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THE GEOLOGY OF THE THIERRY Cu-Ni MINE, NORTHWESTERN ONTARIO*

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The Thierry Cu-Ni mine is located in the Uchi Volcanic Belt, Superior Structural Province, 450 kilometres northwest of Thunder Bay, Ontario, near the town of Pickle Lake. The regional geology consists of an east-west-trending belt of Archean metavolcanic rocks, predominantly pillowed mafic flows with minor felsic volcanic and metasedimentary rocks. These have been intruded by granitoid stocks and mafic to ultramafic rocks that range in composition from gabbro to peridotite. Four main types of Cu-Ni sulfides are recognized: breccia ore, mylonite ore, bornite ore and disseminated sulfides. The regional metamorphic grade is middle amphibolite facies; mineral and chemical data suggest that temperature and pressure reached approximately 600°C and 5.5 kbar. These rocks have undergone late dynamic metamorphism, which produced a shear zone and a system of conjugate faults. Where mafic and ultramafic rocks were sheared, a mylonite was produced consisting of fragments of hornblende in a matrix of chlorite and biotite. Chemical alteration is associated with the dynamic metamorphism; whole-rock data indicate that Ca, Na and Si have been removed from the mylonite, and K was added. The sulfides are of magmatic origin, but their distribution within the mine was modified by dynamic metamorphism. Both mylonite and breccia ores were emplaced during the mylonitic event. The bornite ore was formed by the enrichment in copper of amphibolite-schist blocks in the mylonite.

Keywords: copper-nickel sulfides, magmatic origin, metavolcanic rocks, amphibolite facies, mylonite, Thierry mine, Ontario.

SOMMAIRE

La mine de Cu-Ni de Thierry est située dans la ceinture volcanique d'Uchi, province structurale du Supérieur, à 450 kilomètres au nord-ouest de Thunder Bay, en Ontario, près de la ville de Pickle Lake. La ceinture, de direction Est-Ouest, contient des roches volcaniques archéennes, où prédominent des coulées mafiques à coussinets avec quelques roches volcaniques felsiques et métasédimentaires. Injectés dans ces roches, on trouve des stocks granitiques et des roches mafiques à ultramafiques dont la composition varie de gabbro à péridotite. On distingue quatre types principaux de sulfures de Cu-Ni: minerai bréchifié, minerai mylonitisé, minerai à bornite et sulfures disséminés. Le degré de métamorphisme régional atteint le facies amphibolite moyen; d'après les données minéralogiques et chimiques, la température et la pression auraient atteint environ 600°C et 5.5 kbar. Ces roches ont subi un métamorphisme dynamique tardif, qui a produit une zone de cisaillement et un système de failles conjuguées. Où les roches mafiques et ultramafiques furent cisaillées s'est formée une mylonite caractérisée par des fragments de hornblende dans une matrice de chlorite et de biotite. Une altération chimique a accompagné le métamorphisme dynamique; les données chimiques sur roches globales révèlent un apport de K et un lessivage de Ca, Na et Si de la mylonite. Les sulfures sont d'origine magmatique, mais leur distribution dans la mine a été modifiée par le métamorphisme dynamique. Les minerais bréchifié et mylonitisé se sont tous deux formés au cours de la mylonitisation. Le minerai à bornite provient de l'enrichissement en cuivre des blocs de schistes amphibolitiques dans la mylonite.

(Traduit par la Rédaction)

Mots-clés: sulfures de cuivre et de nickel, origine magmatique, roches métavolcaniques, facies amphibolite, mylonite, mine Thierry, Ontario.

INTRODUCTION

The purpose of this paper is to document the petrology, structural geology, and chemical alteration of the rocks at the Thierry mine and their relationship to copper-nickel mineralization (Patterson 1980, Patterson & Watkinson 1983). The Thierry mine, owned by Umex Inc., is located 450 km northwest of Thunder Bay, Ontario (Fig. 1). Drilling has delineated 14 million tonnes of 1.60% copper (Canadian Mines Handbook 1981). The Thierry ore is enclosed in mafic to ultramafic rocks and their sheared equivalents.

GENERAL GEOLOGY OF THE PICKLE LAKE GREENSTONE BELT

The Thierry mine occurs in the Pickle Lake greenstone belt (Figs. 1, 2) of the Uchi Lake Subprovince of the Superior Province (Sage & Breaks 1982). The Cat Lake – Williams Lake batholithic complex occurs to the northwest, and granitoid rocks of the God's Lake Subprovince, to the north and east. All rocks are Archean except for some Proterozoic diabase dykes.

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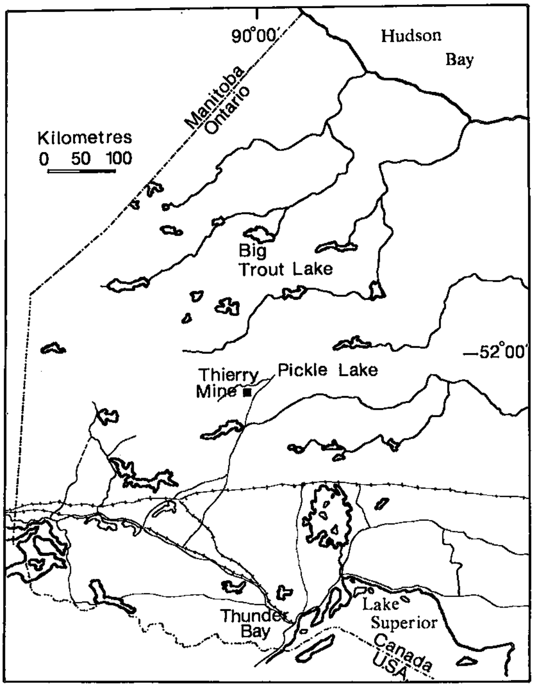

FIG. 1. Location of the Kapkichi Lake area and the Thierry mine, northwestern Ontario.

The predominant rock-types of the belt are tholeiitic, mafic to intermediate, massive to pillowed flows. Ironstone and greywacke to siltstone occur as units as thick as 100 m intercalated with the volcanic rocks. Dacite and quartz feldspar porphyry occur in the Pickle Crow area.

These units were intruded by the Pickle Lake, Hooker-Burkoski and Ochig Lake granitoid stocks. Mafic to ultramafic rocks result from later intrusions; the largest of these bodies is found near July Falls, and a group of smaller intrusive bodies, one of which is host to the Thierry mine, occurs near Kapkichi Lake.

All these rocks have been folded about northeast-trending axes (Pye 1956). Faults are predominantly parallel to foliation or at a high angle to it. The metamorphic grade varies from greenschist to amphibolite facies.

PETROLOGY OF THE MAFIC AND ULTRAMAFIC ROCKS

The mafic to ultramafic rocks that host the Thierry mine consist of 75% metagabbro, 20% mafic metagrabbo and 5% talc-carbonate schist. The metagabbro and mafic metagabbro are texturally and chemically gradational, as shown by mapping, petrography and whole-rock compositions along the 312 crosscut (Fig. 3). The metagabbro is composed of 50–80% amphibole and 20–50% plagioclase. This unit grades to a mafic metagabbro containing 0–20% plagioclase and 80–100% hornblende. The hornblende, commonly with exsolved actinolite, has developed by metamorphism of clinopyroxene and plagioclase (An_{60}) (Fig. 4a).

Talc-carbonate schist, peridotitic to dunitic in composition, occurs as blocks adjacent to the mylonitic rocks. No direct petrological relationship with the gabbro is apparent owing to deformation. Rare samples contain massive lenses composed of olivine pseudomorphs partly altered to a mixture of talc and serpentine (Fig. 4b). Carbonate in the schist is a mixture of dolomite and magnesite (J. Lefebvre, pers. comm. 1977). An olivine–tremolite–chlorite rock, comprising coarse lath-shaped olivine crystals up to 3 cm long in a matrix of tremolite, occurs rarely in association with the talc–carbonate schist.

PETROLOGY OF CHLORITE-BIOTITE SCHIST

The phyllonitic mylonite, a chlorite–biotite schist, occurs in a shear zone that pinches and swells from 2 to 100 metres in thickness (Fig. 5). There is a strong positive relationship between the amounts of biotite and of sulfides in the mylonite. The mylonite commonly includes fragments of relatively undeformed mafic metagabbro, metagabbro, amphibolite schist, diorite, and quartz vein. In hand specimen, the mylonite is dark grey, well foliated and fine grained. It is intensely jointed, with the joint surfaces coated with dark chlorite and sheared sulfides. The mylonite is commonly layered, with white felsic layers, epidote layers and quartz veins from 1 mm to 5 cm thick (Fig. 4c). The layering is complexly folded, commonly leading to interference patterns on a fine scale. Part of the mylonite was brecciated, and fragments of mylonitized material are enclosed in a very fine-grained matrix of chlorite and sulfides (Fig. 4d). The fragments have a random orientation and are variably rounded, bent, fractured and stretched parallel to the foliation (Fig. 4e). The matrix around them exhibits pressure shadows.

Layering results from variation in the relative proportions of fragments and of chlorite and biotite in the matrix. Some quartz-rich layers are mylonitized. Individual grains of quartz are strained and dynamically recrystallized, and occur in a matrix of very fine-grained quartz. Many of the fragments of amphibole have dark green hornblende at the core and colorless actinolite at the rim (Fig. 4f).

There is a complete gradation between the mylonite and mafic metagabbro. Amphibole in the

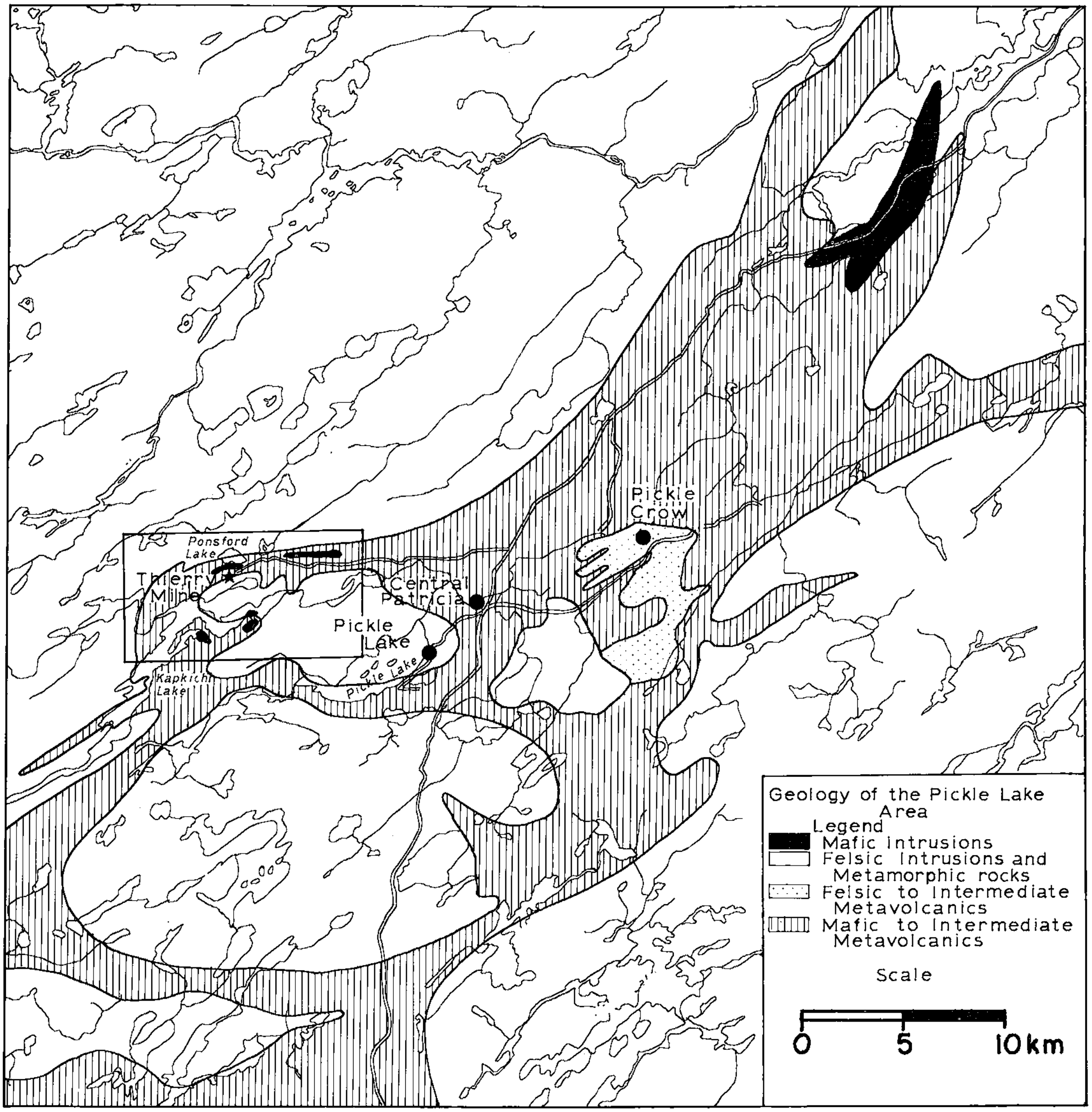

FIG. 2. Geology of part of the Pickle Lake area, from Sage & Breaks (1982) and Patterson (1980).

mafic metagabbro is deformed, bent and fractured, with biotite and chlorite occurring between the fragments. As the amount of deformation increases, the amount of biotite and chlorite increases, the size of the amphibole fragments decreases, and the number of layers increases. Accessory minerals are fluorite, barite, titanite, epidote and carbonate.

Cu-Ni SULFIDE ORES

There are four main types of sulfide associations recognized (Patterson & Watkinson 1983): breccia ore, mylonite ore, bornite ore, and disseminated sulfides, making up 40%, 58%, 1%, and 1%, respectively, of the sulfides at the Thierry mine. The disseminated sulfides, interpreted as metamorphosed primary magmatic sulfides, occur as composite blebs of chalcopyrite, pyrrhotite and pentlandite between olivine remnants or serpentine–talc pseudomorphs of olivine. The breccia ore is composed of 20 to 50% sulfides and consists of angular to rounded fragments of gangue (mafic metagabbro, mylonite and amphibolite) in a matrix of chalcopyrite, pyrrhotite, pyrite and pentlandite (which is

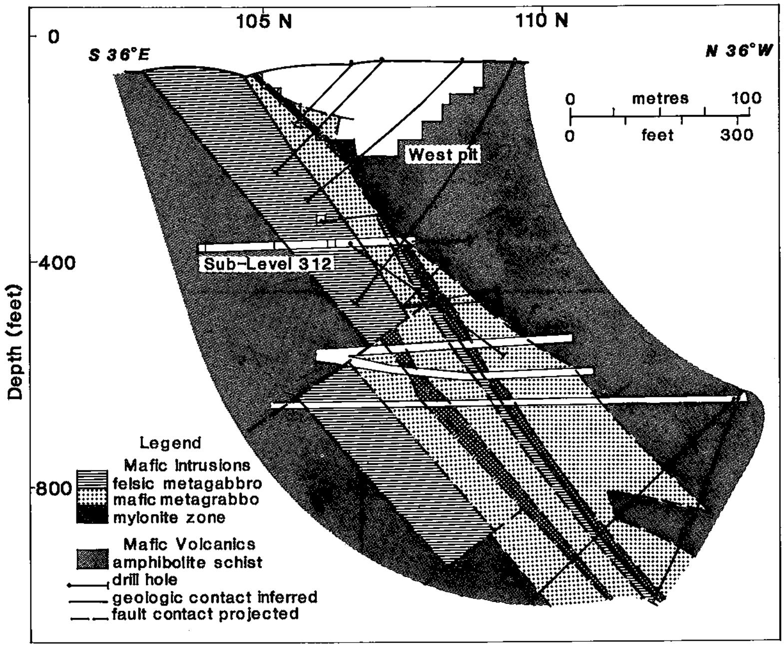

FIG. 3. Geological section 101E, Thierry mine.

partly altered to violarite). The mylonite ore contains 5 to 20% sulfides as stringers of chalcopyrite, pyrrhotite, pentlandite and pyrite that are sheared parallel to the foliation. The breccia ore is gradational into mylonite ore and contains fragments of mylonite.

The bornite ore contains from 1 to 5% sulfides as stringers and disseminations of chalcopyrite and bornite in carbonate veins associated with blocks of amphibolite schist in the main shear-zone.

The mylonite ore and breccia ore have an unusual Cu/Ni ratio of 8 to 1 compared to sulfides occurring in other gabbroic rocks. A more complete description of the ore is given by Patterson & Watkinson (1983).

Structural Geology

The ultramafic rocks occur as blocks adjacent to a mylonite zone, which may be traced for a distance of 2 km in the mine area (Fig. 5). The mylonite zone is thickest (50 m) in the east, section 115E, where it includes large blocks of amphibolite schist containing bornite ore. The mylonite zone is one to two metres thick between sections 103E and 105E. The proportion of matrix to fragments and the thickness of the mylonite zone are greatest where it cuts metamorphosed mafic to ultramafic rocks. Where the zone cuts amphibolites, it consists of relatively undeformed amphibolite blocks that commonly are highly altered to chlorite and epidote, with narrow bands of mylonite between the fragments. Where both the footwall and hanging-wall rocks are amphibolite, the mylonite is barren or weakly mineralized.

There are minor shear-zones subparallel to the main zone (Fig. 5). The contact between the mylonite and the amphibolite schist is very sharp. The amphibolite schist shows only minor deformation. The contact between the mylonite and mafic to ultramafic rocks is less distinct. The ultramafic rocks are less and less deformed with increasing distance from the mylonite.

The internal structure of the mylonite is very complex. Quartz veins and layers rich in epidote, chlorite or biotite define complex folds of several generations that produce interference patterns. Some of the folds are related to "dragging" against the wall rocks and others to faults within the mylonite zone. Distinct fault-bounded zones and blocks of mylonitized rock occur within the main shear-zone. These internal faults do not cross the main shear-zone and are commonly curved and filled with a blue-grey fault gouge.

Associated with the main zone of mylonite are two other fault orientations, conjugate to the main mylonite. They are symmetrical in orientation about the mylonite zone, with their line of intersection in the plane of the mylonite. In general, the faults striking 90°/45°N are cut by faults striking 25°/55°E, which in turn are cut by the mylonite shear 60°/50°N. There are several exceptions where the

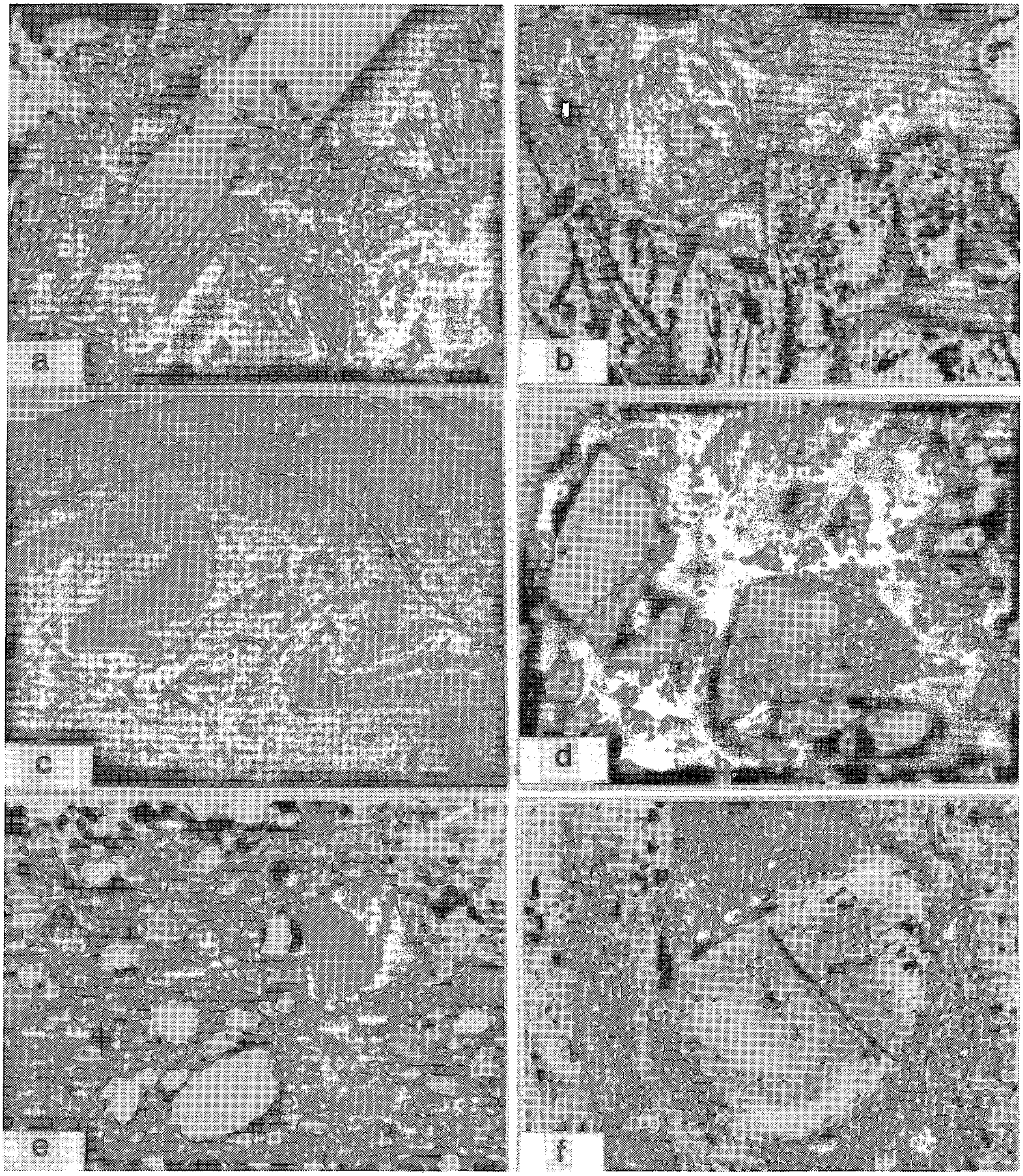

FIG. 4. Photographs of metamorphosed mafic–ultramafic rocks. a. Metagabbro composed of radiating masses of hornblende replacing clinopyroxene with remnant plagioclase (An_{60}). Field of view 5.6 mm. b. Altered dunite showing talc–carbonate–magnetite pseudomorphs after olivine. Field of view 5.6 mm. C. Mylonitized mafic to ultramafic rock with interference patterns defined by folded layers with varying chlorite to biotite ratio; sulfides (chalcopyrite and pyrrhotite) occur as disseminations stretched parallel to foliation and minor stringers cutting the foliation. West pit, second bench. Field of view 10.5 cm. d. Fragments of mylonitized mafic to ultramafic rock in a sulfide-rich matrix. Field of view 5.6 mm. e. Blastomylonite consisting of fragments of hornblende in a matrix of chlorite and biotite. Field of view 2.8 mm. f. A fragment of hornblende with a margin of tremolite–actinolite in blastomylonite (mylonitized mafic to ultramafic rock). Field of view 0.7 mm.

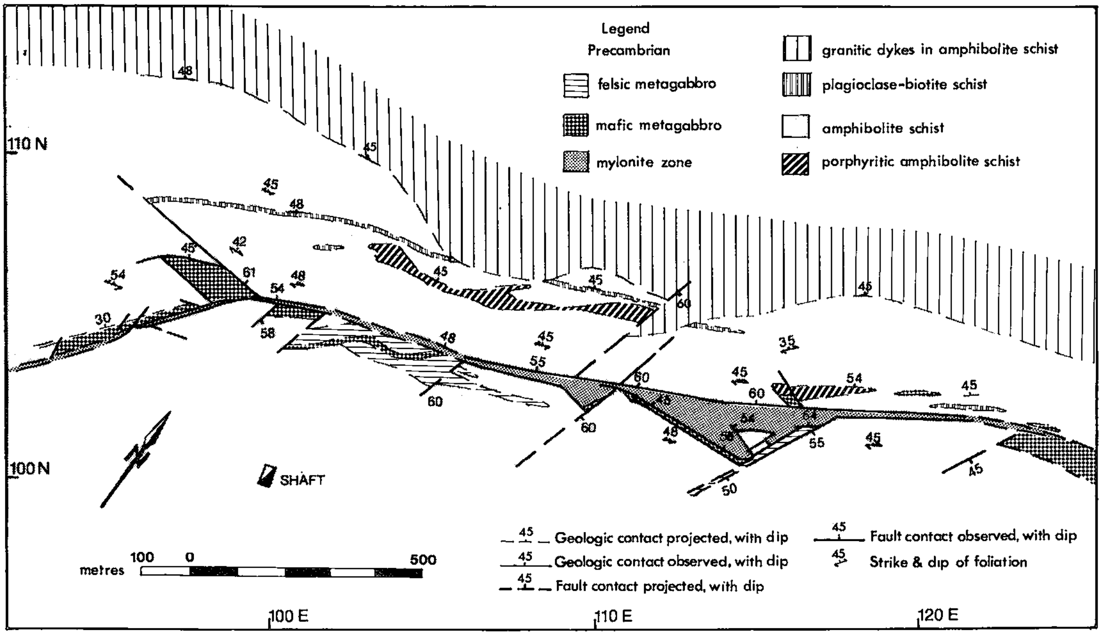

FIG. 5. Geological interpretation of the 100 level of the Thierry mine.

mylonite shear-zone is cut by faults at 25°/55°E, causing offsets of up to 20 metres. This is interpreted as late movement renewed on old shears. Many of the conjugate faults are localized in diorite dykes. Where the conjugate faults cut ultramafic rocks, mylonite is developed, whereas in amphibolite schist only narrow chlorite-coated surfaces are evident. Much of the breccia ore is concentrated where the conjugate faults cut mafic or ultramafic rocks. This pattern of faulting is similar to that developed in tests of triaxial strain (Hobbs *et al.* 1976).

METAMORPHISM

Regional metamorphism

Metamorphic conditions were estimated using geothermometers and geobarometers based on mineral assemblages (Patterson 1980). An estimate of temperature was obtained from the following assemblages of coexisting minerals: i) 608 ± 50°C using the garnet–biotite geothermometer (Thompson 1976), ii) 590 ± 50°C using the calcite–dolomite geothermometer (Goldsmith 1955, Ewert 1977) and iii) 650 ± 100°C using the magnetite-ilmenite geothermometer (Buddington & Lindsley 1964). An estimate of pressure was obtained from the following assemblages of coexisting minerals: i) based on garnet–plagioclase equilibria (Ghent 1977), 5.7 kbar using data of Robie & Waldbaum (1968) or 6.8 kbar using data of Helgeson *et al.* (1978), and ii) 5.6 kbar, based on sphalerite–pyrite–pyrrhotite equilibria (Scott & Barnes 1971, Hutcheon 1977).

Dynamic metamorphism

Textures show that the host rock suffered amphibolite-facies metamorphism prior to the formation of the main mylonitic zone. The presence of high-iron (28% FeO) chlorite in the matrix of the mylonite, however, suggests that greenschist-facies metamorphic conditions existed during the dynamic event. Experimental work in the system Ni-Fe-S (Craig 1973) has shown that pyrrhotite and pentlandite exist as a single phase, monosulfide solid-solution, above 400°C. If deformation took place above 400°C, pyrrhotite and pentlandite would not be mechanically separated. Within the mylonite, pentlandite and pyrrhotite occur as isolated grains, implying that deformation took place at temperatures below 400°C.

CHEMICAL ALTERATION

Samples from the 312-level drift (Fig. 3) across a section of mafic–ultramafic rocks that show only minor deformation and continuous gradation from metagabbro to mafic metagabbro were analyzed by X-ray fluorescence (Table 1). Al_2O_3, MgO, NiO, CaO, K_2O, Na_2O and S values define a continuous

TABLE 1. WHOLE-ROCK COMPOSITIONS, THIERRY MINE

	D22	D25	D15	D12	D4	D6	D10	D14	2110
SiO_2	48.8	48.0	44.9	53.13	43.1	45.6	44.1	46.7	41.9
Al_2O_3	4.47	10.8	12.1	15.19	9.05	8.09	8.12	8.66	7.30
Fe_2O_3	3.12	4.06	4.57	2.09	4.85	4.31	4.07	4.76	12.5
FeO	8.79	11.3	12.7	5.85	13.91	12.3	12.4	13.4	5.83
MgO	18.1	11.3	10.5	3.86	12.97	15.0	12.2	13.4	10.9
CaO	12.7	7.43	7.31	6.27	5.13	4.95	3.81	4.65	4.24
Na_2O	0.80	3.41	3.02	4.81	1.47	1.12	1.09	1.69	0.62
K_2O	0.23	1.15	1.75	2.86	2.48	2.85	2.85	1.86	2.90
TiO_2	0.44	0.59	0.87	0.80	0.53	0.40	0.44	0.42	0.60
P_2O_5	0.07	0.23	0.23	0.17	0.20	0.22	0.16	0.20	0.07
MnO	0.20	0.24	0.25	0.16	0.24	0.22	0.22	0.23	0.28
S	0.06	0.22	0.39	1.17	4.00	2.47	2.80	4.46	10.3
NiO	0.06	0.03	0.03	0.02	0.12	0.09	0.11	0.13	0.34
Cr_2O_3	0.14	0.03	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	0.01
CO_2	0.42	n.d.	n.d.	2.96	1.46	0.99	7.36	n.d.	n.a.
H_2O	1.66	1.33	1.60	0.70	2.60	3.00	1.76	2.22	3.20
Total	100.26	100.12	100.22	100.34	102.14	101.61	101.49	102.78	100.99

D22, D25, D15 and D12: mafic-ultramafic rocks from 312-level drift; D4: hornblende-chlorite-biotite schist, 101E-11291N-1185; D6: hornblende-chlorite-biotite schist, 312/98+75E/-17 150; D10: hornblende-chlorite-biotite schist, 101E-11683N-1593; D14: hornblende-chlorite-biotite schist, 101E-10841N-545; 2110: hornblende-chlorite-biotite schist, location unknown. n.d. not detected, n.a. not analyzed.

trend with distance along the drift (Fig. 6) consistent with a magmatic trend. The composition of the undeformed rocks (wt. % oxides) on the 312-level crosscut and mylonitized mafic intrusive rocks (Table 1) are plotted against Al_2O_3 (Fig. 7). The line on the diagram joins points on the possible magmatic trend shown on the 312-level crosscut. The mylonitized samples plot directly on this trend for Cr_2O_3 (not shown) and MgO whereas K_2O is above the trend and CaO, SiO_2 and Na_2O are below the trend. The iron data (not shown) scatter both above and below the magmatic trend. This is consistent with the hypothesis that Mg, Al and Cr were relatively immobile, K was enriched and Ca, Na and Si were depleted in the mylonitic rocks during dynamic metamorphism.

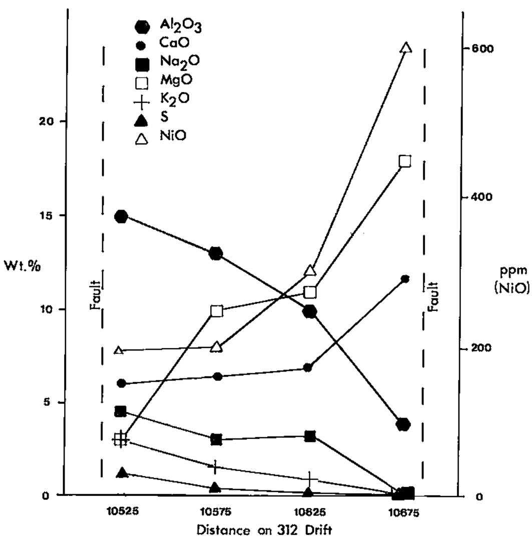

FIG. 6. Variation in Al_2O_3, MgO, NiO, CaO, K_2O, Na_2O and S contents of relatively undeformed mafic and ultramafic rocks on the 312-level drift.

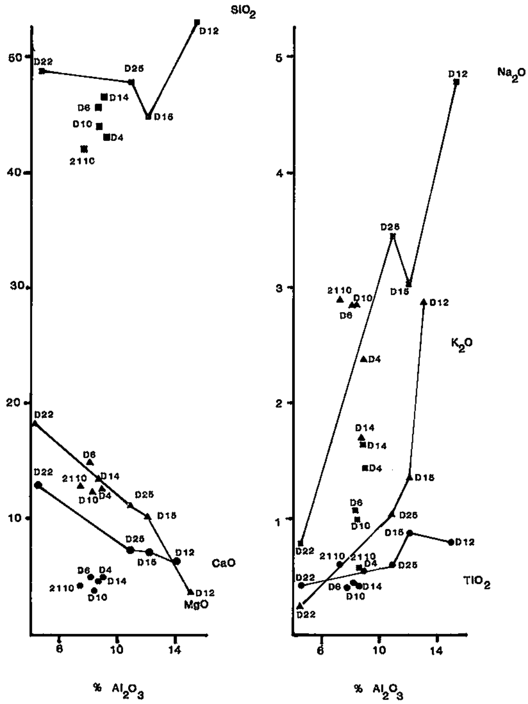

FIG. 7. Chemical variation with alumina: mafic metagabbro (solid squares), metagabbro (solid triangles), chlorite–biotite schist (solid circles) from the Thierry mine. Line joins samples from trend observed on 312-level drift.

The following model is based on the observed textures and changes in bulk composition; hypothetical mineralogical reactions involved are listed in Table 2. 1) The hornblende fragments in the mylonitized mafic metagabbro commonly have rims of tremolite–actinolite. These rims are interpreted to result from the removal of Na, K and Al from the original

TABLE 2. ALTERATION REACTIONS ASSOCIATED WITH MYLONITIZATION

1. Generation of chlorite
   (a) albite + $6(Mg,Fe)^{2+}$ + Fe^{3+} + $12H_2O$ + 2 e^- = chlorite + quartz + Na^+ + $8H_2$
   (b) hornblende + anorthite + $3H_2O$ = chlorite + $3Ca^{2+}$ + $(Na,K)^+O$-1 + 3/2 O_2 + 4 e^-
   (c) 2 hornblende + anorthite + $3H_2O$ = actinolite + chlorite + $7SiO_2$ + 3/2 O_2 + $3Ca^{2+}$ + $2(Na,K)^+$ + 5 e^-
2. Generation of biotite
   chlorite + $2K^+$ + 3 quartz + 2 O_2 + 6 e^- = 2 biotite + 4 OH^-
3. Generation of epidote
   2 andesine + 2 quartz + Na^+ + H_2O = clinozoisite + 3 albite + H^+
4. Alteration of hornblende
   hornblende = actinolite + $(Na,K)^+$ + e^-

Composition of the phases: albite $NaAlSi_3O_8$, chlorite $(Mg,Fe)_5(Fe,Al)_2Si_3O_{10}(OH)_8$, quartz SiO_2, hornblende $(Na,K)Ca_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH,F)_2$, anorthite $CaAl_2Si_2O_8$, andesine $NaCaAl_3Si_5O_{16}$, actinolite $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$, biotite $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$, clinozoisite $Ca_2Al_3Si_3O_{12}(OH)$

hornblende, leaving actinolite (reaction 4). 2) The original rocks, mafic metagabbro and metagabbro, contained plagioclase. Plagioclase is rare in the mylonite, although remnants occur that are partly altered to a mixture of chlorite and epidote. This suggests that reactions 1a and 3 have occurred. 3) The chloritic matrix could have been generated in part by the alteration of hornblende (reactions 1b and 1c). 4) The chloritic matrix could have been converted to biotite by reaction 2, with addition of K from the breakdown of hornblende (reactions 1b, 1c, and 4) or the addition of K from outside the mylonite zone. 5) The silicon and sodium released in the generation of chlorite and actinolite (reactions 1a, 1b, 1c and 4) could react with the wall rocks, predominantly amphibolite schist composed of andesine and hornblende, to produce albite-rich plagioclase and clinozoisite (reaction 3).

Comparing the elements presumed mobile during alteration, based on whole-rock data, to those suggested in the above model, it appears that Na, Ca, and Si were removed from the sheared ultramafic and mafic rocks to produce epidote and plagioclase in the wall rocks, whereas K was added to the mylonite zone to produce biotite. This pattern of alteration was observed in shear zones in amphibolite at Yellowknife, N.W.T. by Kerrich *et al.* (1977).

SUMMARY AND CONCLUSIONS

The Thierry mine occurs in metamorphosed gabbro and minor peridotite that contain a major shear or mylonite zone. Associated with the mylonite is a conjugate system of faults. The regional grade of metamorphism is in the middle amphibolite facies, and the rocks attained 600°C and 5.5 kbar.

The texture of the mylonite suggests that the rock was metamorphosed to the amphibolite facies before dynamic metamorphism. The mineralogy and texture of the sulfides in the mylonitized zone indicate that the last shearing took place at a temperature below 400°C.

The whole-rock chemical compositions are consistent with removal of Ca, Na and Si and addition of K to the rocks in the mylonitized zone. The lack of plagioclase and the alteration of hornblende to actinolite in the mylonite, as well as the enrichment of epidote in the amphibolite wall-rocks, suggest that the alteration of plagioclase and hornblende produced chlorite in the mylonite, releasing sodium and calcium, which generated albite and epidote in the amphibolite. Potassium from the breakdown of hornblende or from metamorphic solutions outside the mine environment altered some of the chlorite in the mylonite to biotite.

The sulfides in the mine are of primary magmatic origin, but their distribution has been strongly affected by the tectonic history (Patterson & Watkinson 1983). The mylonite ore and much of the breccia ore were mobilized as a result of dynamic metamorphism. The occurrence of mylonite fragments in the breccia ore and localization of breccia ore along faults related to the main shear emphasize this relationship. Furthermore, the dynamic metamophic event affected rocks that had undergone metamorphism to conditions of the middle amphibolite facies and that had retrograded to the greenschist-facies grade during the deformation event. The occurrence of bornite ore in amphibolite blocks included in the mylonite suggests that the sulfides were mobilized into the amphibolite during metamorphism.

There are two main possibilities for the mobilization of sulfides from relatively undeformed metamorphosed mafic to ultramafic rock: a) a primary unit of massive sulfide was deformed into the present configuration during dynamic metamorphism, or b) primary disseminated sulfides were mobilized into shear zones by stress-induced diffusion.

Any model of ore genesis at the Thierry mine must take into account the unusual Cu/Ni and chalcopyrite/pyrrhotite ratios in the rocks. According to Naldrett & Cabri (1976), intrusive complexes similar to those at Thierry contain sulfides with a Cu/Ni ratio of 2:1 and a chalcopyrite/pyrrhotite ratio of 1:10. At the Thierry mine, the Cu/Ni ratio is 8:1, and the chalcopyrite/pyrrhotite ratio is 1:1. Experimental work by Kelly & Clark (1975) suggests that the chalcopyrite and pyrrhotite are unlikely to be separated by mechanical shearing alone. Thus, stress-induced diffusion aided by fluid during dynamic metamorphism is preferred to explain the mobilization of the ore elements. The difference in mobility of copper and iron (Barnes 1967) is compatible with the mobilization of copper mechanically and in solution to the shear zone and into amphibolite blocks, whereas iron would have been less mobile. Nickel appears to behave much like iron and, like it, would not be mobilized far from its original site as disseminated sulfides in mafic–ultramafic wall rocks (Patterson 1974).

The operation of such an alteration mechanism would suggest that uneconomic deposits of Cu–Ni sulfides could be modified to produce economic deposits in areas that have undergone dynamic metamorphism or other dynamic events. Other occurrences that have an unusually high Cu/Ni ratio and are enclosed in dynamically metamorphosed rocks are the ores of the Shebandowan mine and the Cu-rich deposits in the footwall at Sudbury.

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