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DIRECTED STUDIES TERM PAPER

TITLE : GEOLOGY AND MINERALOGY OF THE LENORA-TYEE POLYMETALLIC CU-ZN-(PB-AU-AG) SULFIDE DEPOSITS OF MT. SICKER, VANCOUVER ISLAND, B.C.

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Geology and mineralogy of the Lenora-Tyee polymetallic Cu-Zn-(Pb-Au-Ag) Sulfide deposits of Mt. Sicker, Vancouver Island, B.C.

Abstract

The Lenora-Tyee Cu-Zn-(Pb-Au-Ag) volcanogenic massive sulfide deposits are found within the Myra Formation of the Paleozoic Sicker Group of Vancouver Island. The deposits consist of two east-west elongated orebodies located within sericitic cherty tuffs which are interlayered with mudstones and graphitic shales. The orebodies are composed of quartz and barite ores. The quartz ore consists mainly of quartz, pyrite and chalcopyrite whereas the barite ore consists mainly of barite and sphalerite. The Tyee quartz porphyry magma chamber might have provided the heat source for the hydrothermal activity. The geologic setting, style of mineralization and ore mineralogy of the deposits closely resemble that of Kuroko deposits of Japan and Buchans deposits of Newfoundland.

Introduction

The Lenora-Tyee massive sulfide deposits are located on Mount Sicker about 10 km northwest of the Duncan City near the southeastern end of Vancouver Island (Figure 1). These deposits were discovered at the turn of the last century and have been explored and mined intermittently by several campanies. Mining at Lenora was from 1898 to 1907, whereas at Tyee active mining was from 1901 to 1909. A total of 247,273 tons of copper-gold-silver ore (Appendix Table 1) were produced from these mines between 1898 and 1909 (Stevenson, 1945). Production figures for the mines during the mid-part of this century are not well-known. The

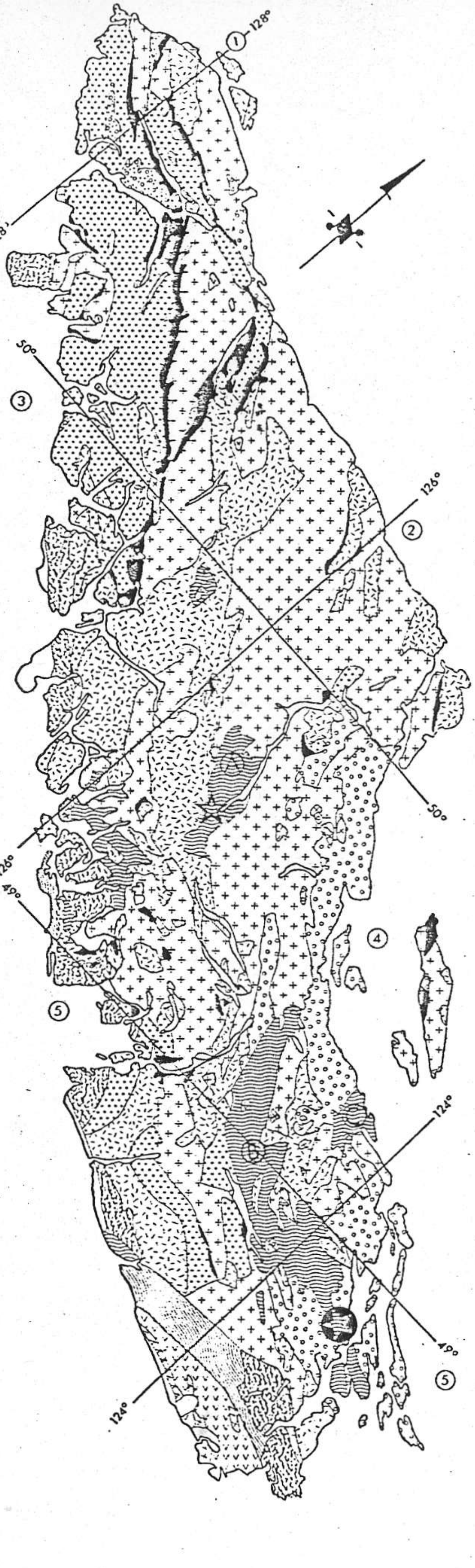


Figure 1.
Geological sketch map of Vancouver Island.
(From Muller, 1980)

LEGEND

CARMANAH GROUP	MIDDLE TERTIARY
CATFACE INTRUSIONS	EARLY TO MIDDLE TERTIARY
METCHOSIN VOLCANICS	EARLY TERTIARY
NANAIMO GROUP	LATE CRETACEOUS
QUEEN CHARLOTTE GROUP KYUQUOT GROUP LEECH RIVER FORMATION PACIFIC RIM COMPLEX	LATE JURASSIC TO EARLY CRETACEOUS
ISLAND INTRUSIONS	EARLY AND (?) MIDDLE JURASSIC
BONANZA GROUP	EARLY JURASSIC
VANCOUVER GROUP PARSON BAY FORMATION QUATSINO FORMATION KARMUTSEN FORMATION	LATE AND (?) MIDDLE TRIASSIC
SICKER GROUP	PALEOZOIC
METAMORPHIC COMPLEXES	JURASSIC AND OLDER

Lenora-Tyee Cu-Zn deposits

Western mines Cu-Zn deposits

① ALERT BAY – CAPE SCOTT, 92 L – 102 I (G.S.C. PAPER 74–8)

② BUTE INLET, 92 K (IN PREPARATION). O.P. MAP 345

③ NOOTKA SOUND, 92 E (IN PREPARATION)

④ ALBERNI 92 F (G.S.C. PAPER 68–50)

⑤ VICTORIA, 92 B, C (FIELD WORK IN PROGRESS: SEE G.S.C. PAPERS 75–1A, p. 21–26 : 76–1A, p. 107–111, 77–1A, p. 287–294.)

A — BUTTLE LAKE UPLIFT
B — COWICHAN – HORNE LAKE UPLIFT
C — NANOOSE UPLIFT

MILES
0 20 40

mineralization is hosted by the Paleozoic rocks of Myra Formation in the Sicker Group of Vancouver Island (Muller, 1980). Similar type of polymetallic sulfides are currently being mined by Western Mines Limited along the Myra Creek near Buttle Lake, in the central part of Vancouver Island (Figure 1). Here, the Myra Creek is the type-locality for the Myra Formation (Muller, op cit). This paper discusses the geology and ore mineralogy of the Lenora-Tyee deposits based on summer field mapping and studies of samples collected from the deposits. Supplementary data from available literature have been used were necessaryto elaborate certain aspects of the deposits. The deposits are also compared with known type-deposits of similar setting, e.g. Kuroko type-deposits.

Geology of Sicker Group

The geology of the Sicker Group of Vancouver Island has been described in details by Muller (1980). The rocks of the Sicker Group are of Paleozoic age and range from Lower or Middle Devonian to Permian, and are probably the oldest rocks on the island. These rocks outcrop in three main structural culminations namely the Buttle Lake Uplift, the Cowichan-Horne Lake Uplift and the Nanoose Uplift (Muller, op cit), Figure 1. Muller has divided the Sicker Group into three main formations. In the order of decreasing age, they are Nitinat Formation, Myra Formation and Buttle Lake Formation. The Buttle Lake Formation is separated from the Myra Formation by the so called "Sediment-Sill Unit" which seems to be gradational between the two formations. The lithologies of each of these formations are summarised below. The Mount Sicker Cu-Zn-(Pb-Au-Ag) sulfide deposits occur in the Cowichan-Horne Lake Uplift of the Sicker Group and are hosted by the Myra Formation.

Lithologies of the Sicker Group Formations (After Muller, 1980):

Buttle Lake Formation : limestone, calcarenitic, crinoidal, commonly recrystallized; interbedded with subordinate or equal thicknesses of calcareous siltstone and chert; some diabase sill

Sediment-Sill Unit : thinly bedded to massive argillite, siltstone and chert with interlayered sills of diabase

Myra Formation : basic to rhyodacitic banded tuff, breccia and (?) lava; thinly bedded to massive argillite, siltstone, chert

Nitinat Formation: metabasaltic lavas, pillowed or agglomeratic, commonly with large conspicuous uralitized pyroxene phenocrysts and amygdules of quartz and dark green minerals; minor massive to banded tuff.

Mine geology

The mine geology is dominated by felsic volcanics which are occassionally interlayered with cherty and argillaceous sediments. The rock types (Appendicies 3 and 4) include felsic lapilli and ash tuffs which are commonly quartz bearing, cherty ashtuffs, graphitic black shale, and rhyolite quartz porphyry. These are intruded by fine to medium-grained diorites which in some places appear to be almost conformable with the volcanics. Where the diorites occur in contact with the volcanics, a thin hornfelsic contact metamorphic aureole is commonly developed. The felsic tuffs within the metamorphic aureole are usually bleached and baked up and exhibit earthy white texture. Some elliptical quartz "eyes" (phenocrysts) in the tuffs show signs of resorption or recrystallization into angular or subhedral rectangular quartz grains. Cherty tuffs are locally transformed into soapstone in the metamorphic aureole. The volcanic tuffs and associated argillaceous sediments have undergone regional low to medium-grade greenschist metamorphism and are now represented by sericite ± chlorite schists and occassionally by graphitic schists and shales. In most cases the penetrative fabric or schistosity due to metamorphism is so intense that it obscures primary volcanic textures and makes distinction between flows and pyroclastics difficult if not impossible. However, the presence of interlayered fine and coarse laminae of pyritic chert in most of the schistose volcanics strongly suggest that these rocks are mainly pyroclastics, possibly lapilli and ash tuffs. The foliation in the rocks has been deformed and drawn into very tight isoclinal drag folds (Plate 1) of varying amplitudes. The folding of the foliation or schistosity suggests that metamorphism possibly preceded or was contemporaneous with deformation. Although the the strike and dip of the foliation is variable due to folding, the general dip direction is commonly towards the south or southwest. The amount of dip varies from 50^{o} to 70^{o}. The stratigraphy seems to follow closely the strike and dip direction of the foliation. The mine sequence of felsic volvanics is terminated south of the Lerona pit by a mojar fault (Appendix 3). The area south of this fault is occupied mainly by intermediate and mafic volcanics.

In contrast with felsic tuffs which seem to be strongly schistose, the rhyolite quartz porphyry (Appendices 3 and 4) is generallyless foliated and commonly exhibits a strong lineation plunging gently toward the east. This porphyry is a very distinctive unit in the mine area and is characterised by the abundance of large elliptical quartz "eyes" up to 8 mm in length, the percentage of which ranges between 5 % and 7 %. It is commonly referred to as "Tyee porphyry" in the mine literature and exploration companies' reports. The same nomenclature is used by Muller (1980). Stevenson (1945) named the same unit "Rhyolite porphyry". From the literature, the relation of of this rhyolite quartz porphyry to the rest of the volcanics is not very clear. Several workers considers it to be intrusive. Stevenson (op cit) noted that "where it was possible to study the relation of the rhyolite to the sediments underground, the rhyolite was seen to intrude the sediments as sills that follow the folding of the sediments". He also observed the dykes of the rhyolite porphyry to cut early phases of the diorites. Outside the mine area, a correlatable rhyolite porphyry has been mapped by Muller (1980). In some localities, Muller observed the rhyolite to exhibit conformable relationship with associated volcanics and sediments in form of sills and (?) flows, whereas in other localities exhibits conformable as well as zigzagging crosscutting contacts. In the latter case, Muller considers the quartz porphyry to have apparently intruded into beds that may have been penecontemporaneous sediments of the Myra Formation. In the present study, a few outcrops of the quartz porphyry mapped on the northern side of the Lenora pit (Appendix 4) do not give any clear relationship to the adjacent felsic tuffs. The surface outcrop pattern of the porphyry, however, seems to be conformable with what is interpreted to be the general trend of the stratigraphy. Age determination on zircons from the quartz porphyry indicates it to be of Lower or Middle Devonian age (Muller, 1980). This age determination gives the oldest age for the Myra Formation as well as the oldest age so far determined for the Sicker Group.

Significance of the Tyee Quartz Porphyry

The significance of the Tyee quartz porphyry can be understood if the available geologic information is intergrated into a broad framework of the evolution of the stratigraphy and the associated sulfide deposits. Petrographic examination of the Tyee quartz porphyry indicates it to consist of quartz and altered feldspar phenocryts set in a fairly uniform fine-grained matrix of quartz and sericite (Plate 2). Sericite occurs as a metamorphic alteration product of phenocryst and groundmass feldspar. This uniform texture suggests the porphyry to be either a volcanic flow or a subvolcanic intrusive, and contrasts strongly with that of the associated volcanics which appear to be fragmental or pyroclastic. The semi-conformable field relationship of the porphyry to the associated volcanics as observed by Stevenson (1945) and Muller (1980) suggests the porphyry to be possibly closely related to the the rest of the volcanics. Stevenson (1945) suggested the mineralization to be related to the rhyolite porphyry and the diorite intrusions, and considered the ore solutions to have originated in the magma chamber from which the porphyry and diorites differentiated. Although a magmatic source of ore solutions is suggested by Stevenson, the ore fluids could have been evolved sea water. Close association of quartz-feldspar porphyries (QFP) and rhyolite domes with volcanogenic massive sulfides has been observed in several deposits (Hopwood, 1976), for example at Noranda (Knuckey et al, 1982; Ikingura, 1984) and in Kuroko deposits (Lambert and Sato, 1974). The porphyries have been envisaged as the source of heat for the hydrothermal activity. A similar role is proposed here for the Tyee quartz porphyry in the formation of Lenora-Tyee massive sulfide deposits. The geologic setting and style of mineralization of the Lenora-Tyee deposits closely resemble that of Kuroko deposits in which sea water involvement has been established. It seems plausible that a shallow magma chamber for the Tyee porphyry probably acted as a heat source for the generation of hydrothermal fluid circulation in the volcanic pile and leaching of metals, followed by the precipitation of the metals as sulfides on the sea floor (Appendix 2). Further studies will be needed to evaluate critically the role of the Tyee quartz porphyry in the formation of the Lenora-Tyee massive sulfide deposits. Emphasis has to be placed on the elucidation of the relationship of the porphyry to the rest of the volcanic stratigraphy. Understanding of the shape and dimensions of the porphyry could assist in assessing its potential as a heat source for the hydrothermal activity in the area. Oxygen and hydrogen isotope studies of hydrothermally altered rocks could also give clues about the origin of ore fluids.

Mineralization

The mineralization occurs as two E-W elongated massive sulfide orebodies within the felsic tuffs (Figure 2). Black shale or argillite is commonly found along the mineralized horizon. The underground geometry of the orebodies has been described by Stevenson (1945) who mapped the mine workings in 1941 and 1944. The two orebodies are found about 46 m apart and are referred to as the north orebody and the south orebody by Stevenson. The north orebody is estimated to have a strike length of 518 m and a down dip width of 36 m. The thickness varies from 0.3 m to 3 m. The south orebody has a length of 609 m, a vertical extent of about 46 m and a thickness of 6 m. Two main easterly trending faults displace the orebodies (Figure 3). The north fault displaces the south orebody about 61 m upward and an unknown distance eastward with respect to the north orebody (Stevenson, 1945). The south orebody is partly exposed on the surface in the Lenorapit (Appendix 3), although the ore has been completely mined out. In the Lenora pit, the massive sulfide mineralization is underlain by massive to finely laminated or bedded cherty pyritic tuffs (Plates 3a and 3b) which grade into strongly sericitized ash tuffs towards the base. The footwall sequence of sericitic tuffs close to the ore horizon are locally interlayered with black sericitic shale or argillite (Figure 4). The exposed massive sulfides consist mainly of fine-grained pyrite within a matrix of fine to medium-grained quartz. The cherty tuffs and associated sulfides are exposed on the northern wall of the Lenora pit (Appendicies 3 and 4). Unmineralized quartz-feldspar phyric felsic tuffs (Plate 4) underlain by black mudstone and graphitic shale, are exposed on the southern wall of the Lenora

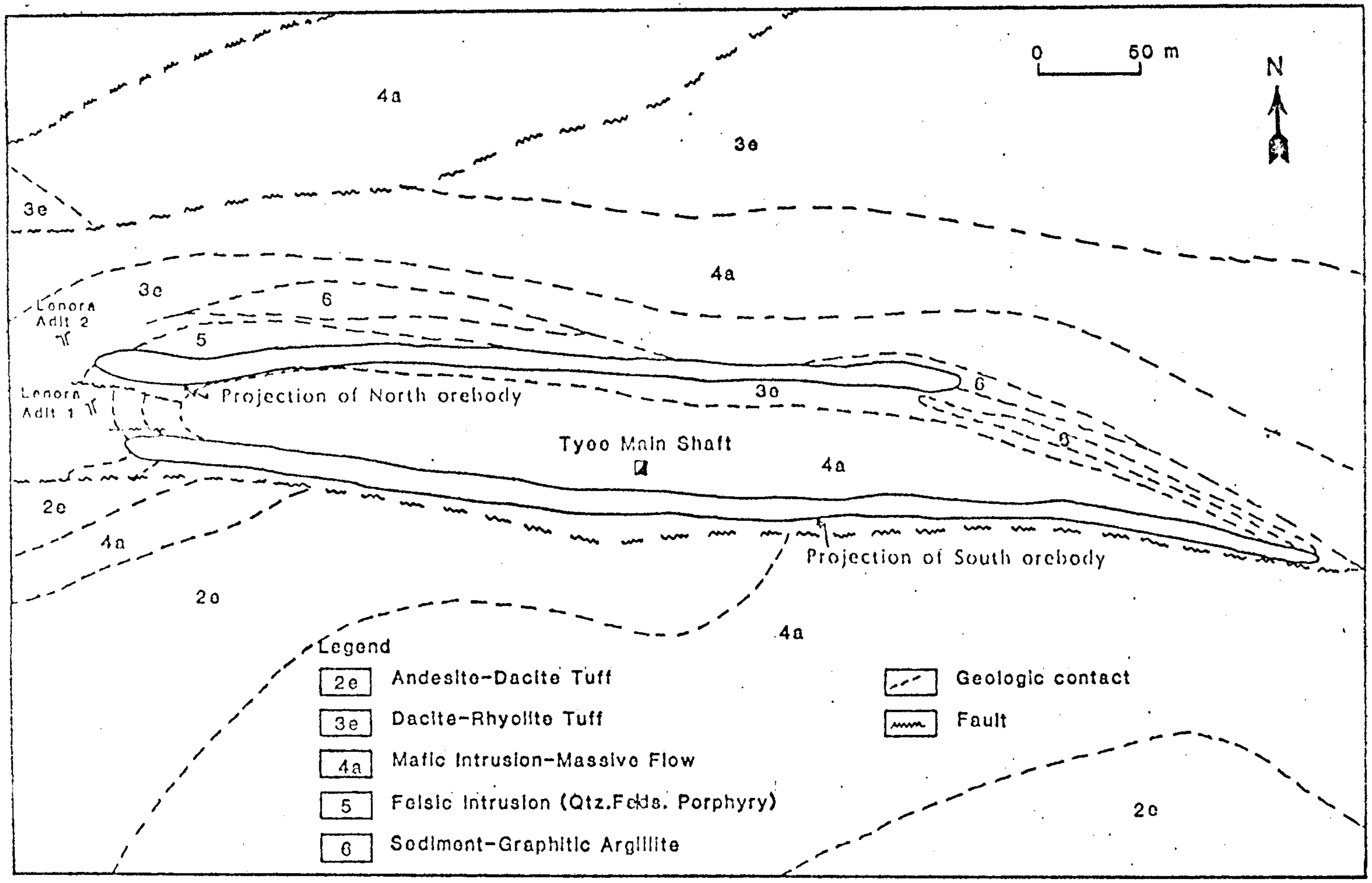


Figure 2. Lenora-Tyee Mine Geology. (Extracted from Falconbridge Copper Corporation,Postuk Fulton Option Compilation, April, 1984). 2e is the youngest volcanic unit on this map.

pit. These rocks possibly represent the hanging wall rocks of the south orebody.

The age relationship of the mineralization to the host rocks is not fully established. Earlier workers consider the mineralization to be younger than the host rocks and hence referred to the two orebodies as the north vein and the south vein, possibly with the implication of replacement or fissure filling type of mineralization (Stevenson, 1945). Stevenson (op cit) interpreted the mineralization to post-date the folding and metamorphism of the sediments. He mentioned that narrow veins of barite ore that cut folded sediments indicate post-folding age and unreplaced fragments of schistose sediments within the ore indicate a post-metamorphism age. From the present study, the field relationship and the general setting of the mineralization and host rocks however do not seem to support the earlier views. The occurrence of the mineralization within bedded cherty tuffs along certain stratigraphic horizons strongly suggest the mineralization to be possibly syngenetic and probably to have formed subaqueously by hydrothermal exhalative processes at the sea floor. In this respect, the Lenora and Tyee deposits appear to share common characteristics with other known deposits of similar setting, for example, the Kuroko-type deposits. Subaqueous deposition of the massive sulfides at Lenora and Tyee is further confirmed by the presence of argillaceous sediments or shales which occur directly below and above the ore horizon. Post-ore metamorphism and deformation might have mobilized the sulfides and led to the formation of narrow ore veins observed to cut folded rocks by Stevenson (op cit). The veins could also be

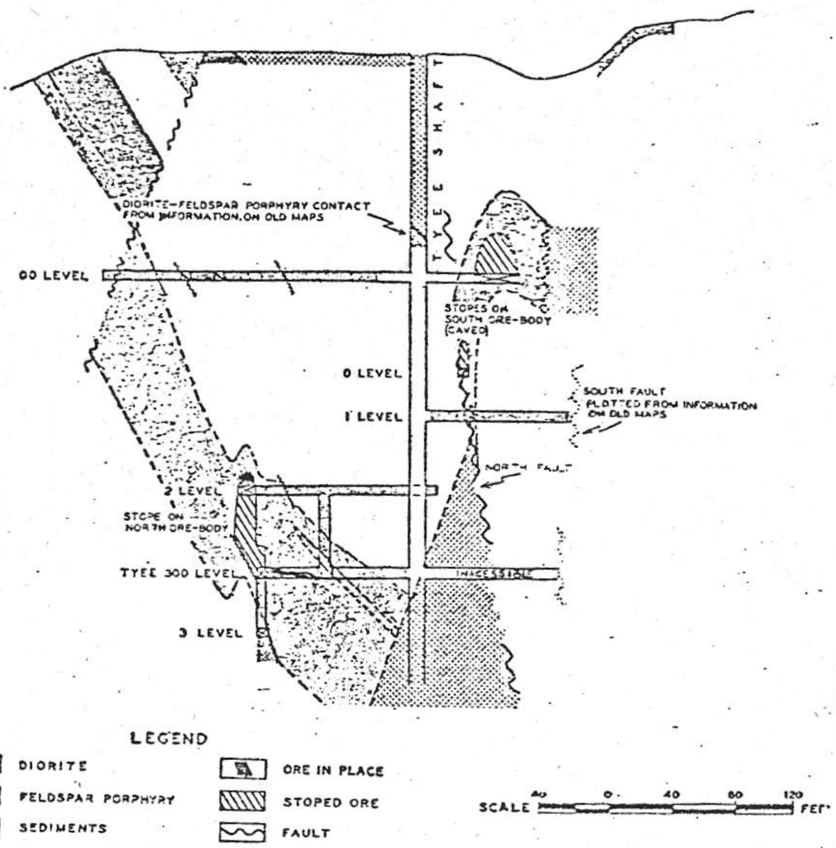


Figure 3. North-south cross-section through the Tyee shaft, showing stopes on the North and South orebodies.
(From Stevenson, 1945)

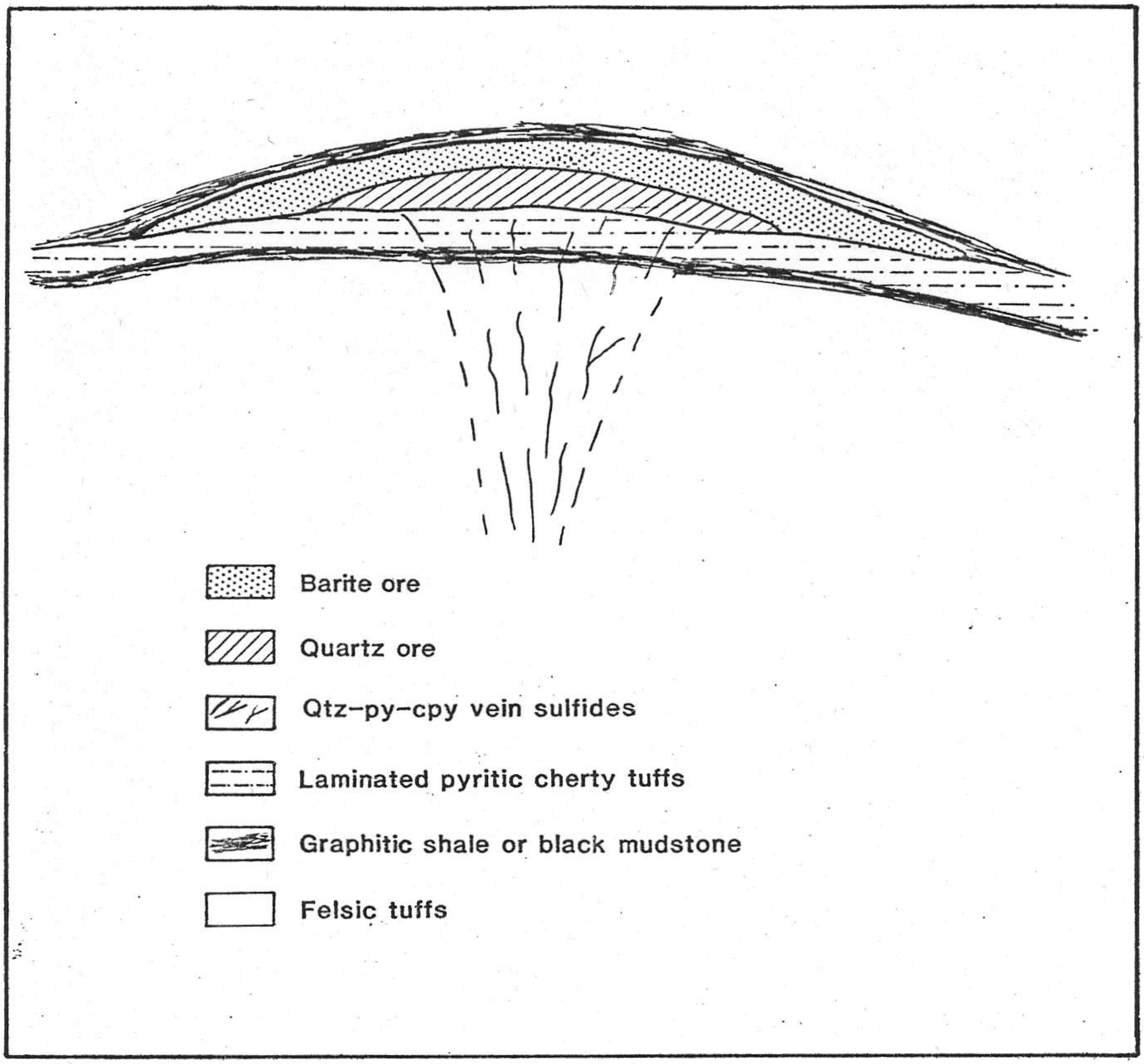


Figure 4. Generalized geometry of the Lenora-type orebody

associated with circulating hydrothermal fluids in the late stages of deformation. Evidence of post-ore deposition hydrothermal activity is also given by the quartz veins which cut the massive sulfides and the host rocks.

Ore mineralogy

Two closely associated ore-types are recognised. There is "barite ore" which consists mainly of barite and sulfides, with small amounts of quartz; the other type of ore is called "quartz ore", this consists mainly of quartz, pyrite and chalcopyrite. The disposition of the two ore-types within the orebodies is not well-known. However, surface mapping done in the Lenora pit by the author and preliminary underground mapping done in the Lenora Adit No. 2 by Dave Lefebure (1984) suggest the quartz ore to form the base of the orebodies and is possibly overlain by the barite ore. The generalized geometry of the Lenora-type orebody is illustrated diagramatically in Figure 4.

The chemical and mineralogical compositions of average quartz and barite ores have been analysed by Stevenson (1945) and the results are summarized in Tables 2, 3 and 4 in the Appendix. The ore mineralogy and texture of samples used in the present study are described below.

Barite ore

Is a gray coloured fine-grained massive ore consisting about 75 % barite, 20 % sulfides and 5 % quartz and calcite. The ore rarely exhibit weak streaky banded texture. Banding is defined by fine discontinuous streaks of sulfides alternating with barite streaks or laminae. The petrography of the sulfide mineralogy is summarised below and the textures are illustrated in Plates 5 to 12.

Sphalerite : 10 - 15 %

Disseminated grains and irregular bodies within barite matrix (Plates 6 and 7). Commonly forms interlocking or sutured contacts with barite host.

Galena : 2.5 %

Irregular to skeletal grains within sphalerite (Plate 8). Also found along grain contacts of sphalerite and barite. Locally replaces sphalerite (Plate 9) or chalcopyrite (Plate 10).

Chalcopyrite : 1.5 %

Occur as disseminated grains within barite matrix and along sphalerite and barite grain contacts (Plates 6, 8, and 10). Rarely found as blebs or irregualar tiny grains in sphalerite.

Pyrite : 0.5 %

Isolated anhedral to subhedral fractured grains in barite matrix. Most pyrite grains are commonly replaced by sphalerite, chalcopyrite or galena and are found as ghosts or remnants in the ore (Plate 11).

Tetrahedrite :

Occur in trace amounts along sphalerite and galena grain boundaries (Plate 9) and also as isolated grains in barite matrix.

Chalcocite :

Found locally in very minor traces and appears to be a secondary mineral.

Mineral paragenesis

Textural relationships amoung the sulfide minerals in barite ore indicate the following paragenetic associations: sphalerite-chalcopyrite-galena, pyrite-sphalerite-galena, sphalerite-galena-tetrahedrite, tetrahedrite-chalcocite. From these mineral associations, the following generalized paragenetic sequence emerges : Pyrite-sphalerite-(chalcopyrite)-galena-tetrahedrite-chalcocite. Because these sulfides have been metamorphosed it is difficult to attribute their present textures to primary deposition. Sulfides tend to re-equilibriate rather faster with increasing temperature during metamorphism (Vokes, 1969). Re-equilibriation usually destroys primary textures and forms minerals and textures stable under prevailing metamorphic conditions. The above mineral paragenetic associations and sequences may therefore be result of re-equlibriation by metamorphism.

Quartz ore

This is a light-coloured yellowish-white ore. Unlike the barite ore, the mineralogy of quartz ore is rather simple. Pyrite and chalcopyrite are the principal sulfide minerals in the ore. Quartz is very abundant as a gangue mineral whereas barite and carbonates are virtually absent. Minor traces of sericite occur in the gangue. The mineralogical composition of quartz ore varies from predominatly quartz-pyrite assemblage through quartz-pyrite-chalcopyrite assemblage to quartz-chalcopyrite assembalge. In all these mineral assemblages quartz may constitute up to 50 % of the ore. Pyrite commonly exhibits fine-grained sugary texture in most hand specimens. In polished thin sections pyrite occur as massive aggregates and subhedral grains which are commonly fractured or brecciated (Plate 12) and veined by quartz. Chalcopyrite occurs disseminated or as irregular bodies in the quartz gangue.

Although significant amounts of gold and silver have been recovered from the sulfide ores (Table 1), no separate silver or gold minerals were observed in polished thin sections. This suggests that silver and gold are probaly incorporated in the lattices of the sulfide minerals.

Hydrothermal alteration

Hydrothermal alteration is widely spread in the mineralized volcanic tuffs. Strong sericite alteration is observed in the rocks below the ore horizon in the Lenora pit. Chlorite alteration is observed very rarely in a few places in the mine area. Generally sericite alteration seems to be widely developed in the surface exposures than chlorite alteration. The subsurface geometry of these alterations is unknown. Silicification was not observed in rocks mapped during this study, although it has been documented by Stevenson (1945) who mapped the underground mine workings. Sericitized rocks exhibit very simple mineralogy. Sericite and quartz are the main minerals (Plate 13). Calcite is commonly found as an accessory mineral. Remnants of feldspar phenocryts occur in weakly or moderately sericitized rocks.

Chlorite alteration was examined only in one thin section and appears to replace sericite.

Discussion

The geologic setting and ore mineralogy of Mount Sicker Lenora-Tyee massive sulfide deposits resemble that of other Phanerozoic volcanogenic sulfide deposits, especially the Kuroko-type deposits. Both Mt. Sicker and Kuroko deposits occur as stratiform polymetallic deposits associated with felsic volcanic rocks. Pyroclastics are abundant in both types of deposits. Argillaceous sediments in the form of mudstones and shales interlayed with volcanic tuffs occur in Mt. Sicker deposits as well as in Kuroko deposits, although the sedimentary component is much less in the former. Association of massive sulfides with bedded cherty tuffs in Mt. Sicker deposits suggests that the sulfides were precipitated subaqueously possibly by hydrothermal exhalative processes. A similar mechanism has been suggested for the formation of Kuroko deposits (Lambert and Sato, 1974; Franklin et al, 1981). The occurrence of bedded barite ores in both deposits suggests that the ores formed as chemical precipitates. The ore and gangue mineralogy of both deposits is similar, although neither anhydrite or gypsum have been identified in the Mt. Sicker deposits. Sericite and chlorite alterations are developed both in Mt. Sicker and Kuroko deposits. Other close analogues of Mt. Sicker deposits are the Buchans deposits of Newfoundland. A good description of the geology and mineralogy of Buchans deposits has been given by Thurlow and Swanson (1981) and Strong (1981). These deposits exhibit almost all the features outlined above for Kuroko and Mt. Sicker deposits.

Although many similarities exist between Mt. Sicker deposits and Kuroko and Buchans deposits, there are also differences. Rhyolite domes or bodies which exhibit close spatial and genetic relationship to mineralization in Kuroko deposits and partly in Buchans deposits have not been found in Mt. Sicker deposits particularly at Lenora and Tyee. The Tyee rhyolite quartz porphyry, however, could be a good analogue although its relationship to the stratigraphy and mineralization is not yet well-understood. Mineralogical ore zonation is less developed in Mt. Sicker deposits than in Kuroko deposits although this could be partly due to the fact that the Mt. Sicker deposits have not been well studied. Gypsum and anhydrite are common in Kuroko deposits but have not been found in Mt. Sicker deposits as well as in Buchans deposits. Fragmental or transported breccia ore found in Kuroko and Buchans deposits seems to be absent in Mt. Sicker deposits.

Summary and conclusion

The Lenora-Tyee polymetallic massive sulfide deposits are associated with the felsic volcanic rocks of the Myra Formation of Paleozoic Sicker Group of Vancouver Island. The sulfide mineralization occurs as two east-west elongated massive sulfide orebodies within sericitic cherty tuffs. The volcanic rocks have been metamorphosed to sericite + chlorite schists whereas the associated argillaceous sediments have been transformed into sericitic and graphitic shales. Folding appears to post-date or to have been contemporaneous with metamorphism. The mineralization is stratiform and possibly formed subaqueously by hydrothermal exhalative processes. The Tyee quartz porphyry magma chamber might have been the heat source for the hydrothermal activity. The massive sulfide orebodies consist of two closely allied ore-types known as quartz ore and barite ore respectively. The quartz ore is light-coloured and consists mainly of quartz, pyrite, and chalcopyrite. Barite ore is gray-coloured and contains mainly barite and lesser amounts of sulfides. Sphalerite is the principal sulfide mineral in the barite ore followed by galena. The emplacement of the mineralization was accompanied by widespread sericite alteration in the host rocks. Chlorite alteration is much less developed. The geologic setting, style of mineralization and ore mineralogy of Lenora-Tyee deposits bear much resemblance to the Kuroko deposits of Japan and the Buchans deposits of Newfoundland.

References

Franklin, J.M.; Sangster, D.M. and Lydon, J.W., 1981. Volcanic associated massive sulfide deposits. 75th Econ. Geol. Ann. Vol., p. 485-627.

Hopwood, T.P., 1976. "Quartz eyes" bearing porphyroidal rocks and volcanogenic massive sulfide deposits. Econ. Geol., v. 71, p. 589-612.

Ikingura, J.R., 1984. Hydrothermal alteration and Cu-Zn sulfide mineralization in the D-68 zone, Corbet mine, Noranda district, Quebec, Canada. M. Sc. Thesis, Carleton Univerisity, 205 p.

Knuckey, M.J., Comba, C.D.A. and Reverin, G., 1982. Structure, metal zoning and alteration at the Millenbach deposit, Noranda, Quebec. GAC Spec. Pap. 25, P. 255-295.

Lambert, I.B. and Sato, T., 1974. The Kuroko and associated ore deposits of Japan : A Reveiw of Their Features and Metallogenesis. Econ. Geol., v. 69, p. 1215-1236.

Muller, J.E., 1980. The Paleozoic Sicker Group of Vancouver Island, British Columbia. GSC Paper 79-30, 23 p.

Stevenson, J.S., 1945. Geology of the Twin "J" Mine. CIMM Transc., v. XLVIII, p. 294-308.

Strong, D.F., 1981. Notes on ore mineralogy of the Buchans district; In Swanson, E. A., Strong, D.F. and Thurlow, J.G. (eds.) : The Buchans ore bodies; Fifty Years of Geology of Mining. GSC. Spec. Pap. 12, p. 143-160.

Thurlow, J.G. and Swanson, E.A., 1981. Geology and ore deposits of the Buchans area, central Newfoundland; In Swanson, E.A., Strong, D.F. and Thurlow, J.G. (eds.) : The Buchans ore bodies; Fifty Years of Geology of Mining. GSC. Spec. Pap. 12, p. 113-142.

Vokes, F.M., 1969. A Review of the Metamorphism of Sulfide Deposits. Earth Sci. Reviews, v. 5, p. 99-143.

APPENDIX 1

Table 1 : Production from Mt. Sicker mines

Mine	Tons	Gold, Oz	Silver, Oz.	Copper, lb.	
Lenora (1898-1907) ..	78,983	10,349 0.13 oz/T	279,935 3.54 oz/T	5,951,227	3.76%
Tyee (1901-1907)	168,290	24,517	441,278	12,876,369	3.83%
		~~0.36~~ 0.15 oz/T Au	2.62 oz/T		

(From Stevenson, 1945)

APPENDIX 1

Table 2 : Analyses of Mt. Sicker ores (From Stevenson, 1945)

	1	2	3	4	5	6	7	8
Gold, oz/ton	0.14	0.075	0.20	0.01	0.01	0.03	0.026	0.04
Silver, oz/ton	2.87	2.05	4.0	4.8	0.3	1.5	3.6	0.9
Copper, per cent ..	4.56	1.32	1.05	2.06	0.84	2.10	0.86	7.06
Lead, per cent	....	0.6	0.4	2.3	1.0	0.9	1.1	trace
Zinc, per cent	....	6.12	7.6	19.7	8.8	12.3	17.8	0.21
Iron, per cent	....	....	21.9	5.23	8.59	4.77	3.42	8.43
Lime, per cent	6.60	....	....	....	....	....	....	....
SiO_2, per cent	13.50	....	6.10	13.20	2.88	9.62	4.40	68.14
$BaSO_4$, per cent ...	37.30	....	26.3	32.5	59.3	51.9	47.7	1.12

1. Average assay of ore from Tyee mine during 1904, mostly from South orebody ?
2. Average assay of ore mined by Twin "J" 1943-44, mainly from North orebody
3. Barite ore, North orebody
4. Barite ore, North orebody
5. Barite ore, North orebody
6. Barite ore, South orebody
7. Barite ore, South orebody
8. Quartz ore, North orebody

Table 3 : Mineralogical composition of 'Barite Ore' (%)
(Calculated from chemical analyses in Table 2)

Column in Table 2	Pyrite	Chalco-pyrite	Sphal-erite	Galena	Barite	Quartz	Calcite (calculated)
3.......	45.0	3.4	11.3	0.5	26.3	6.1	7.4
4.......	7.4	6.0	29.4	2.7	32.5	13.20	8.8
5.......	17.0	2.4	13.2	1.2	59.3	2.88	4.0
6.......	6.3	6.1	18.3	1.0	51.9	9.62	6.7
7.......	5.5	2.5	26.6	1.3	47.7	4.40	12.0

(From Stevenson, 1945)

APPENDIX 1

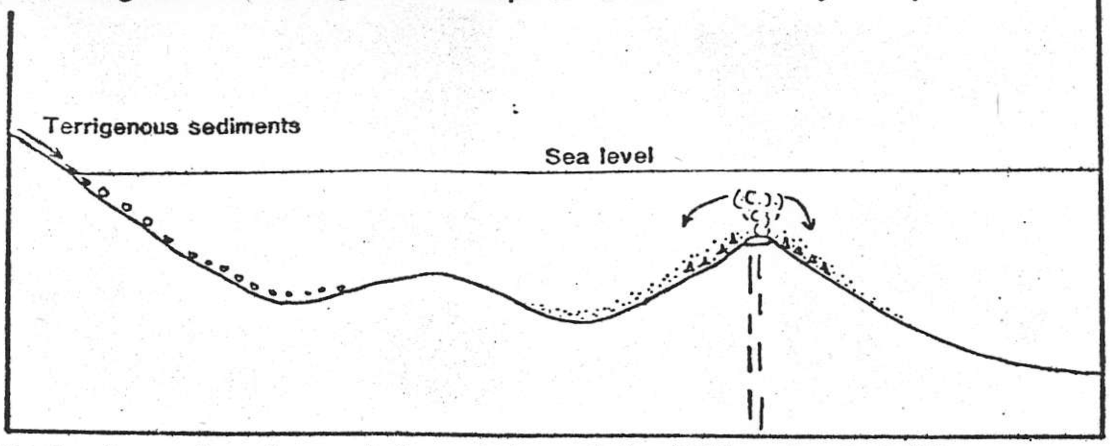
Table 4 : Mineralogical composition of a typical 'Quartz Ore' (%)

Pyrite	4.1	Barite	1.1
Chalcopyrite	20.5	Quartz	68.1
Sphalerite	0.3	Calcite	5.6
Galena	trace		

(From Stevenson, 1945)

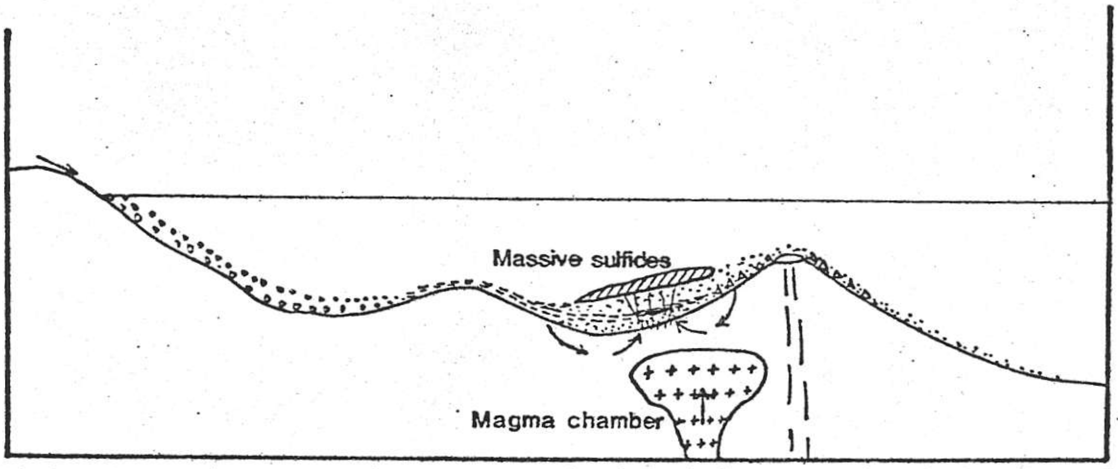
Diagrams illustrating the development of the Lenora–Tyee deposits

A.



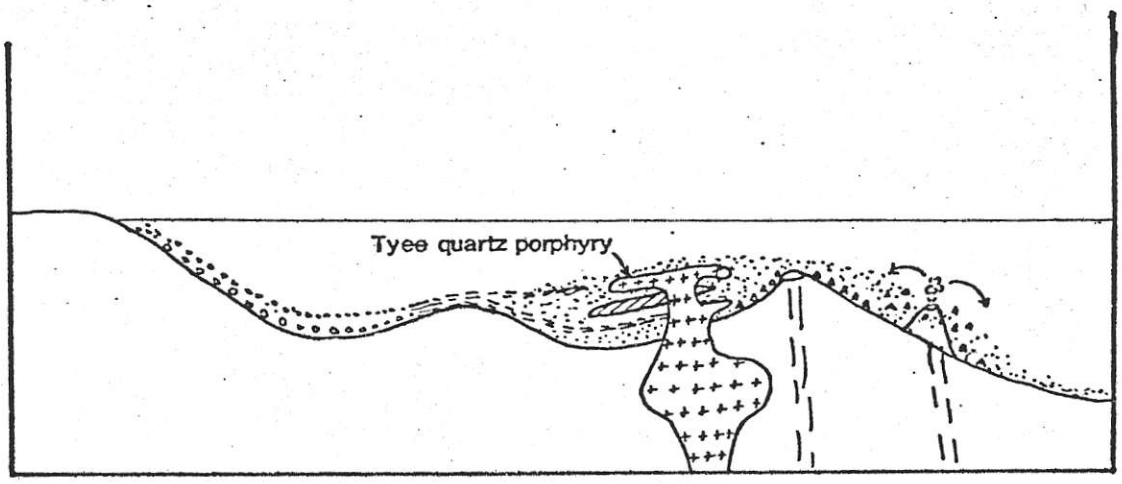
Explosive volcanism and deposition of lapilli and ash tuffs.

B.



Rising Tyee quartz porphyry magma chamber induces active hydrothermal activity in the volcanic pile, followed by the deposition of sulfides on the sea floor.

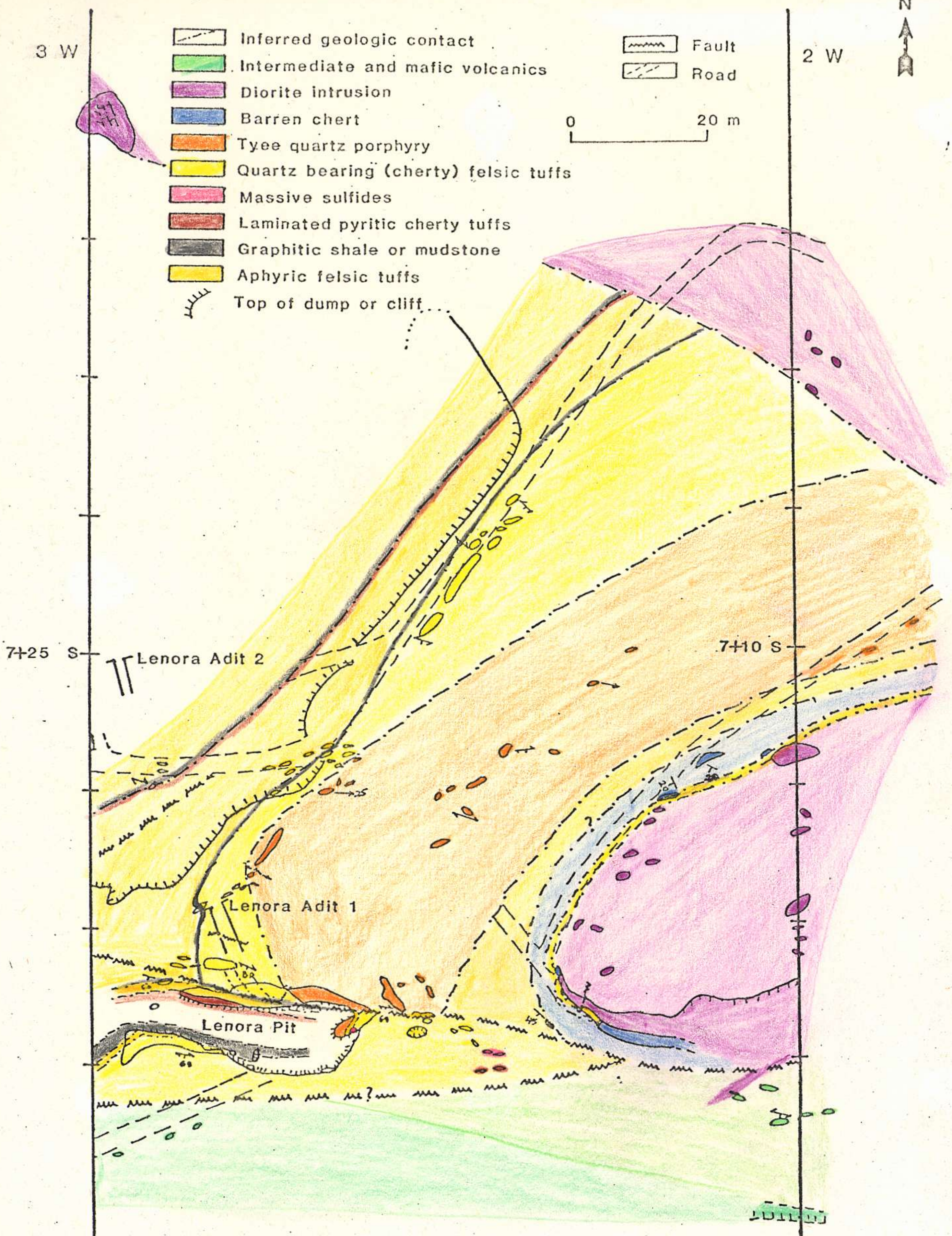
C.



Final emplacement of the Tyee quartz porphyry as sills and flows.

APPENDIX 3

Lenora Mine Geology (Ikingura, 1984)



APPENDIX 5

Mineral abbreviations :

bar	barite
cal	calcite
che	chert
cpy	chalcopyrite
gal	galena
py	pyrite
qtz	quartz
ser	sericite
sph	sphalerite
tet	tetrahedrite

PLATES

Field of view : 4.20 mm for Plates 1, 2, 3b, 4, 14.

2.64 mm for Plates 5, 6, 7, 8, 9, 10, 11, 12, 13.

Plate 1. Drag folds in a sericitic shale

Plate 2. Tyee quartz porphyry : quartz phenocryst set in a uniform fine-grained groundmass of quartz and sericite

Plate 3a. Laminated pyritic cherty tuff exposed in the Lenora Pit

Plate 3b. Photomicrograph of the laminated cherty tuff

Plate 1

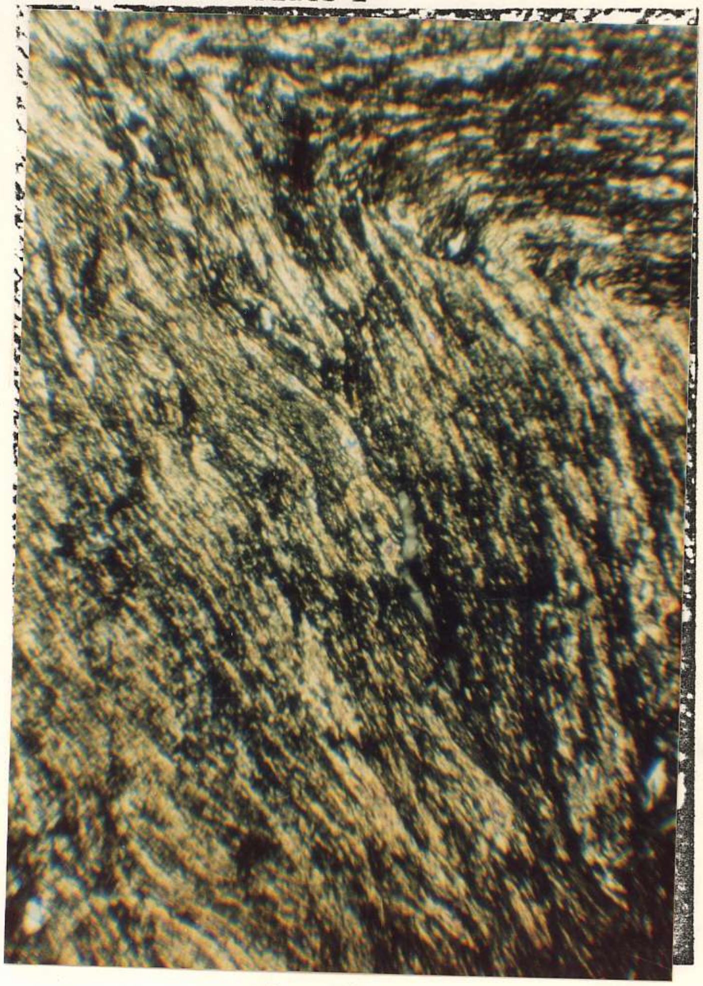
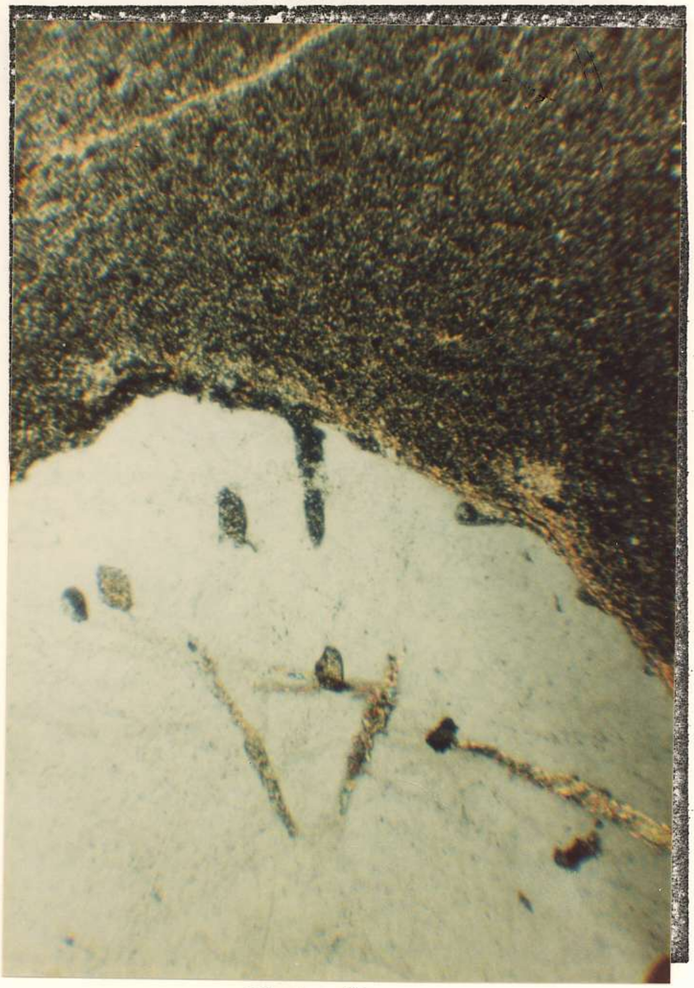


Plate 2



~~Plate 3a~~

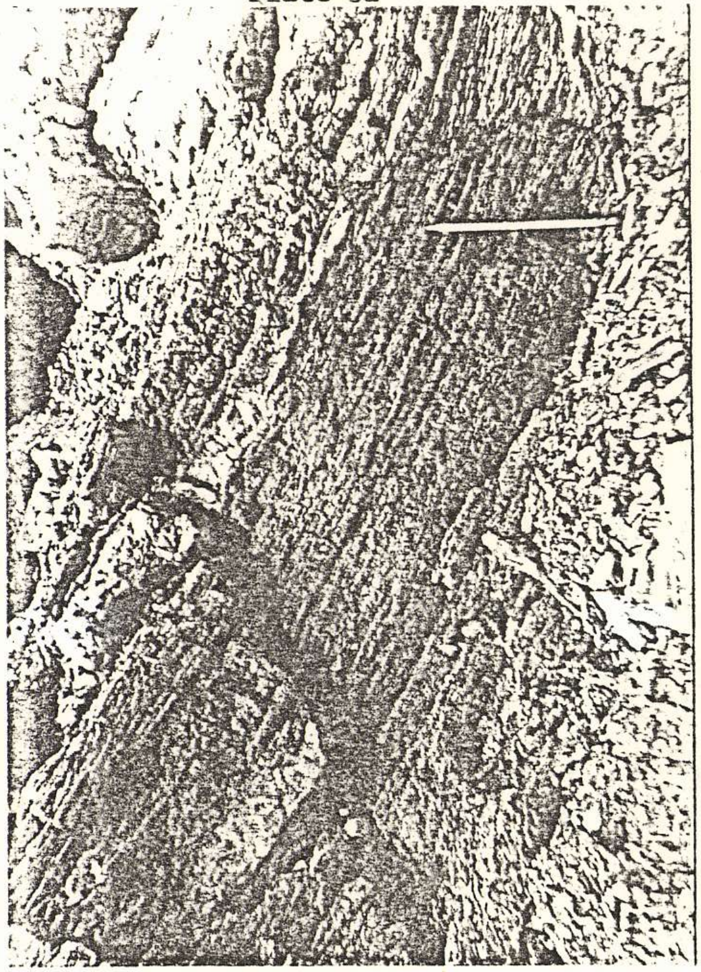


Plate 3b

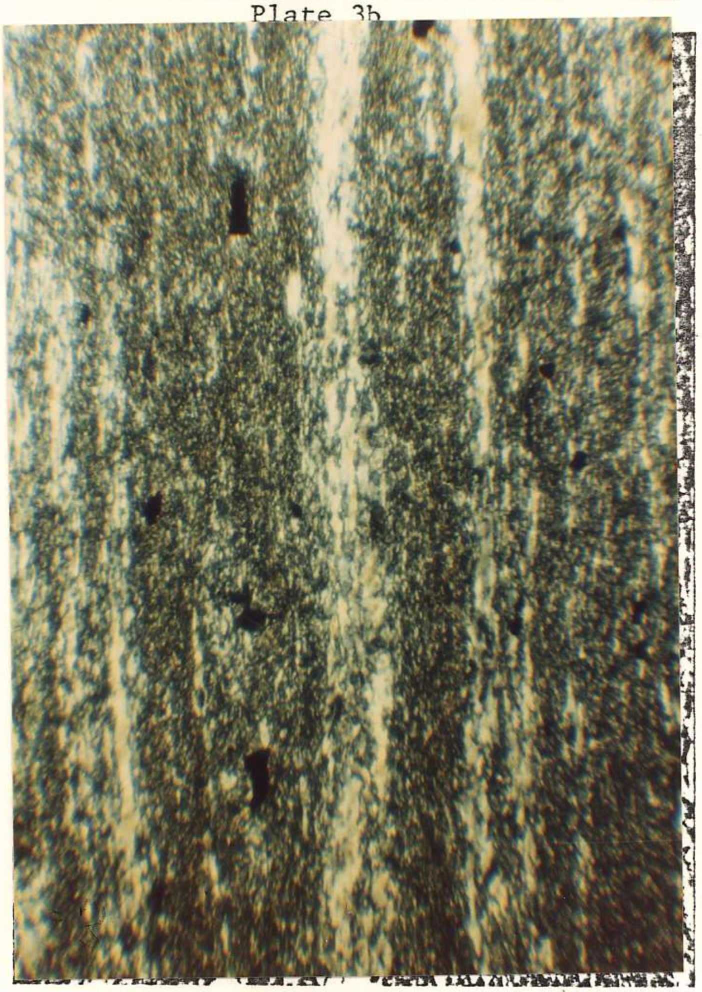


Plate 1

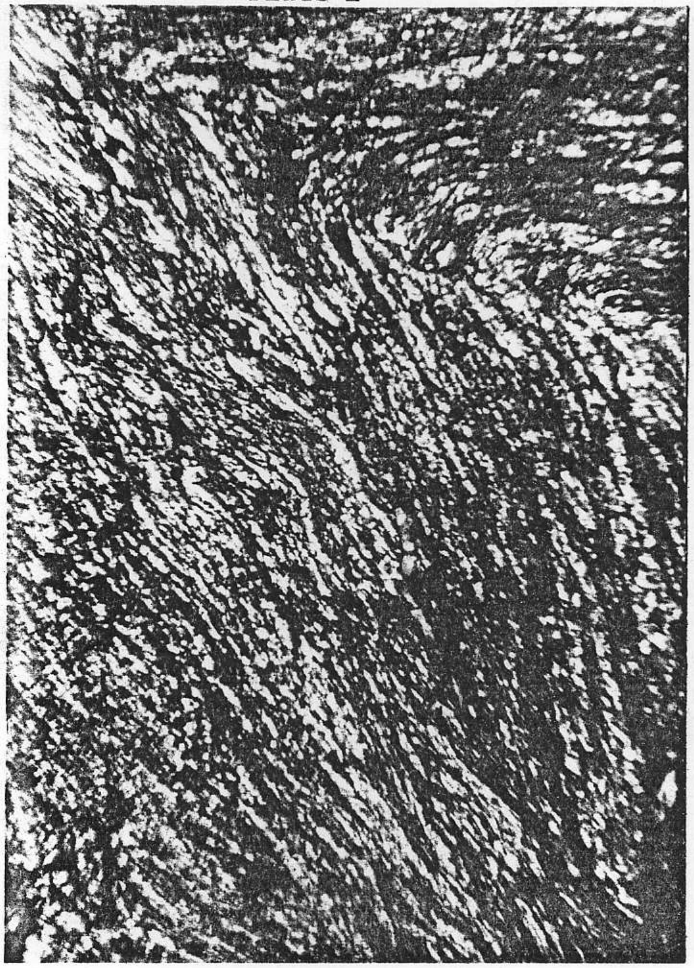


Plate 2

Plate 3a

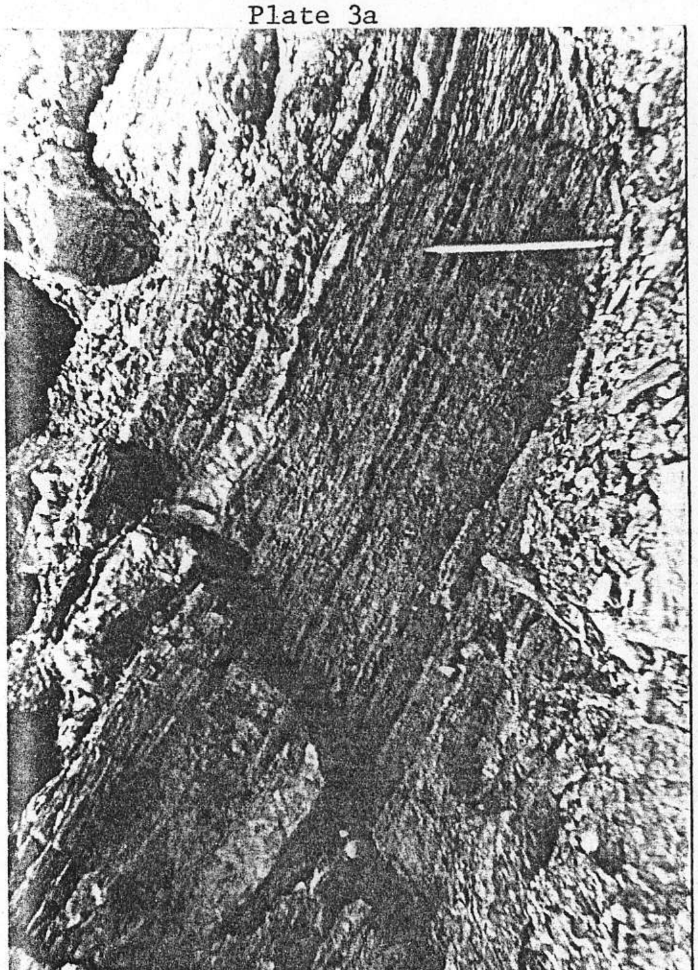
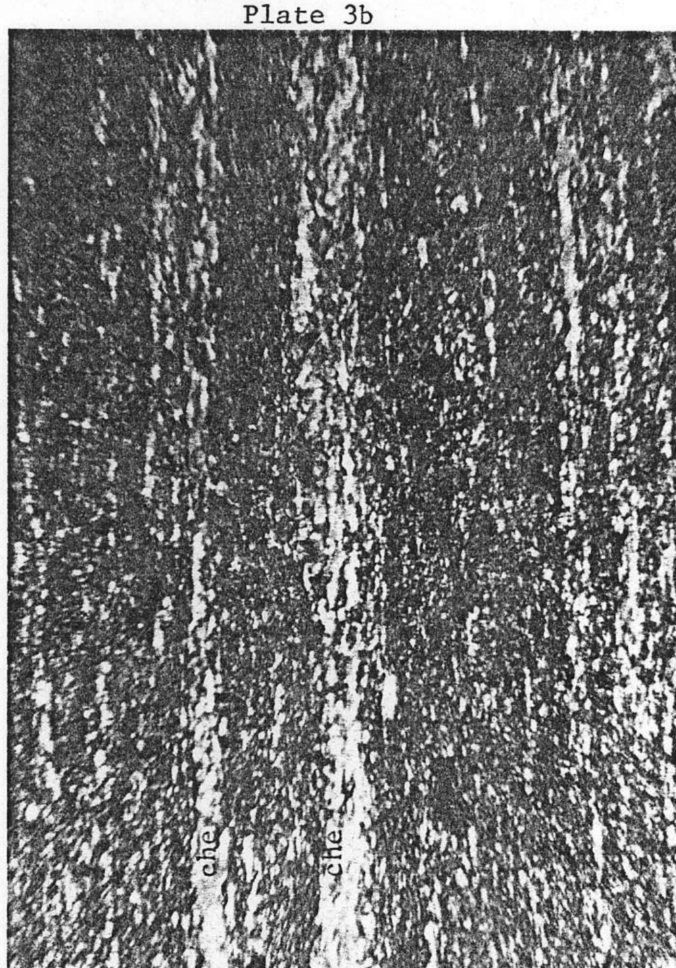


Plate 3b



APPENDIX 5

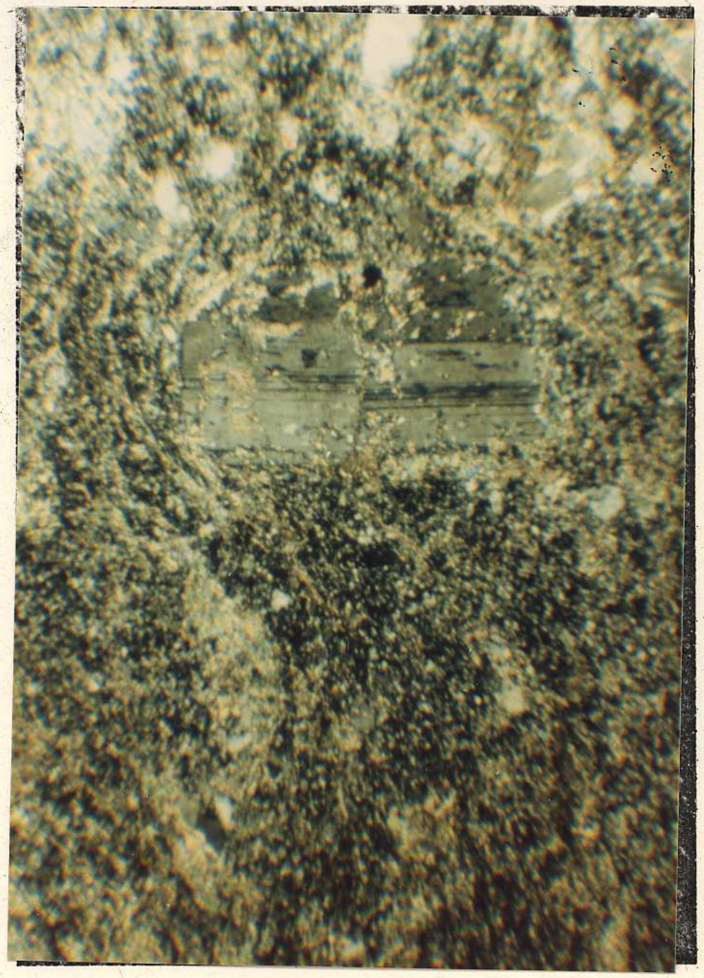
Plate 4. Quartz-feldspar phyric tuff showing incipient metamorphic breakdown of groundmass and phenocryst feldspar to sericite

Plate 5. Barite ore; opaque minerals are sulfides

Plate 6. Sphalerite-chalcopyrite-galena assemblage in barite ore

Plate 7. Sphalerite-chalcopyrite-galena assemblage in barite matrix

Plate 4



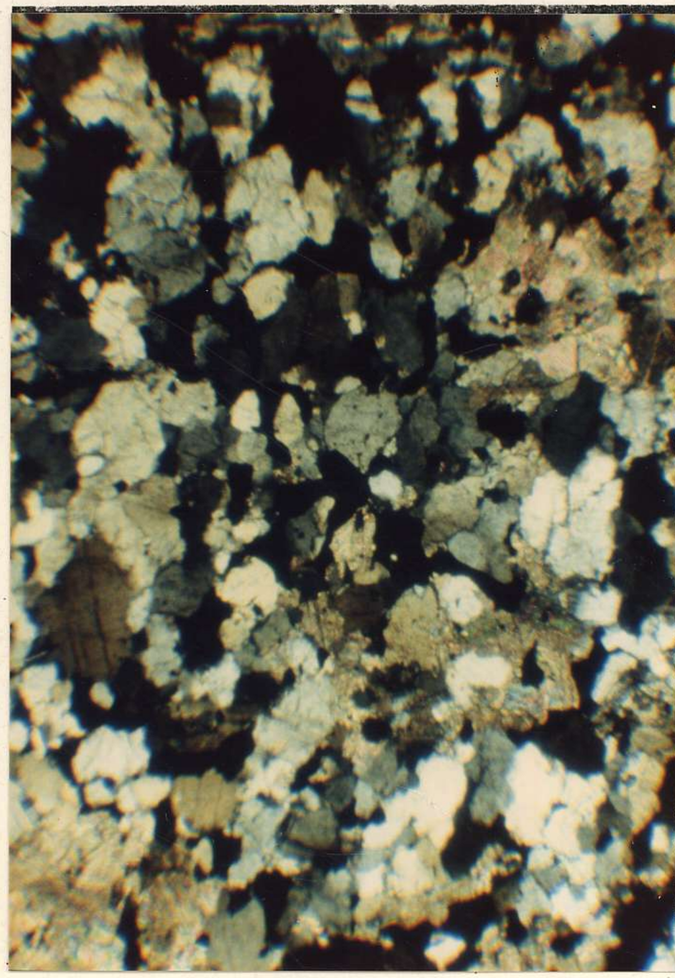


Plate 6

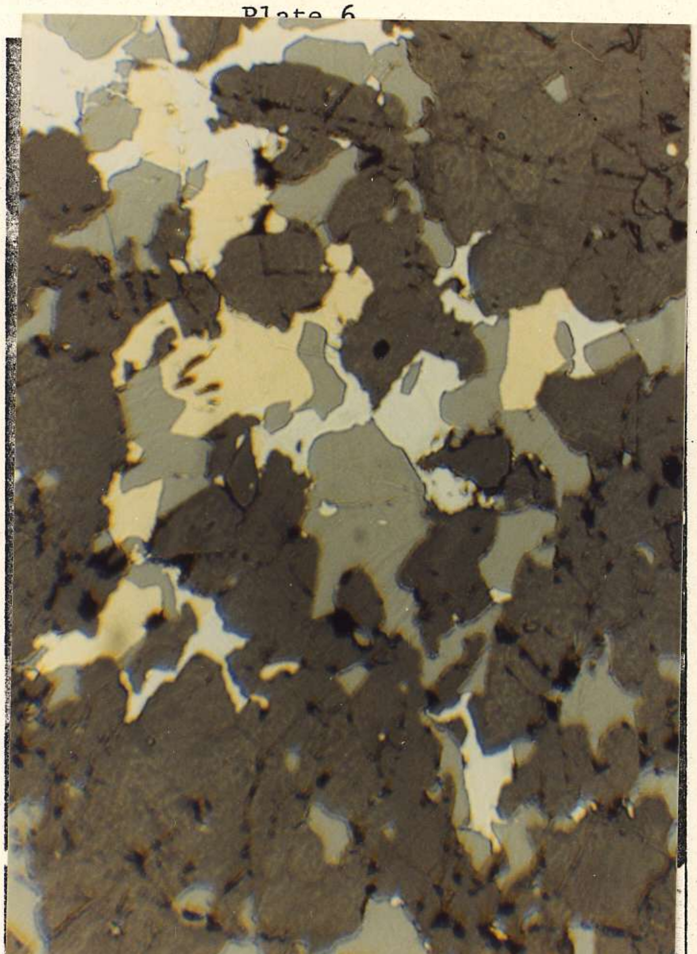


Plate 7

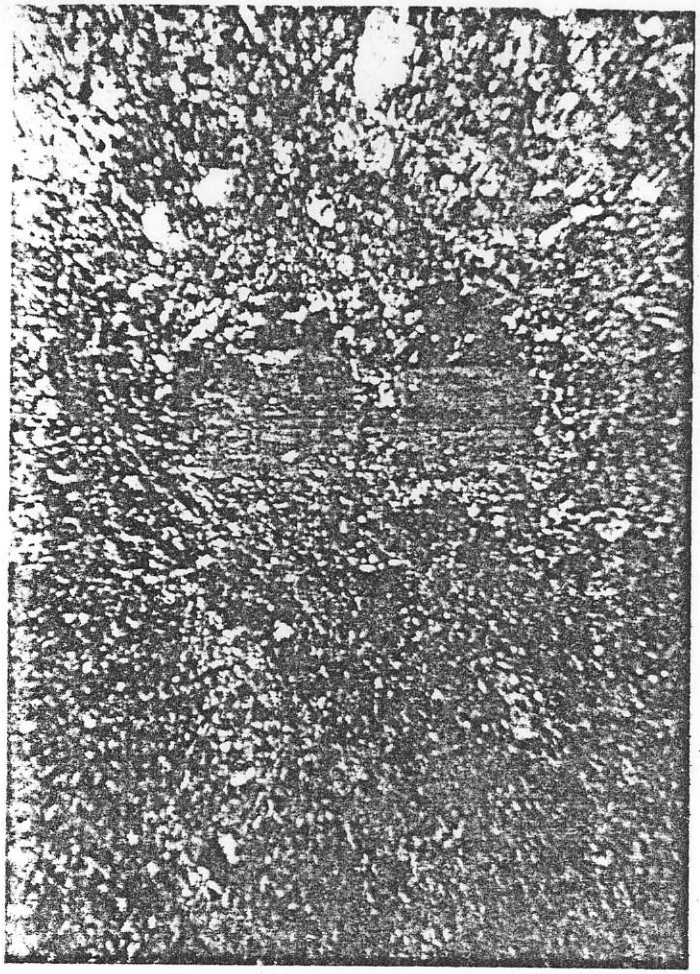


Plate 6

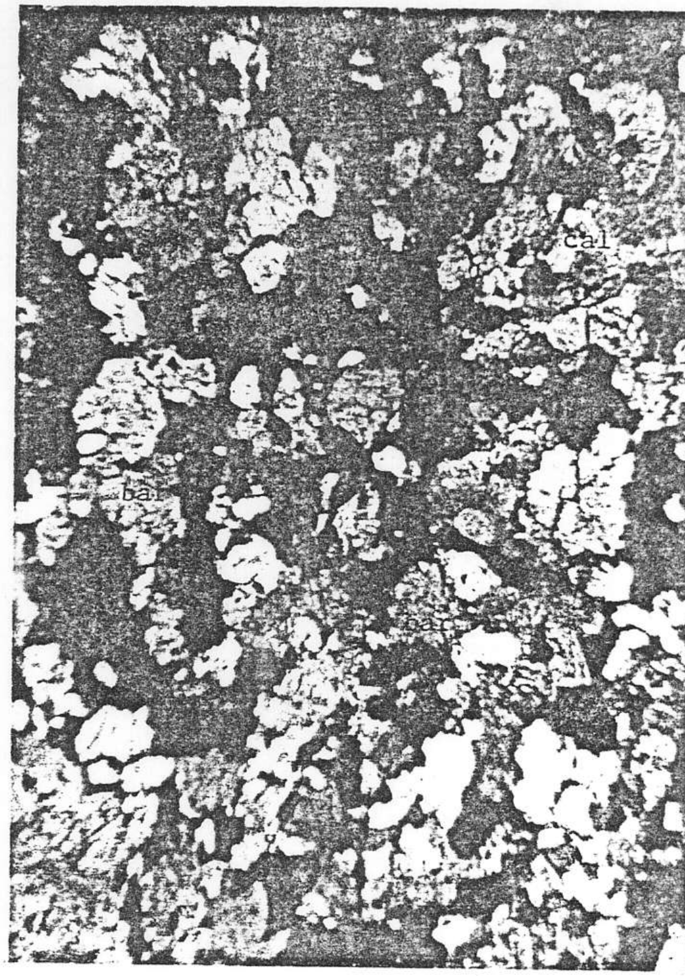
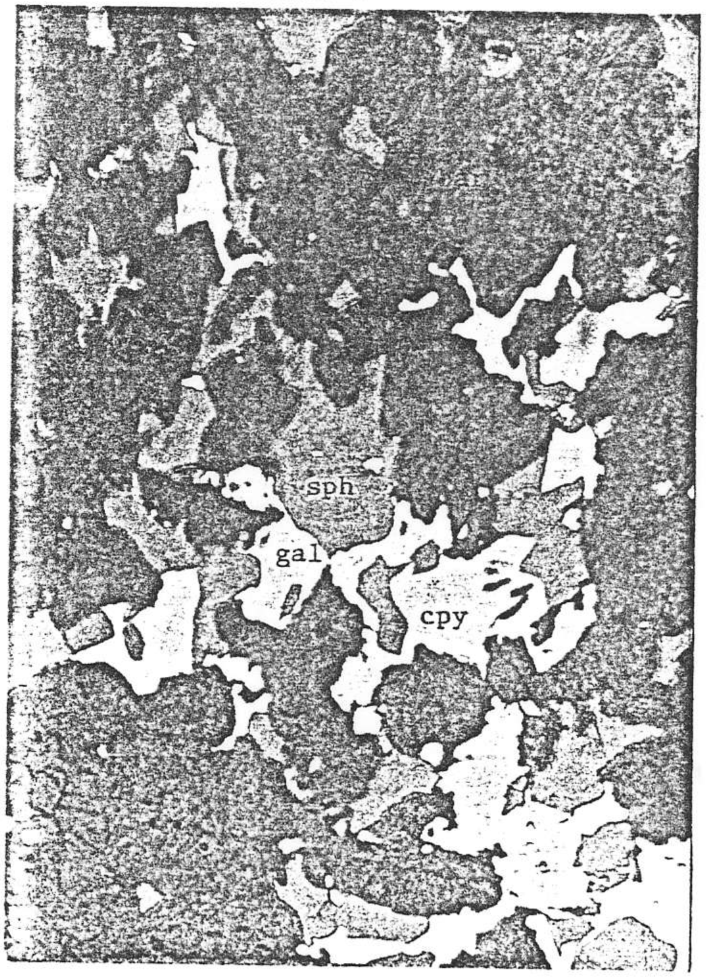


Plate 7



APPENDIX 5

Plate 8. Irregular and skeletal galena grains dispersed in barite matrix

Plate 9. Tetrahedrite in contact with sphalerite and galena. Local replacement of sphalerite by galena is observed in this photomicrograph

Plate 10. Chalcopyrite concentrated along barite-sphalerite grain contacts

Plate 11. Pyrite ghost remnant after replacement by sphalerite

Plate 8

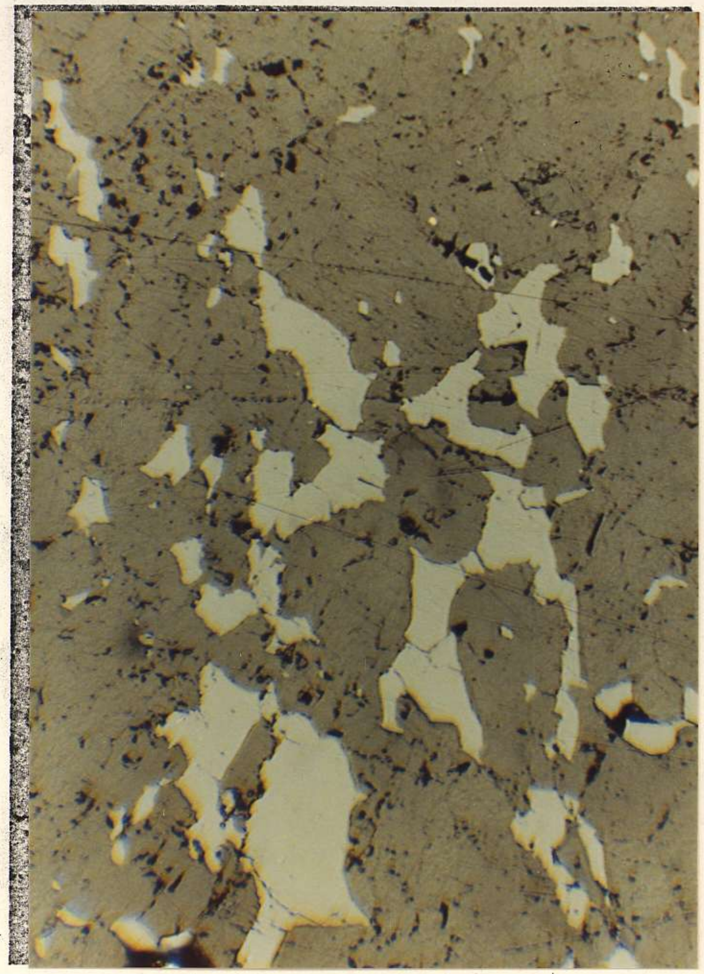


Plate 9

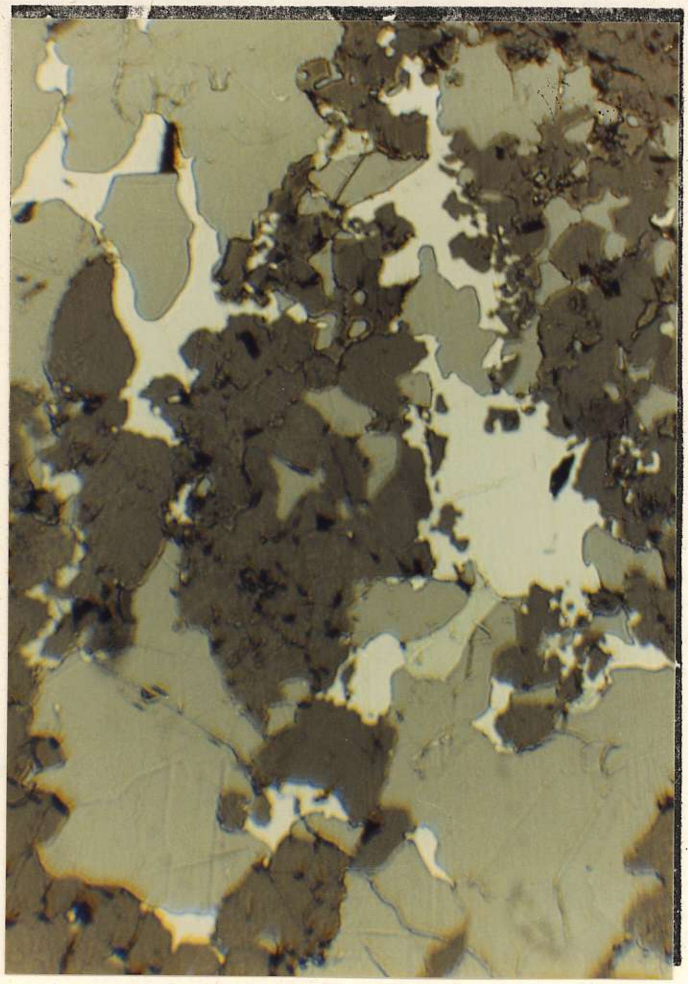


Plate 10

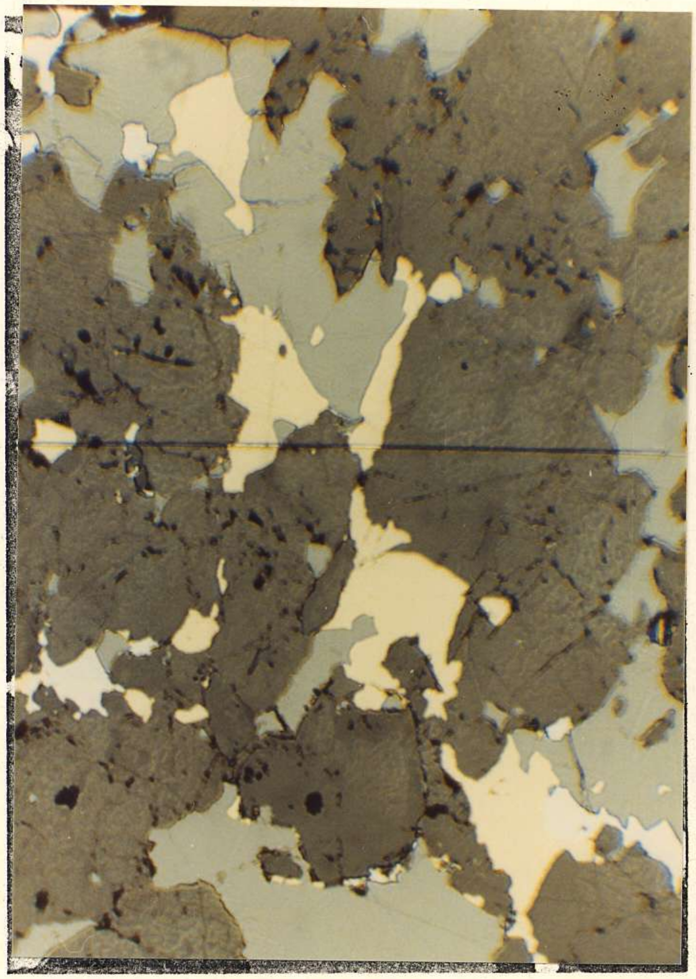


Plate 11

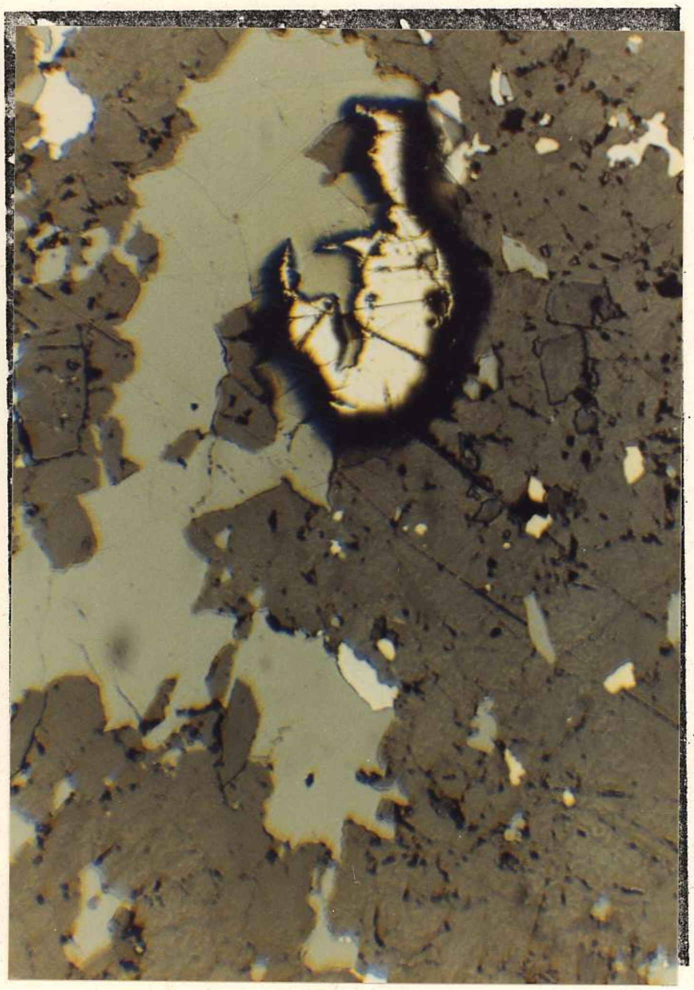


Plate 8

Plate 9

Plate 10

Plate 11

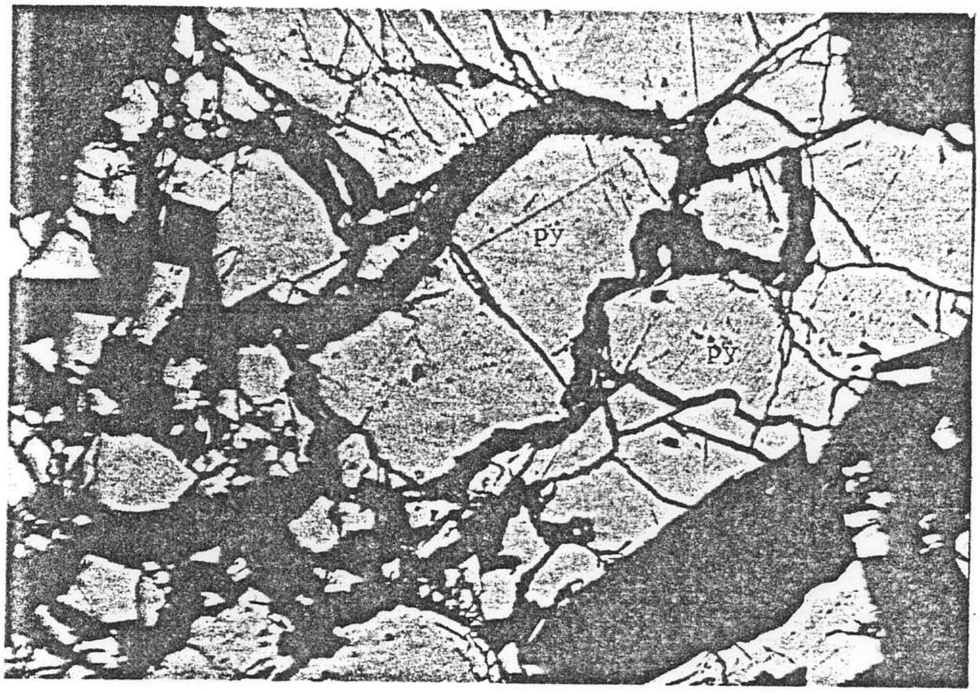


Plate 12. Quartz ore: Fractured pyrite veined by quartz gangue

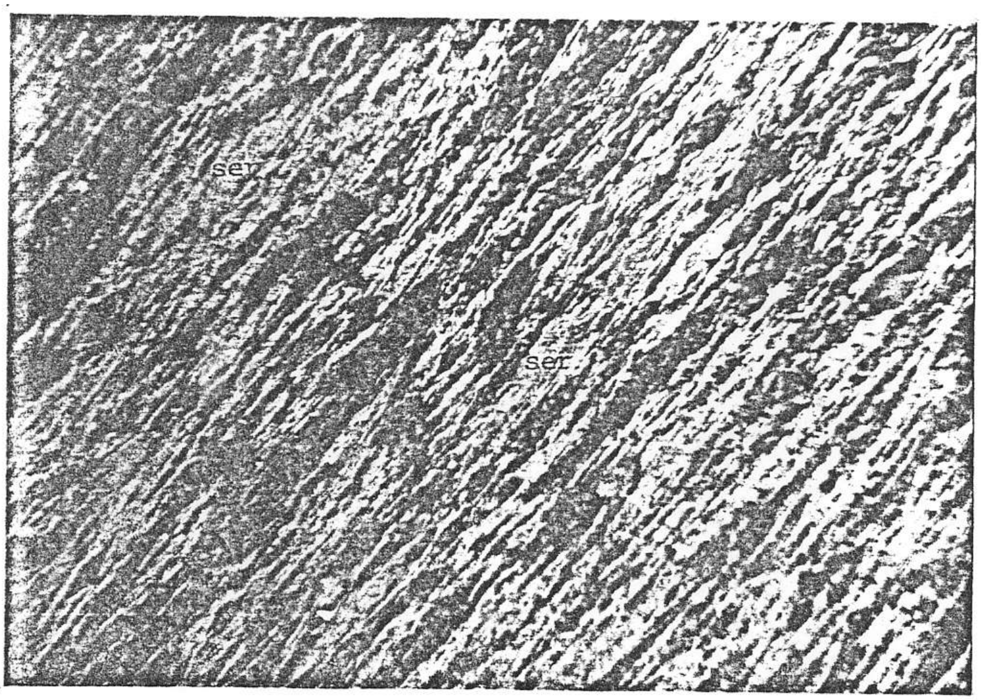


Plate 13. Hydrothermally sericitized felsic tuff; yellowish mineral is sericite, gray mineral is quartz

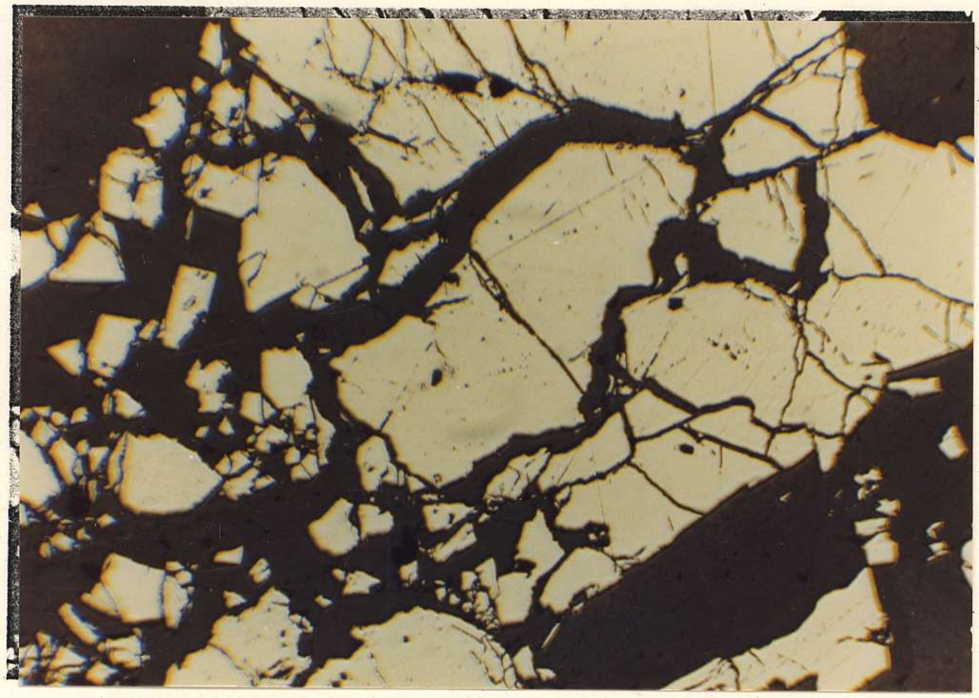


Plate 12. Quartz ore: Fractured pyrite veined by quartz gangue

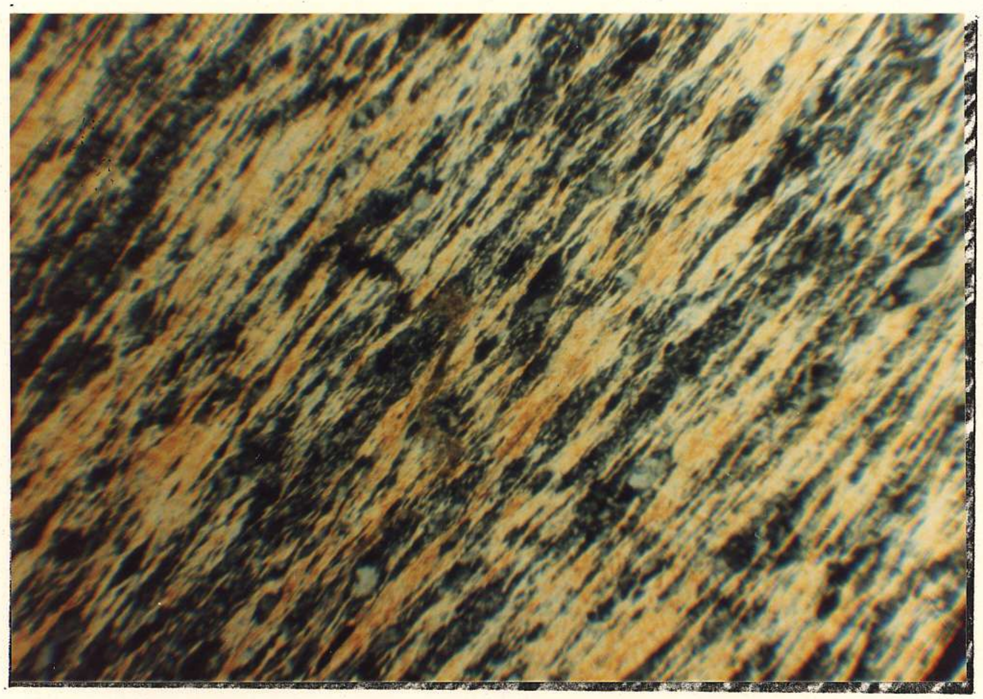


Plate 13. Hydrothermally sericitized felsic tuff; yellowish mineral is sericite, gray mineral is quartz