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GEOLOGY OF THE MASKWA WEST NICKEL DEPOSIT, MANITOBA

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ABSTRACT

Mineralization at Maskwa West occurs in the metaperidotite basal unit of the Bird River sill, a layered and differentiated ultramafic to gabbroic body, intrusive into the sedimentary and volcanic rocks of the Archean Bird River greenstone belt in southeastern Manitoba. Mineralogy of the host rock consists of talc, carbonate, chlorite, lizardite, chrome spinel and secondary magnetite. Talc and carbonate have preserved an equigranular network texture outlined by secondary magnetite, inherited from the serpentinization of primary silicates. Lizardite in these rocks is derived from the serpentinization of secondary regenerated olivine. Disseminated sulfides form a zone at the base of the sill and rapidly decrease in quantity stratigraphically upwards. Pyrrhotite, pentlandite, chalcopyrite and pyrite are the primary sulfide phases, but extensive near-surface supergene alteration has transformed pyrrhotite to marcasite+pyrite and pentlandite to violarite. Ni, Co, Fe and S contents of the primary and secondary sulfides are variable and show a generally high Ni content in marcasite. The development of hematite in the secondary sulfides is widespread. The sulfide mineralization is considered to have been a magmatic phase of the intruding magma, settling towards the base of the sill, close to its feeder source. Extensive textural modifications have resulted from sulfide recrystallization and remobilization, combined with CO_2 metasomatism during and following metamorphism in the lower amphibolite facies.

SOMMAIRE

On trouve la minéralisation à Maskwa Ouest dans l'unité métapéridotitique à la base du filon-couche Bird River, intrusion stratiforme différenciée dont les membres ultramafiques à gabbroïques recoupent les roches volcaniques et sédimentaires de la ceinture de roches vertes archéennes de Bird River, dans le sud-est du Manitoba. Les roches encaissantes contiennent: talc, carbonates, chlorite, lizardite, spinelle chromifère et magnétite secondaire. Le talc et les carbonates conservent une texture équigranulaire réticulée, héritée du stade de serpentinisation des silicates primaires et mise en évidence par de la magnétite secondaire. La lizardite de ces roches résulte de la serpentinisation d'une olivine métamorphique. Les sulfures disséminés, abondants à la base du filon-couche, diminuent rapidement quand on remonte l'échelle stratigraphique. Pyrrhotine, pentlandite, chalcopyrite et pyrite sont les sulfures primaires; une altération supergène superficielle de grande extension a transformé la pyrrhotine en marcasite + pyrite et la pentlandite en violarite. Les teneurs en Ni, Co, Fe et S des sulfures primaires et secondaires sont variables; en général, la marcasite a une forte teneur en Ni. L'hématite est courante parmi les assemblages secondaires. La minéralisation semble due à une phase magmatique sulfurée, en suspension lors de l'emplacement du magma silicaté, mais qui se serait déposée à la base du filon-couche, près du conduit alimenteur. Des modifications de la texture du minerai proviennent de recristallisations des sulfures, accompagnées de métasomatisme carbonaté, qui ont eu lieu pendant et après le métamorphisme du facies amphibolite inférieur.

(Traduit par la Rédaction)

INTRODUCTION

The Maskwa West nickel deposit is located in the Bird River area of southeast Manitoba, 160 km northeast of Winnipeg. In 1969, exploration and mining operations on the property came under the control of Dumbarton Mines Limited, a Manitoba company jointly owned by Maskwa Nickel Chrome Mines Limited and Consolidated Canadian Faraday Limited. Production of copper–nickel ore from the Dumbarton mine spanned the period from August 1969 until December 1974, during which time 1,539,290 metric tons of ore grading 0.81% Ni were mined. Discovery of the Maskwa West zone by diamond drilling in May 1974, at a distance of 1.2 km southwest of Dumbarton, prolonged base-metal production in the area until June 1976. Open-pit mining of the upper portion of the Maskwa deposit produced 365,730 metric tons with an average grade of 1.16% Ni and 0.20% Cu. Nickel sulfide mineralization remaining beneath the open pit, of the order of 700,000 tons, contains slightly more than 1% Ni, considered uneconomic at the present time.

The Maskwa West deposit is a low-grade disseminated sulfide zone consisting of marcasite–pyrite, violarite, pentlandite, pyrrhotite and chalcopyrite in a matrix of talc, carbonate, chlorite and serpentine minerals. This assemblage comprises part of the metaperidotite basal unit of the Bird River sill, a layered ultramafic to gabbroic body intrusive into the volcanic and sedimentary rocks of the Bird River greenstone belt.

GEOLOGICAL SETTING

The Bird River greenstone belt, comprising Archean supracrustal volcanic and sedimentary rocks of the Rice Lake Group, is considered to be an integral part of the English River gneissic block of the western Precambrian Shield (Wilson 1971, Beakhouse 1977). Aspects of the geology of the Bird River greenstone belt have been described by various authors (Springer 1950, Davies 1952, 1955; Davies *et al.* 1962, Trueman 1975, Trueman & Turnock 1975). The belt trends east-west, has a width of 5–10 km and straddles the Bird River for a strike length of 55 km from Lac du Bonnet in the west to the Manitoba–Ontario border in the east (Fig. 1). A second, somewhat discon-

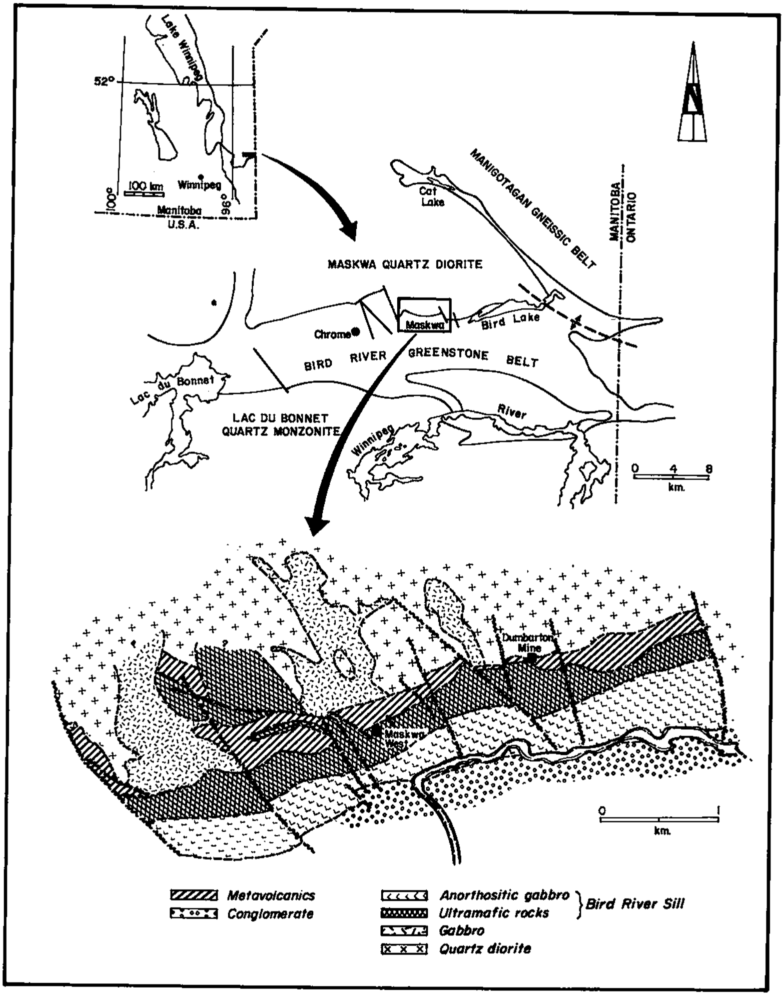


FIG. 1. Location map of the Bird River greenstone belt, Manitoba, and geology of the Maskwa portion of the Bird River sill.

tinuous belt up to 5 km wide trends northwest from Bird Lake to the Cat Lake area. The two belts constitute the limbs of a major anticline with an axis plunging east to southeast. The area between the fold limbs is occupied by the Maskwa Lake quartz diorite, one of a number of oval-shaped plutons grouped as the Great Falls quartz diorite (McRitchie 1971). The area to the south of the east–west belt is occupied by the postorogenic Lac du Bonnet quartz monzonite, the youngest and largest pluton in the area.

Petrological, structural and metamorphic studies of the rock units comprising the Bird River belt are documented by Davies (1955), Butrenchuk (1970), Trueman (1971), Karup-Møller & Brummer (1971), Juhas (1973), and Trueman, Turnock & Bond (1975). Lithologies include pillowed basalt, andesite, rhyolite, tuffs, iron formation, calcareous sediment, conglomerate, greywacke and turbidite. Intrusive into these units are a variety of igneous rocks of diverse compositions and ages, including gabbro, quartz–feldspar porphyry, diabase and the large differentiated ultramafic to anorthositic gabbro body termed the Bird River sill. The sill is classified as synvolcanic by Trueman (1971), and its compositional layering indicates a top facing to the south, in conformity with pillow structures in adjacent volcanic rocks. A complex and varied sequence of metamorphic indicator assemblages in the rocks of the belt results from three periods of regional folding, and places the grade of metamorphism for the area of interest in this study in the lower amphibolite facies (Juhas 1973, Trueman & Turnock 1975, Trueman, Posehn & Stoeterau 1975). Rb–Sr whole rock age determinations by Penner & Clark (1971) indicate an age of 2650(35) Ma for the Bird River volcanic rocks, 2640(135) Ma for the Maskwa Lake quartz diorite and 2495(130) Ma for the Lac du Bonnet quartz monzonite pluton.

Northwest–southeast faulting is a prominent structural feature of the belt. Although apparent horizontal displacement on these faults may be as much as 4–5 km, they do not extend across the central sedimentary units of the belt. It is assumed in some cases that they swing into east–west-trending strike faults (Davies 1955); verification of this has been observed in the Maskwa West pit.

THE BIRD RIVER SILL

The Bird River sill is a differentiated ultrabasic to basic complex within the volcanic rocks of the Rice Lake Group. Faulted segments of the sill attain a length of about 30 km in the Bird River belt, whereas in the Cat Lake area, approximately 11 km of the sill are exposed. Average thickness of the sill is close to 1000 m, but significant departures from this are recorded locally.

The type section of the sill is on the Chrome property, where Trueman (1971) has identified seven rock types comprising 45 distinct layers. The lower ultramafic section is 180 m thick and has 19 layers of serpentinized peridotite, 18 layers of interbanded chromitite and serpentinized peridotite and an overlying pyroxenite layer. The bands of cumulate chromite towards the top of the ultramafic section have been the subject of research in terms of mineralogy and economic geology (Brownell 1942, Bateman 1943, Osborne 1949, Gait 1964, Raicevic 1977). The upper gabbroic section has an estimated thickness of 365 m and consists of seven layers of gabbro, anorthositic gabbro and anorthosite.

Additional smaller bodies of ultramafic rocks, such as those occurring northwest of Maskwa (Fig. 1), are considered to be either part of the main sill, with intervening volcanic rocks occurring as a xenolith within the sill (Davis 1955), or block-faulted slices from the sill (Juhas 1973). Intense northwest and west–northwest faulting in this area lends some support to the latter hypothesis. An additional possibility considered here is that these fault-disrupted ultramafic bodies are exposed remnants of a feeder pipe through which intrusion of the Bird River sill took place. The presence of local gabbroic intrusions, combined with evidence from volcanic lithologies and facies changes, strongly suggest the proximity of a volcanic vent (Trueman & Turnock 1975). Intense talc–carbonate alteration of the main sill at Maskwa and the structural location of the Maskwa sulfide zone fit a model of genesis, based on the presence of such a volcanic centre in this portion of the Bird River greenstone belt.

At Maskwa West the ultramafic unit of the Bird River sill is covered by thick overburden in an area of low swampy ground. All geological information has been obtained from exploration diamond-drill-core and pit mapping. Geology of the open-pit area and an interpreted cross-section through the entire ultramafic zone are shown in Figure 2. On this section, the ultramafic unit is 160 m thick, and has a dip ranging from 60° at the surface to 90° about 120 m below surface. Drilling on adjacent sections, however, indicates that the ultramafic–footwall

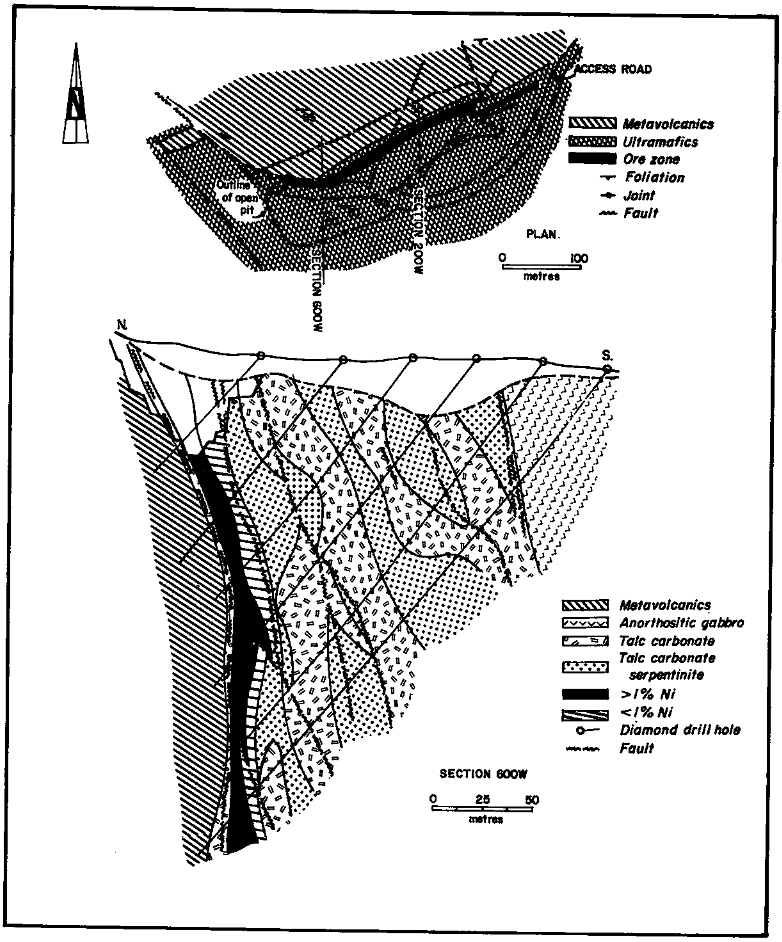


FIG. 2. Geology of the Maskwa West open pit area and geological cross-section 600W.

contact and sulfide zone generally maintain a 60–80° southeast dip to the deepest level investigated.

Layering in the ultramafic unit of the sill, documented by Trueman (1971) for the Chrome property, is not apparent at Maskwa, where it is obscured by pervasive talc–carbonate alteration. Subparallel irregular zones of dark grey talc-carbonate rock alternate with a greyish-green, spectacularly mottled rock containing up to 60% dark green serpentine in a matrix of talc and carbonate. Contacts between the two rock types are either gradational or commonly abrupt at sheared surfaces. Tectonized surfaces occur at the contacts of the ultramafic zone with overlying anorthositic gabbro and underlying basic volcanic rocks. The latter contact is especially obscured by a zone of intense shearing and carbonate alteration up to 6 m in width.

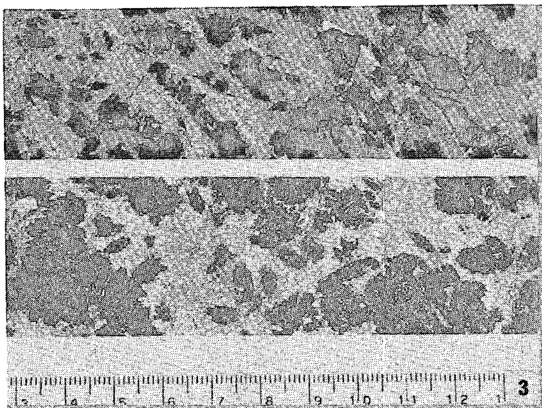
Sulfide mineralization at Maskwa West occurs on the north side or stratigraphic base of the ultramafic unit and has been traced by diamond drilling for a total length of 1280 m. It is only within a strike length of 300 m, however, that the nickel content of the sulfides is sufficiently high to be of economic interest. Northeast from the open-pit area, sparse sulfides define the zone for a length of 850 m, until terminated at a prominent northwest fault near Dumbarton mine. Southwest from the pit, mineralization is encountered for approximately 130 m, until lost in an area of complex faulting. At the open pit, mineralization has a true thickness of between 3 and 20 m, with an average of 12 m.

Within the zone of disseminated sulfides, there is an increase in sulfide content and nickel grade towards the base. An arbitrary division of the zone can thus be made into higher- and lower-grade sections, with the dividing point between them placed at a grade of 1% Ni (Fig. 2). With the exception of minor sulfides accompanying carbonate in late fractures and shears, the remaining mass of ultramafic rock is essentially devoid of sulfides. At sporadic intervals within the footwall volcanic rocks exposed in the pit, massive copper- and nickel-rich sulfides (6–9% Ni) form gash veins and narrow veinlets. These sulfides are considered to have been remobilized from the main zone during metamorphism and related fault movements.

Copper and nickel values from 38 drillhole intersections of the ore zone give an arithmetic average Ni/Cu ratio of 5.8 and an average Cu/Cu + Ni ratio of 0.15. This mineralization is thus nickel-enriched, compared to some deposits in gravity-differentiated sills and complexes (Naldrett 1973).

Petrology and composition of the ultramafic rocks

The ultramafic unit of the sill at Maskwa West comprises a suite of grey talc–carbonate rocks containing varying amounts of dark



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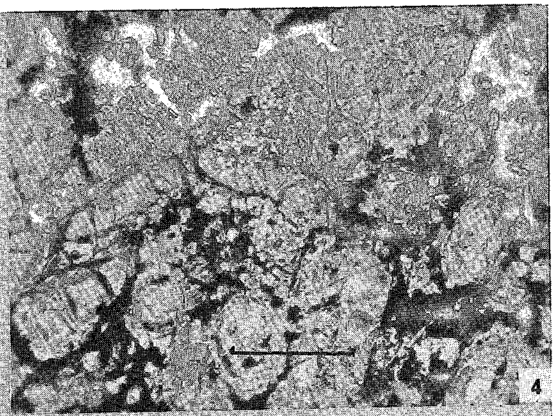

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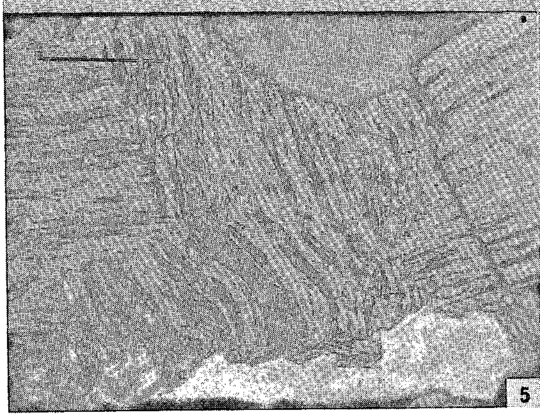

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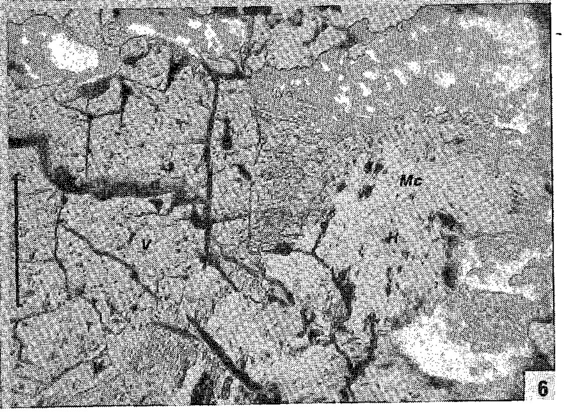

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FIG. 3. Morphology of serpentine patches (dark) in talc–carbonate matrix (light). Drill core samples, Maskwa West. Scale in cm.

FIG. 4. Magnesite pseudomorphs after olivine (grey) with minor talc (white). Interstitial sulfides and oxides (black). Sample S–6. Scale bar is 0.5 mm.

FIG. 5. Banded intergrowth of marcasite–pyrite (white), with hematite and magnetite (grey), replacing original pyrrhotite. Sample 73–138. Scale bar is 0.1 mm.

FIG. 6. Marcasite (Mc) and hematite (H) replacing original pyrrhotite. Section also contains violarite (V) and magnetite (Mg). Sample 62–329. Scale bar is 0.1 mm.

TABLE 1. CHEMICAL ANALYSES OF SELECTED ROCK TYPES FROM THE BIRD RIVER SILL

	A	B	C
SiO_2	37.20	31.90	36.36
Al_2O_3	2.35	1.58	3.14
Fe_2O_3	9.18	10.53	8.82
FeO	3.33	4.37	4.02
CaO	7.20	11.0	2.77
MgO	24.9	22.5	31.92
Na_2O	0.04	0.00	0.035
K_2O	0.02	0.00	0.015
H_2O	6.28	5.85	10.84
CO_2	7.20	10.73	1.23
TiO_2	0.08	0.08	0.187
P_2O_5	0.04	0.06	0.260
S	0.89	0.45	0.069
Cr_2O_5	-	-	0.265
MnO	0.10	0.18	0.158
NiO	0.39	0.28	0.228
CuO	0.09	0.10	0.027
ZnO	-	0.02	-
C	0.22	-	-
-O/S	0.36	0.18	-
	99.15	99.45	100.34

A. Sample 44-177-190. Average composition of 3.96 m of talc-carbonate-serpentine-chlorite rock in drill hole 44. Analyst - J. Gregorchuk, Manitoba Dept. Mines. Courtesy P. Theyer.

B. Sample 74-81-95. Average composition of 4.27 m of talc-carbonate-serpentine-chlorite rock in drill hole 74. Analyst - J. Gregorchuk, Manitoba Dept. Mines. Courtesy P. Theyer.

C. Average composition of 6 samples of Bird River sill serpentinite. Analyst - K. Ramlal, Univ. Manitoba. (From Juhas 1973).

green to slightly reddish serpentine (Fig. 3). Irregularly-shaped patches of serpentine range up to 3 cm across and display highly serrated margins with surrounding talc–carbonate. This feature is attributed to the platy growth habit of a number of mutually interfering crystals. Elongate bladed crystals of serpentine without preferred orientation are also commonly observed in the talc–carbonate matrix. Serpentine morphologies of this type are indicative of an origin by serpentinization of regenerated metamorphic olivine; this is the topic of a separate paper in preparation. The serpentine polymorph in all cases is mesh-textured lizardite.

Talc, carbonate and chlorite, accompanied by primary subhedral chrome spinel (14.7% Cr_2O_3) and secondary magnetite, comprise the matrix to lizardite. Talc is generally platy in habit, but also forms fine-grained aggregates with carbonate. Dolomite, magnesite and calcite are all identified by X-ray powder diffraction, with dolomite being most abundant in the samples tested. Magnesite forms massive pseudomorphs after equant olivine grains, preserving a primary magmatic texture as illustrated in Figure 4. Calcite forms late cross-cutting veinlets and coarse mosaic patches in the rocks. Chlorite occurs as bladed replacements of talc, fine-grained scaly patches associated with primary chrome spinel or magnetite, and as streaky patches along shears.

The chemical compositions of two samples of the Maskwa host rock are given in Table 1, columns A and B. These are compared with the average composition of six samples of serpentinite from other locations in the ultramafic unit of the Bird River sill (column C). The analyses indicate that the Maskwa rocks have undergone extensive serpentinization and carbonatization and clearly do not represent original compositions.

Sulfide mineralization

Disseminated sulfides, in composite grains and irregular patchy areas, constitute between 10 and 20% of the volume of the ore zone. They are dispersed among the silicate and carbonate minerals of the host ultramafic rock, with only rare indications of a primary magmatic texture. It is clear that considerable sulfide recrystallization and redistribution has taken place.

Sulfide assemblages vary gradationally within the mineralized zone, from the normal primary association of pyrrhotite–pentlandite–pyrite–chalcopyrite at deeper levels, to an oxidized assemblage consisting of marcasite–pyrite–violarite–chalcopyrite closer to surface. Production from the open pit consisted predominantly of oxidized ore.

Initial oxidation of primary sulfides is evident in the formation of violarite from pentlandite. An accompanying reaction observed in some samples is the marginal alteration of pyrrhotite to a second generation of violarite. This is attributed to an availability of excess Ni^{2+} ions from the pentlandite–violarite reaction. However, in the Maskwa ore there is usually a direct alteration of pyrrhotite to marcasite. In its incipient stage, marcasite develops as fine streaks parallel to the pyrrhotite cleavage and proceeds outward until the conversion is complete. The transformation of pentlandite to violarite and pyrrhotite to marcasite involves the release of Fe^{2+} ions and results in either a banded marcasite–hematite/magnetite texture (Fig. 5) or in diffuse areas of hematitization within the marcasite (Fig. 6).

The oxidation of sulfides at Maskwa West is essentially identical to that described in some well-documented cases of supergene alteration (Nickel *et al.* 1974, Keele & Nickel 1974, Thornber 1975, Watmuff 1974). The oxidized assemblage is predominant to a depth of about 40 m, below which point an increasing percentage of unaltered pyrrhotite and pentlandite is

TABLE 2. RELATIVE PROPORTIONS OF GANGUE, SULFIDE AND OXIDE CONSTITUENTS IN DRILLHOLES 53 AND 41, SECTION 200W

Sample No.	Serp	Chl	Talc	Carb	M-Py	Viol	Cp	Po	Pnt	Mag-Hem	Est. % Total Ox + Sulf
41-185	--	5	71	24	45	8	7	--	--	39	14
41-195	--	4	41	55	43	13	--	--	--	44	13
41-202	--	2	49	49	4	--	2	77	11	6	47
41-206	3	3	51	43	20	--	7	27	7	40	30
41-214	20	8	63	8	40	7	3	7	--	42	40
41-218	15	--	60	25	10	8	10	30	5	37	40
41-224	--	24	55	21	15	16	--	18	--	50	17
53-47	22	9	54	15	39	--	--	--	--	61	15
53-51	25	10	45	20	38	13	3	--	--	46	13
53-57	37	8	26	30	55	12	--	--	--	33	22
53-68	40	11	46	3	49	14	--	--	--	37	23
53-77	47	11	32	10	44	12	--	--	--	44	15
53-87	33	7	4	56	44	7	--	--	--	49	19
53-95	5	20	60	15	61	11	4	--	--	23	13
53-97	39	8	49	4	33	7	--	--	--	60	14

Serp. - serpentine, Chl. - chlorite, Carb. - carbonates, M-Py - marcasite-pyrite, Viol. - violarite, Cp. - chalcopyrite, Po. - pyrrhotite, Pnt. - pentlandite, Mag-Hem. - magnetite-hematite.

present. This feature is evident from the listed proportions of gangue, sulfide and oxide constituents in two drillhole intersections (Table 2) and the plot of these values in Figure 7. Some oxidation of sulfides has been noted in drillholes to a depth of at least 150 m, suggesting ready access of solutions down fault and shear zones.

Composition of the sulfides

A sample of Maskwa ore (W–G–27) studied for metallurgical test purposes contains 1.17% Ni, 0.23% Cu and 4.62% S as determined by chemical analysis. The metal content of this sample closely approximates the average value present in the mined portion of the ore zone

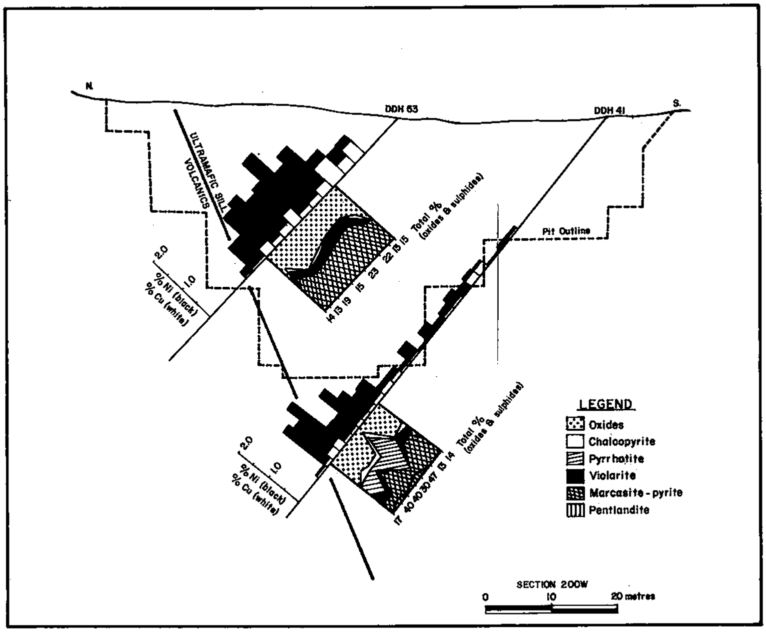

FIG. 7. Section 200W through Maskwa open pit showing distribution of copper–nickel values and some mineral proportions in DDH 53 and 41. Line of section is located on Fig. 2.

TABLE 3. ELECTRON MICROPROBE ANALYSES OF COEXISTING SULFIDES MASKWA WEST DEPOSIT, TEST W-G-27

	Vol. %	Fe†	Ni	Co	S	Total
Pyrite-Marcasite	58	43.6	3.68*	0.13	51.5	98.9
Violarite	17	25.2	31.7	0.77	40.9	98.6
Pyrrhotite	12	60.4	0.71	0.10	38.7	99.9
Pentlandite	3	29.3	36.3	1.10	33.3	100.0
Chalcopyrite	10	29.6	-	-	33.2	-
Overall avg.	100	40.7	8.7	0.25	45.8	
To basis of 4.62% S		4.1	0.87	0.03	4.62	

* Range 0.1 - 10.0% Ni † wt. %

Analyst: G. Springer, Falconbridge Metallurgical Laboratories

(1.16% Ni, 0.20% Cu), and can thus be used to estimate overall phase proportions. Electron microprobe analyses of the sulfide constituents in sample W–G–27, together with volume percentages, are listed in Table 3. The abundance values are based on an examination of 100 sulfide grains with diameters greater than 20 µm. However, widespread fine intergrowths of pyrite and marcasite with violarite introduce inaccuracies in the determination of phase compositions and proportions. In view of this, a correction factor has not been applied for density differences in making the conversion from volume to weight proportions.

Overall average contents of Fe, Ni, Co and S are also listed in Table 3, together with calculated metal contents on the basis of 4.62% S. The fact that the chemically determined ratio of 1.17% Ni per unit of 4.62% S cannot be confirmed by a mineralogical analysis seems to be due to an underestimation of the violarite content. Some confirmation of this is obtained by analyses in the size fraction less than 20 µm, which indicates that there is more Ni per unit sulfur in the smaller grains than in the larger ones. Phase proportions of 12% pyrrhotite, 3% pentlandite, 50% pyrite–marcasite, 25% violarite and 10% chalcopyrite give a ratio 1.12% Ni *per* 4.62% S, close to the value established by bulk chemical analysis. Variations in the proportions of pyrite–marcasite, violarite, pentlandite and pyrrhotite from near-surface to deeper levels and the inhomogeneity in the composition of pyrite–marcasite (0.10 - 10.0 wt. % Ni) and violarite (29.5 – 35.5 wt. % Ni) suggest that these figures should be regarded as an approximation.

DISCUSSION

The basal position of the sulfides within the ultramafic section of the Bird River sill at Maskwa West and the gradual decrease of disseminated sulfides upward provide strong evidence for a primary magmatic segregation origin for the ore. Sulfides have an interstitial relationship to pseudomorphed olivine grains, but have undergone textural modification during metasomatism and metamorphism of the host rock. Textures preserved in the talc–magnesite–dolomite–serpentine assemblage indicate an olivine-rich composition for the original ultramafic rocks. Adjacent faulted segments of the sill lack a pervasive talc–carbonate alteration. The basal unit of the Chrome property is serpentinized peridotite, consisting of rounded ovoids of serpentine after olivine, poikilitically enclosed in pyroxene which is extensively altered to tremolite (Trueman 1971).

In addition to talc–carbonate alteration, the Maskwa portion of the sill is somewhat unique in the presence of a satellite ultramafic body on its north or footwall side. This body occupies an approximate central position to a group of three irregularly shaped gabbro bodies that are intrusive into the Maskwa Lake quartz diorite. Contact relations between the two types are not observed and the geology is complex owing to late faulting. However, mapping and ground magnetic survey interpretation suggest that the satellite ultramafic body is a sheared extension of a basal projection of the sill into footwall volcanic rocks. It is considered that this represents a feeder pipe, from which the intrusion spread out laterally, approximately equal distances to the east and west. The gabbroic intrusions indicate a continuing episode of magmatic activity in this area. Ancillary evidence of a vent structure north of Maskwa is obtained from lithologies and facies changes within the layered sequence of metavolcanic rocks of the area. A suspended immiscible sulfide phase in the intruding magma can be envisaged as settling out quickly in a zone immediately adjacent to the conduit, at the present location of Maskwa West. The concentration of sulfides on the east side perhaps indicates an initially greater flow in this direction. The quantity of sulfide available for magmatic settling seems to have quickly diminished with increasing distance from the source.

Three episodes of folding have been identified in the Bird River area; the first event is coincident with development of mineral assemblages in volcanic and sedimentary rocks, indicative of a grade of metamorphism in the lower amphibolite facies. The sill rocks were initially folded and faulted during this major event. The lack of talc–carbonate alteration in adjacent faulted segments of the sill suggests that major disruption of the sill preceded extensive CO_2 metasomatism, which was thus restricted to the Maskwa segment closest to the volcanic centre. The initial carbonate (magnesite) alteration took place under static conditions, as seen by its replacement of undeformed olivine crystals. Metamorphic conditions at the climax of the first event are considered to have been adequate for the regeneration of secondary olivine (Greenwood 1967, Johannes 1969). The sulfide minerals of the ore zone presumably recrystallized at this stage, and, owing to partial mobilization and redistribution, lost some of their primary magmatic textures.

Prior to or during the second fold event, the main period of talc–carbonate (dolomite) alteration occurred, partly replacing some of the newly generated olivine. This fold event created structures of a passive nature, formed about east-trending, south-dipping axial planes. It coincided with the development of east-trending schistosity evident in all of the rock units in the area and is assumed to have caused additional faulting and shearing in the low-strength talc–carbonate zones of the sill at Maskwa. The third folding event deformed the earlier fold axes and resulted in simple open folds in the youngest sedimentary unit (Trueman, Posehn & Stoeterau 1975). The development of calcite in round mosaic patches, granular replacement zones and late cross-cutting veinlets is the final manifestation of CO_2 metasomatism. Pyrite, millerite and rare veinlets of pale-green, poorly crystalline serpentine accompany the calcite.

Supergene alteration of the sulfides is most evident in the upper 40 m of the ore zone, where there is almost complete transformation of pentlandite to violarite and pyrrhotite to marcasite+pyrite, with accompanying formation of hematite and magnetite. Oxidation decreases in intensity downward, but has had access to sulfides at deeper levels by way of shear zones.

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