THE UNIVERSITY OF MANITOBA

THE GEOLOGY AND SOME GENETIC ASPECTS OF FOX MINE MINERALIZATION, NORTHERN MANITOBA

by

FORTUNATUS CHIGOZI OBINNA

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ABSTRACT

The Fox Lake copper-zinc deposit is an example of an orebody within a metamorphic environment. Laboratory study of the sulphides, the host meta-sedimentary and meta-volcanic rocks reveals that the host rocks and the ore were involved in repeated metamorphic processes.

However, there is a relatively narrow band of low grade (Greenschists facies) metamorphic rocks adjoining the ore and this grades imperceptibly into the higher grade metamorphic (Amphibolite facies) country rocks. This is the "alteration zone" of the orebody.

Petrographic study leads to the suggestion that the alteration zone resulted from retrograde metamorphism induced by hydrothermal solutions. This introduces a paradox in the time relationship between the ore emplacement and metamorphism. This paradox is unresolved.

The major effects of wall rock alteration, sericitization, chloritization and minor propylitization are exhibited mainly in the alteration zone. Sporadic sericitization, epidotization and chloritization occur at isolated points within the higher grade host rocks but these are irregular. The occurrence of such mineral as anthophyllite and cordierite is interpreted to result from a possible Mg-Fe metasomatism associated with hydrothermal alteration.

The textural relationships of the massive sulphides also suggest the influence of mobilization under metamorphic conditions. Some of these features are cataclastic fractures in pyrite, the coarse grain size of pyrite, the ribbon-like extensions of chalcopyrite and pyrrhotite along pyrite-sphalerite or pyrite-silicate gangue grain boundaries, and sulphide subgrain development unoriented with respect to one another. These features are explained as the results of annealing and mobilization related to deformation and metamorphism.

The metal distribution of the massive sulphide zone is in general agreement with many epigenetic deposits. Minor departures from the usual geochemical trend are probably due to the effects of post-ore migration of metals or base-exchange reactions induced by hydration or metamorphism.

An epigenetic origin of the ore is suggested. It is further suggested that the ore probably followed the andesitic basaltic volcanic rocks which were all involved in later phases of deformation and metamorphism probably during Kenoran and Hudsonian orogenic epochs.

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CHAPTER I

INTRODUCTION

The Fox Lake deposit is one of the metallic deposits within a greenstone belt of the Churchill structural province. The close spatial relationship of the orebody to highly metamorphosed volcanic and volcano-sedimentary sequences introduces many genetic problems. Chief of these problems is the separation of those features of the ore deposit related to the metamorphic history of the ore and host rock from those features which are attributable to the primary emplacement of the ore.

The present study is designed to investigate some aspects of the petrology, mineralogy and base base metal distribution of the Fox Lake mineralization with a view to understanding the probable genesis of the orebody. The observations in this study will be compared to those made by other workers on the characteristic features of other orebodies in the Archaen greenstone belt in similar geologic settings.

LOCATION AND ACCESS

The Fox Lake deposit is located 27 miles west-south-west of Lynn Lake, Northern Manitoba. Figure 1 shows the location of the orebody within the greenstone belt of the Lynn-Fox district.

An all weather road between the Fox Lake mine and Lynn Lake was completed in 1972 and regular transportation is provided between the

Fox mine and Lynn Lake. In addition there are bush roads and access lines through which an investigating geologist can get access to the rock exposures in the thesis area.

FIELD WORK

During the summer of 1973 the writer was engaged in a mapping programme of the region surrounding the Fox mine area including the Fox-Snake Lakes area to the Dunphy lakes-Wolfe lakes zone and the Hatchet-Todd Lake areas (Fig. 1).

In addition the writer studied the lithological relationships of 2100 level of the Fox mine starting from the main cross-cut, proceeding across the ore zone to the north in the country rock to the exploration drift in the hanging wall. The object of this investigation was to study the spatial relationships of the host rock and massive sulphides as well as the minor structural features in the 2100 level of the mine. This portion of the investigation was made possible by the Mine Geology Department of Sherritt Gordon Mines, Limited, Lynn Lake who provided staff escorts and plans for the sections of the mine studied.

Part of the field investigation consisted of logging and collection of drill core samples from the Fox mine. This exercise as well as the provision of the plans of the various levels and sub-levels and the relevant sections was also made possible through the cooperation of the staff of Sherritt Gordon Mines Limited. The additional samples from drill cores and the 2100 level were processed in the University of Manitoba for the present study.

PREVIOUS WORK

The earliest geological investigation in the Lynn Lake district dates back to the period between 1932 and 1948. Within this period, the Geological Survey of Canada conducted a series of reconnaissance mapping projects of 4 miles to one inch in and around the Lynn Lake district. Other geological activities consisted of private prospecting around the McVeigh Lake areas.

The most recent published work on the Lynn-Fox geology was by the Manitoba Mines Branch. The mapping program was started in 1946 and completed in 1950. The field investigations were led by geologists working in different areas of the Lynn Lake district. The accumulated geological data from the various field groups were compounded into a volume by G. C. Milligan (1960). Emslie and Moore (1961) also published a later report on the geology of the area between Lynn Lake and Fraser Lake.

The work of Milligan (1960) is the most recent comprehensive account on the main lithological types and the structural relationships of the main formations in the Lynn-Fox district. The field and age relationships as outlined by Milligan (1960) have provided a useful basis for subsequent research in the district.

Since the commencement of mining operations in the Lynn Lake area, Sherritt Gordon Mines Limited has been engaged on active geophysical and geological work around the district. In 1961, a horizontal loop electro-magnetic and magnetic survey was followed by diamond drilling which intersected the mineralization of the Fox mine.

Diamond drill from surface to the 2,000 level indicated an initial reserve of 1,226,900 tons of ore with 1.74% copper and 2.34% zinc in 1965. The company is at present extending the mining to the 2,200 level and the reserve in December, 1973 was 11,800,000 tons at a grade 2.03% copper and 2.5% zinc.

ACKNOWLEDGEMENT

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CHAPTER II

REGIONAL SETTING

The Wasekwan Group

The Fox Lake region is part of the Churchill structural province of the Canadian Shield. The oldest rock group of the areas, the Wasekwan group, comprises a conformable series of basic, intermediate and acidic volcanic rocks related agglomerates, tuffs breccias and sedimentary sequences. The sedimentary sequences comprise mainly greywackes, impure quartzites, conglomerates, banded iron formations and magnetite-bearing shales. (See Table of Formations, Table 1).

The Wasekwan conglomerates consist of quartz and quartzite pebbles in an arenaceous matrix. The impure quartzites located dominantly in the McVeigh-Lynn Lake areas contain minor muscovite and biotite with occasional hornblende.

Banded iron formations occur at isolated localities. The iron formations are frequently associated with magnetite bearing slates.

The best known exposures of agglomerates occur to the south east of Dunphy Lakes. They consist of large pyroclastic fragments set in a matrix of quartzite. Stanton (1949) suggested that these represent pyroclastic remnants blown explosively into sedimentary basins.

The amphibolites of the Wasekwan are derived mainly from the basic and intermediate volcanic rocks. These greenstones comprise essentially plagioclase and hornblende with occasional garnet, anthophyllite and sillimanite porphyroblasts. The texture and mineralogical

TABLE I

TABLE OF FORMATIONS*

Pleistocene and Recent

Sand, gravel, till and boulder deposits, clays.

Unconformity

Precambrian

Post-Sickle Intrusive Group:

Quartz-feldspar porphyry, quartz porphyry, Pegmatites, aplites, pegmatitic granites, Microcline grainites, Gneissic and massive biotite tonalites, Diorites.

Kisseynew-type Gneisses:

Quartz-plagioclase-biotite-hornblende gneisses, pegmatitic and aplitic granites. Granitoid paragneiss, granite gneisses. Amphibolites (garnetiferous and anthophyllite bearing) Muscovite-biotite-schist and pegmatites.

Intrusive Contact

Sickle Series:

Arkose, quartzites; slatey sediments. Conglomerates and derived schists; Interbedded arkoses and quartzites.

Angular and Erosional Unconformity

Pre-Sickle Intrusive Group:

Biotite granite, leuco-granodiorites, Quartz diorites, hornblende-biotite-diorites, Undifferentiated gabbros, norites, peridotites and included volcanics.

Intrusive Contact

Wasekwan Series:

Banded iron formations and magnetite bearing shales; Tuffs, agglomerates, flow breccias with interbedded sediments; Siliceous and intermediate volcanics, Massive and pillowed lava (andesitic and basaltic); Interbedded sedimentary, volcanic and tuffaceous rocks; Greywackes; tuffs and interbedded flows; conglomerates.

composition of these amphibolites vary over short intervals. In the region of Fox mine, for example, they range in texture from fine-grained greenish black rocks with distinct planar fissility and slately cleavage to dense coarse-grained schistose varieties. The compositional differences of these two sub-divisions is commonly based on the feldspar and quartz contents. The textural differences observed in the field appear to be related to differences in the amount of shear to which these amphibolites were subjected.

The Wasekwan has been deformed during the subsequent phases of deformation associated with the Hudsonian and Kenoran orogenic events. Belts of isoclinally folded Wasekwan have been mapped around Fox Lake. Small scale interference patterns such as cross folds, and plications on the limb of south-west dipping fold limbs of anticlines have been noted in the Eager Lake area. Some of these have been invaded by later intrusions.

The top and base of the Wasekwan volcanics have been obliterated by intrusive rocks but the sedimentary facies of the Wasekwan group have not been so affected. Stanton (1949) and Milligan (1960) suggested the Wasekwan sediments are younger than the volcanics and may have been derived from the erosion of the older Wasekwan volcanic rocks.

The Pre-Sickle Intrusive Rocks

The Wasekwan is intruded by a group of basic, intermediate and acid rocks classified as the Pre-Sickle intrusive group. The most extensive of the Pre-Sickle intrusions are the norites and gabbros. Next in order of abundance are the quartz-diorites, granites and granodiorites and minor pegmatites.

The Pre-Sickle gabbroic intrusions at Lynn Lake are associated with amphibolite masses which constitute the host rocks of the copper-nickel deposit at Lynn Lake. Similar intrusions have been noted in isolated localities in the district but these are not associated with any significant mineralization.

Stratigraphic correlation to date (e.g. Milligan, 1960, Allan, 1949, Stanton, 1949) shows that these post-Wasekwan intrusions do not intrude the Sickle group. The basis of stratigraphic correlations between outcrops by most workers in the area was for the most part subjective. Comparisons were based on field relationships. This method has for long proved more reliable than methods based on correlations of chemical analyses, such as the Larsen type variation diagrams which showed the same systematic variations for the same rock groups of different ages from widely separated localities, (Milligan, 1960).

The Sickle Group

The Sickle group rests unconformably on the Wasekwan group and the Pre-Sickle intrusive group. The group comprises arkoses, quartzites, amphibolites and deformed conglomerates.

Plate 1. Sickle conglomerate - Lynn-McVeigh road exposure. Note flattened clasts of granitic and acid volcanic material aligned parallel to strike of foliation. Ellipsoid clasts reflect direction of maximum deformtion. Groundmass is recrystallized arenaceous material - Quartz-biotite schist.

Plate 2. Deformed Wasekwan amphibolites. Note low angle intersection of layering with foliation. Evidence for post foliation deformation seen in the crumpled quartzo-feldspathic veinlets and local folding of the main foliation north-east of the exposure. Location: Shore line of Hatchet Lake south-west of Fox mine.

The Sickle conglomerates comprise granitic pebbles, fragments of quartzites, greywackes, cherty materials in quartz-mica groundmass. Good exposures of these are seen at the road cutting on the Lynn-McVeigh road (Plate 1). The granitic pebbles are presumed to be derivatives of post-Wasekwan intrusions eroded at the time of the deposition of the Sickle group sediments. This fact and the evidence of varying degrees of metamorphism adduced by Milligan (1960) are some of the evidence in support of unconformable relationship of the Sickle and Pre-Sickle groups.

The arkoses, quartzites, greywackes, and slates are exposed in varying thicknesses in the southern end of Hasset Lake and Laurie River. Most of these sediments have been metamorphosed to varying degrees and folded. The exposed Sickle units north of Fox Lake were deformed into a basin-like structure whereas the southern limit of the exposures, which is the northern limb of an overturned syncline have plications and minor cross folds which were of later formation.

Metamorphism on these range from low to medium grade. The amphibolites are derived from the metamorphism of calcareous sediments and basic volcanics.

The Sickle-Wasekwan unconformity is not easily recognised in the field. This could probably be due to a short lapse between the deposition of the series (Ruttan, 1955).

The Kisseynew Type Gneisses

The Kisseynew type gneisses are medium to high grade metamorphic rocks which are presumed to be derived from the Wasekwan and Sickle series.

Plate 3. Deformed arkose (Wasekwan) showing meso-isoclinal folding on earlier relict banding.
Location: north-east Fox mine near Snake River.

Plate 4. Relict pillow structures in metavolcanic (andesite) Exposure west-north-west Fox Lake Wasekwan group.

The group comprise medium grade quartz-feldspar-biotite gneisses, quartzo-feldspathic-hornblende gneisses, sillimanite schists, stratiform granitoid paragneisses, aplitic dykes, and pegmatite bands.

Megascopically, the gneisses are flesh coloured and well banded with a characteristic discordant banding due to subsequent anatectic melting. The Kisseynew type gneisses have been mapped in isolated localities around Eager Lake, and parts of Laurie Lake west of Fox mine.

Most of the gneisses could be classified within the amphibolite facies. From petrographic data it has been possible to distinguish various subfacies within the broad classification although considerable overlap is inevitable. The mineralogy and chemical composition of the amphibolites vary particularly in calcium and silica content. It has been suggested (Milligan, 1960) that these amphibolites were derived partly from lime rich sediments and partly from volcanogenic sediments of basaltic to andesitic affinities.

Post-Sickle Intrusive Rocks

The Sickle series are invaded mainly on the eastern part of the Lynn-Fox area by intrusive rocks comprising gabbros, diorites, and granites. These intrusions constitute the Post-Sickle intrusive rocks. The oldest member of the group is discordant with the Sickle conglomerates. Isolated occurrences of gabbros and granitic intrusions in various parts of the district have been mapped as Post-Sickle because of their geological setting.

The granite-granodiorite members of the group occur in small areas around McVeigh, Story and Lynn Lakes. The granite-granodiorite members of the Post-Sickle are presumed younger than the diorites and gabbros.

LOCAL SETTING

The dominant rock group within the vicinity of the Fox mine is the Wasekwan metavolcanics (amphibolites) Figure 1. Subordinate metasedimentary sequences, mainly metamorphosed arkoses, quartzites and greywackes occur within the same broad belt. Part of the sedimentary sequences are probably of Sickle or Wasekwan age.

The whole belt has been deformed and metamorphosed during the Hudsonian and Kenoran orogenies (Stockwell, 1964). The belt of amphibolites within which the Fox mine lies has been folded isoclinally and intensely metamorphosed. The main lithological group within the immediate vicinity of the Fox mine is shown in the map (Figure 1). The present account of the local geology of the Fox lake area depends to a large degree on the results of the field investigations conducted by the writer during the summer of 1973.

The best exposures of the surface geology can be seen around the Fox mine area Snake Lake and the south Western portion of the mine around the shoreline of Hatchet Lake and Tod Lake. The region around the Dunphy Lakes is almost devoid of surface exposures and although previous workers (Milligan, 1960) have shown the area to be dominantly of granodioritic rocks, the present writer is of the opinion that such correlations were not based on the surface geology as the area is covered by much drift.

The mineralogical and textural relationships of the Wasekwan amphibolites around Fox mine lead to the interpretation that the rocks

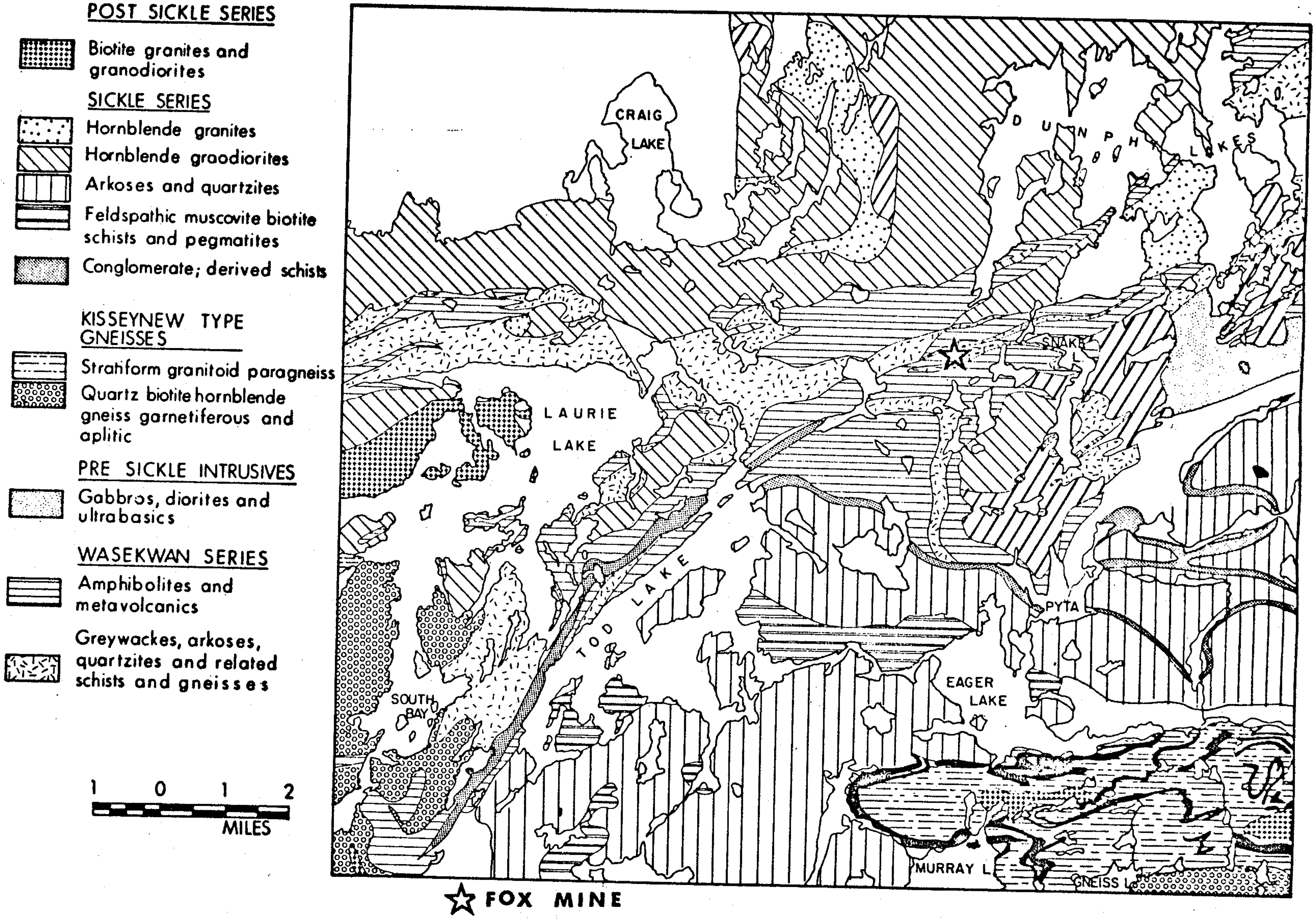

Figure 1. Local geology around the Fox Mine greenstone belt.

(Milligan, 1960)

have different parent rocks of mainly igneous affinity but with varying degrees of metamorphism and deformation. The most abundant variety is fine grained highly melanocratic rock with pronounced slatey cleavage and no segregation banding. These have been generally called 'andesite' by the Fox mine geologists on the assumption that their parent rock was of andesitic composition.

The coarser grained variety is denser with a distinct linear fabric marked by hornblende crystals separated by finer grained whitish to greyish feldspars. These coarser grained amphibolites contain large porphyroblasts of garnets, occasional sillimanite knots and some radiating anthophyllite needles. Isolated exposures of these rocks east of Fox Lake and the north eastern end of Tod Lake area contain epidotized bands similar to those occurring in some samples from the 500 level of the orebody.

The Wasekwan arkoses, greywackes, and impure quartzites occur in narrow belts within the predominant Wasekwan group. The Wasekwan arkoses occupy a narrow belt extending from the south western part of the Snake River through Fox Lake and thin out around the Western end of the Wasekwan amphibolites east of the shore line of Hatchet Lake. The contact relation between the Wasekwan quartzites and arkoses is gradational in places but the outcrops of the quartzites pinch out along the strike.

The exposures of the graywackes are more continuous than those of the arkoses and quartzites. Along the Lynn-Fox Lake road, exposure of greywackes with evidence of pronounced boudinage structures occur by the road side near the Snake River. Ordinarily, the greywackes are fine grained and in many places exhibit distinct fracture cleavage and evidence of simple shear on a small scale.

Isolated occurrences of gabbroic rocks and diorttes have been mapped around the Fox Lake area. Good exposures of these rocks near the orebody occur near the shoreline of Fox Lake and east of the Dunphy Lakes. The most abundant intrusive rock is coarse melanocratic gabbro, some of which contains disseminated sulphides.

Locally, the strata around the orebody dip to the north west and it has been suggested the strata are overturned with axial plane trending N 75 E (Stanton, 1949). The exposed rocks in the areas bordering this zone show little change in attitude except the granites and granodiorites north of the mine where the rocks have vertical dips or very high dips with occasional ptygmatic folds in the late stage granitic intrusions which do not have a definite regional trend. These ptygmatic folds were presumably developed on the later phase pink granites which resulted from anatectic melting of older granites.

Penetrative minerals and clast lineation have been noted on the planes of foliation of the banded gneisses north of the mine area and these have been found to be parallel to the general strike of the orebody. Minor faults occur all along the vicinity of the orebody and some of these intersect the orebody itself without significant displacement. The general trend of these minor structures could be useful in reconstructing the nature of the deformation which affected the area in general.

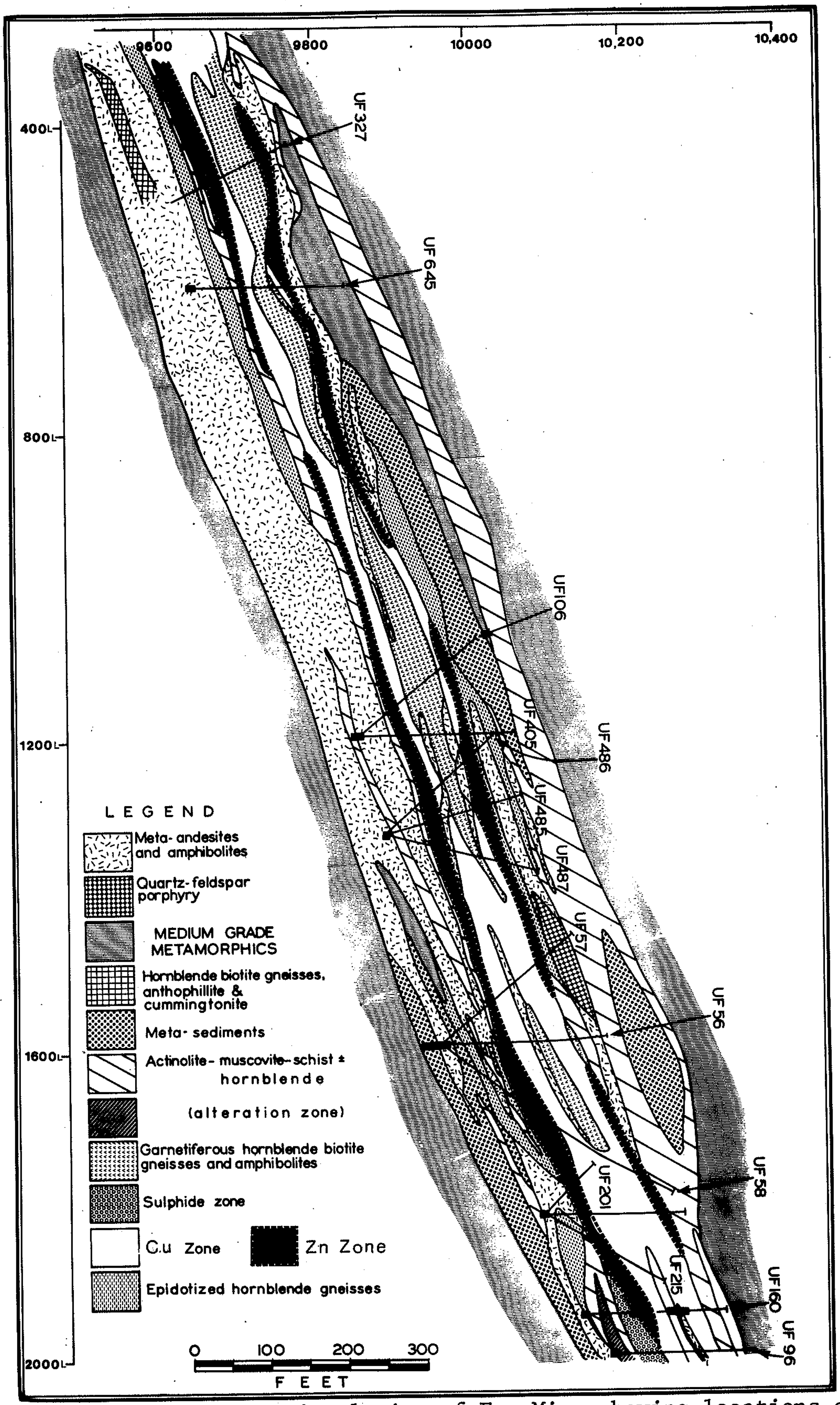

Figure 2. Cross sectional view of Fox Mine showing locations of pertinent Diamond Drill holes studied. (Modified from Sherritt Gordon section 7105E for the Fox Mine).

FORM OF THE OREBODY

The orebody has an approximate average width of 65 ft. and a length of 1,500 feet, (Figure 2) at surface. The ore zone is dominated by massive sulphides with subordinate disseminated sulphides. The major sulphides are pyrite, chalcopyrite, pyrrohotite, arsenopyr te and sphalerite. These sulphides can be distinguished with ease in a megascopic examination of hand specimens. Minor sulphides other than these have been detected in the course of the laboratory examination of the polished sections and these have been described in the chapter on ore Mineralogy.

The orebody is generally conformable with the host rocks which are chiefly amphibolites, quartz-hornblende-biotite gneisses and metasedimentary groups (arkoses). The arkoses are grouped among the other in a broad sense. This is because they occur at some distance from the zone of massive sulphides although minor sulphides disseminations occur sporadically in them.

The immediate contact of the ore with the wall rock is sharp and marked by clear alteration zones of variable width. The contact rocks are mostly rocks of the lower greenschist facies, such as quartz-sericite schists, quartz-biotite-chlorite schists. It is suggested that these are products of hydrothermal alteration of the host amphibolites and gneisses. A diagramtic illustration of the general relationships as noted at the 2,100 level is shown in Figure 3.

Figure 4 illustrates a common feature in the ore zone. Blind sulphides, chiefly chalcopyrite, occur at various points in the meta-

Figure 3. Plan across the 2,100 level from the main 'cross cut' intersection through the ore zone to the 'Exploration Drift'

Key to Numbers:

58	to Exploration Drift Junction - Arkose zone
59-58	Quartz-hornblende biotite gneiss. Highly epidotized, garnet bearing.
59	Amphibolite gradational to quartz-biotite-hornblende gneiss (58-59)
60	Discordant quartz-feldspar porphyry.
61-62	Quartz-biotite-muscovite schist local alteration band.
62-63	Quartz-biotite-sericite schist with high sericite content
64	Unaltered metavolcanic (andesite) rock within local alteration zone.
65	Basic feldspar porphyry with large porphyroblasts of calcic plagioclase in a melanocratic groundmass.
66	Garnet bearing amphibolite
67	Quartz-hornblende-biotite gneiss with epidote stringers.
68	Apophyses of granitic material (with no orientation). Some joints suggesting tectonic effects and brittle deformation. Pyrrhotite mineralization.
69-72	Quartz-biotite-hornblende gneiss local alteration, garnet bearing. Late stage discordant quartz veinlets. Mineralization mainly chalcopyrite.
73	Minor bands of quartz-sericite-biotite schists within the massive sulphide zone.
74	Amphibolite with disseminations of chalcopyrite and local alteration bands of quartz-biotite-sericite schists.

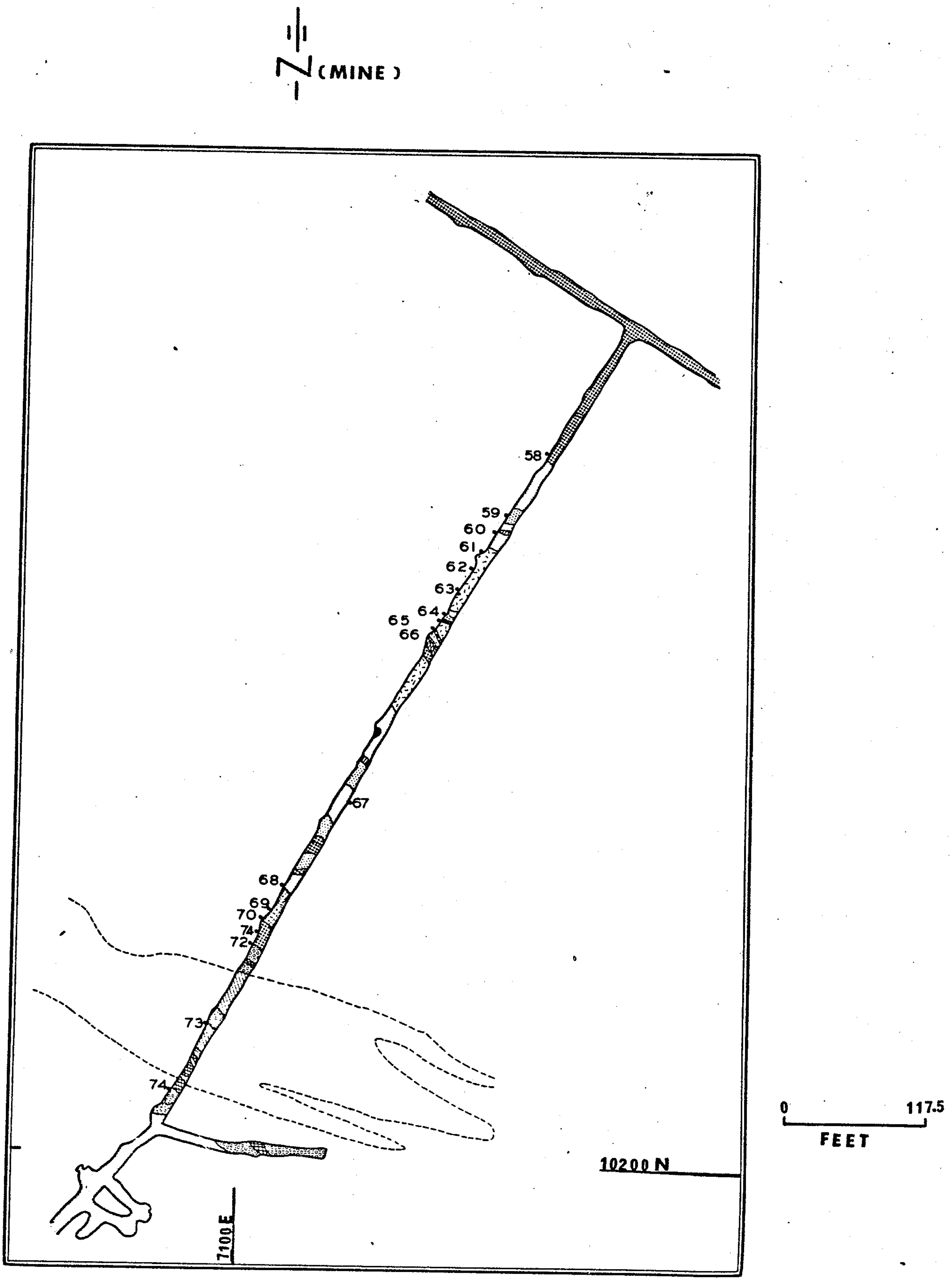

Figure 3. Plan of the 2100 level from the main cross cut through the ore zone to the Exploration Drift.

morphosed wall rocks. In some places fractures originating from post-ore brittle deformation are preferentially enriched with pyrite-pyrrhotite-charcopyrite veinlets. The transecting fractures are filled with massive sulphides and quartzo-feldspathic material. It is suggested that the remobilization of sulphides was a possible cause of the preferential enrichment of these fractures by sulphides. The dominance of chalcopyrite in blind veinlets away from the massive sulphide zone is probably related to the higher relative mobility of copper (Gill, 1960), McDougal et al, 1961).

Figure 3 also shows the massive sulphide relationships at the 2,100 level. The eastern portion of the 'exploration drift' is occupied by barren garnetiferous hornblende-biotite schists. These garnet bearing schists grade imperceptibly into higher grade rocks. Two distinct foliations related to two fold events were noted here. It would appear that the first schistosity direction is axial planar to the first or earlier micro-fold and has been re-folded by the second folding. This is inferred from the fact that the second foliation on which it is superimposed appears folded by the latest fold event. This minor structure could not be traced for a long distance because of obliteration by mining.

The gneisses grade into a wide arkose zone which dominates the rest of the exploration drift but does not continue to the area where the ore zone occurs, (Figure 3). The banding in these arkoses appear more as relict sedimentary features than foliations induced by metamorphism. Isolated cases of relict cross-bedding have been suspected. Relict tectonic breccias and isoclinal microfolds near

Figure 4

Key to the numbers on diagram.*

1. Blind massive sulphide vein, (mainly chalcopyrite) with quartzo-feldspathic intrusion intersecting the vein.

2. Massive sulphide, pyrite, and chalcopyrite in an old fracture sharply intruding the country rock with no link to the ore zone. Migration probably through fractures or intergranular pores or planes of foliation, may be a secondary mobilization feature.

3. In filling of old fracture by pyrite. Massive sulphide appears to have migrated through the joint (7) which extends deep into the ore zone area No. 73, Figure 3.

4. Chalcopyrite within a re-opened fracture zone quartzo-feldspathic veinlet pre-dates the chalcopyrite whose intrusion led to the displacement of the older quartz vein. A further re-mobilization feature.

5, 6. Blind massive sulphide veinlet part of which extends into the open vein occupied by quartz and calcite (6)

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*Diagram reproduced from a slide photograph taken by the author at the 2,100 level of the Fox mine.

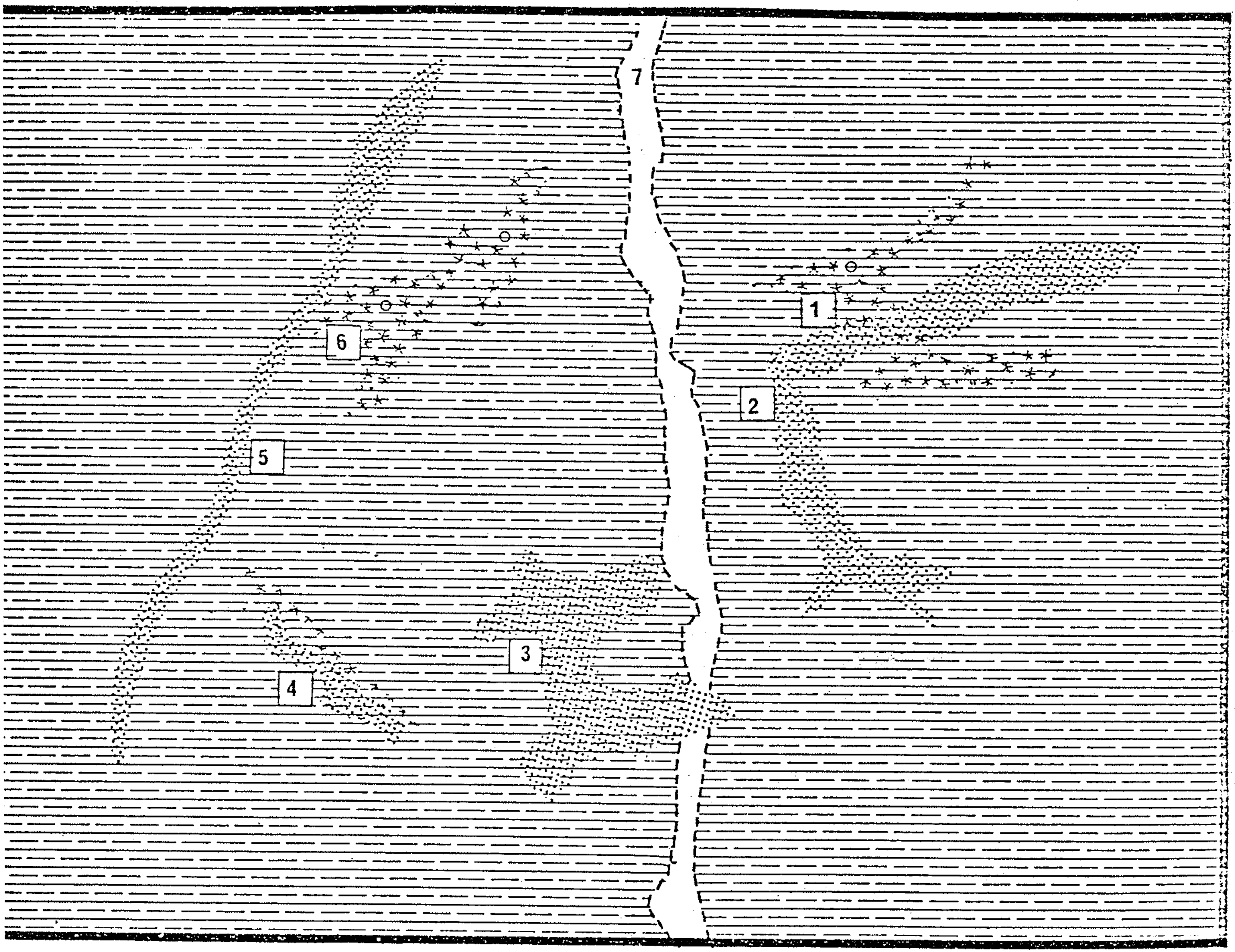

Figure 4. Diagramatic view of disseminations of sulphides into adjacent host rocks at 2,100 level of the Fox mine. (See opposite page for significance of numbers).

the ore zone suggest that these rocks have been involved in complex deformation events.

The arkose zone is followed by the zone of amphibolites and hornblende schists at the main crosscut. From here these amphibolite facies rocks are transected sporadically by bands of quartz-sericite-schists, and quartz-biotite -epidote schists which continue to the ore zone. It is suggested that low grade assemblages nearest the ore were probably the result of retrograde metamorphism induced by ore solutions. This introduces the difficulty of separating the time intervals between the emplacement of the ore, regional metamorphism and retrograde metamorphism. This paradoxical situation is open several possible interpretations but is at present unresolved.

CHAPTER III

PETROLOGY OF THE MINE SERIES

General Statement

The following descriptions are based on the study of the rock suites adjoinining the orebody. The study does not include the surface rocks in the vicinity of Fox Lake. Most of the samples were from diamond drill hole cores derived from different portions of the entire orebody. The mode of sampling is summarized in Appendix 1.

The petrographic study consisted of laboratory examination of 50 thin sections, 9 of which were polished. The polished thin sections were derived from the dissiminated zones of the orebody. The object of studying them was to examine the textural relationships between the silicates and ore minerals. Modal amounts of the minerals were obtained by counting 1000 to 2000 points for each rock type (including all samples for chemical analyses, Table 2). Chemical analyses of 12 samples from a drill hole (D. D. H. 789 & 793, located in Figure 2a) is presented in Table 2. The samples are in part from the altered zone, and in part from the country rock. Mineralogical modes of the samples listed in Appendix 1 are presented in Table 3. This includes samples from the altered zone (most of which contain disseminated sulfides) and microscopically-visible-altered and unaltered country rock.

The altered portion of the country rocks which surrounds the orebody (also rare isolated pods up to 3 feet across) is recognised by

TABLE 2

CHEMICAL ANALYSIS OF FOX MINE SILICATES

Sample No.	A13	A16	A17	A18	A19	A25
Ref. No.	1	2	3	4	5	6
SiO_2	32.70	48.20	75.50	55.0	53.05	55.40
Al_2O_3	2.01	1.82	2.81	2.20	13.18	15.29
Fe_2O_3	36.04	25.82	7.75	24.66	7.25	3.14
FeO	3.60	10.80	5.60	3.40	8.80	6.20
MgO	0.13	0.04	0.12	0.61	3.32	5.13
CaO	0.16	0.12	1.62	3.08	8.31	6.16
Na_2O	0.019	0.009	0.108	0.058	2.48	4.12
K_2O	0.00	0.00	0.10	0.27	0.16	0.04
TiO_2	0.00	0.00	0.03	0.00	2.32	1.26
P_2O_5	0.20	0.17	0.07	0.15	0.78	0.21
MnO	0.03	0.01	0.03	0.04	0.29	0.26
S	32.8	24.10	7.10	20.20	0.70	3.27
Total	99.58	100.79	100.75	99.58	100.64	100.48
Cu	0.14	0.34	1.30	0.0096	0.0168	0.0096
Zn	4.08	0.24	0.31	0.029	0.025	0.032
PPM						
Ag	9	7	24	6	4	4
Cd	125	226	51	364	37	19
Ni	19	17	13	17	19	20
Pb	127	101	343	380	115	314
Co	125	226	51	364	37	19

Chemical Analyses (cont.)

Sample No.	A27	A28	B3	B7	B9	B15
Ref. No.	7	8	9	10	11	12
SiO_2	48.50	61.00	58.90	42.60	27.20	53.05
Al_2O_3	14.96	14.18	14.12	15.18	1.62	1.58
Fe_2O_3	4.96	2.78	11.15	5.28	46.34	31.98
FeO	7.40	4.20	2.80	9.80	2.20	2.20
MgO	8.00	5.25	4.61	3.08	0.05	0.07
CaO	11.78	8.25	0.91	8.31	0.04	0.07
Na_2O	2.56	2.04	1.88	3.76	0.018	0.030
K_2O	0.16	1.17	1.25	0.28	0.00	0.00
TiO_2	0.93	0.40	0.43	3.64	0.00	0.00
P_2O_5	0.15	0.12	0.10	0.61	0.23	0.16
MnO	0.27	0.16	0.10	0.09	0.01	0.01
S	0.29	0.74	7.4	7.8	36.1	2 .8
Total	100.60	100.28	100.69	99.83	100.24	100.75
Cu	0.0056	0.0093	0.095	2.66	2.25	0.066
Zn	0.009	0.010	0.019	0.160	0.70	0.34
PPM						
Ag	4	2	3	13	14	2
Cd	5	2	3	7	27	15
Co	54	24	41	9	199	4
Ni	52	27	38	18	11	20
Pb	29	10	86	312	37	38

*All totals computed after subtracting the oxygen equivalents of sulphur from gross totals.

TABLE 3

Modal Percentages of Mineral Assemblages from Selected Samples

Mineral Sample No.	A79 *	B7	AF66 *	AF93	AF89	AF92	B3 *
Plagioclase	25	15	24	25	25	22	10
Quartz	10	-	-	10	25	20	25
Biotite	15	5	-	27	20	30	5
Hornblende	-	-	6	-	11	-	-
Actinolite	26	-	-	25	-	-	-
Anthophyllite	12	-	-	-	-	-	-
Tremolite	-	-	25	-	-	4	-
Epidote	-	5	-	-	-	4	-
Clinozoisite	-	-	-	5	-	-	-
Sphene	-	20	8	-	4	-	5
Garnet	-	-	2	-	-	-	-
Muscovite	-	-	6	-	15	-	10
Sericite	-	-	-	6	5	8	10
Sillimanite	-	-	-	-	-	-	-
Cummingtonite	-	-	-	-	-	-	-
Chlorite	10	7	8	-	-	-	10
Cordierite	-	-	-	-	-	-	-
Magnetite	-	5	7	3	3	4	-
Ilmenite	-	3	-	-	-	-	5
Sphalerite	-	30	-	-	-	-	13
Chalcopyrite	-	-	-	-	-	-	-
Pyrrhotite	-	-	-	-	-	-	-
Pyrite	2	-	-	-	-	-	-

*Alteration zone samples.

TABLE 3 (contd.)

Modal Percentages of Mineral Assemblages from Selected Samples

Mineral Sample No.	AF55	A27 *	AF108	B2	AF88	AF97	A28	AF70 *
Plagioclase	30	27	20	25	28	22	27	25
Quartz	25	6	5	8	5	9	-	-
Biotite	14	-	-	-	13	-	18	-
Hornblende	-	20	35	31	16	-	3	32
Actinolite	-	-	-	-	5	-	-	-
Anthophyllite	-	15	-	-	-	21	-	-
Tremolite	15	-	-	-	-	-	-	-
Epidote	-	-	-	6	-	-	5	-
Clinozoisite	-	-	-	-	-	-	-	-
Sphene	-	-	-	5	-	-	4	-
Garnet	-		-	-	8	-	-	-
Muscovite	-	-	-	-	-	-	-	-
Sericite	5	15	-	6	8	18	-	23
Sillimanite	15	-	-	-	-	-	-	-
Cummingtonite	-	-	-	-	-	-	-	-
Chlorite	-	13	-	-	5	23	-	-
Cordierite	-	-	-	-	-	-	-	-
Magnetite	-	-	2	2	2	6	7	5
Ilmenite	6	5	-	1	7	2	2	3
Sphalerite	-	-	-	16	5	-	-	-
Chalcopyrite	-	-	-	-	5	-	-	-
Pyrrhotite	-	-	-	-	-	-	-	-
Pyrite	-	-	-	-	-	-	2	9

*Alteration zone samples.

TABLE 3 (contd.)

Modal Percentages of Mineral Assemblages from Selected Samples

Mineral / Sample No.	AF71 *	B12	AF102	AF106	AF114	B4 *	AF57
Plagioclase	20	15	32	26	30	22	43
Quartz	10	-	8	6	11	10	6
Biotite	-	15	10	-	18	-	-
Hornblende	-	-	-	-	-	-	30
Actinolite	20	-	-	-	-	-	-
Anthophyllite	-	25	-	-	20	-	-
Tremolite	-	-	-	28	-	-	-
Epidote	-	-	-	10	-	-	-
Clinozoisite	-	-	-	-	-	-	-
Sphene	10	9	-	2	-	-	3
Garnet	-	-	-	-	-	-	13
Muscovite	-	-	22	-	-	13	-
Sericite	17	-	-	-	-	24	-
Sillimanite	-	-	18	5	-	-	-
Cummingtonite	-	-	10	11	-	-	-
Chlorite	10	-	-	-	-	5	-
Cordierite	-	15	-	-	15	-	-
Magnetite	3	7	-	5	-	-	3
Ilmenite	-	6	-	3	6	-	2
Sphalerite	7	-	-	-	-	-	-
Chalcopyrite	-	-	-	-	-	-	-
Pyrrhotite	-	-	-	-	-	-	-
Pyrite	-	-	-	-	-	-	-

*Alteration zone samples.

the presence of friable chlorite and sericite in hand specimen. It has been mapped as shown in Figure 2. The contact between friable altered and massive unaltered rock is sharp. Additional alteration particularly the development of sericite in plagioclase, and the presence of chlorite crystals, can be detected in thin section microscopy but not in hand specimen. This alteration is found to accompany rocks in quartz and muscovite.

The Alteration Zone

The major lithological types are quartz-sericite-biotite schists, quartz-muscovite-sericite schists (with or without epidote and quartz-biotite-chlorite-actinolite schists. The characteristic assemblages of these low grade rocks are shown in Table 3 (marked by asterisk).

The alteration zone is seen in hand specimen as friable, porous rock adjacent to ore. It is 5 to 25 feet (Figure 2). Rocks outside this zone may also show the sericitization of plagioclase and the presence of chlorite in thin section, so microscopic study can extend the width of the alteration zone.

The alteration of plagioclase by sericitization is widespread but in very variable amounts. Most of the plagioclase samples from the alteration zone are albite, but there are rare grains of oligoclase which may be interpreted as relics of the higher grade country rock. Determination of plagioclase composition was based on the few twinned samples encountered. Michel-Levy method was adopted in such instances. In other cases, particularly the untwinned varieties, determination was

i

Such

based on the refractive index method. As a general observation, the more calcic plagioclase was found outside the alteration zone.

The replacement of biotite by chlorite was noted in samples AF 67, 88, 91, 104 and 114. This is evidence of hydrothermal alteration.

The commonest opaque minerals are pyrite, chalcopyrite, pyrrhotite, and sphalerite and these occur as inclusions in micas and quartz. In most samples, trails of opaque minerals follow the trend of the foliation concentrated in lenses and layers.

Although there is a general prevalence of schistose texture, some samples with mineral assemblages distinctly within the alteration zone (Sample B7) show granoblastic fabric. In Sample B7 (Plate 5) the dominant minerals are sphalerite, sphene, quartz, sericite and minor accessories. The rock has a distinct granoblastic fabric with irregular sphene crystals which are interstitial between ragged aggregates of sphalerite. Sphene was found to have unusual optical properties: highly birefringent, very strongly pleochroic from dark red to reddish brown to brown, biaxial negative. Confirmatory identification was made through X-ray diffraction analysis.

Sample A28 (Plate 6) is recrystallized mylonite or fine grained meta-tuff. It would appear the original rock was subjected to dynamic metamorphism, which affected the foliated arrangement of the green amphibole, which was followed by a phase of recrystallization and recovery when the strains released. Polygonized and equant grains of quartz are abundant between the amphibole and biotite crystals.

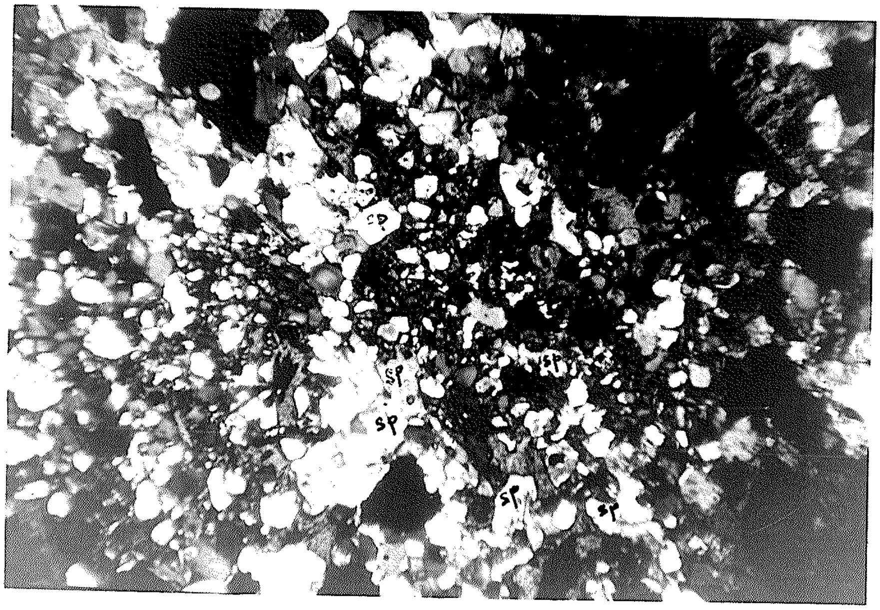

Plate 5. Altered amphibolite. Note granoblastic fabric. White minerals (sp) are highly birefringent, poikiloblastic sphene. Sphalerite grains (dark) interstitial. Other constituents, sericite, plagioclase (untwinned) and epidote.

Sample B7 x35 crossed nicols

It is interpreted that the rocks of the alteration zone are products of a hydrothermal retrograde type of metamorphism. The presence of some relic minerals which are characteristic of the higher grade country rock assemblages would suggest the parent rocks before alteration were of the same mineralogical composition as the country rock. In the absence of an appreciable evidence of shear or other major structural adjustments taking place during the alteration process, it is suggested the alteration process was mainly the result of the changes in the bulk chemistry of the pre-existing rocks. This metasomatism has affected the growth of chlorite (in part as discrete crystals, in part as replacements of biotite and amphibole) and sericite (replacing plagioclase). Thus, retrograde metamorphism may have been made possible through the introduction of H_2O bearing gases and volatiles from the ore fluid through fracture zones, foliation planes or intergranular pore spaces.

Comments on the Wall Rock Alteration Suites

Twelve samples were chosen from drill holes collared on the 510 sub-level at horizontal inclination in the western portion of the Fox mine. The purpose of this was to examine possible metal variations from the zone immediately adjoining the massive sulphides to the zone of relatively unaltered rocks. The relevant drill holes are UF 789 and UF 793 (Figure 2a). Major and trace element analyses were performed for these and the results are tabulated in Table 2 and plotted graphically in Figure 5. The samples are plotted with contents of the chemical components versus a distance from the orebody. The country rocks, and

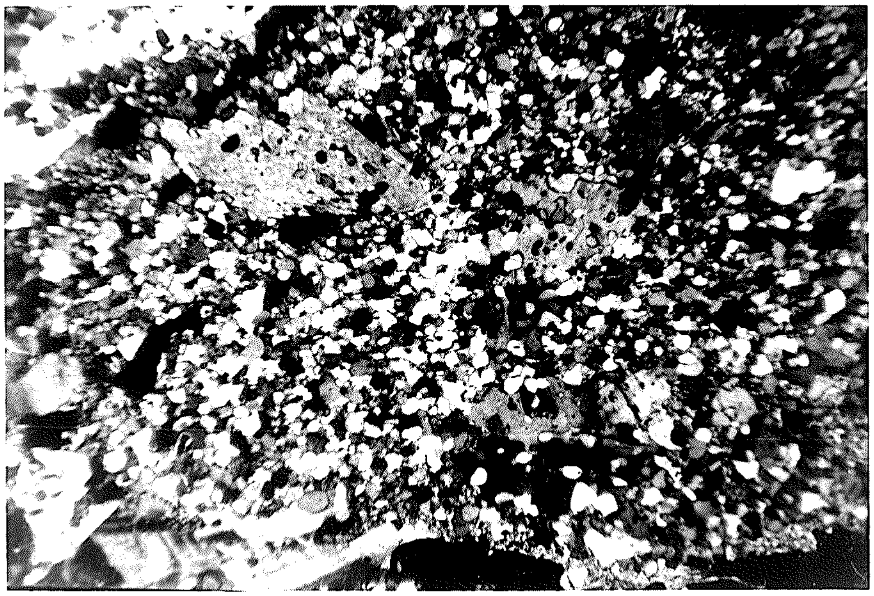

Plate 6. Recrystallized mylonite showing polygonized quartz and feldspar grains. Quartz and feldspar grains are possible syntectonic crystals. Larger irregular grains of anthophyllite (poikiloblastic) at lower right are post-tectonic crystals. Note irregular orientation of opaque minerals (pyrite).

Sample A28 x35 crossed nicols.

the alteration zone rocks have a considerable variety of original bulk compositions because they are a folded series of meta-volcanic and meta-sedimentary rocks; however, an overprint of chemical variation greater than the original variation can be seen in those rocks which occur closer than 16 feet from the orebody.

Silica values closest to the ore zone show a progressive increase outwards to the zone 10 to 20 feet distance from the ore zone which is well within the alteration zone. The modal percentages of rocks taken in equivalent locations also reflect a similar trend in the percentage of quartz.

Sericitization was the dominant alteration process nearest the ore zone. Higher silica percentage around 10 to 20 feet distance from the ore zone could be related to silicification imposed on an earlier sericitized zone. Silicification of sericite could be aided by higher H^+ and OH^- ions which promote the break down of alkali feldspars and the precipitation of quartz (Meyer and Hemley, 1967). Periodic influx of silica is a common feature during hydrothermal alteration associated with ore emplacement. Evidence for such an influx of silica is ubiquitous in the mine where barren and mineralized quartz veins intersect host rocks and massive sulphides.

From the sequential relationships noted from polished thin sections and polished sections (see Chapter 4 below), it would appear silicification and sericitization were mainly associated with the mineralization of sphalerite and pyrite.

The zones of chloritization are more linked with zones of higher relative MgO and FeO values at approximately 20 feet to 30 feet from the

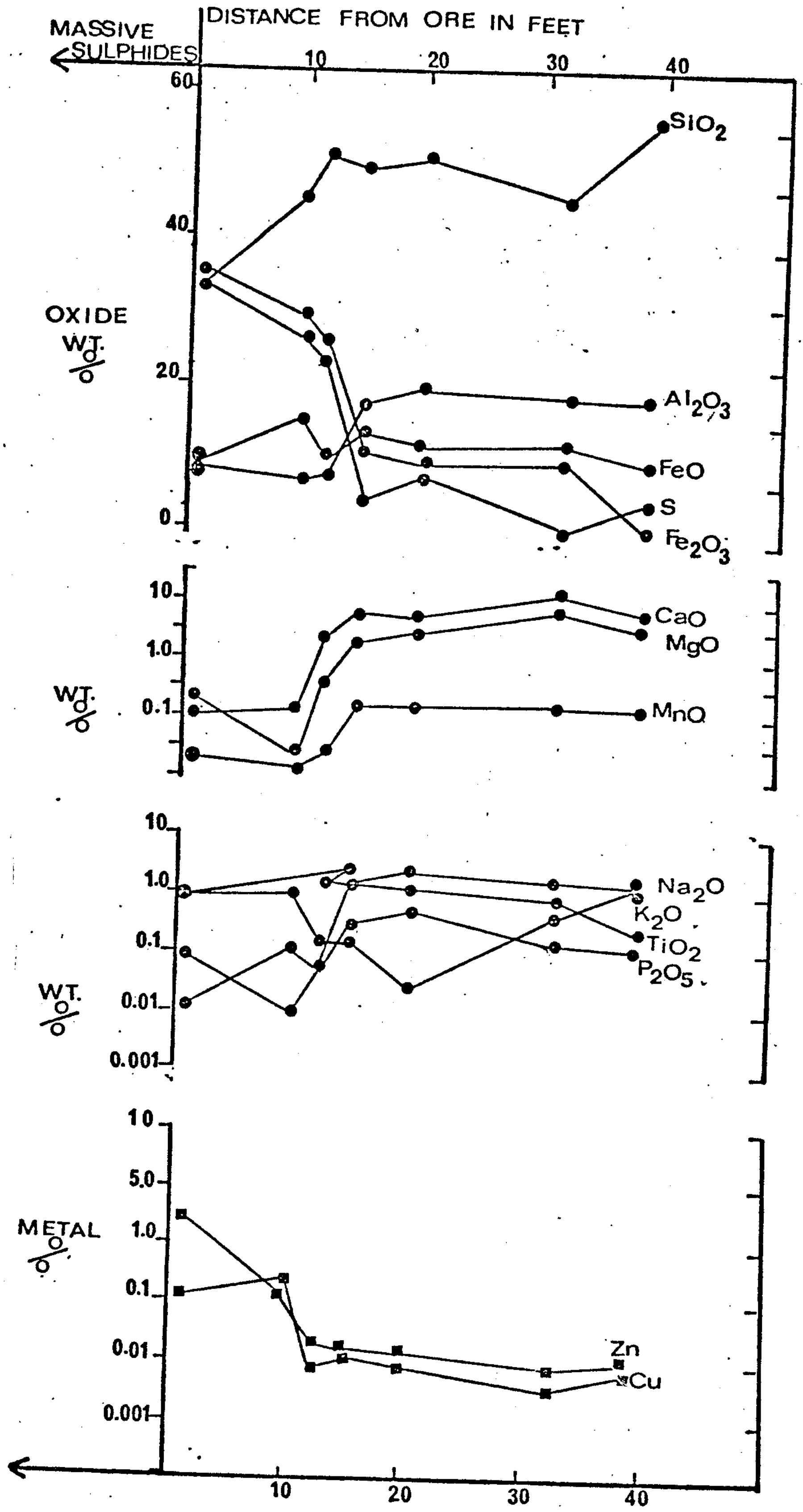

Figure 5. Chemical Variation Diagram Wall Rock Alteration Study

(Ref. Nos. 1,2,4,5,6,7,8, Table 2)

ore. Aluminium shows a lower relative amount nearer the ore than the zone 15 to 20 feet from the ore. This depletion may be associated with mobilization of Al^3 during the deposition of the sulphides and the sericitization reations.

The Fe_2O_3 : FeO ratios show that iron was at a higher oxidation state closest the orebody. Higher iron content nearer the orebody, as shown in Figure 5, indicates that iron was a major constituent during the phases of mineralization. Higher sulfur values are directly related to high base metal ratios nearer the ore zone. CaO, Na_2O, MgO and P_2O_5 values diminish between 10 to 20 feet from the ore zone. Coversely, K_2O shows an increase at about 7 to 8 feet from the ore zone.

Enrichment of Fe, S, base metals and K at the alteration zone nearest the ore could be interpreted by appealing to influx of materials from ore solutions. Relative depletion of CaO, Na, and Mg nearer the ore may be a result of base exchange reactions involving hydrolysis reactions (Meyer and Hemley, 1967). Alternatively the inverse relationships between silicates and sulphides could be interpreted to result from the addition of sulphides during mineralization and the removal of silicates.

These chemical variations are reflected in the mineralogy. Although sericite is noticeable in practically all sections they are more in abundance in those rocks closest the ore where K_2O values are highest. Thus, sericitization was more intensive around the ore and occurs as incipient alteration products in those rocks away from the main alteration zone.

TiO_2 values reflect no significant variation pattern which can be related to ore emplacement. Sphene is however, an accessory constituent in most samples but occurs as an essential constituent in one case B7 (Plate 5) where it exhibits an interstitial growth relation with sphalerite.

Petrographic study shows hydrothermal alteration proceeded further into the country rocks, although the evidence may not be obvious in hand specimen. The partial alteration of anthophyllite porphyroblasts (Plate 7), AF79 which is 2 feet from a sulfide pod) to fibrous chlorite may be interpreted to be due to hydrothermal alteration.

A consideration of the mineral assemblages listed in Table 2 leads to the deduction that metasomatism along a possible P_{H_2O} gradient might have been associated with the wall rock alteration process. The alterations produce chlorite, sericite and calcite. The hydrothermal alteration appears to have taken place under conditions similar to those described as the "potassium silicate assemblage" of Meyer and Hemley (1967). It could be suggested therefore, that the search for alteration halos with features similar to the ones close to the ore should include recognition of mineral assemblages with distinct evidence of Mg-Fe metasomatism, since this process is invariably associated with alterations generated by ore forming fluids.

The Higher Grade Rocks of the Mine Series

The higher grade country rock suites of the mine area surround the alteration zone, as shown in Figure 2. They are a folded sequence of meta-volcanic and meta-sedimentary rocks in part foliated, in part

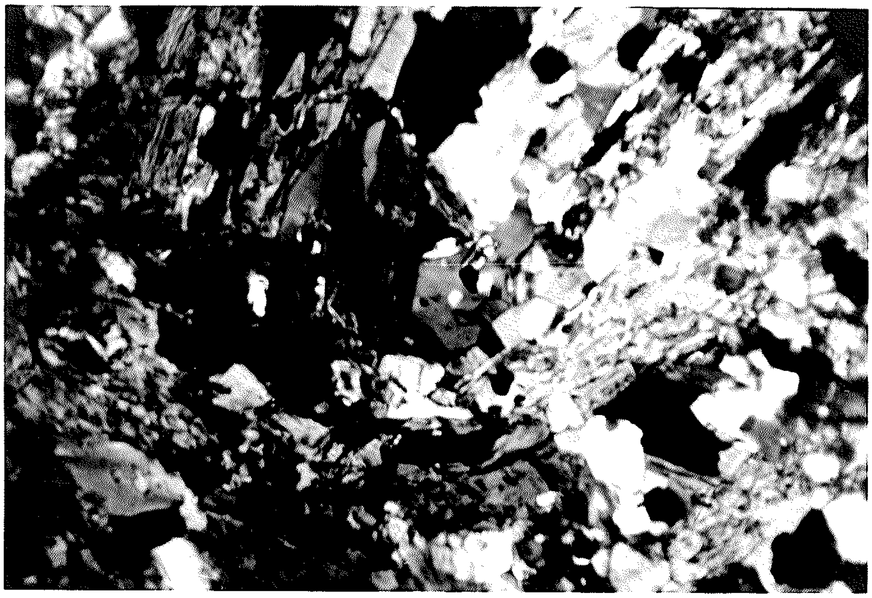

Plate 7. Anthophyllite biotite gneiss. Sub-idioblastic anthophyllite partially altered (post-tectonic) Biotite crystals mark trend of schistosity. Equant quartz grains (white). Opaque minerals are mainly euhedral.

Sample AF79 x 35 crossed nicols.

fine-grained granoblastic. Layering is interpreted to be a relic sedimentary feature.

The Amphibolites

The amphibolites are the most abundant rocks of the mine. These rocks consist essentially of plagioclase and hornblende with variable amounts of biotite, garnet, quartz, anthophyllite, epidote, chlorite, clinozoisite, sphene and opaque minerals. The grain size is fine and medium-grained, varying in layers. The texture is dominated by the hornblende or actinolite, which is commonly elongated in a lineation, or, also commonly, neither elongated nor aligned so that the rock is granoblastic (massive). All the amphibole is pokiloblastic, full of inclusions of quartz, apatite, plagioclase and magnetite. The quartz and plagioclase occur as polygonal (mosaic) groundmass.

The plagioclase composition ranges between An^{33} to An^{52}. Most crystals are untwinned. The few twinned crystals exhibit combined carlsbad/albite twins or polysynthetic twins mainly. The crystals occur as subidioblastic elongate grains with distinct preferred alignment. Deformation twins and undulose extinction due to strain are characteristic features in samples from the 2100 level (AF111). Saussuritization of the plagioclase is evident in plane polarised light as dusty aggregates on the larger crystals. Close to the ore zones, the alteration is more strongly developed, and takes the form of shreddy sericite replacing the plagioclase (strong in alteration zone). In some unoriented post-tectonic plagioclase crystals, hornblende crystals are noted in poikiloblastic relationship with the plagioclase crystals (AF108)

Hornblende crystals are green, subidioblastic and poikiloblastic. The range of grain size (from fine, 0.3 m.m., to medium 1 m.m.), and the variation in the degree of orientation and form is striking. The latter may reflect a variation in the degree of penetration of shearing deformation in various layers of the rock. The fine and variable grain size may reflect some interplay of original grain size of the rock and the effect on growth of bulk composition.

In one sample (AF113) there are two coexisting amphiboles, viz, a blue-green hornblende (common) and a colorless clinoamphibole (rare, possibly cummingtonite).

Biotite is rare in the amphibolites, the crystals are pale brown to dark brown and are generally oriented along the schistosity planes. The minerals are usually strongly pleochroic, sub-idioblastic and of variable grain size. Early-tectonic cyrstals in some specimens are bent and show occasional kink banding (B14), whereas late-tectonic crystals are oriented across the foliation.

Other accessory constituents noted in several specimens are epidote, clinozoisite, chlorite, sphene apatite, and opaque minerals. In some samples taken from the eastern wing of the main exploration drift of the 2,100 level, garnet porphyroblasts with irregular fractures were noted. They occur also near the ore zone in lesser amounts (e.g. AF96).

The ore minerals tend to be crudely aligned along the dominant planes of schistosity. They vary in shape from euhedral to rounded grains. Their general relationship would suggest a possible deposition in lenses and layers guided by the schistosity planes or other planes of weakness.

The amphibolites are mostly derived from basic to intermediate volcanic rocks, but some of them have an unusually high content of quartz and biotite, and rarely epidote, which combined with layering of approximately one inch thickness, suggests derivation of some amphibolites from mixed siliceous, calcareous and volcanogenic sediments.

The Biotite Schists

These schists were in part, uncommonly, mapped as gneisses where they contained layers and lenses of quartz, irregularly distributed, 1 to 20 m.m. thick. However, these quartz lenses may be relic quartzite beds, or deformed quartz veinlets, and these rocks are not gneissic in the usual sense.

The biotite schists are common members of the mine series. They differ from the amphibolites in that they have more biotite, plagioclase feldspars and essential quartz. The rocks have distinct planar fabric marked by the dimensional orientation of biotite. They may contain garnet porphyroblasts (AF88), cummingtonite (AF110, AF88) grown across the foliation in a post-tectonic manner, muscovite (AF61, A2) in a similar post-tectonic growth.

Rare post-tectonic biotite crystals are also oriented randomly and are presumed to be of later nucleation. Polygonized quartz grains suggest recrystallization effects due to annealing. As with the amphibolites, the opaque minerals are crudely aligned along the foliation bands.

The composition of these schists leads to a deduction that their parent rocks may be mixed argillaceous calcareous sediments and/or rocks of volcanic affinities with essential quartz such as rhyolites and dacites.

Porphyroblasts of Anthophyllite and Cummingtonite

Anthophyllites occur as large porphyroblasts in some samples. The textural relationships in most of these lead to the interpretation that the anthophyllite crystals are post tectonic. In hand specimen, the crystals of anthophyllite can be seen as sub-radiating aggregates intersecting the foliation (AF60, AF79).

Some crystals of anthophyllite are poikiloblastic and have inclusions of quartz, apatite, plagioclase and ore (Plate 8). Anthophyllite was found to co-exist with large porphyroblasts of cummingtonite in Sample B1 from the 510 sub-level. Other minerals present are biotite, chlorite, and ore. In general, the anthophyllite-cummingtonite rocks occur some distance away from the ore zone.

Muscovite-Cordierite Schists

Muscovite-cordierite schists are rare rock types of the mine series. The rocks are medium grained with distinct schistose texture. The schistosity is generally marked by the lenticular muscovite crystals in sub-parallel alignment (AF102, B3).

In all cases, cordierite occurs as large subidioblastic crystals, moderately birefringent, partially altered, containing dusty inclusions of secondary alteration products, and quartz.

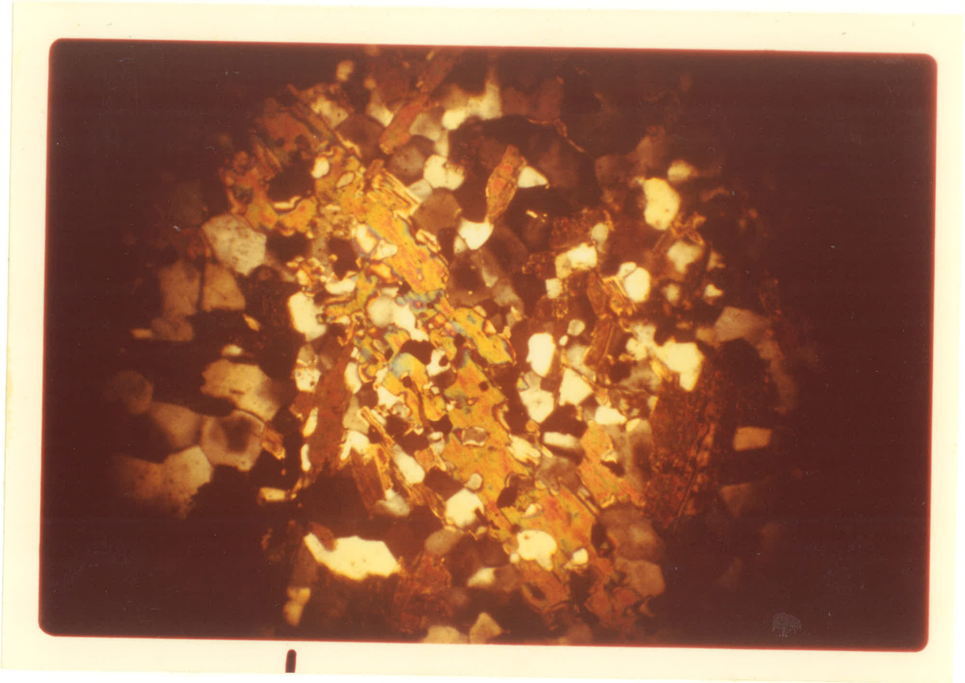

Plate 8. Anthophyllite bearing rock. Evidence for polymetramorphism seen in the intersection of foliation planes. Later foliation planes marked by biotite, minor quartz and untwinned plagioclase, some zoned. Earlier foliation marked by poikiloblastic anthophyllite and chlorite.

Sample AF110 x35 crossed nicols.

Muscovite occurs as equilibrium minerals in all cases, and in sample AF102 some crystals are kinked, suggesting probable post-tectonic effects. Sericitization of plagioclase in sample B3 and the presence of accessory chlorite would suggest probable hydrothermal alteration effects.

Calc-silicate Crystalloblastic Rocks

The calc-silicate crystalloblastic rocks AF71, and AF75 were sampled from two widely separated points located at UF 645 and UF 485 respectively (see Figure 2).

The rocks consist essentially of large irregular highly birefringent epidote, and calcite. Other minerals noted in subordinate amounts are sphene, chlorite and magnetite. The rocks exhibit a distinct crystalloblastic texture.

It is suggested that these rocks are products of metamorphism of calc-silicate rocks interbedded with the parent volcanic rocks of the Mine series.

Discussion of the Grade of Metamorphism of the Mine Series

It has been described above how the alteration zone is an overprint of hydrothermal-type alteration, adjacent to ore zones, on to the country rock mine series of meta-volcanic and meta-sedimentary rocks. The alteration is therefore a retrograde type of metamorphism, but it is restricted to zones and not regional in extent. The metamorphism of the Mine series is interpreted to be regional, prograde, low-pressure facies series (Abukuma type of Winkler, 1967), of the lower amphibolite facies. The mineral assemblages are compared to an equilibrium ACF diagram for this facies in Figure 6, and the textures are discussed below. However, it should be noted that this regional metamorphism is not simple, as shown by complex mineral-textural relationships. These complexities are (1) the variation in development of foliation; (2) the variation in grain size; (3) kinks in the regional foliation; (4) growth of anthophyllite, cummingtonite, biotite and muscovite cross-cutting the regional foliation.

The variation in development of foliation is unusual. The biotite schists and most of the amphibolites are well-foliated, and it appears that the development of this foliation was coincident with the recrystallization of most of the minerals at the culmination of metamorphism. However, the foliation is absent from some of the amphibolites (granoblastic) and it is interpreted that the deformation was not severe and was absorbed by some but not all of the rock units.

The variation in grain size from very fine (0.2 m.m.) to medium (1.2 m.m.) is a characteristic of greenstones that have been metamorphosed at Greenschist or Lower Amphibolite Facies, but not at higher grades.

Kinks in the main foliation (e.g. AF102) indicate minor deformation after the development of the regional foliation. Similarly, the crystallization of anthophyllite, cummingtonite, biotite and muscovite across the foliation is a stage in the metamorphism that is later than, and possibly retrograde, the major recrystallization.

The ACF plot Figure 6 follows the lines recommended by Winkler (1967). In addition to the usual correction scheme outlined by Winkler (1967), further correction had to be made for the Fe_2O_3, FeO contents

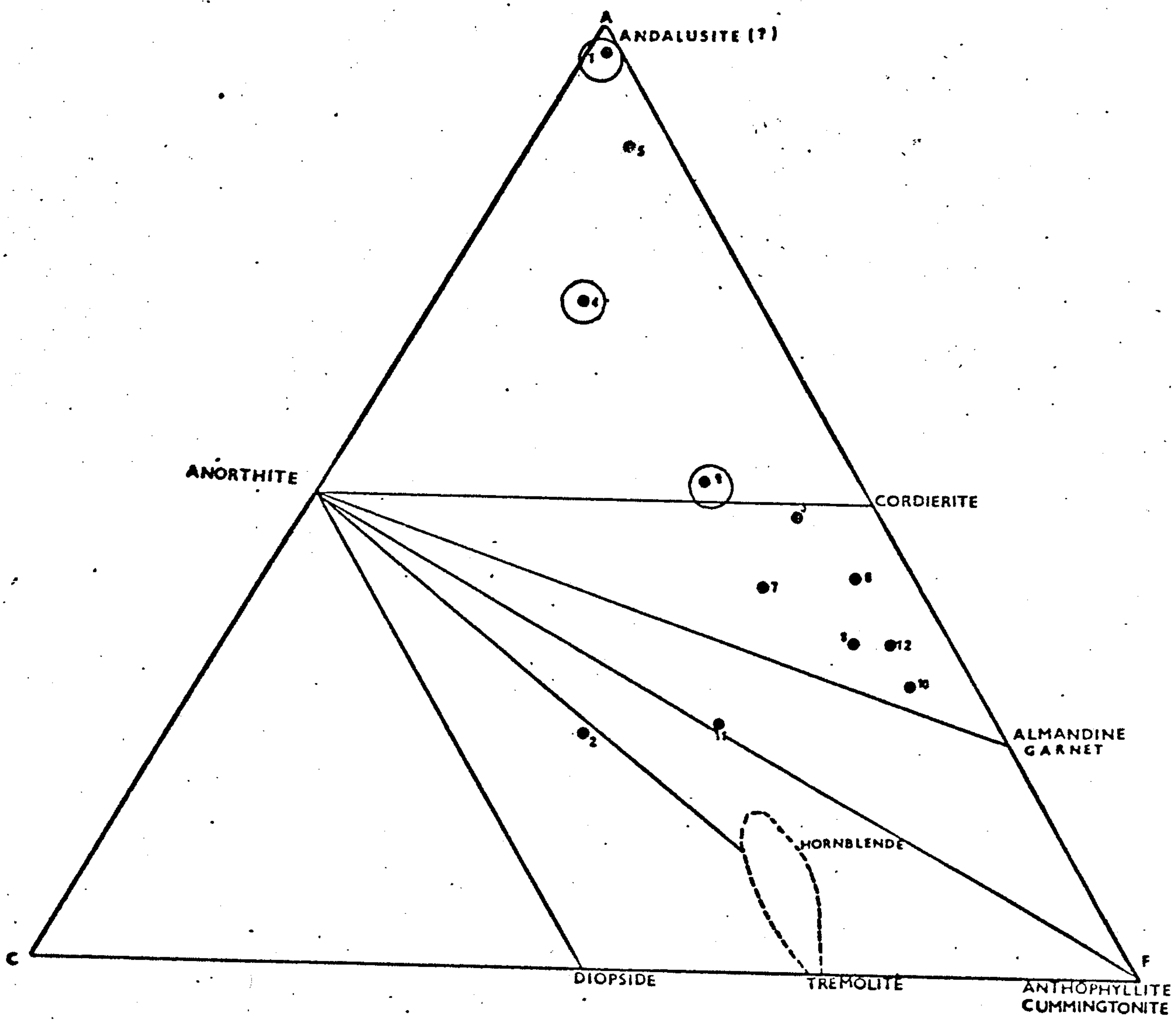

FIGURE 6 A.C.F. Diagram for lower Amphibolite facies (Abukuma type) for chemically analysed rocks (Table 2) correspnding numbers.

Correction (subtractions) made for content of sulfides #1, 2,4, as CuFeS, and FeS_2. Values calculated to 100% mol. proportions.

$[Al_2O_3] + [Fe_2O_3] - [Na_2O] + [K_2O] = A$

$[CaO] - 3.3\ [P_2O_5] = C$

$[MgO] + [MnO] + [FeO] = F$

○ alteration zone samples.

of the co-existing pyrite, pyrrhotite, sphalerite, and chalcopyrite. The reason for this can be understood from the chemical analyses which show unusually high sulfur values. Distinction had to be made between the proportion of iron tied with sulfur and those tied with the silicates.

Consideration of the bulk chemical composition of the rocks leads to the conclusion that garnet is of the almandine variety. Thus garnet would plot on the AF join of the ACf diagram. The anorthite-garnet tie line and the andalusite-cordierite tie lines are quite in harmony with the plot of the points.

Points 1 and 4 on Figure 6 have large corrections for sulfide contents, and in fact contain sericite and chlorite. Similarly, point 9 is an altrred rock, but large pseudomorphs of sericite and chlorite have the form and appearance of altered cordierite, and the rock is interpreted to be an altered quartz-plagioclase-muscovite-cordierite-biotite schist.

Points 7 and 10 are amphibolites, which plots in the Plagioclase-Garnet-Cordierite region. However, the mode (Table 3) shows that it actually contains Plagioclase-Hornblende-Cummingtonite.

Point 8 also plots in the Plagioclase-Garnet-Cordierite region, but the mode is Plagioclase-hornblende.

In spite of this representation, considerable caution is to be applied in defining the assemblages in terms of the intensive parameters such as P_{H_2O}, oxygen fugacity, and temperatures as could be done for assemblages from areas with no mineralization, where the form of the mineral assemblages have not been disrupted by later processes such as retrograde metamorphism which was aided by hydrothermal solutions.

In the case of the Fox mine assemblages, however, the interpretation of the possible phase relations and equilibria through the ACF plot is done with due consideration of retrograde metamorphism as an additional factor in the determination on the appearance and disappearance of mineral phases.

Consideration of the mineral assemblages leads to the conclusion that their highest sub-facies was the andalusite-cordierite-muscovite-almandine sub-facies of the cordierite amphibolite facies. This places the theoretical temperature range at 550 to 650° C, and $P = P_{H_2O}$ to 2 to 7 kilobars (Winkler, 1967).

Greenwood (1964) suggested that anthophyllite could be formed in the presence of steep gradients in the activity of H_2O either from uniform temperatures within the range 500-550° C or in thermal gradients extending outwards from an intrusion. It is suggested that the generation of anthophyllite in thermal gradients coupled with a possible metasomatic introduction of Mg and Fe could be responsible for the anthophyllite assemblages.

Schreyer (1965) has shown that chlorite, muscovite and quartz would yield cordierite and biotite within the temperature range 500-535° C and 4 kilobars water pressure and this is well within the stabilities of magnesium rich anthophyllite.

Phase relations in hydrothermal alterations are dependent not only on the P_{H_2O} but also on the activity of other components in solution. The presence of sulfides in most assemblages would suggest volatile constituents were present in sufficient amount to reduce the activity of water and disrupt the equilibrium of mineral assemblages or leads to the generation of phases that were not predicted by the ACF diagram. It is suggested that the mineral association in sample B7 (Plate 5) from the 510 sub-level could be explained along this line.

Pre Metamorphic Rocks

The rocks of the Fox mine have been subjected to complex metamorphism. The observed petrographic textures and chemical compositions point to derivation from different rocks. Consideration is also given to possible tectonic influence such as shearing. For example, in the sample AF28 (Plate 6) the textural relations of the recrystallized mylonite suggest metamorphism was probably preceded by shearing.

It is suggested that the rocks of the alteration zone were derived from the amphibolites, hornblende-gneisses of the country rock. This is deduced from the development of sericite at the expense of plagioclase in the alteration zone, the presence of oligoclase as relic minerals and the replacement of amphiboles, biotite and the ferromagnesians by chlorite.

The suggestion is that the amphibolites were derived from basic to intermediate igneous rocks such as basalts, andesites and tuffs. It is further suggested that the biotite schists, meta-greywackes, meta-arkoses are products of mixed volcano-sedimentary and sedimentary sequences interbedded with volcanic rocks.

CHAPTER IV

SULPHIDE ORES FROM THE FOX MINE

The ores of the Fox mine are divisible into two main groups: the massive sulphides, comprising 60 to 80% by volume sulphides and the disseminated ores containing 20 to 30% of the total rock composition. Most of the samples studied were from drill cores collared at different levels of the mine. The massive sulphides were polised in the usual way while the disseminated sulphide samples were made into polished thin sections. Structure etching was carried out for six selected samples with suitable reagents as recommended by Ramdohr (1969).

The massive sulphide ores consist essentially of pyrite, chalcopyrite, sphalerite, pyrrhotite, arsenopyrite minor amounts of silver, tetrahedrite (Fahlore), traces of gold, and suborninate magnetite and ilmenite, minor galena. Table 4 shows the mineral compositions by volume for some of the massive sulphide samples from the mine.

PYRITE

Pyrite is the most abundant mineral in the massive sulphide zone. Most of the crystals are idioblastic and some show distinct cubic and pyritohedral outlines (Plate 9). The size of the crystals is variable but they range in general from .9 m.m. to 3 m.m.

The individual pyrite idioblastic grains show irregular fractures suggesting intensive cataclastic effects which could be related to post mineralization deformation (Plates 11 & 12).

TABLE 4

Percentage composition by volume of selected specimens from the massive sulphide zone - 510 sub-level, Fox Mine.

Mineral / Sample No.	B5	B9	B18	B15	B11	B16	B17	B13	B8
Pyrite	30	34	42	30	48	24	41	40	21
Pyrrhotite	20	2	12	11	16	2	17	10	9
Chalcopyrite	32	18	8	19	10	10	20	12	13
Sphalerite	10	7	23	5	14	19	10	20	23
Arsenopyrite	-	-	-	-	-	13	-	-	14
Magnetite	-	3	-	3	-	-	3	-	4
Ilmenite	-	-	-	-	-	-	2	-	2
Gold	-	-	trace	-	-	-	trace	-	-
Tetrahedrite	-	3	-	-	2	-	-	-	-
Silver	-	-	-	-	-	5	-	-	3
*Pentlandite	-	trace	-	-	-	trace	-	-	-
Silicate Gangue	8	20	15	35	15	12	4	18	11

*Trace amount of pentlandite determined from exsolution lamellae on pyrrhotite.

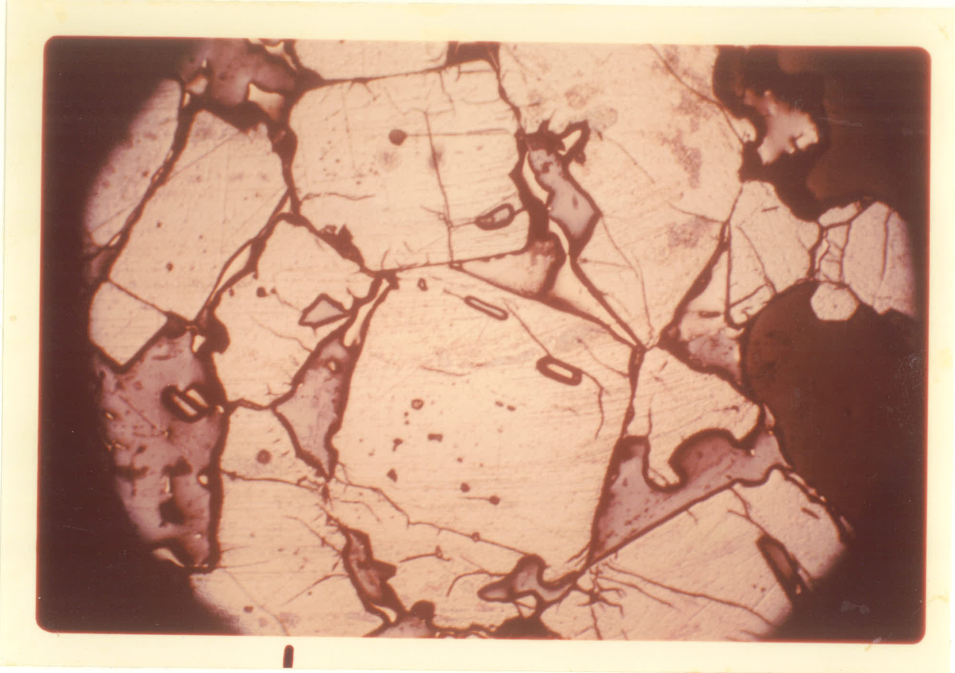

Plate 9. Idiomorphic (cubic) crystals of pyrite with rims marked by xenoblastic pyrrhotite (pinkish yellow) and dark gangue mineral (silicate). Idiomorphic inclusions on pyrite are possible primary minerals.

x 40 crossed nicols.

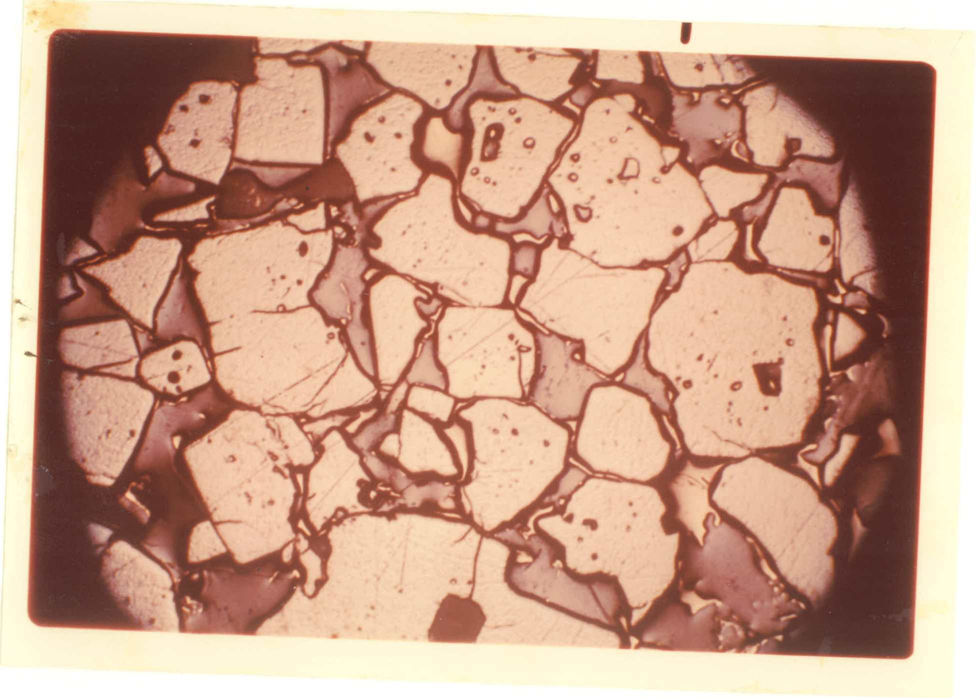

Plate 10. Subidioblastic pyrite grains rimmed by irregular ribbons of pyrrhotite and chalcopyrite. Sphalerite (greyish blue) are larger interstitial grains some with inclusions of chalcopyrite (centre). Rims of pyrite-sphalerite also occupied by greyish brown magnetite.

x 40 crossed nicols.

Some of the pyrite grains are xenoblastic and contain inclusions of pyrrhotite and magnetite. The interstices between adjacent pyrite masses are occupied by irregular xenoblastic pyrrhotite, sphalerite and chaldopyrite. Textural relationships indicate a later age of the interstitial minerals. The intergrowths of pyrite-pyrrhotite have low dihedral angels while the sphalerite-pyrite triple junctions show an apparent high dihedral angle relationship. The rims of some pyrite crystals are marked by arsenopyrite ang gangue (Plates 11 & 16).

The form of pyrite could indicate formation at different stages of mineralization. The coarseness of grain size indicates crystallization or re-crystallization under conditions of high grade metamorphism (Stanton, 1964, Ramdohr, 1969). The multiple fractures are due to cataclasis and recovery related to annealing processes.

Although the term 'idioblastic' has been used in the description of the form of the pyrite crystals, it may be argued also that the cubic crystals (Plate 9) are primary 'idioblastic' features. This variation in form is probably related to important genetic deductions: Pyrite is one of the sulphide minerals that recrystallize at high temperatures and if the idioblastic crystals are due to re-crystallization then it would mean the temperatures for the re-equilibration of pyrite may have been attained, and the idioblastic forms are due to inhibited crystal growth as suggested by Ramdohr (1969). The idiomorphic form in Plate 9 may be primary and would suggest there was no re-crystallization which points to differences in conditions of formation of the two forms observed.

PYRRHOTITE

Pyrrhotite is a major constituent of the massive sulphides. In most specimens the crystals occur as irregular lensoid grains concentrated along the grain boundaries between pyrite and sphalerite. The mineral is identified easily by its characteristic pinkish brown colour and xenoblastic forms (Plates 10, 11 & 12). Etched specimens (e.g. Plate 14) show minute lamellae, probably spindles of pentlandite. The general relations in most samples suggest replacement by pyrite.

Pyrrhotite is one of the sulphide minerals characterized by a high susceptibility to re-crystallization and reactivity and the occurrence along grain boundaries between larger plates of pyrite and sphalerite leads to the deduction that most of the minerals may have been derived through the exsolution of excess iron from sphalerite in the course of annealing in the presence of much sulphur and/or the break down of pyrite at temperatures below the stability limits of pyrite to yield pyrrhotite and sulphur. Both of these possibilities are feasible under the conditions of medium grade metamorphism and repeated deformation resulting in annealing and re-crystallization (Stanton, 1964, MacDonald, 1965).

CHALCOPYRITE

Chalcopyrite is found in practically all specimens examined. The mineral is characterized by a high lustre and a greenish yellow colour. It occurs is irregular xenoblastic ribbons surrounding pyrite, gangue and sphalerite (Plate 12). Exsolution of chalcopyrite from sphalerite plates is noted in many samples along regular lamellae

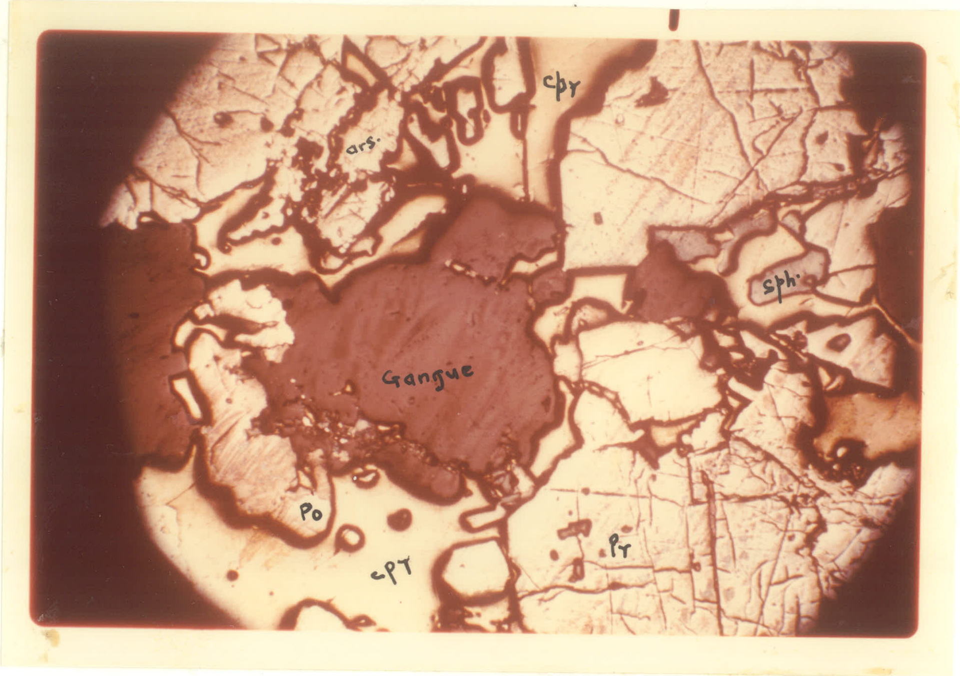

Plate 11. Irregular pyrite fractures (lower right) occupied by remobilized pyrrhotite (Po) chalcopyrite (cpy) in worm-like extensions into fractures in dark silicate gangue, and intimately associated with arsenopyrite (ars). Pyrrhotite with indistinct exsolution lamellae of pentlandite (lower left). Tetrahedrite greyish white on left of pyrrhotite. Gangue mineral is chlorite.
x 40 etched. crossed nicols.

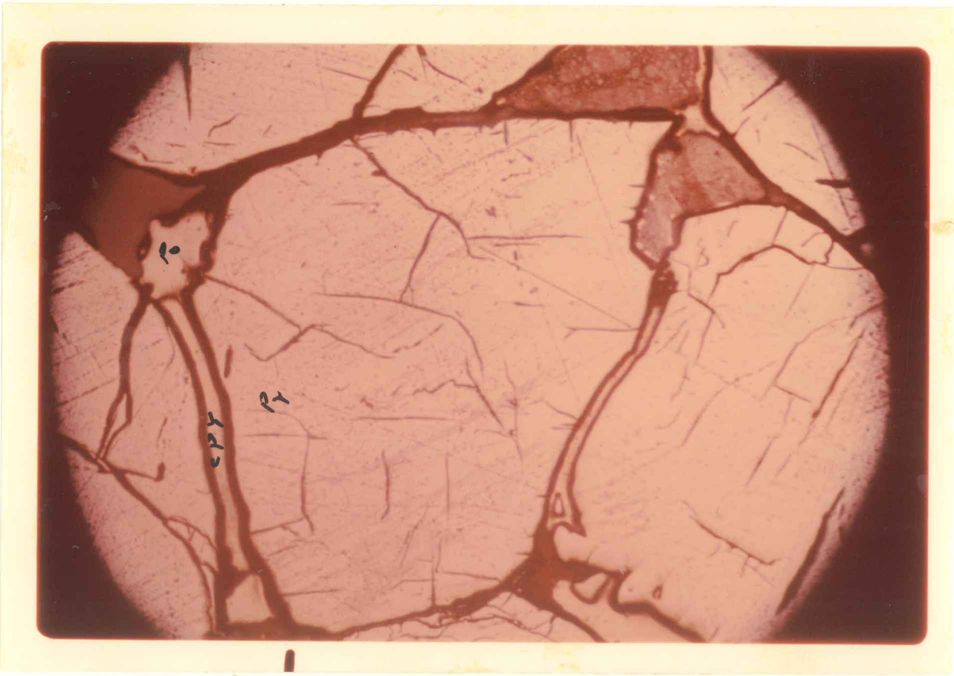

Plate 12. Cataclastic fracture on pyrite grains - a possible annealing feature. Note regular bracelike extensions of chalcopyrite (cpy) and pyrrhotite along large grain boundaries. Magnetite also present along grain boundaries.
x 80 crossed nicols.

of the host crystals.

Chalcopyrite is relatively more abundant in the disseminated sulphide zone than the massive zone. In most disseminated sulphide samples they exhibit a crude preferred alignment to the platy silicate minerals which mark the schistosity planes.

The occurrence of chalcopyrite along grain boundaries is interpreted to be due to the response to possible tectonic effects after primary mineralization. It is suggested that a possible mode of deformation may have been a plastic smearing out in response to pressure. The form of the ribbon-like crystals would also suggest a response to mobilization by translation. The cataclastic fractures noted on pyrite grains are distinctly absent in the chalcopyrite grains (Plates 11 & 16).

Chalcopyrite is found in intimate association with such minerals as tetrahedrite, pyrrhotite, and gold traces in the specimens where these minerals were noted.

SPHALERITE

Sphalerite occurs as sub-idioblastic to xenoblastic plates approximately .2 m.m. to .9 m.m. width on average. In all cases, it is easily identified by its characteristic low reflectivity and bluish-grey tinge. The mineral is also present in the disseminated sulphide zone but is considerably lower in abundance than chalcopyrite. Evidence of deformation twinning is noticeable in etched samples although this is not very obvious in Plate 14.

In some specimens B9 (Plate 10) the relationship along pyrrhotite-sphalerite boundaries would suggest a later occurrence of pyrrhotite in

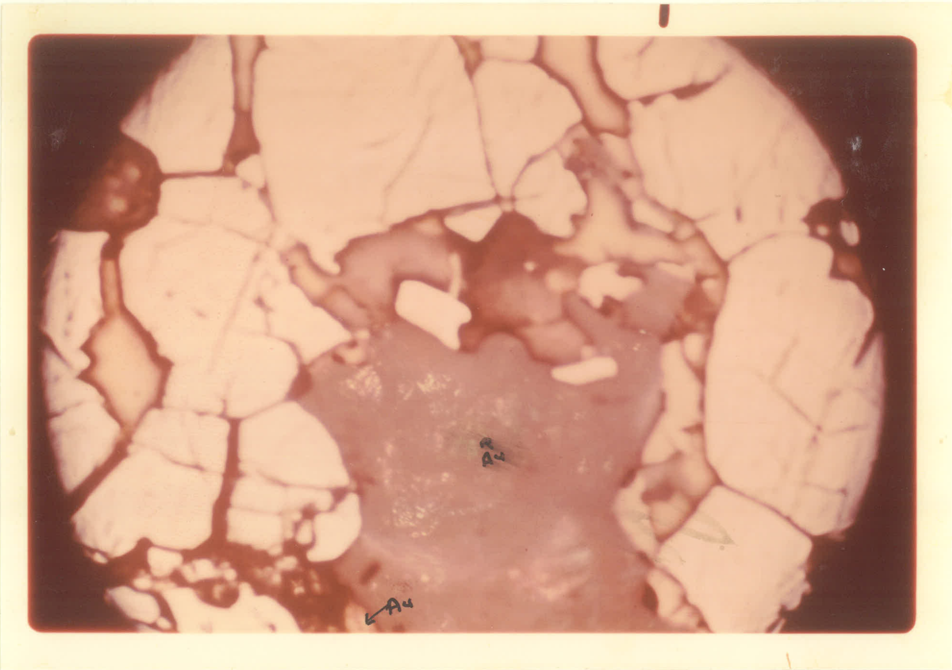

Plate 13. Chalcopyrite between grain boundaries of irregularly fractured pyrite also note in intimate association with gold (reddish yellow, au.). Wormlike extensions of chalcopyrite is a probable remobilization feature related to metamorphism.

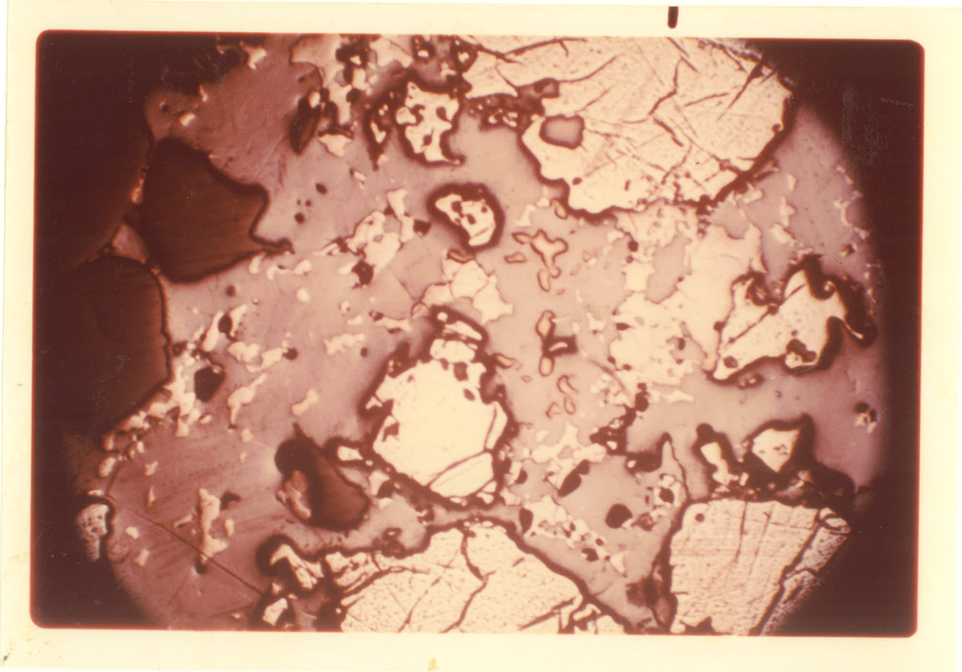

Plate 14. Large sphalerite grain (centre) with irregular inclusions of yellowish pink pyrrhotite and chalcopyrite (greenish yellow). Note exsolution lamellae on pyrrhotite (lower right). Sphalerite grains also includes brownish grey magnetite.

etched x 40 crossed nicols.

the paragenetic sequence. The deduction here is that some of the pyrrhotite grains may have formed from the excess iron 'sweated out' of sphalerite, given a high enough sulphur content in the bulk chemical composition and conditions of high stress on the primary sphalerite.

In other samples (e.g. Plates 14 & 16), the extension of chalcopyrite tongues into sphalerite would suggest remobilization, probably metamorphically activated. Irregular fractures in some of the sphalerite grains may suggest cataclastic response due to post crystallization deformation.

ARSENOPYRITE

Arsenopyrite occurrences are rare in the samples studied. In the few samples where they occur (Plates 11 & 15), the crystals are whitish with inconspicuous yellowish tinge and grain sizes of approximately 2 m.m. Most of the crystals occur as irregular xenoblastic grains in intimate association with chalcopyrite and pyrrhotite. Crystallization of these minerals appears to have been later than the minerals with which they are associated. This is inferred from the general occurrence of the mineral grains along cataclastic cracks and grain boundaries of larger minerals.

In one specimen the mineral is intimately associated with gold and no genetic relationship is directly suggested between arsenopyrite and gold occurrences.

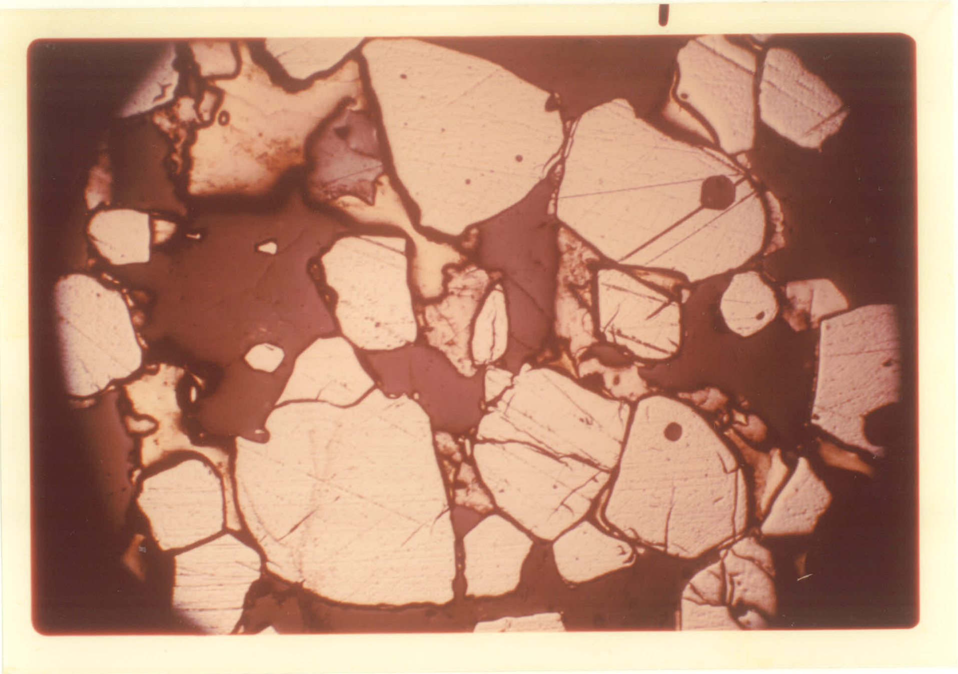

Plate 15. Large idioblastic grains of pyrite rimmed by pyrrhotite, gangue, chalcopyrite, and yellowish white arsenopyrite. Texture reflects a possible flow of chalcopyrite and pyrrhotite along pyrite-gangue boundaries.
x 40 crossed nicols.

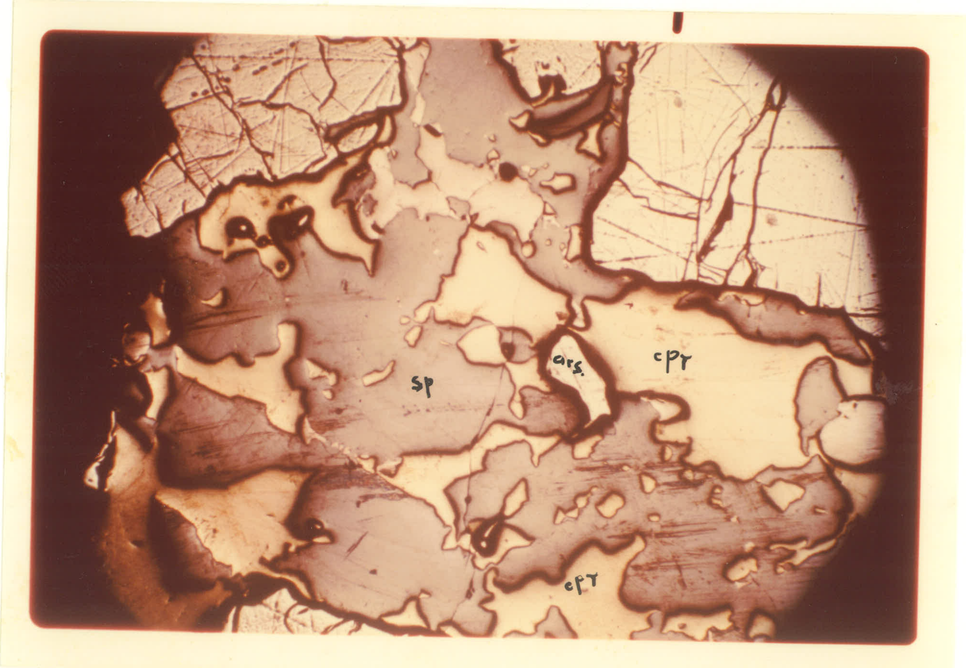

Plate 16. Large xenoblastic (bluish grey, sp) sphalerite with extensions and blebs of chalcopyrite (cpy) and an isolated poikiloblastic arsenopyrite (whitish). Extensions of chalcopyrite tongues into sphalerite is a possible secondary textural feature.
x 40 crossed nicols.

TETRAHEDRITE

Xenoblastic grains of olive yellow brown tetrahedrite appear to be the only members of the Fahlore group present in the samples studied. Tetrahedrite grains are enclosed in one specimen (Plate 11) by sphalerite and in another specimen it was found in intimate relation with pyrrhotite and chalcopyrite (Plate 18) with selvages of pyrite on another section surrounding gangue minerals and chalcopyrite.

Textural relations in these two specimens suggest the tetrahedrite is of secondary origin, having been developed on old boundaries of chalcopyrite or pyrrhotite. It would also appear that the antimony content of the analysed massive sulphides (Table 6) is tied with the tetrahedrite content of the massive sulphides. The optical properties suggest the mineral is tetrahedrite and not tennanite which is the arsenic bearing member of the Fahlore group. The low arsenic content of the massive sulphides and the presence of arsenopyrite also confirm the deduction that all the arsenic occurs mainly as arsenopyrite.

MAGNETITE AND ILMENITE

Magnetite and ilmenite were noted among the opaque constituents of the orebody. Magnetite is common in massive sulphide ores as well as the disseminated sulphide zone. It is also present as an accessory constituent of the host rock silicates. The mineral is greyish white with brownish tints. The occurrence among massive sulphides is sporadic. In most cases it is found in association with sphalerite (Plate 14), and in many other cases at the boundary of gangue minerals (silicates) and

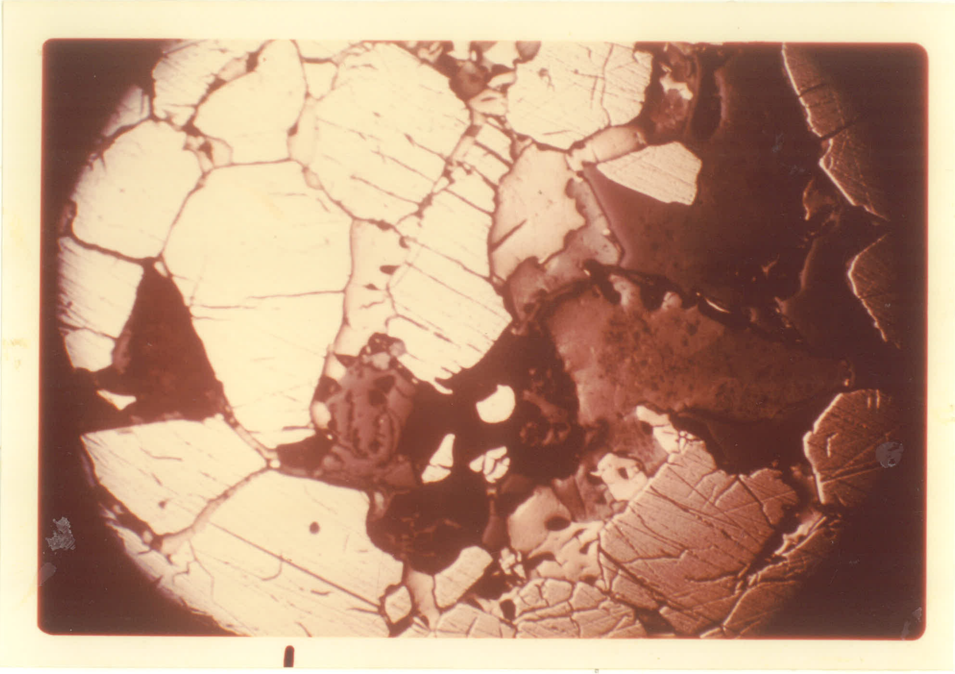

Plate 17. Regular fractures of pyrite filled by indistinct later phase sulphides (pyrrhotite) and gangue. Adjacent pyrite boundaries occupied by interstitial chalcopyrite and greyish brown magnetite. Silver occurs as a bright white inclusion on gangue (centre).

x 40 crossed nicols.

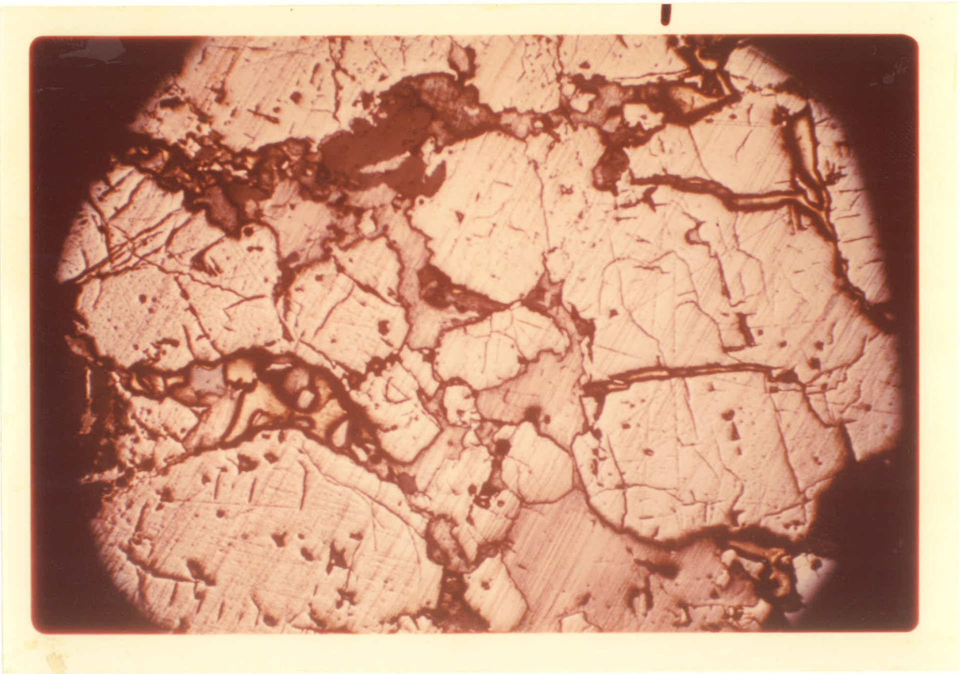

Plate 18. Typical case of sub-grain development along grain boundaries. Cataclastic pyrite sub-grains are unoriented with respect to one another. Cataclastic texture points to annealing effects. Chalcopyrite and pyrrhotite and tetrahedrite noted along grain boundaries are of later development.

x 40 crossed nicols.

pyrite (e.g. Plate 17).

Ilmenite is present mainly in the disseminated sulphide ores where they appear to be related to the anthophyllite occurrences. Few grains were detected on gangue minerals in specimen B9 (Plate 10). It is probable that the ilmenite and magnetite may have resulted from the dissociation of titano-magnetite which breaks down at minimal stress to give rise to ilmenite and magnetite (Ramdohr, 1969).

THE PRECIOUS METALS

Native silver and gold are found in minor amounts in the samples of sulphides examined. Gold occurs as minute bright yellow specks in intimate association with chalcopyrite (Plate 13) while silver occurs as cream white irregular aggregates in some specimens (Plate 17) interstitial between the gangue minerals and pyrite. In all cases, silver is less than 2 m.m. in width.

Owing to the fine grain size of these minerals the deduction on their paragenetic sequence can only be speculative. It is suggested the minerals are of hydrothermal origin. The bright yellow colour of the gold specks would suggest a low silver content.

METAL VARIATION AND ZONING

Figure 7 and Figure 8 illustrate the average variations in 2 selected drill holes of 510 intersection. The summary logs of the major sulphides are indicated below the diagrams. The mineralogical variation and the general pattern of zoning is noticeable in polished sections but the limitation is interpreting the paragenetic sequences rests on the involvement of the orebody in post ore emplacement metamorphism.

The metal variation diagram for UF 789 (Figure 7) shows a crude bimodal variation for zinc. The latter is not quite reflected in the diagram for UF 793 (Figure 8). The major difference between the two sections is the very low zinc content near the 120 feet zone in section UF 789 which is not reflected in section UF 793.

Copper values show a general higher content toward the southern sector in both diagram. This fact has been shown by the generally higher chalcopyrite content of the massive sulphides in this zone.

In both diagrams the highest silver values are associated with zones of high copper values. The sympathetic relationship of copper and silver is further reflected in copper-silver diagram in Figure 10 (Page 76). The relationship is not easily observed in polished sections because of the rarity of silver in the specimens studied.

The zonal pattern is not easily discerned through mineralogical investigation because of the effect of metamorphism mentioned above. However, it would appear from the logs that the general pattern is still faithfully preserved. For example, ore of high copper and zinc values in both diagrams is associated correspondingly with high chalcopyrite and sphalerite contents respectively. Thus any mobilization effects related to metamorphism was for a short distance and did not necessarily disrupt the general pattern of zoning.

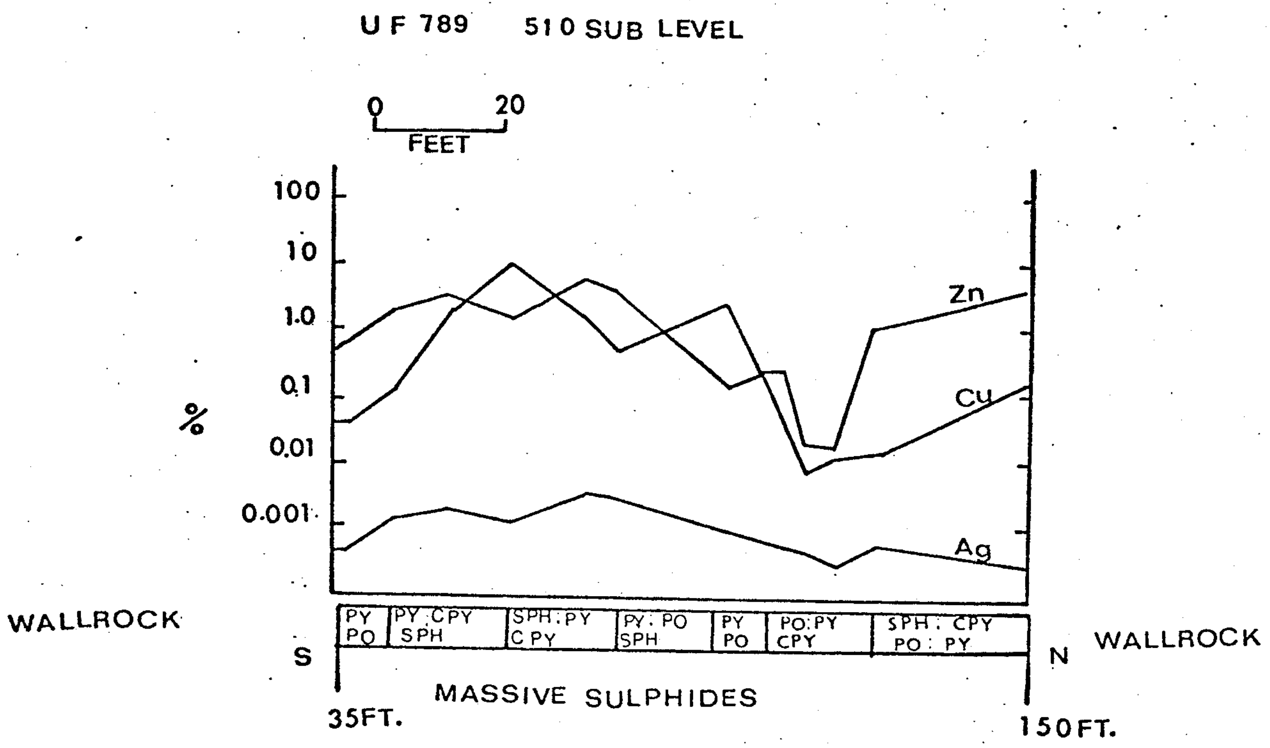

FIGURE 7. Orebody Metal Variation Diagram
Diamond Drill Hole UF 789
(Data A4-A22 Tables 5 & 6)

EVIDENCE FOR METAMORPHISM AND DEFORMATION OF THE SULPHIDES

Textural, mineralogical and field evidence point to the fact that the ore minerals were involved in deformation and metamorphism. The ore zone as observed in the 2,100 level main cross cut shows a distinct conformity with the general trend of the host rocks. The chilled border zone of the immediate wall rock contact was involved in retrograde metamorphism following changes in the pressure-temperature conditions, and hydration affecting the earlier meta-volcanics.

The texture of the sulphides (see Plates 11 - 18), suggest that the minerals with the greatest ease of deformation notably chalcopyrite and pyrrhotite intruded grain boundaries of more brittle minerals such as pyrite and the gangue silicate minerals. This is a general feature in all the sulphide specimens investigated. Chalcopyrite of low dihedral angles interlock against pyrite-sphalerite and generally assume shapes which suggest they migrated to grain boundary triple junctions between pyrite grains or pyrite-sphalerite grains. Such features are possible effects of later phase deformation which affected the larger pyrite and sphalerite plates resulting in the smearing out of the more mobile and plastic chalcopyrite. The general relationships are shown in Plates 12, 13, 14 and 18.

The cubic pyritohedral grains of pyrite may be primary features, but the larger idioblastic grains with irregular fractures (Plates 11 & 18), point to re-crystallization and deformation under conditions of high temperature and pressure. The development of recrystallized idioblastic grains of pyrite and the occurrence of interstitial minerals at the grain boundaries has been interpreted to be due to deformation effects on

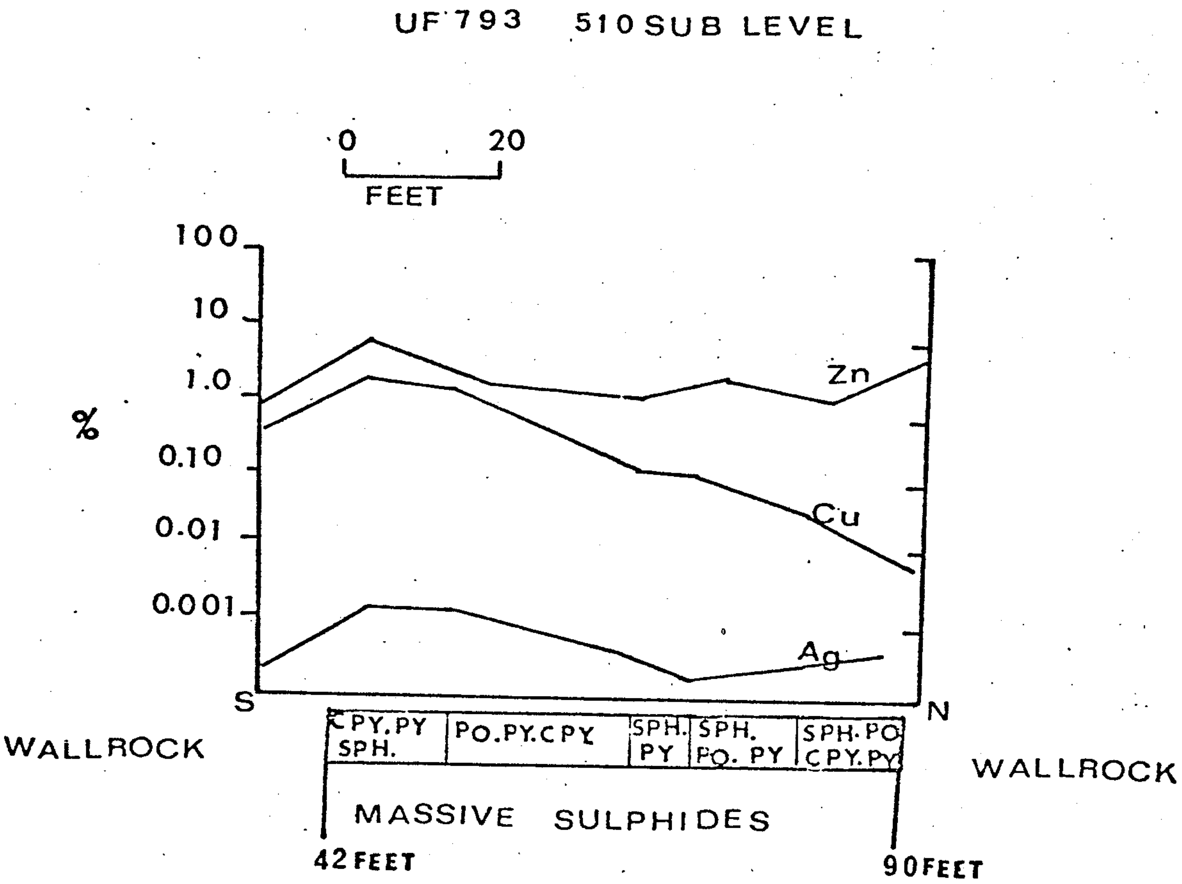

FIGURE 8. Orebody Metal Variation Diagram
Diamond Drill Hole UF 793
(Data: B5-B18, Tables 5 & 6)

sphalerite or to the break down of pyrite with the release of pyrrhotite under pressure-temperature conditions corresponding to the amphibolite facies.

The exsolution of chalcopyrite from large sphalerite crystals is a common feature observed in most sphalerite bearing specimens. Hardy and Heal (1954) suggested that exsolution of foreign materials from minerals could result from deformation. The extent of the exsolution of chalcopyrite from sphalerite cannot be easily estimated due to the possible migration of the exsolved minerals to grain boundaries on re-crystallization and the subsequent growth of the host minerals.

The gangue-sulphide junctions are occupied in some specimens by sub-grains (Plate 18) which are products of strained grains unoriented with respect to one another. In some samples the gangue-sphalerite junctions are curved (Plate 14) with sphalerite forming brace-like extensions into adjacent pyrite.

In general, the interfingering of grains into one another, the occupation of minor phases along grain boundaries and the fracturing shown by most pyrite grains reflect the effects of annealing which could have taken place under repeated stress conditions and high grade metamorphism (MacDonald, 1965). Exsolution effects due to changes in temperature and sulphur fugacity have also been noted by some workers.

CHAPTER V

SULPHIDE GEOCHEMISTRY

Tables 5 to 7 show a list of sulphide specimens systematically sampled from the ore zone and analysed for the elements Zn, Cu, Ag, Pb, Cd, Ni, S, Fe, Co, Sb, Au, and Sn. Figures 9 to 14 are the plots of the metal variations. The comparison of the elements was based on the general geochemical association of elements and also with a view to investigating any similarities in metal associations which could be related to orebodies in similar geological settings.

The slopes are regression lines calculated through the principle of least square regression analysis. They thus mark the trend or the loci of the points at which deviation is at the minimum. For purposes of interpretation the scheme shows that the square of the values of correlation coefficients represent the level of predictability of one element or pair with the other. The correlation coefficients demonstrate the strength of the relationships between pairs and the least level of significance taken on these plots was .05 and all comparisons that fell below this were not represented in the diagrams. The calculation follows the recommendations of Freund (1973).

The ternary diagram (Figure 9) shows high zinc and copper values in two zones respectively and a generally low lead content in the massive sulphides.

Silver shows a greater sympathetic relation with copper (Figure 10) than zinc, and it would appear high silver values are related to increasing copper values rather than zinc.

The scatter of points in the Cu-Cu+Zn diagram (Figure 11) illustrates the zonal arrangement of zinc and copper. The diagram further shows that zinc and copper have no direct relationship but are concentrated respectively in different zones of the orebody.

The cobalt-nickel diagram (Figure 12) hardly shows any interrelationship in the distribution of these two elements. This is probably due to the preference of nickel for pyrrhotite.

The values for zinc and cadmium (Tables 5 and 6) show that Zn^2 (0.83 Å and Cd^2 (1.03 Å) have a partial diadochic relationship and this is in harmony with principles outlined by Ringwood (1955) and Nockolds (1967). However, this interpretation cannot be applied in all cases because high zinc values in some samples are not coincident with a high cadmium content.

The inverse relationship of zinc and cobalt (Figure 13) would suggest a non-preferential diadochic relationship of cobalt in sphalerite tetrahedral sites as predicted by Ringwood (1955).

Cobalt and nickel are usually present in the silicates and sulphides as bivalent cations and their non-sympathetic relationships with any of the major elements would suggest mobilization of these elements into silicate host rocks, aided by the escape of sulphur bearing volatiles. The migration of sulphur into the host rocks is reflected in the generally high sulphur content of the analysed host rocks (Table 3).

Higher cobalt content relative to nickel in the massive sulphides can be explained also by the ability of cobalt to form stable chlorocomplexes in hydrothermal environments in the same way as the major elements, copper and zinc (Faulkner, 1969). Nickel has less tendency to form such complexes in hydrothermal environments. It would appear that the nickel content of the massive sulphide zone is tied with the pyrrhotite.

Some workers have also noted higher cobalt:nickel ratios in similar orebodies. Kilburn (1960) noted that Co : Ni ratios in Flin Flon is 2:1 and Schist Lake 3:1. In a comprehensive trace element study of sphalerites Kullerud (1963) showed that 17 out of 54 samples contain nickel and cobalt of average concentration 24 ppm for nickel and 181 ppm for cobalt. Of 213 analyses of massive sulphides made by Bunham (1959) 59 contained both nickel and cobalt. Cobalt was found to be 154 ppm and nickel 20 ppm. These examples of apparent preferential concentration of cobalt in place of nickel are cited to show that the trends in this study are not peculiar.

The apparent antipathetic relationship between iron and zinc (Figure 14) is related to a high sulfur fugacity resulting from the transformation of pyrite to pyrrhotite with the release of sulfur. Depletion of the iron content of sphalerite is aided by high sulfur content (MacDonald, 1965) but the high sulfur content reflected in the chemical analyses of the Fox mine sulphides and host rocks precludes any suggestion of total derivation of sulphur through this reaction alone.

The gold content in the samples analysed is rather insignificant (Table 7). Although traces of gold were noted in polished sections, the gold content of the massive sulphides is far less than the silver content.

Table 6 shows the values for tin. The analysis shows that the tin content is very low and is not directly related to any of the major elements.

The pattern of major and trace element distribution follows the general trend of most epigenetic hydrothermal deposits. It is suggested that minor departures from the general trend may be related to remobilization of elements during metamorphism. It is probable that the hydrothermal fluid was enriched in sulphur and this might have had significant influences in the general distribution of elements.

TABLE 5

MAJOR ELEMENT ANALYSES OF FOX MINE SULPHIDES
510 Sub-level

Sample No.	Ref. No.	Cu	Zn	Fe	S	(wt. %)
A4	1	0.88	0.052	39.6	46.7	
A6	2	3.20	0.120	39.2	44.1	
A7	3	5.00	2.24	34.4	36.8	
A8	4	2.56	9.16	34.0	42.7	
A9	5	5.88	4.36	30.4	34.2	
A10	6	7.68	2.04	35.2	40.0	
A11	7	5.44	0.61	38.0	44.9	
A22	8	0.17	5.60	34.2	41.7	
A20	9	0.11	1.08	38.4	43.4	
B5	10	2.52	8.80	34.4	42.8	
B8	11	2.48	3.00	40.0	45.5	
B11	12	0.18	1.64	38.2	44.3	
B13	13	0.15	2.56	34.8	40.4	
B16	14	0.05	2.08	40.0	44.1	
B18	15	0.09	1.76	41.2	45.9	

TABLE 6

TRACE ELEMENT ANALYSES OF FOX MINE SULPHIDES
510 Sub-level

Sample No.	Ref. No.	Pb	Sn	Ni	Ag	Co	Cd	Sb	(ppm)
A4	1	8	10	4	6	650	10	43	
A6	2	34	10	4	16	116	12	17	
A7	3	16	30	7	26	44	66	85	
A8	4	40	20	12	15	5	223	17	
A9	5	44	55	5	37	48	120	10	
A10	6	33	52	10	47	63	64	50	
A11	7	71	10	10	33	409	28	17	
A22	8	42	10	8	4	5	160	8	
A20	9	11	10	40	7	112	37	8	
B5	10	21	10	15	21	52	195	8	
B8	11	133	30	15	27	38	79	42	
B11	12	23	0	26	5	52	45	42	
B13	13	47	10	25	3	21	65	50	
B16	14	6	10	21	5	7	65	10	
B18	15	2	10	14	6	78	51	10	

Analyst: R. Hill

TABLE 7

Gold Content of the Massive Sulphide Zone*
510 Sub-level

Sample No.	Gold (oz./ton)
A4	Trace
A6	Trace
A7	0.01
A8	0.01
A9	Trace
A10	Trace
A11	Trace
A13	Trace
A16	Trace
A17	0.16
A18	0.01
A19	Nil
A20	Trace
A22	Nil
A25	Trace
A28	Trace
B3	Nil
B5	0.01
B9	Trace
B11	Trace
B13	Trace

*Analyst: A. M. Mackay
Manitoba Mines Branch.

Figure 9 to 14

Metal variation diagrams for Fox mine massive sulphides.

Figure 9	Zn-Cu-Pb ternary
Figure 10	Cu-Ag diagram
Figure 11	Cu-Cu+ Cn diagram
Figure 12	Co-Ni diagram
Figure 13	Co-Zn diagram
Figure 14	Fe-Zn diagram

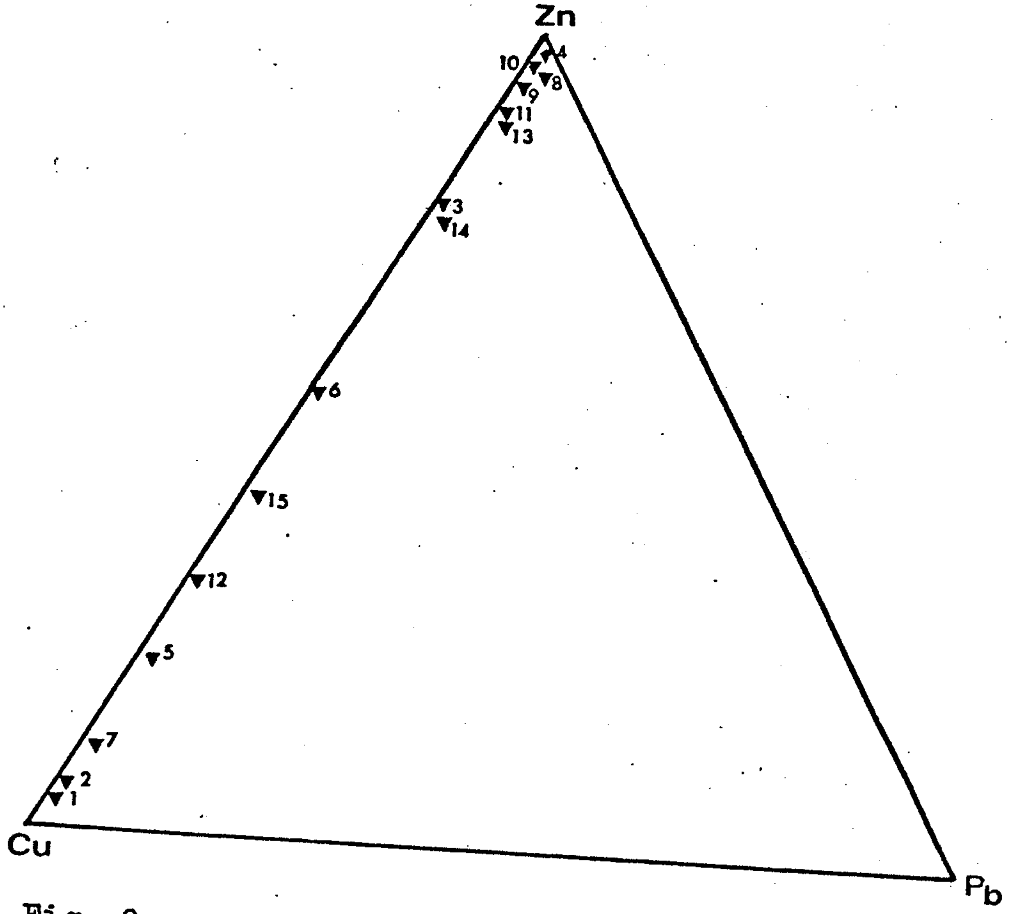

Fig. 9

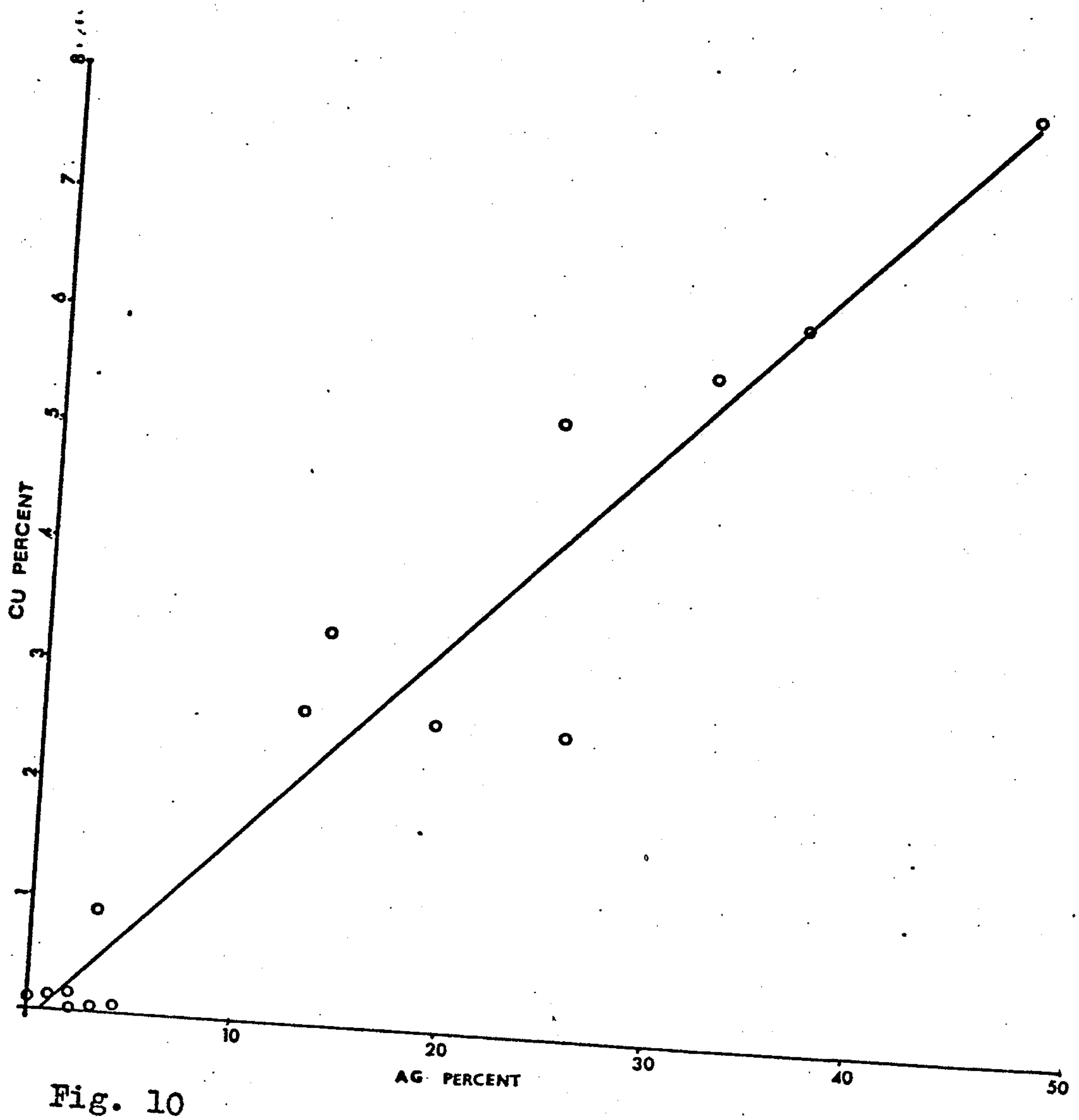

Fig. 10

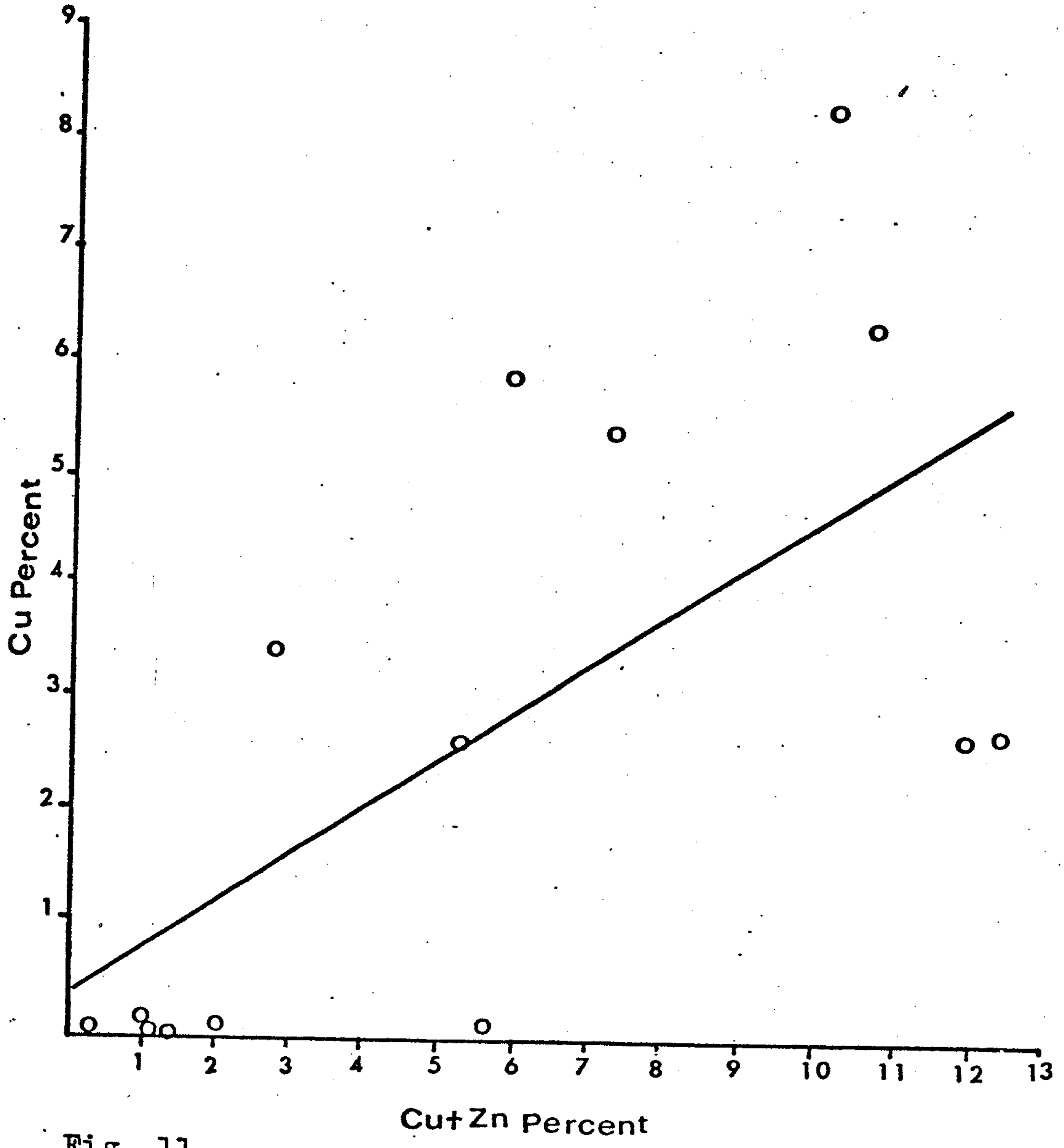

Fig. 11

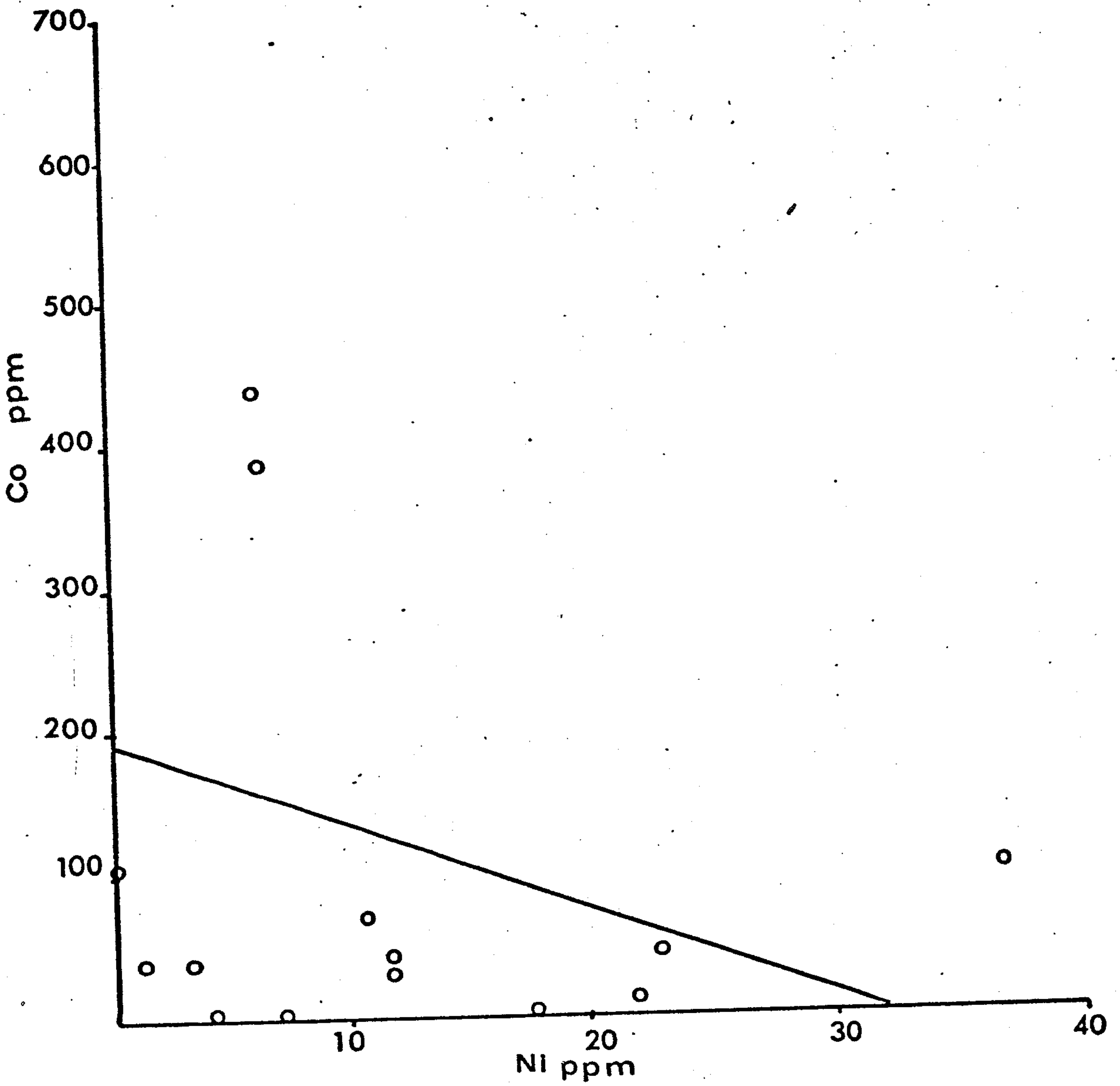

Fig. 12

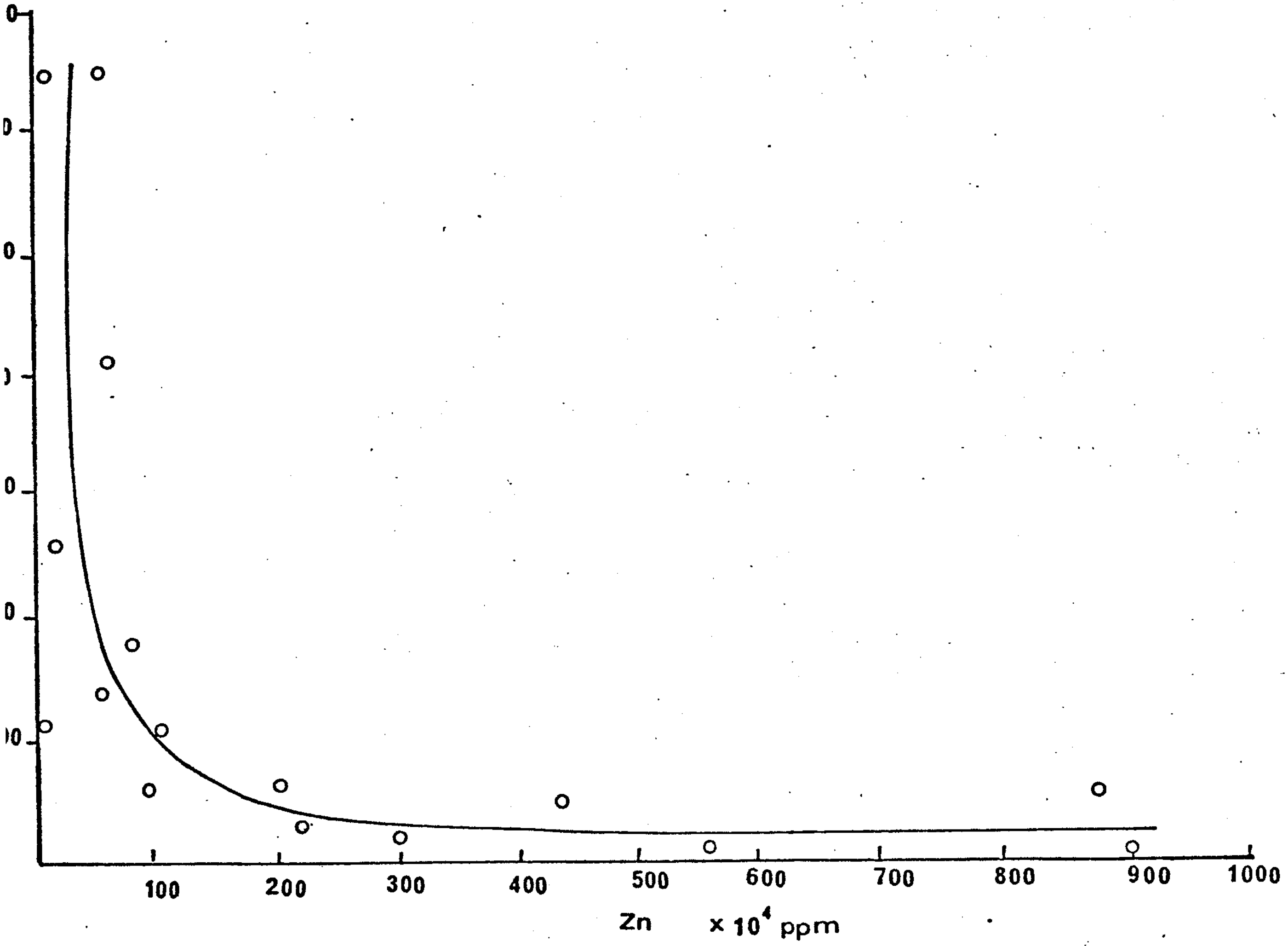

Fig. 13

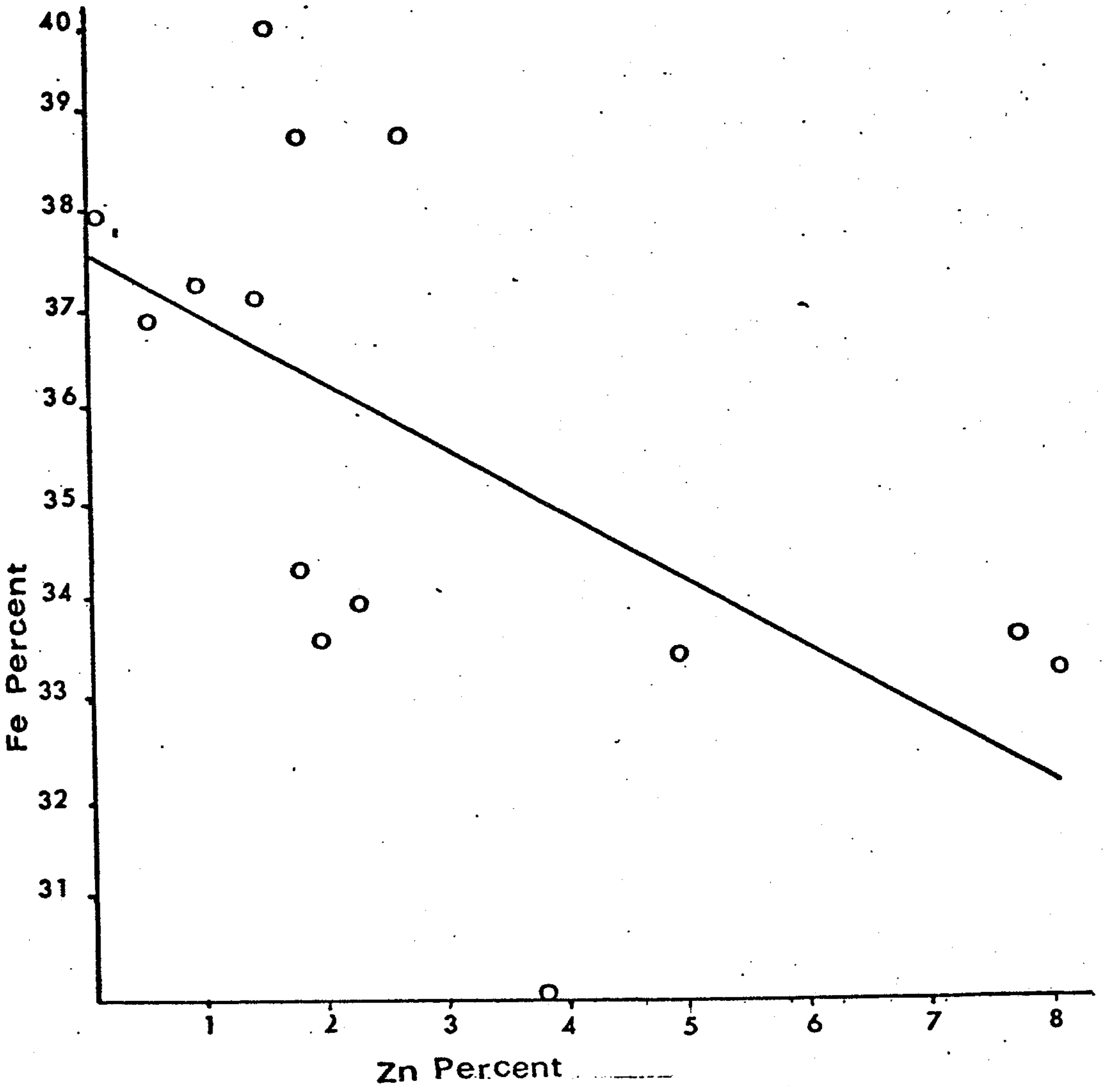

Fig 14

CHAPTER VI

DISCUSSION ON THE GENETIC ASPECTS OF FOX LAKE MINERALIZATION

Discussion on the genetic aspects of Fox Lake copper-zinc deposit is based on certain criteria resulting from the present field and laboratory study.

Firstly, the orebody has a spatial relationship with Archaen volcanic rocks. The exact petrochemistry of the lavas and the nature of derivation is not clear but from petrographic evidence it is suggested the rocks are dominantly of intermediate (andesitic) parentage. The lavas were probably interbedded with sedimentary sequences such as greywackes arkoses, and quartzites. Both the volcanics and the associated sedimentary rocks were subjected to repeated episodes of metamorphism and deformation of varying intensities.

Secondly, the host rocks have been metamorphosed to the andalusite-cordierite-muscovite sub-facies of the cordierite amphibolite facies. This means that temperatures of the order of 500-650° C and $P=P_{H_2O}$ of about 2 to 7 kilobars must have been attained. The amphibolite facies rocks grade imperceptibly at the ore zone to an alteration zone comprising assemblages of the greenschist facies.

Thirdly, the orebody is a typical "Copper-Zinc" type as distinct from the "Copper-Lead-Zinc" type of the Cordilleran belt, (Wilson and Laznicka, 1972). However, it is worthy of note that the dominant host rock of the Fox Lake deposit (meta-andesites) differs from those of many copper-zinc deposits of the greenstone belts in the Churchill and Superior structural provinces. For example, the Archaen copper-zinc deposits in the Superior province such as those of the Mattagami Lake and Noranda have rhyolites and not andesites as their dominant host rocks (Vokes, 1972).

Textural and mineralogical study have revealed that both the orebody and surrounding host rocks were involved in metamorphism. While the evidence for a total generation of ore through metamorphism is lacking it must be mentioned that a clear morphological distinction between primary and mobilized aspects of the orebody is not easily drawn.

The grade of metamorphism attained and the associated temperatures and pressures permit the assumption that the process of metamorphism must have modified the original configuration of the orebody. Brett and Kullerud (1967) in their study of the system Cu-Fe-S and similar sulphide systems have shown that generation of sulphide liquid by melting is feasible. The workers also showed that the generation of sphalerite, galena, pyrite and related base metal sulphides may begin below 700° C with negligible effects from volatiles such as CO_2 and H_2O. Craig and Kullerud (1968) working on the quarternary system Cu-Fe-Pb-S showed that the temperature of liquid appearance decreases with addition of Cu and Fe, reaching a minimum of 508° C. Thus it would appear as suggested by Vokes (1971) that metamorphic heating of ores containing copper, Zinc, lead, sulphur and minor elements would lead to a differential melting with the formation of melts rich in Cu, Zn, As, Sb, Ag and S. Such ores would presumably remain in the vicinity of the primary orebody until redeposition is made possible by tectonic controls (Vokes, 1971).

The evidence for mobilization based on the textures of ores and the mineralogy was indicated in the preceding pages. That the sulphide melt in Fox mine was mobilized is further indicated by the in filling of veins and fractures with sulphide rich masses close to the ore zone (Figure 4). The healing of cataclastically deformed pyrite and sphalerite by the introduction of more mobile phases such as chalcopyrite along fractures and grain boundaries have been noted in the discussion on the mineralogy of the massive sulphides. The coarse grain size of earlier phases such as pyrite and sphalerite may have resulted from re-crystallization associated with high grade metamorphism.

The differences in the pattern of distribution of copper and zinc may be related to the greater mobility of chalcopyrite than sphalerite and pyrrhotite. The foregoing, coupled with the effects of annealing mentioned in Chapter 4 are some evidences in support of metamorphism and deformation, but these were secondary features which affected the original ore deposited from hydrothermal solutions.

The involvement of ore and country rock in repeated metamorphism on one hand and the occurrence of an alteration zone around the ore reveals a paradoxical situation: If the alteration zone resulted from the modification of the country rock by ore forming fluids, then it could be argued that the amphibolite facies metamorphism pre-dates the emplacement of the ore. However, this is contrary to the observations made in the present study.

The problem here is the time relationship between the influx of the ore forming fluids, the deposition of the sulphides, the formation of the alteration zone and the regional metamorphism which affected the host rock and ore. The interpretation of the possible time relationships between these processes could be given along any lines but the author has not resolved this problem.

CONCLUSION

The Fox Lake copper-zinc deposit is an epigenetic hydrothermal orebody in a metamorphic environment. The evidence from laboratory study of the sulphide and the host rocks indicated in the preceding chapters lead to the conclusion that the ore and host rocks were involved in repeated metamorphic processes. The metamorphism of the Mine series is interpreted to be regional, prograde, (Abukuma type of Winkler, 1967) of the lower amphibolite facies.

The pre-existing rocks were mainly andesites, and basalts, tuffs agglomerates and sedimentary sequences. It is suggested that the host andesitic and basaltic lavas were deposited in successions of considerable thickness on an earlier volcanic material. The associated sedimentary group, volcanogenic greywackes, quartzites and arkoses may have been deposited in a tectonic environment which was later subsided.

Eugeosynclinal volcanism of andesite type probably occurring in a very early stage of the tectonic cycle was probably associated with base metal sulphide mineralization (Wilson and Laznicka, 1972). Alternatively, it could be argued that the hydrothermal ore emplacement followed the initial phase of deformation and metamorphism. The major phase of metamorphism and deformation probably took place during the Kenoran and Hudsonian times.

The zone of alteration (Greenschist facies rocks) next to the ore has been interpreted to result from the alteration of the higher grade country rock following the influx of ore forming solutions. This feature introduces the question of the time relationship between ore emplacement, prograde metamorphism, and retrograde metamorphism. There may be probable answers to this question but it has not yet been resolved.

The Fox Lake copper-zinc deposit differs in its geological setting from many copper-zinc deposits in different parts of the Canadian shield. The Fox mineralization occurs in meta-andesites but many others of the Churchill and Superior structural provinces occur in rhyolites.

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APPENDIX 1: LIST OF SAMPLES, FOX MINE

A. Order of sampling along drift 2,100 level, Figure 3.

STATION	NO.	Megascopic Description of Samples
58	AF 94	Dark amphibolite schist, fine grained, well foliated, quartz-calcite lenses.
60	AF 96	Dark, fine grained amphibolite, garnet porphyroblasts, very weak foliation.
61	AF 97	Light, poorly foliated, fine grained meta-greywacke, altered, chlorite, sulfides.
62	AF 98	Dark amphibolite-hornfels with sulfide lenses.
63	AF 99	Fine grained meta-greywacke, poorly foliated.
64	AF 100	Dark fine grained amphibolite, poorly foliated.
65	AF 101	Fine grained biotite-amphibolite schist.
66	AF 102	Light fine grained, meta-arkose.
67	AF 103	Light fine grained meta-arkose, micro altered-chlorite + sericite.
68	AF 104	Medium grained biotite schist, micro-altered chlorite + sericite.
69	AF 106	Dark, fine grained poorly foliated amphibolite.
70	AF 108	Light, medium grained amphibolite-hornfels.
71	AF 109	Light, fine grained meta-greywacke, disseminated sulfides, micro-altered chlorite + sericite.
72	AF 110	Light, fine grained disseminated sulfides micro-altered chlorite.
74	AF 111	Light, fine grained meta arkose.
75	AF 112	Medium grained amphibolite.
76	AF 113	Fine-medium grained amphibolite with disseminated sulfides.

B. Order of samples from Diamond Drill Hole UF 57, Figure 2

FOOTAGE	NO.	Megascopic Description
9 (feet)	AF 47	Dark, fine grained, meta-andesite, interlayered with quartzite, no foliation.
13.6	AF 48	Light fine grained meta-arkose.
32	AF 49	Light fine grained meta-arkose, amphibolite porphyroblasts.
35	AF 50	Light fine grained meta-arkose, amphibolite porphyroblasts.
40	AF 53	Dark fine grained amphibolite-hornfels.
168	AF 55	Light fine grained biotite-quartz poor schist.

C. List of samples from Diamond Drill Hole UF 485 shown in Figure 2.

FOOTAGE	SAMPLE NO.	Megascopic Description
20 feet	AF 59	Medium dark fine grained amphibolite hornfels.
33	AF 60	Light, radiating amphibole needles in amphibolite.
47.5	AF 61	Mica schist with post-tectonic muscovite
48 - 117	Massive Sulphides	
119	AF 62	Sulphide blebs in meta-arkose
121	AF 63	Biotite schist, crumbly.
124	AF 64	Disseminated sulphides (fine grained meta-greywacke)
126	AF 65	Dark, medium grained poorly foliated amphibolite
127	AF 66	Dark fine grained lineated amphibolite
129	AF 67	Light fine grained biotite-schist. Micro-altered chlorite.
129.5 - 131	Massive Sulphides	
131	AF 68	Medium dark, medium grained amphibolite hornfels.
133	AF 69	Medium dark, medium grained amphibolite hornfels.
148	AF 70	Dark amphibolite, foliated, sulfide pods.
152	AF 71	Dark fine grained amphibolite, fractured with calcite veins, micro-altered, decomposed biotite.

D. List of samples from Diamond Drill Hole UF 645, shown in Figure 2.

FOOTAGE	SAMPLE NO.	Megascopic Description
48.5 Feet	AF 72	Fine grained amphibolite
50	AF 73	Fine grained meta-arkose, disseminated sulfides.
57.6-96.2	Massive Sulfides and disseminated sulfides.	
100	AF 74	Dark, fine grained amphibolite horfels.
100	AF 75	Medium grained epidote-amphibole-calc-silica
125	AF 76	Fine grained light meta-arkose with sulfides
130	AF 77	Porous, crumbly, sericite schist (altered)
132	AF 78	Crumbly sericite schist (alteration halo)
133	Sulfide pod.	
135	AF 79	Porphyroblastic amphibole in arkose.
137	AF 80	Medium grained meta-greywacke.
138-139	Minor Sulfide pod.	
140	AF 81	Dark, fine grained poorly foliated amphibolite.
145	AF 82	Fine grained muscovite schist with disseminated sulfides.
150	AF 84	Porphyroblastic amphibole in arkose.
162	AF 85	Meta-arkose.
165	AF 86	Meta-arkose.
167	AF 87	Dark, fine grained poorly foliated amphibolite.

E. List of samples from Diamond Drill Hole UF 789 shown in Figure 2a.

FOOTAGE	SAMPLE NO.	Megascopic Description
13 feet	A 1	Light, fine grained meta-arkose.
28	A 3a	Light, fine grained biotite schist, disseminated sulfides.
29	A 3b	Light, fine grained meta-arkose with disseminated sulfides.
37-78	Massive Sulfides.	
84	A 12	Blebs of disseminated sulfides in meta-arkose.
96	A 14	Blebs of disseminated sulfides in meta-arkose.
98	A 15	Medium dark amphibolite with biotite, poorly foliated.
121-150	Massive Sulfides.	
157	A 23	Medium dark amphibolite (with biotite) poorly foliated.
159	A 24	Dark, fine grained amphibolite, weak foliation.
161	A 26	Dark, fine grained amphibolite, weak foliation, rare disseminated sulfides.
182	A 28	Dark, fine grained amphibolite, weak foliation, rare, disseminated sulfides.

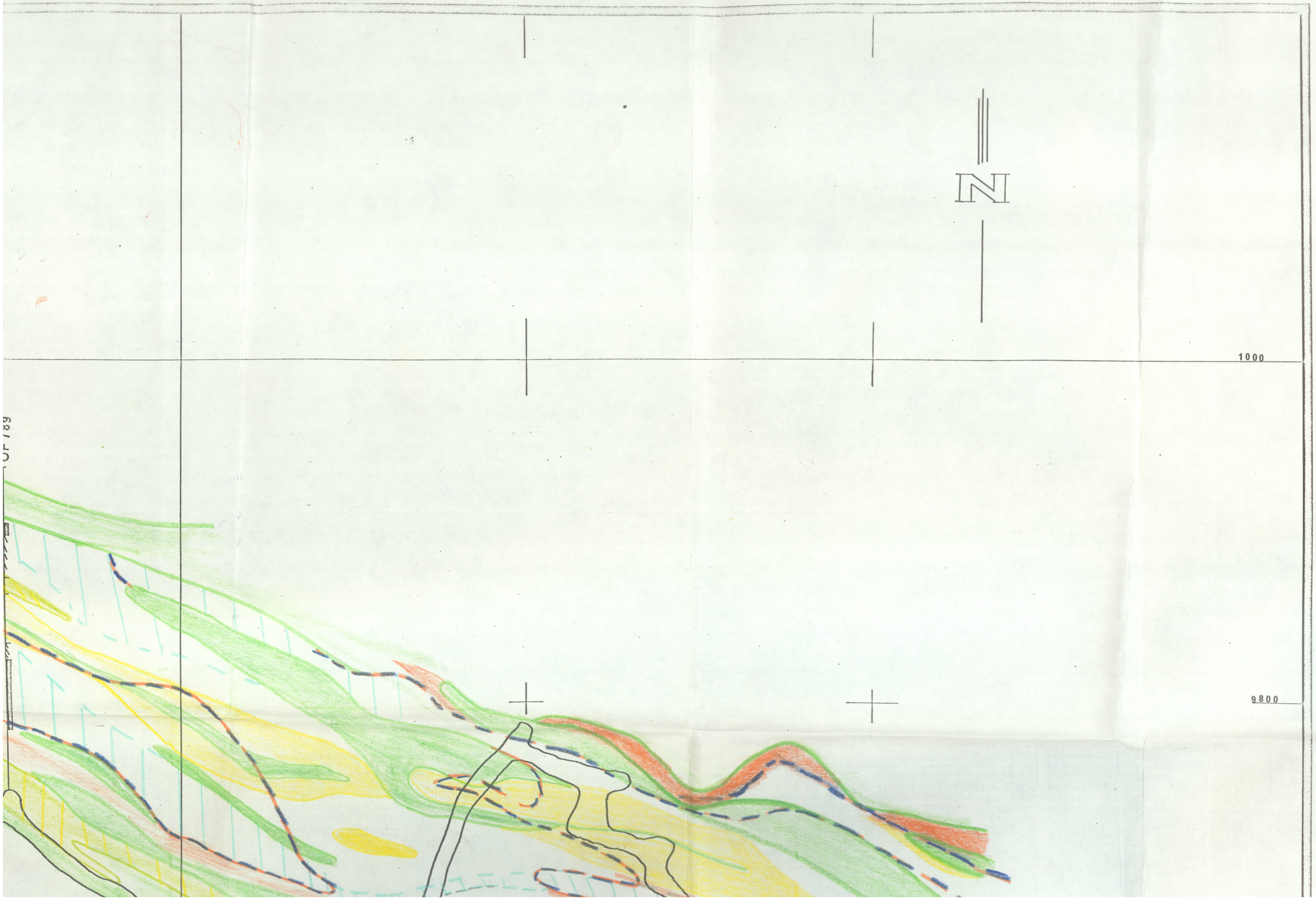
F. List of samples from Diamond Drill Hole UF 793 shown in Figure 2a.

FOOTAGE	SAMPLE NO.	Megascopic Description
8 feet	B 1	Meta-arkose, disseminated sulfides.
16	B 2	Dark, fine to medium grained amphibolite, weak foliation, disseminated sulfides.
23	B 3	Light, fine grained muscovite schist, sericite layers, disseminated sulfides.
36	B 4	Quartzite layers, disseminated sulfides, in sericite schist.
42-50	Massive Sulfides	(B 5 - B 6)
55	B 7	Amphibolite with poikiloblastic sphene.
56-89	Massive and Disseminated Sulfides	(B 7 - B 13)
86	B 12	Porphyroblastic biotite-amphibolite, disseminated sulfides.
92	B 14	Muscovite-altered sericite.
100-114	Massive Sulfides	(B 15 - B 18)
118	B 19	Dark, fine grained amphibolite, weak foliation.

G. List of samples from 2,100 level, Exploration Drift East.

Location No.	Sample No.	Megascopic Description
52	AF 88	Biotite schist, with layers of quartz and quartz + amphibole; micro altered chlorite + sericite.
53	AF 89	Medium grained amphibolite, poor foliation.
54	AF 90	Dark, medium grained amphibolite foliated.
55	AF 91	Meta-arkose, sericite schist, fine grained, micro-altered-chlorite + sericite.
56	AF 92	Light medium grained meta-granite with seams of biotite.
57	AF 93	Meta-andesite, dark, fine grained, poor foliation, amphibole-biotite hornfels.


UF793
UF789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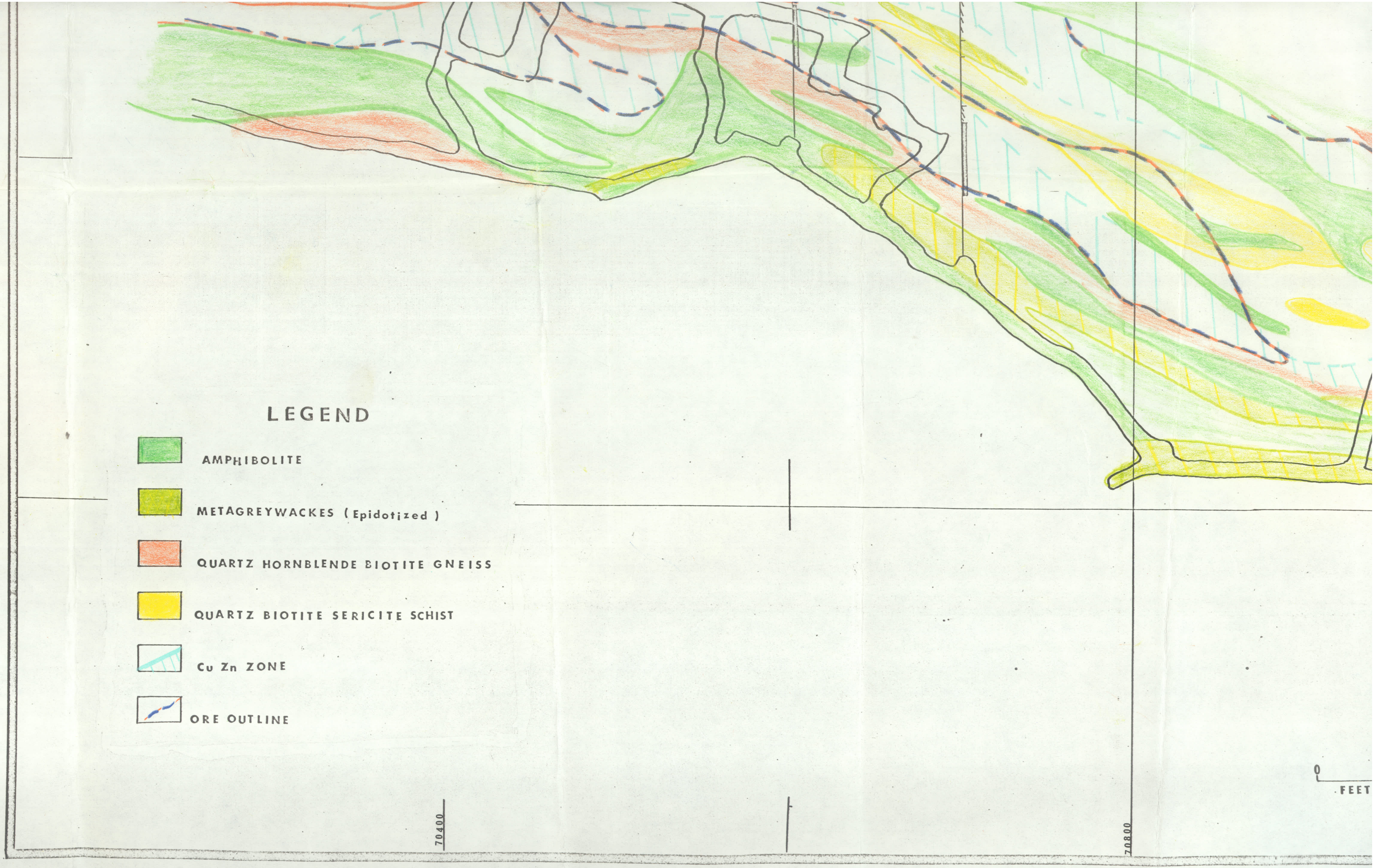

FIG. 2a THE 510 SUB LEVEL FOX MINE

B LEVEL FOX MINE