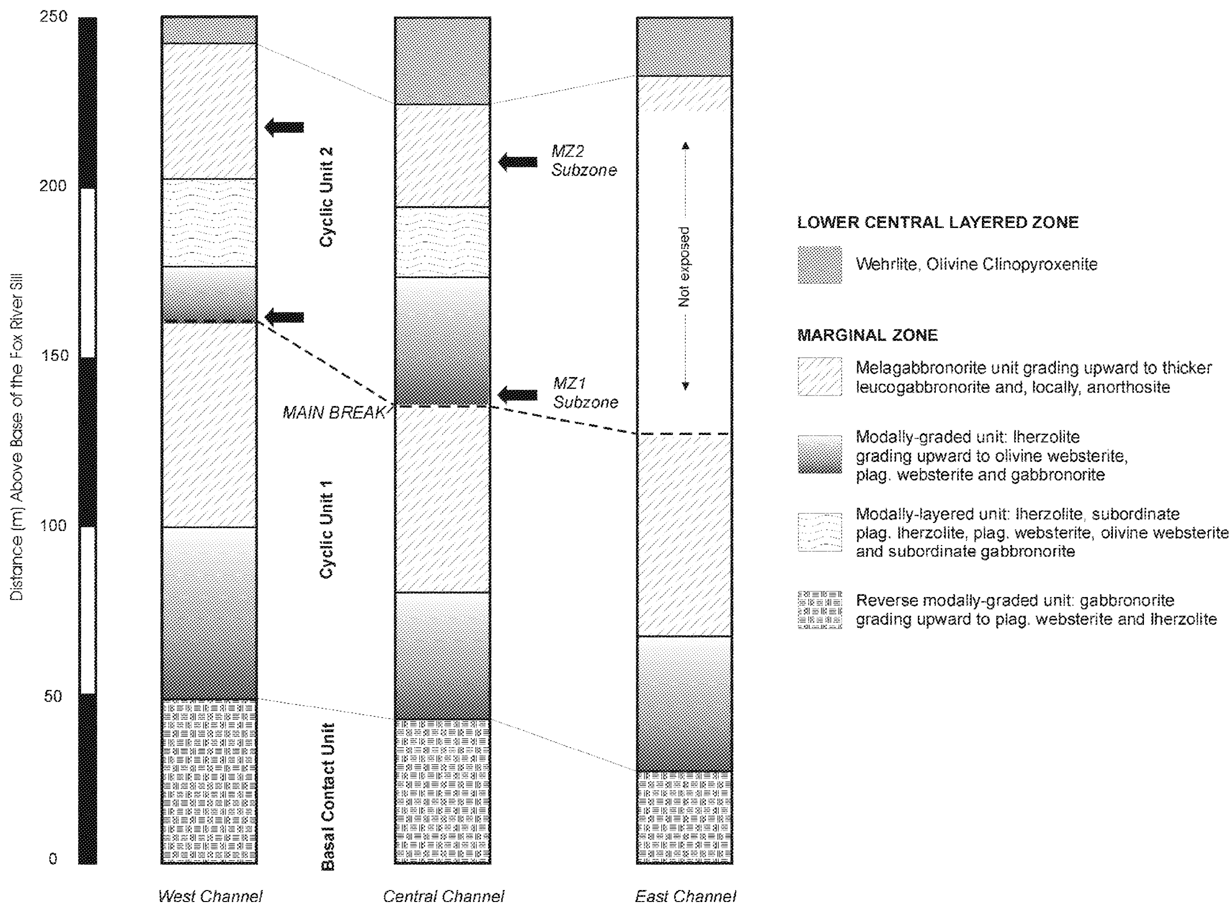

Figure GS-13-4: Measured lithostratigraphic sections for the Marginal Zone of the Fox River Sill, based on mapping (1999) in the eastern, central and western channel complexes, Great Falls outcrop area. Stratigraphic nomenclature adapted from Scoates (1990).

basal contact zone and the first cyclic unit (Fig. GS-13-3) of the Marginal Zone was observed in the east channel area. Here, the two units are separated by an abrupt, planar contact between gabbronorite and overlying lherzolite.

Trace to minor amounts (<2%) of disseminated pyrrhotite and chalcopyrite occur in association with siliceous xenomelt in the lowermost exposed part of the basal contact unit. In the central channel, coarse-grained to varitextured leucogabbronorite is intruded by irregular, centimetre to metre wide, fine-grained gabbronorite veins. Some of the fine-grained gabbronorite appears to have chilled against the leucogabbroic unit but in turn, is cut by veins of varitextured hornblende leucogabbro. The hornblende leucogabbro veins are interpreted to represent partial melts formed during the emplacement of the fine-grained gabbronorite.

In the west channel area, the lowermost exposed 20 metres of the basal contact zone consists of hornblende gabbro in which the textures become finer grained to both the north and the south of a central medium- to coarse-grained hornblende gabbro unit. These textural variations suggest that the hornblende gabbro represents the first pulse of magma to enter the protochamber of the Fox River Sill, and quenched along both the roof and the floor of the chamber (see also Scoates, 1990). Ascending hydrous fluids produced by contact metamorphism and partial melting of the underlying Middle sedimentary formation may also have contributed to variable crystal sizes in the basal contact zone and could account for presence of hornblende in this zone.

Cyclic Unit 1

Cyclic unit 1 has an average thickness of ca. 100 m in the Great Falls area. It comprises an ca. 40 m thick ultramafic zone and an overlying, ca. 60 m thick leucogabbronorite zone. The ultramafic zone grades upward, although not systematically, from lherzolite to olivine gabbronorite to plagioclase websterite to melagabbronorite. The contact between the ultramafic and leucogabbronorite zones is exposed in the east channel and involves an abrupt change from plagioclase lherzolite or melagabbronorite to gabbronorite or leucogabbronorite. The leucogabbronorite zone grades upward from gabbronorite in the lowermost ca. 10 m to leucogabbronorite. The top of the unit consists of one or more <20 cm thick anorthosite layers.

Cyclic Unit 2

In the central channel section, the base of cyclic unit 2 is a ca. 20 cm thick, medium-grained, equigranular clinopyroxenite layer. The clinopyroxenite layer is overlain by a ca. 40 m thick ultramafic zone comprising a lower modally-graded lherzolite - websterite - melagabbronorite unit and an overlying, centimetre- to metre-scale layered unit composed of lherzolite, plagioclase websterite and melagabbronorite (Fig. GS-13-4). The top of the ultramafic part of cyclic unit 2 and overlying leucogabbronorite unit are separated by a ca. 5 m thick, modally layered zone comprising several lherzolite, plagioclase websterite and gabbronorite layers. The leucogabbronorite zone has a gabbronorite base that grades upward to leucogabbronorite. Disseminated pyrrhotite ± chalcopyrite occurs sporadically within the middle and upper parts of the leucogabbroic unit (see below).

The top of cyclic unit 2 has an abrupt, planar, modal contact with an overlying wehrlite layer representing the base of the Lower Central Layered Zone (Scoates, 1990). The Lower Central Layered Zone is distinguished from the Marginal Zone by a greater abundance of olivine-rich rock types, a much more limited range in modal mineral compositions and a preponderance of simple phase layer contacts (typically defined by the appearance or disappearance of olivine) in contrast to the predominant modal layer contacts in the Marginal Zone. In both the Marginal Zone and the Lower Central Layered Zone, mesocumulate and orthocumulate textures are predominant and grain sizes rarely exceed 5 mm. However, at one location in the Great Falls area partly resorbed pyroxene megacrysts occur in peridotite in the basal part of the Lower Central Layered Zone (Fig. GS-13-5).

SULPHIDE MINERALIZATION IN THE MARGINAL SERIES, GREAT FALLS AREA

Disseminated sulphide mineralization was recognized at three stratigraphic positions within the Marginal Zone (below).

Basal Contact Zone

Disseminated pyrrhotite and chalcopyrite mineralization is erratically distributed over the lowermost several metres of the basal contact zone, within hornblende gabbro, gabbronorite and varitextured hornblende leucogabbronorite. In the east channel area, the mineralization occurs in abundances of up to several percent but averages only 1%. The sulphides are interpreted to represent minor concentrations of immiscible magmatic sulphide liquids that developed in the first pulse(s) of magma to enter the protochamber of the Fox River Sill. The spatial association with siliceous xenomelts and varitextured hornblende leucogabbro may indicate that the sulphides developed in response to assimilation of contact melts derived from pyritic siltstone and mudstone of the underlying Middle sedimentary formation. Given these results, the potential for the development of Ni-rich massive sulphide deposits at the base of the sill warrants additional investigation. Ongoing petrographic and lithogeochemical analyses, including S isotopic analyses, should help to constrain the genesis of the basal contact zone sulphide mineralization.

Cyclic Unit 2

Two sulphide-bearing zones were delineated by mapping of surface outcrops within cyclic unit 2 of the Marginal Zone. The lowermost of these is referred to as the MZ1 (i.e., Marginal Zone 1) subzone, and the uppermost zone, the MZ2 subzone. The MZ1 subzone consists of a narrow, <50 cm thick zone of disseminated chalcopyrite and pyrrhotite mineralization and occurs ca. 20 cm to 1.5 m above the "main break" fault. The best exposure of the mineralization is present at the original discovery outcrop, referred to here as the MZ1 showing, located on the eastern braid of the west channel (Fig. GS-13-3). The MZ1 showing is a <10 to 30 cm thick

Figure GS-13-5: Pyroxene megacrysts in the base of the Lower Central Layered Zone, Great Falls area.

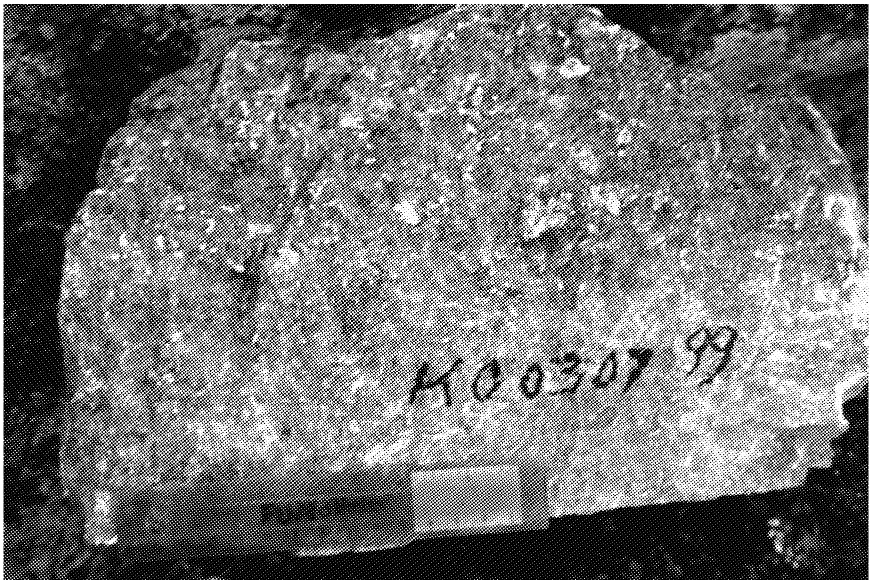

Figure GS-13-6: MZ1 Zone. Disseminated, blebby and net-textured pyrrhotite and chalcopyrite mineralization developed within a gabbroic band near the base of cyclic unit 2, Great Falls area.

sulphide zone developed ca. 1.5 m above the "main break" (Fig. GS-13-6). At the discovery outcrop, the sulphides are hosted by an arcuate shaped, ca. 10 to 50 cm-thick and <3 m long hornblende-bearing gabbroic layer that grades upward into anorthosite. The layer has a concave upward shape and may represent a pothole structure formed by erosion of the lower part of the ultramafic zone in cyclic unit 2. Pyrrhotite and chalcopyrite form coarse-grained blebs up to 1.5 cm in diameter, as well as net-textured, interstitial aggregates (Fig. GS-13-6). The sulphide content increases from the lower part of the mineralized layer, which has the highest total sulphide abundance (ca. 30%) and pyrrhotite: chalcopyrite ratio, to the upper part of the layer, which contains only a few percent sulphides and has a pyrrhotite:chalcopyrite ratio of ca. 1:2. The average sulphide abundance in the MZ1 showing is ca. 5% with an average pyrrhotite:chalcopyrite ratio of ca. 2:1.

The MZ1 subzone was also detected in the central braid of the western channel and in the central channel. In the former, trace to ca. 1% disseminated pyrrhotite and chalcopyrite occur at a distance of ca. 1 - 2 m above the "main break". Here, the sulphides occur in a narrow (<1 m thick) band at the base of an arcuate-shaped, several metres thick and >several metres long leucogabbroic layer that is petrologically and morphologically similar to the mineralized gabbroic layer at the MZ1 showing. We interpret both of these mineralized gabbroic layers as pothole structures developed near the base of the uppermost cyclic unit in the Marginal Zone. In the central channel, a diffuse band of mineralized lherzolite overlies the basal clinopyroxenite layer of cyclic unit 2 and is situated ca. 50 cm above the "main break" (Fig. GS-13-4). The sulphide content averages 1-2% and the sulphides occur as disseminated, interstitial and locally blebby pyrrhotite and chalcopyrite.

The MZ2 subzone represents a diffuse zone of erratically disseminated sulphide mineralization in the upper, leucogabbroic part of cyclic unit 2 (Fig. GS-13-4). The mineralization typically consists of <1% pyrrhotite and subordinate chalcopyrite, and is contained in massive leucogabbronorite or in <50 cm thick varitextured gabbroic layers that have higher sulphide contents (up to 15%). In the westernmost braid of the west channel system, blebby chalcopyrite and pyrrhotite occur in approximately equal proportions in anorthosite and leucogabbronorite. In contrast to the MZ1 subzone, which is only a few centimetres to ca. 1 m thick, the MZ2 subzone is typically several metres thick.

Despite the Pd-rich and sulphide-rich nature of the MZ1 showing, neither subsequent mapping nor lithogeochemical studies have identified mineralization that has a comparable sulphide or Pd tenor in either the MZ1 or MZ2 subzones. Therefore, It is possible that MZ1 showing is a localized feature. Nonetheless, the existence of the MZ1 showing signifies that processes favourable for concentrating PGE-rich magmatic sulphides were operative during crystallization of the Marginal Zone. If the MZ1 showing represents a classic PGE reef, the low PGE tenor of sulphides in the overlying MZ2 subzone and in the underlying parts of the Marginal Zone might be expected because the sulphides contained in PGE reefs are believed to represent effective concentrations of sulphides that scavenged PGE from large volumes of magma. The apparent lack of lateral continuity of PGE-rich sulphide mineralization in the MZ1 subzone, Great Falls area, requires further investigation. We recommend that additional mapping, lithogeochemistry and, ultimately, geophysics and drilling be carried out to determine if there are more substantial concentrations of PGE-rich sulphides within the Marginal Zone of the Fox River Sill, perhaps in larger (e.g. hundreds of metres long) pothole structures.

LITHOGEOCHEMISTRY

In addition to the above mentioned assay data, major, minor and trace element analyses will be obtained for ca. 140 samples collected from the Marginal Zone in the Great Falls area. This information will be used to develop a genetic model for the sulphide mineralization in the basal contact zone and cyclic unit 2.

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