THE DUNDONALD DEPOSIT: AN EXAMPLE OF VOLCANIC-TYPE NICKEL-SULFIDE MINERALIZATION

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ABSTRACT

The Dundonald nickel deposit, located approximately 50 km northeast of Timmins in the Ontario portion of the Abitibi greenstone belt, is hosted by a sequence of locally south-facing, steeply dipping, 1 to 30 m thick ultramafic to basaltic flows, komatiitic in composition. Nickel sulfides occur as net-textured and disseminated mineralization in the olivine cumulate zones of some peridotitic flows and as semi-massive mineralization within some basal chill zones and a few interflow volcano-sedimentary horizons. Pentlandite ($\pm$ violarite) predominates in the sulfide assemblage, accompanied by minor to trace amounts of pyrrhotite, millerite, maucherite, godlevskite, heazlewoodite, gersdorffite, sphalerite, chalcopyrite, and magnetite. The overall grade of the deposit is approximately 1.5% Ni, 0.03% Cu. The net-textured and disseminated nickel sulfide in the olivine cumulate zones of mineralized peridotitic flows is interpreted to have formed *in situ* by gravitational settling of immiscible sulfide droplets carried in suspension in a phenocryst-rich komatiitic magma. Field relationships and "colloform-textured" massive pentlandite in a devitrified matrix suggest that the interflow nickel-rich sulfides were emplaced in a hot, mobile, fluid state and most likely "leaked" into intercalated carbonaceous volcano-sedimentary horizons from basal accumulations in overlying peridotitic flows. The few mineralized flows are piled one on top of the other or are intercalated with unmineralized flows, giving rise to multiple, *en échelon*, somewhat tabular mineralized horizons that lack substantial lateral continuity.

SOMMAIRE

Le gîte nickelifère Dundonald, situé environ 50 km au nord-est de Timmins dans la partie ontarienne de la ceinture des roches vertes de l'Abitibi, se trouve dans une succession de coulées komatiitiques ultramafiques à basaltiques de 1 à 30 m d'épaisseur; celles-ci, par endroits, pendent fortement vers le sud. Les sulfures de nickel ont une texture réticulée ou sont disséminés dans les zones d'olivine cumulative de certaines coulées péridotitiques ou encore possèdent un aspect semi-massif dans certaines zones de refroidissement rapide et dans quelques inter-coulées volcano-sédimentaires. La pentlandite ($\pm$ violarite) prédomine parmi les sulfures; elle est accompagnée de faibles quantités ou traces de pyrrhotine, millérite, mauchérite, godlevskite, heazlewoodite, gersdorffite, sphalérite, chalcopyrite et magnétite. Les teneurs globales en Ni et Cu du gîte sont de 1.5 et 0.03%, respectivement. Le sulfure de nickel disséminé et réticulé des zones à cumulats d'olivine des coulées péridotitiques minéralisées semble s'être formé *in situ* à la suite du dépôt par gravité de gouttelettes immiscibles transportées en suspension dans un magma komatiitique riche en phénocristaux. Les observations faites sur le terrain et celle de la texture "colloforme" de la pentlandite massive dans une pâte dévitrifiée indiquent que les sulfures riches en nickel des inter-coulées ont été introduits à l'état fluide, mobile et chaud dans des intercalations volcano-sédimentaires carbonacées, à partir d'accumulations formées à la base des coulées supérieures. Les rares coulées minéralisées sont empilées l'une sur l'autre ou sont interstratifiées avec des coulées stériles, formant ainsi quantité d'horizons minéralisés, vaguement tabulaires, en échelons, sans grande continuité latérale.

(Traduit par la Rédaction)

INTRODUCTION

The Dundonald deposit, which grades 1.5% Ni, 0.03% Cu, occurs in the southeast quadrant of Dundonald township. It is one of seven small nickel deposits located within a 50 km radius of Timmins in northern Ontario (Eckstrand 1972, 1973) which are spatially associated with synvolcanic lens-shaped bodies of peridotite and pyroxenite (Naldrett & Gasparrini 1971). Previous investigators have described the mineralization at the Dundonald deposit as net-textured and joint-controlled in the centre of an "overlying lens" (Naldrett 1964), as concentrations of nickeliferous sulfides in concordant ultrabasic intrusions and adjacent wall
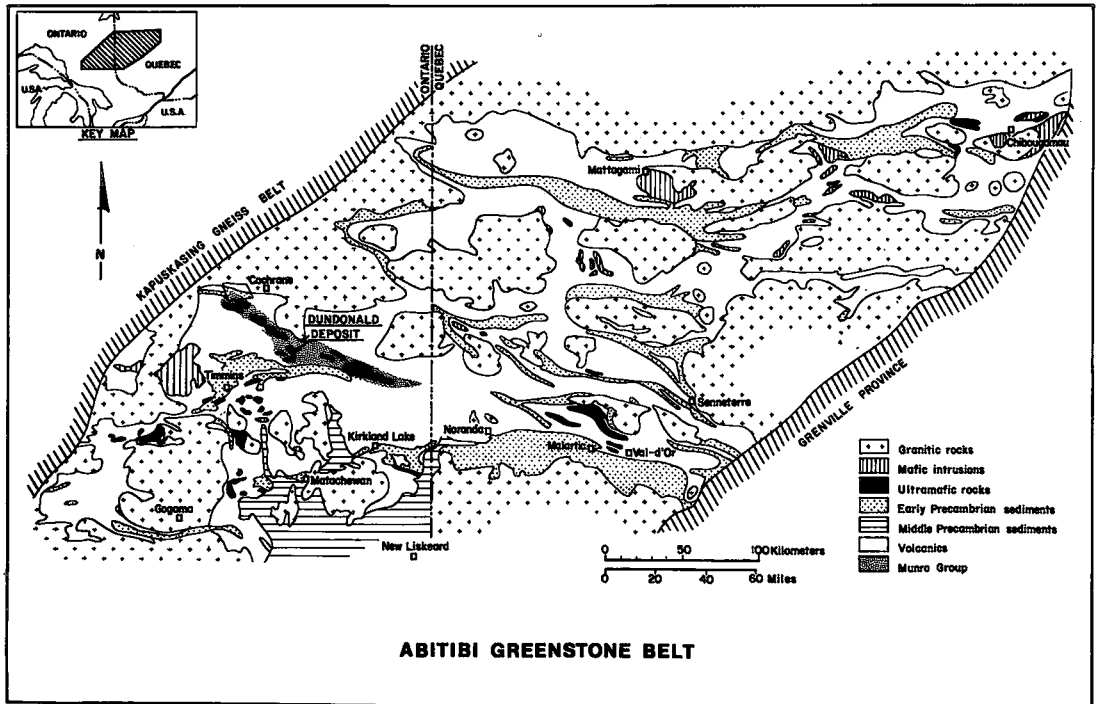
FIG. 1. General geology of the Abitibi greenstone belt (modified after Naldrett 1973).

rocks within a folded volcanic sequence (Kilburn *et al.* 1969), and as blebs, stringers and fine disseminations associated with graphitic breccia zones close to peridotite–pyroxenite contacts generally towards the base of the lens (Naldrett & Gasparrini 1971). Partly stimulated by discovery of large ultramafic-related nickel deposits in the Eastern Goldfields of Western Australia and the growing awareness of the extrusive characteristics of many of these ultramafic rocks, more detailed field and laboratory studies were conducted by Falconbridge geologists on the Dundonald deposit. The results of these studies are presented here and collectively demonstrate the true volcanogenic nature of the nickel-sulfide mineralization.

GEOLOGICAL SETTING

The Abitibi greenstone belt in the Canadian Shield (Fig. 1) is described by Goodwin & Ridler (1970) as an east-west trending, composite tectonic unit consisting of relatively weakly metamorphosed mafic to felsic volcanic rocks with coeval intrusions, volcanic sediments and large granitic batholiths. The axes of the iso-

clinal folds in the 'supracrustal' rocks are parallel to the eastward trend of the belt. Gneissic rocks form the north and south boundaries, whereas the younger Grenville and Kapuskasing crystalline belts truncate the greenstone belt to the east and west, respectively. The Dundonald deposit lies within a northwest-southeast-trending band of predominantly volcanic rocks, termed the Munro Group (Arndt 1976), in the Ontario portion of the belt.

Within Dundonald and Clergue townships, the most striking geological feature is a layered peridotite-gabbro body, referred to as the Dundonald sill (Fig. 2), that intrudes a sequence of predominantly intermediate to felsic tuffs, volcanic breccias and flows. Although the distorted "W"-shape of the sill was attributed to folding by Naldrett (1964), more recent mapping suggests that the sill was intruded as something other than a planar structure and was later faulted into its present configuration (Comba 1972). A series of thin, discontinuous ultramafic flows, termed "overlying lenses" by Naldrett (1964) and Naldrett & Mason (1968), occur proximal to the sill. The Dundonald deposit encompasses the area occupied by Naldrett's "lens 5" in Figure 2.
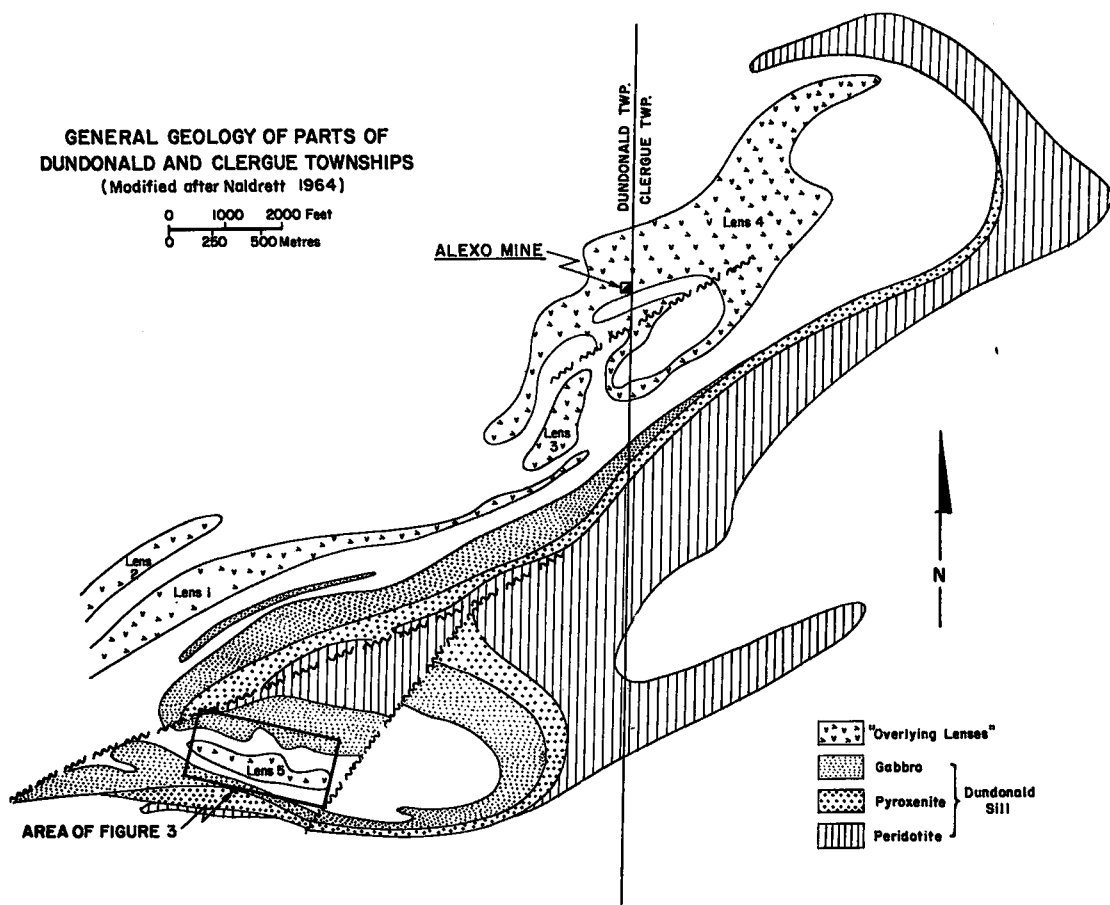
FIG. 2. Geology of parts of Dundonald and Clergue townships (modified after Naldrett 1964).

GEOLOGY OF THE DEPOSIT

The rocks of the Dundonald deposit suboutcrop, and as such, the geology presented in simplified plan view in Figure 3 has been interpreted primarily from diamond-drill core. The host-rock sequence strikes west-northwest, tops south and dips steeply to the south. These magnesium-rich rocks occupy an elliptical area roughly 120 x 1500 m, and unconformably overlie intermediate volcanic rocks to the north. Within the sequence, peridotitic, pyroxenitic and basaltic flows have been recognized; they exhibit textures analogous to those of komatiite flows 50 km to the east in Munro township and described in detail by Pyke et al. (1973), Arndt (1976) and Arndt et al. (1977). Individual flows range less than 1'm to approximately 30 m in thickness. Strike lengths are less easily determined from drill-hole intersections, but are believed to be of the order of 50 m or more.

Bands (<0.5 m to several m thick) of volcano-sedimentary material, including layered cherty tuff (exhalite?), lapilli tuff and carbonaceous, pyritiferous sediment, occupy interflow horizons and can commonly be traced for hundreds of metres along strike.

Extrusion of the komatiitic lavas appears to have been cyclical, commencing with outpourings of barren pyroxenitic lava followed by and terminating with peridotitic lavas. Concentrations of nickeliferous sulfides appear particularly associated, though not exclusively, with the stratigraphically lowest peridotitic flows in each cycle. At least two cycles have been identified and seem to become younger to the east (Fig. 3). Olivine-spinifex texture is commonly spectacularly developed in peridotitic flows in the western half of the deposit, whereas in the eastern half, the olivine-rich flows are almost devoid of spinifex.
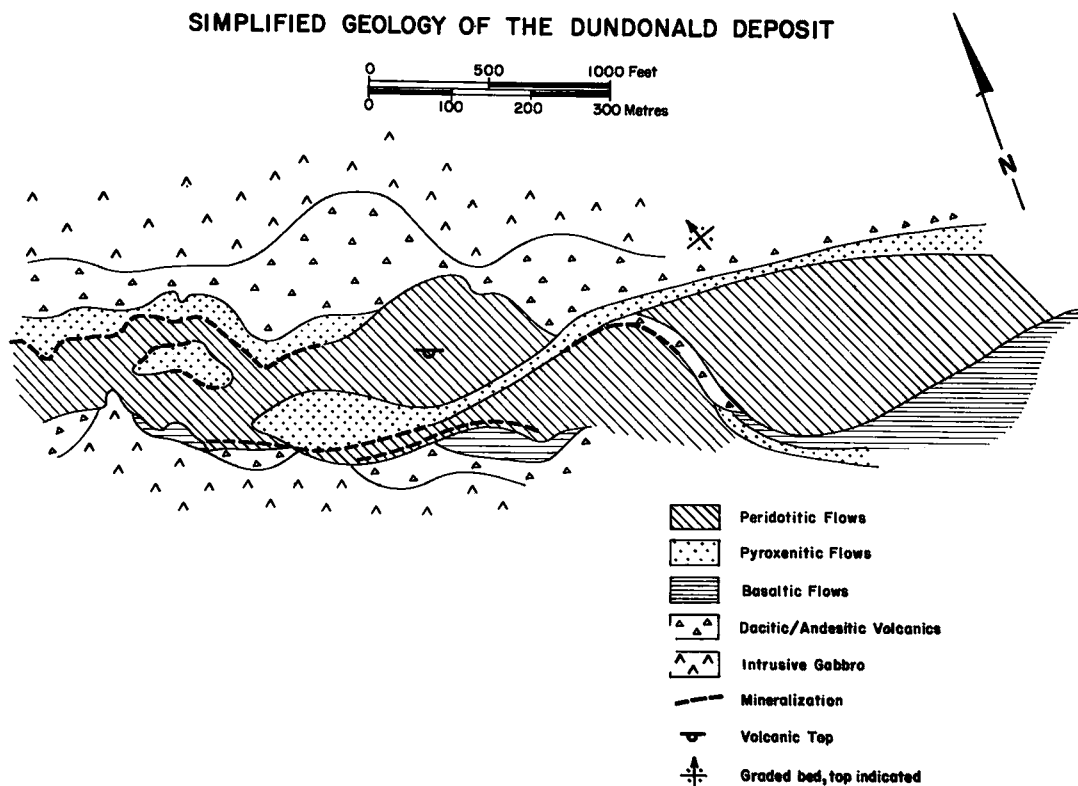
SIMPLIFIED GEOLOGY OF THE DUNDONALD DEPOSIT

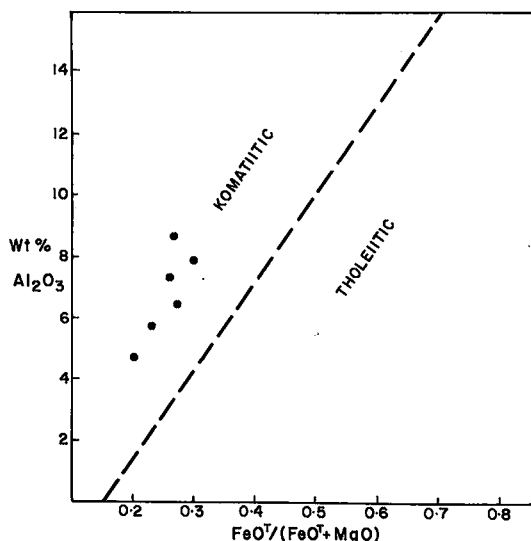FIG. 3. Simplified plan view of the geology of the Dundonald deposit.

FIG. 4. Al_2O_3 vs. $FeO^T/(FeO^T+MgO)$ diagram showing that the Dundonald peridotitic flows are komatiitic in composition. The dashed line separating the komatiitic from the tholeiitic field is from Naldrett & Goodwin (1977). Complete analyses of the samples are given in Table 1.

PETROLOGY OF THE MINERALIZED PERIDOTITIC FLOWS AND ASSOCIATED SEDIMENTS

Petrographically the Dundonald peridotitic flows appear almost identical to peridotitic flows described from Munro township, from Mt. Clifford, Western Australia (Barnes *et al.* 1974) and from La Motte township, Québec (Lajoie & Gélinas 1978). Compositionally they are komatiitic (Table 1, Fig. 4). A section through a mineralized peridotitic flow with an upper spinifex zone from the deposit is diagrammatically illustrated in Figure 5. Generally only the bottom third of the cumulate zone is mineralized. Sulfides, where present, appear first as weakly disseminated blebs and gradually increase in proportion downward to where they form typical "net-textured" mineralization (Fig. 6) at the base of the cumulate zone. Within the basal chill-zone semi-massive pentlandite may occur as "colloform-like" masses (Fig. 7) or as "tongue-like" protuberances (Fig. 8). Flow thickness does not seem to control sulfide content. The sulfide assemblage is relatively simple, consisting of pentlandite (33 at. % Ni) and heazlewoodite with traces of millerite, godlev-

OVERLYING FLOW

Interflow graphitic sediments or pyroclastics

Chilled and fractured amygdaloidal flow top

OLIVINE SPINIFEX

"Foliated" texture resulting from orientation of elongated euhedral and skeletal olivine crystals parallel to flow contacts.

Medium to fine-grained cumulate.

Massive blebs and dusty disseminations of sulphide

Intercumulate sulfide content increases downward

Note: All textures exaggerated for clarity.

COMPLETE FLOW

Intercumulate sulfide matrix forms. "net texture"

Basal chill of sulphide bearing flow.

Sulfides in interflow sediments or chilled and fractured flow top of underlying flow.
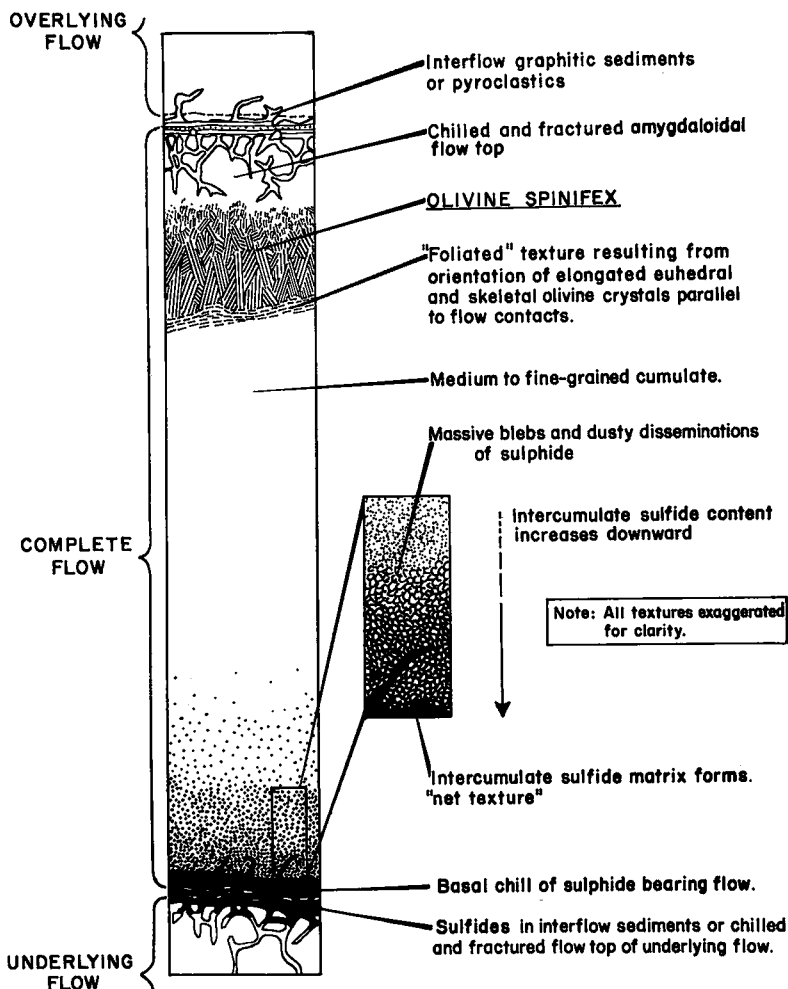
UNDERLYING FLOW

FIG. 5. A diagrammatic cross-section (not to scale) through a portion of a typical mineralized peridotitic flow (modified after Pyke *et al.* 1973).

skite (Ni_7S_6), maucherite ($Ni_{11}As_8$), gersdorffite, sphalerite, chalcopyrite and magnetite.

In places, beneath and in sharp contact with the basal chill-zone is a highly mineralized horizon termed "interflow ore". Interflow ore is characterized by: (1) the presence of graphite nodules and fragments (Fig. 9), (2) elongate to spheroidal masses of partly violaritized pentlandite commonly rimmed by graphite (Fig. 10), (3) an abundance of graphitic sulfide-rich breccias with volcanic clasts (Figs. 11, 12), and (4) a slightly more Fe-rich sulfide assemblage (*i.e.*, pentlandite ± pyrrhotite), most likely the result of assimilation of some pyritiferous sediment. The thickness of interflow ore horizons rarely exceeds 4 to 5 metres.

Tuffaceous carbon-rich beds may be inter-calated with interflow ore. Where mineralized, these sediments consist of bands or nodules of (exhalative?) pyrite (Fig. 13) in a poorly crystalline carbonaceous groundmass. The pyrite nodules have been observed in all stages of replacement by pyrrhotite.

FORMATION OF THE DEPOSIT

The relatively undisturbed volcanic stratigraphy of the deposit and the high degree of preservation of primary textures indicates that little or no post-depositional deformation or mobilization of sulfides has occurred. The present configuration is interpreted to have evolved in the following manner. Extrusion of peridotitic lava
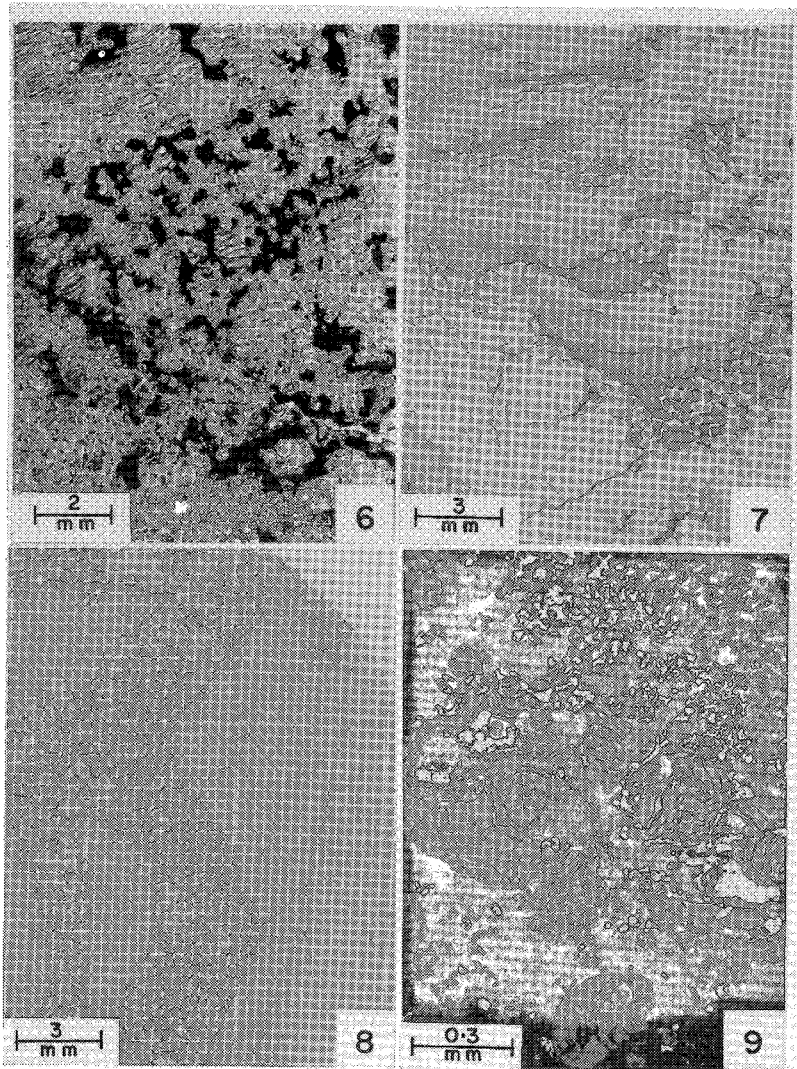
FIG. 6. Lower portion of olivine cumulate horizon. Partial "net-textured" sulfides (black). Transmitted light.

FIG. 7. Mineralized basal chill-zone. Colloform, "quenched" massive pentlandite in a devitrified matrix. Incident light.

FIG. 8. Mineralized basal chill-zone. "Quenched" protuberances of massive pentlandite in a devitrified matrix. Note also the sharp contact with the flow-top breccia of the underlying flow. Transmitted light.

FIG. 9. Interflow ore horizon. Graphite nodules (grey) interspersed with and partly enclosing nickeliferous sulfides (white). Incident light.

was interspersed with sedimentation of carbonaceous, pyritic chert and lapilli tuff. An immiscible nickeliferous sulfide melt existed as droplets carried in suspension within some of these flows. Subsequently, the sulfide droplets were concentrated by a combination of gravitational settling and by entrapment within depressions or structural embayments in the paleosurface on which the lavas were extruded. The sulfide melt that became concentrated in this manner formed a liquid layer that ran along and formed part of the base of the flowing magma. A portion

of the melt "leaked" into the porous underlying volcano-sedimentary horizon to form the "interflow ore". The remainder of the sulfide melt crystallized *in situ* in the basal cumulate zone of flows as intercumulus blebs forming the net-textured and disseminated mineralization. The few mineralized flows are stacked one on top of the other or intercalated with unmineralized flows, giving rise to multiple, *en échelon*, somewhat tabular mineralized horizons that lack substantial lateral continuity.
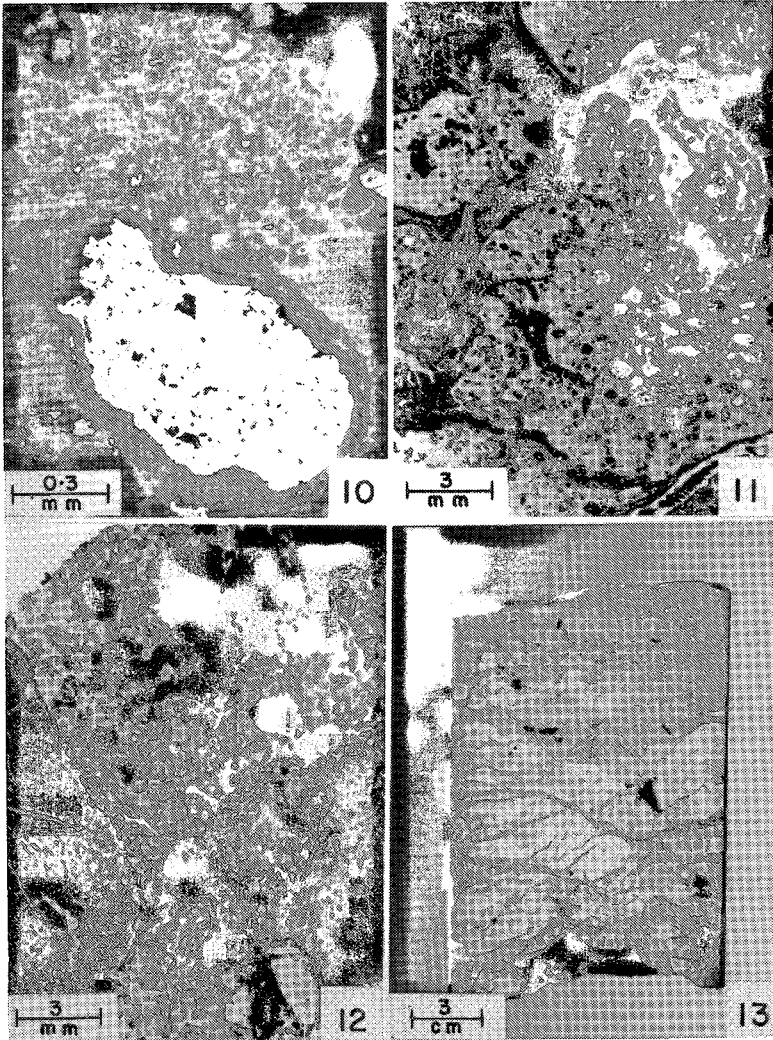

FIG. 10. Interflow ore horizon. An elongate, partly violaritized mass of pentlandite (white) is rimmed by graphite (grey). Note also the abundance of smaller graphite concretions.

FIG. 11. Interflow ore horizon. Nickel sulfides (black) occur both within and between devitrified fragments. Transmitted light.

FIG. 12. Interflow ore horizon. Mixture of volcanic rock and scoriaceous graphite fragments with minor pentlandite. Transmitted light.

FIG. 13. Interflow sedimentary material. Nodular, exhalative pyrite (white) partly pseudomorphed by pyrrhotite (grey). Incident light.

TABLE 1. CHEMICAL ANALYSES OF ROCKS FROM PERIDOTITIC FLOWS

	1	2	3	4	5	6
SiO_2	40.2	41.3	39.5	40.4	40.4	38.1
MgO	30.7	25.7	28.0	26.5	28.9	40.3
FeO^T	9.2	9.6	10.1	9.2	8.6	6.2
Al_2O_3	4.3	6.0	7.9	6.7	5.2	3.1
CaO	2.5	5.7	4.5	5.9	4.4	0.1
K_2O	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Na_2O	0.07	0.08	0.04	0.08	0.06	0.04
TiO_2	0.21	0.28	0.36	0.39	0.27	0.18
Cr_2O_3	0.32	0.31	0.27	0.39	0.26	0.17
LOI	10.2	8.2	9.2	8.2	10.3	11.2
TOTAL	97.80	97.27	99.97	97.86	98.49	99.49

(1) flow-top breccia; (2,3) olivine spinifex; (4,5) skeletal olivine; (6) olivine cumulate. All elements except sodium were determined by X-ray fluorescence.

DISCUSSION

The relationship observed between intercalated ultramafic flows and sediments with nickel mineralization is not unique to the Dundonald deposit, but has been described in varying degrees from other Archean nickel deposits in Western Australia (McCall 1972, Hudson 1972) and in the Abitibi greenstone belt in Canada (Eckstrand 1972, 1973).

For the Kambalda deposits, Ross & Hopkins (1975) have suggested that the disseminated/matrix ore and the massive ore formed coevally and that the latter originated as a separate extrusion of a magmatic sulfide liquid. In a recent synthesis on Western Australian volcanic-type nickel deposits, Barrett et al. (1977) stressed the importance of metamorphic and deformational processes in the evolution of nickel-sulfide ores. They attributed the present distribution and characteristics of massive ore at the Windarra and Nepean mines to remobilization of disseminated ores during metamorphism (amphibolite grade), but at the same time conceded that considerable evidence exists in support of the prior existence of magmatic sulfides (i.e., the disseminated ores). In contrast, Lusk (1976) has suggested that a volcanic-exhalative origin for these massive nickel sulfide deposits is also feasible, as many of these seem morphologically and stratigraphically similar to volcanic-exhalative massive Cu–Zn deposits.

As indicated earlier, the grade of metamorphism at the Dundonald deposit is at most greenschist facies and primary textures are extremely well preserved. Textures indicative of structural deformation are lacking. Hence, the distribution of nickel-sulfide ore at the Dundonald deposit appears to have remained unchanged since initial solidification. The increase in intercumulate sulfide content downward within the olivine cumulate portion of some peridotitic flows and the presence of what can be regarded as "quenched" semi-massive sulfides in the basal chill-zones provides strong evidence for a synvolcanic, magmatic origin of the nickel mineralization. The suggested genetic model explains many of the observed ore/host-rock relationships. However, in some instances, these relationships are not always as depicted in Figure 5. For example, some mineralized intersections have been found to consist of only interflow nickel sulfides, with the overlying peridotitic flows barren of sulfide. A rigorous application of the model requires the complete settling out of an immiscible sulfide liquid from the overlying flow. If such is the case, then it is conceivable that the mass of molten sulfide at the base of the flow could behave as a "sulfide flow" if allowed to escape from beneath the confines of the flow above.

The poorly crystalline interflow carbonaceous material, which is interpreted as relics of material of sedimentary (bacterial?) origin, implies that the subaqueous environment into which these mineralized and barren komatiitic flows were extruded was oxygen-poor; extrusion probably occurred within a relatively shallow basin of limited lateral extent. Introduction of the flows into the basin resulted in volatilization of some of the carbon which was subsequently redeposited as graphite at flow contacts. Graphite is particularly common in interflow ore horizons, where it delicately coats sulfide blebs and vitreous fragments alike.

J.C. Cowan and Dr. O.R. Eckstrand; however, the authors remain solely responsible for its contents. Mrs. G. Atkinson is responsible for the drafting and Mr. A. Gribbons for the photography.

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