THE GEOLOGY AND GENESIS OF THE SULPHIDE ORES OF CYPRUS

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by

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ABSTRACT

Detailed field and laboratory data are presented on the geological setting, stratigraphy, structure, mineralogy, texture and geochemistry of seven sulphide orebodies from Cyprus. These orebodies occur at different stratigraphic horizons in the Troodos Pillow Lava Series which were produced by Mesozoic submarine basaltic volcanism. Most of them are intersected by post mineralization, feeder dykes to olivine basaltic pillow lavas, which occur stratigraphically above these orebodies.

A distinction is made between the two iron-rich sedimentary formations referred to as Ochre and Perapedhi umber which occur in places stratigraphically above the orebodies. The umber occurs stratigraphically higher in the succession separated in some places from the ochre by the volcanic phase of the olivine basaltic pillow lavas. It is the first sediment deposited after the final cessation of volcanic activity and its metals have been derived from the weathering of lavas. It has no genetic relation to the sulphide mineralization. The ochre directly overlies some orebodies and is normally restricted to their boundaries. It is suggested that the ochre was essentially derived from submarine oxidation of the underlying sulphide ores.

Most orebodies of Cyprus are characterized by distinct vertical zoning comprising in downward succession a zone of massive ore, a zone of sulphide with silica and a stockwork zone. It is suggested that the lenticular massive ores were formed in caldera-like depressions on the lavas by subaqueous fumarolic activity during hiatuses in volcanicity. Hypotheses are outlined to account for the original and present composition, structure, texture and geochemistry of the massive ores. It is suggested that the primary massive ore was made up of compact pyritic ore which consisted mostly of euhedral zoned pyrite containing minor amounts of chalcopyrite and sphalerite. Subsequently it underwent considerable oxidative leaching and secondary enrichment under submarine conditions. The characteristic conglomeratic structure and high porosity of the massive ore and its complex mineralogy and texture are considered to be secondary features associated with the submarine leaching of the original compact pyritic ore.

The sulphide-silica zone, where it occurs, owes its character to replacement by silica of the lower part of the massive ore. The stockwork zone represents the roots of the orebodies and consists of veins and disseminations of pyrite in silicified chloritized and argillized lavas. The veins represent fillings of fractures in the lavas by sulphides. The disseminated pyrite is believed to have been essentially produced by sulphurization of titaniferous magnetite in the lavas and it often contains anhedral leucoxene.

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CHAPTER I

INTRODUCTION

1. Historical outline of the sulphide mining industry in Cyprus

Cyprus is certainly one of the first places, if not the first, where the use of copper, and its production from the smelting of sulphide ore were discovered. The question whether the word copper was derived from the name of the Island or vice versa has not been answered by the Scholars and Archaeologists. The widespread colourful gossans which were produced by the oxidation of uplifted blocks of sulphide ore to limonite in many of the Cyprus deposits, and the marked colour contrast between these gossans and the surrounding lavas drew the attention of the early inhabitants of Cyprus.

These early inhabitants most probably used first the native copper which was scattered in the vicinity of the gossans. The supposition of occurrence of native copper in the vicinity of gossans is supported by the finding of native copper in the vicinity of many deposits during their exploitation in the last four decades, although most of them had been extensively worked by the ancients. The gossans were probably considered by the ancients to represent naturally burned sulphide ore and after the native copper was depleted they probably tried to recover copper through the artificial burning of the massive ore underlying the gossans.

The ancients in their exploration were definitely guided by the gossans and there is no occurrence of gossan or iron staining in Cyprus which was not tested. The investigation of the gossans was mostly done by untimbered inclined shafts and galleries. Ancient underground galleries with timber support or untimbered as well as square crip-timbered vertical shafts extending to considerable depth were encountered in many orebodies. Ancient ladders, hand windlasses, ropes, wedges, baskets, oil lamps and fragments of pottery were also found in many deposits. A thorough description of these findings illustrated with many photographs was given by Bruce (1937). Petropoulos (1967) reports that the mining method used by the ancients was a cut-and-fill system. The mining was thorough and carefully planned and in many cases, although considerable tonnages of ore were mined, no apparent signs of subsidence exist around these orebodies.

The widespread occurrence of ancient slag testifies also to the extensive ancient mining and smelting activity in Cyprus. At the Skouriotissa mining area (Fig. 2.1) the ancient slag heaps are estimated at more than 2 million tons (Bruce 1937) and there are at least as much as 40 other smelting sites which are scattered over the island. No substantial remains of the smelting furnaces were found except stones and fused clay scattered in the slag piles.

It appears that the smelting furnaces had been built at places with a favourable breeze, preferably close to the orebodies, and with available fuel and water.

It is difficult to determine conclusively what type of ore the ancients were mining and smelting. Bruce (1937) suggested that they preferably mined the sulphated ore which was more easy to smelt. The occurrence, however, of ancient mining workings in many orebodies down to depths where sulphation of the ores was most unlikely to have had occurred suggests that the ancients exploited also copper-rich sulphide ores. It is certain that they did not produce copper from carbonate, silicate, and oxide minerals of copper because these minerals are very rare in the Cyprus ores.

Two types of ancient slag are recognized in Cyprus. The first type is a weathered red slag, which contains high iron and considerable amounts of silica and which has been attributed to pre-Phoenician mining and smelting activities. The second type, the most abundant, is a vitreous black slag which contains less iron and more silica than the red slag; it also contains considerable amounts of manganese and has been considered to be the product of post-Phoenician mining and smelting activities. The ancients were processing massive cupreous ores with almost no siliceous gangue and very low manganese content. Therefore, the silica and manganese which are found in the slags have been added during the smelting of the ores; their probable function was the fluxing of the iron and the increase of the fluidity of the slags. However, the form in which both the silica and manganese have been added, and their source are questions which have not been satisfactorily answered.

Recent archaeological evidence indicates that in Cyprus mining and smelting were active 4000 years B.C. Archaeologists believe

that copper from Cyprus was used in making the Cretan bronze of Knossos at about 2500 B.C. Bear (1963) gave a summary of the existing historical references to Cyprus copper. He reports that "Copper and spearheads found in Cyprus tombs have been dated to the Middle Bronze Age and there are records of 108 blocks of pure copper that were shipped to Egypt in the reign of Thotmes III about 1470 B.C. Alexander the Great had a Cyprian sword of hardened copper or bronze. There are references to Cyprus copper in the writings of Homer. He described his heroes wearing Cyprian armour and mentions a king of Amathus (Old Limassol) sending Agamemnon, the ruler of Mycene a fine shield before the Trojan expedition ....". A description of how the ancient mines were worked was given by Galen who in 166 A.D. visited the orebodies near the ancient town of Soli (Skouriotissa mining area). Recent carbon dating of ancient timber (Kortan personal communication) indicates that most of them are older than 300 ± 60 B.C.

The mining and smelting activities in Cyprus lapsed after the decline of the Roman Empire at the end of the fourth century A.D. Since then no mining activity is known to have had occurred in the Island until 1882 when Mr. John Pearce carried out prospecting work at Limni (Petropoullos 1967). In 1914 G.G. Gunther started systematic drilling at Skouriotissa and five years later at Mavrovouni. In the 1930s some other companies including the American Smelting and Refining, the Pyrites Company Limited (Rio Tinto) and the Anonyme Hellenic Company of Chemical Products and Manures were investigating various occurrences of gossans in the Island. In the last four decades over 30 orebodies greatly varying in size and grade have been discovered.

Revival of production commenced in 1921 with the mining of the Skouriotissa orebody, whereas exploitation of the Mavrovouni orebody started in 1929. At Limni the first ore was mined in 1937; in the same year Hellenic Mining Company started producing ore from Kalavasos, in 1951 from Sha-Kambia, in 1952 from Mitsero-Agrokipia and in 1965 from Memi and North Mathiati. At present iron and copper sulphides are the main mineral products of the island and, as in ancient times, their production is of vital importance to the economy of the Island.

2. Some Genetic Aspects of the Massive Sulphide Ores.

The Massive sulphide deposits are normally large solid masses of pyrite and/or pyrrhotite which frequently contain one or more sulphides

of copper, zinc and lead. These deposits have a wide geographical distribution but tend to be more common in the northern hemisphere. They have been extensively exploited for a long time for their pyrite and/or base-metal content in Cyprus, Spain, Turkey, Japan, U.S.S.R. Germany, Norway, Sweden, U.S.A. and Canada.

The massive sulphide deposits have a variable size and their tonnage ranges from several tens of thousands to over 100 million tons. The shape of these deposits may be irregular or pod-like but more often is lenticular made up of a single lense or of a series of closely spaced smaller lenses in parallel or en-enchelon arrangement. They are conformably enclosed in rocks which resulted from volcanic activities in geosynclines and in many cases constitute an integral part of the geosynclinal volcanic pile. The contact of the sulphide ore with the overlying rocks is invariably sharp whereas its contact with the underlying rocks in many cases is gradational. The volcanic rocks which are associated with the massive sulphide ores may be basic intermediate or acidic and their age ranges from Precambrian to Neogene Tertiary. The sulphide ores and associated volcanics are found either completely unaltered and unmetamorphosed or more often involved in various grades of metamorphism.

The genesis of the massive sulphide deposits still remains a major unresolved geological problem. Since the second half of the last century many contradicting hypotheses have been proposed to interpret the genetic history of these deposits. Similarities in mode of occurrence, composition, wallrock relationships, mineralogy and textures have led many geologists to suggest a common origin for the massive sulphide deposits which occur in various well known mining districts throughout the world.

Many geologists particularly in the United States have considered that the massive sulphide deposits were generated from hydrothermal solutions that metasomatically replaced the enclosing rocks after their consolidation. Thus these deposits are epigenetic and the space of the sulphide ore was occupied by solid rock which was removed by solution. (Lingren (1933); Bateman (1952); Kinoshita (1927); Williams (1934); Cullis and Edge (1922). Most geologists envisaged magmatic origin for the hydrothermal solutions but other sources such as lateral sacretion, ascending heated meteoric waters, mingling of magmatic hydrothermal

solutions with meteoric water, discharging of magmatic gases and vapours into meteoric waters have been also proposed. The temperature of the hydrothermal solutions was considered to range from 175° to 350°C (Lindgren 1933); they were capable of transporting sufficient amounts of mineral constituents in solution. These solutions moved from source to the site of deposition through available openings in the rocks and under favourable structural settings and physicochemical conditions replaced metasomatically the enclosing rocks and deposited the massive sulphide ores.

The common high purity of massive sulphide deposits and their sharp contacts with the enclosing rocks have led some geologists to suggest an origin through a concentrated iron and copper sulphide matte (Spurr 1923). The sulphide matte was considered to have been segregated from a deep-seated primordial magma of andesitic to basaltic composition through the agency of H_2S that was dissolved in the fluid magma (Goodchild (1919); Thomae (1923)). A concentration of sulphide through gravity separation of immiscible liquid layers during the cooling of an originally molten earth was postulated by Brown (1950). He suggested that the concentrated sulphide magma was forced to move upwards to its resting place as vapours containing little or no water by the weight of solid rock resting on it.

The origin of some massive sulphide deposits was attributed by some geologists, to solutions activated during metamorphism. The water of these solutions was derived from the open spaces of sedimentary and volcanic rocks or it was released by dehydration of hydroxyl bearing minerals. The metamorphic waters were considered to be able to leach sufficient quantities of dispersed elements (Domarev (1967)) or to concentrate metals which are released from silicate minerals during metamorphic transformations (De Vore 1955) to form large deposits. A genetic connection of some massive sulphide ores with palingenesis and granitization of metal bearing volcanic and sedimentary rocks was suggested by Gavelin (1955) and Sullivan (1959). Knight (1957) suggested an origin of massive sulphide ores from dispersed sulphides, originally deposited syngenetically within sedimentary basins and remobilized to their resting place under the influence of heat produced by intrusion of granite or deep burial metamorphism.

At the beginning of this century the concept of submarine volcanic-sedimentary origin was suggested by Fukunchi (1902) for certain Japanese massive sulphide deposits. The same process of formation was later suggested for certain pyritic massive ores in the Norwegian Caledonides (Carsterns, 1919) and for the Kuroko ores in Japan (Okashi, 1919). In the last three decades the close association of the massive sulphide deposits with products of submarine volcanism was realized and considerable support has been given throughout the world to the theory of an exhalative-sedimentary origin. (Hegemann (1948); Ehremberg et al (1954); Kraume (1955); Watanabe et al (1956, 1959); Oftedahl (1958); Smirnov (1960); Williams (1962); Skripchenko (1967); Anderson (1969).

An interplay between volcanic and biogenic factors in the formation of massive sulphide ores was stressed by Stanton (1960) who suggested that the absence of either factor precludes any significant concentration of sulphide. The importance of biogenic contribution in the formation of massive sulphide was questioned by the experiments of Rickard (1968), by the reported pyrite content in a variety of recent sedimentary environments (Dunham 1961) and by sulphur isotopes studies (Smirnov 1968). Recent experiments also indicate that rapid inorganic formation of pyrite is possible in slightly acid and oxygen deficient environments when sufficient supply of ferric iron and hydrogen sulphide occurs (Roberts et al 1969).

The term exhalative implies that the sulphur and metals which are required for the formation of massive sulphide ores were transported as vapours (Oftedahl, 1958) whereas Barton (1957), Roedder (1967) and Barnes and Czamanske (1967) suggest that they were transported as hydrous fluids. The physical and chemical characteristics of the hydrous fluids are hotly debated but the recent discoveries of metal-bearing hot saline brines at the Red Sea and the Salton Sea geothermal areas made geologists to suggest the importance of alkali chloride solutions in the genesis of the sulphide ores (White 1968). The relative role of diagenesis and the possible effects of metamorphism (many of these deposits have undergone varying grades of metamorphism) are also hotly debated in the last ten years (Vokes, 1969).

3. Scope and Methods of the Present Research

In August, 1964 the writer joined the Cyprus Geological Survey as local mining geologist in a joint United Nations Special Fund - Cyprus Geological Survey Project for a survey of Mineral and Ground water resources in Cyprus. The above Project for mineral exploration defined the zone between the top of the Basal Group and the base of the Perapedhi Formation. The exploration included geological mapping, regional as well as detailed, airborne and ground geophysical surveys, testing of applicability of geochemical techniques, and drilling. In 1965 the writer won a scholarship from the State Scholarship Foundation of Greece and in 1966 he was accepted as a postgraduate research student in the Department of Mining Geology, Imperial College London.

The scope of the present research is the study of many aspects of the geology of the Cyprus sulphide ores including their petrography, stratigraphy, structure, mineralogy, geochemistry and origin. A relevant fact that has never been disputed is that the Cyprus sulphide ores are restricted exclusively to the extrusive Pillow Lavas Series of the Troodos Igneous Complex and constitute an integral part of this submarine volcanic pile. Thus the present research is restricted to the sulphide ores and the surrounding Troodos Pillow Lava Series; it also includes the Perapedhi Umber (the base of the postvolcanic sedimentary succession) because it was considered by most geologists to be related with the sulphide mineralization.

In the present research no detailed study of the Troodos Pillow Lava Series is attempted. Such studies can be found in the memoirs and many published and unpublished reports of the Cyprus Geological Survey. The Troodos Pillow Lavas are also the subject of detailed study by research students in British, French and American Universities. In the present research emphasis is laid on the relationship of the Pillow Lavas with the orebodies studied. An attempt is also made to find field and petrographic criteria to distinguish mineralized from unmineralized Pillow Lavas; such distinction would help to define the stratigraphic position of these orebodies in the lava sequence which in turn is important for future exploration for new massive sulphide ores.

The present research consists of an extensive field and laboratory work. In the first part of this thesis it is attempted to present only factual field and laboratory evidence avoiding as much as possible any interpretation. In the second part of the thesis a personal interpretation of the field and laboratory data is presented.

The field work for this study was carried out from 1966 to 1968 and included:

(a) Regional mapping of 3 important mining areas in collaboration with the United Nations Mining Geologist Dr. D. L. Searle. Two of these mining areas occur at the northern side whereas the third one occurs at the southern side of the Troodos Igneous Complex.

(b) Detailed mapping and sampling of 7 orebodies contained in the three mining areas mapped. The 7 orebodies were selected to be as representative as possible of the sulphide ores in Cyprus. For a comparative study many samples were taken from all the known orebodies in Cyprus.

(c) Compilation, where possible, of all the available information on the orebodies including unpublished reports, drillhole data, mine plans and assay plans.

(d) Logging and sampling of a considerable number of drillholes through and around the orebodies.

(e) Detailed mapping and sampling of unmineralized basaltic dykes which intersect some sulphide deposits.

(f) Construction of geological sections and/or isometric projections, showing the relationship of the 7 orebodies with the surrounding lavas, the effects of faulting on the present form and attitude of the orebodies and the zoning of the ore in the various orebodies.

(g) Preparation and study in the Cyprus Geological Survey of thin sections of samples from the pillow lavas, the orebodies and the unmineralized basaltic dykes which intersect the sulphide ores.

Intensive laboratory studies on many samples of sulphide ore, mineralized and unmineralized pillow lavas, unmineralized dykes, Umber and

Ochre were carried out in the Department of Mining Geology Imperial College, London from 1968 through 1970. The laboratory studies included:

(i) X-ray diffraction analyses carried out on mineralized lavas (62 analyses), unmineralized lavas (10 analyses), unmineralized dykes intersecting sulphide ores (8 analyses),ochre and umber (34 analyses) in order to supplement the optical and/or chemical studies of these rocks. All these analyses were carried out in the X-ray laboratory of the Geology Department, Imperial College. In the same laboratory X-ray powder photograph analyses were carried out as a supplement to the optical studies of the ore mineralogy of the massive ores.

(ii) A study of the major and minor element chemistry of the sulphide ore, the umber and ochre. In most orebodies the major element chemistry of the sulphide ore was studied from assay data provided by the Hellenic Mining Company. The major element chemistry of the umber and ochre was studied from 10 partial major element analyses carried out in the Department of Pure Geochemistry Imperial College and from data compiled from the memoirs and other publications of the Cyprus Geological Survey. The trace elements Cu, Zn, Ni, Co content in the sulphide ore, umber and ochre were determined with Atomic Absorption Analyses carried out by the Chemical Laboratory of the Cyprus Geological Survey. In the same laboratory several partial major element analyses of mineralized lavas were carried out for a preliminary study of the chemical changes in the basaltic lavas during their mineralization.

(iii) A detailed study of the geochemistry of pyrite and chalcopyrite in various orebodies and in different zones within the orebodies. For this study fifty four pure pyrite and twelve pure chalcopyrite samples from orebodies throughout Cyprus had been prepared. The trace element Co, Ni, Ag, V, Cr, Ti, Mn, etc. content in the above samples was determined quantitatively using the Hilger Large Quartz Spectrograph (E 742) and employing a cathode layer technique with Pd as internal standard, in the Pure Geochemistry Department, Imperial College.

(iv) Electron probe microanalyses with the Cambridge MKI micro-analyser of the Mining Geology Department Imperial College, using an excitation voltage of 25 KV and carbon-coated specimens. The results were corrected for such errors as those caused by absorption effect, atomic number effect, background fluorescence, characteristic fluorescence, etc. Electron probe work included full analyses of the ore minerals, idaite pyrrhotite, and tennantite quantitative analyses of iron content in sphalerite and cobalt content in pyrite, as well as qualitative work on the mode of occurrence of manganese in umber and ochre.

(v) A detailed study in reflected light in both air and oil of about 200 polished sections of sulphide ore ochre, umber, mineralized and basaltic dykes intersecting sulphide ore. Of these polished sections 162 had been prepared in the Mining Geology Department Imperial College whereas the rest had been prepared in the Cyprus Geological Survey. Most of ore microscopy work was carried out in the ore mineralogy laboratory of the Mining Geology Department using a Reichert Zetopan ore microscope. Many samples were examined in the Department of Micropalaeontology Imperial College using a Carl-Zeiss Photo-microscope 0054 with Automatic Exposure Setting Device. For detailed studies in very high magnifications the Cambridge Stereoscan MK IIA Scanning Electron Microscope of the Micro-palaeontology Department was used. During the ore microscopy work emphasis was laid on the detailed textural study of the sulphide ore, on the relationship of the various sulphides in the ore, their paragenetic position and their probable genetic significance. The detailed textural studies entailed the extensive use of electrolytic and chemical etching techniques. Finally for the better presentation of the ore microscopy work about 300 photomicrographs had been prepared by the writer in the photography section of the Department of Geology Imperial College.

(vi) The determination of some physical properties of the massive sulphide ores. This included the determination of porosity and thermal conductivity of the massive sulphide ores in various orebodies.

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CHAPTER II

A GENERAL OUTLINE OF THE GEOLOGY OF CYPRUS

1. General Statement

Cyprus is an island covering an area of about 9000 square kilometres and is situated in the northeastern corner of the Mediterranean between the Anatolian Plateau and the Foreland of the African Shield. The island is topographically and structurally divisible into three major belts running roughly parallel and with an east-west orientation.

From north to south these belts are: (a) The Kyrenia Range constituting a segment of the outermost arc of the Alpine Chain; it consists mainly of Permocarboniferous to Middle Miocene Sediments. Basaltic pillow lavas and sills are associated with the Maestrichtian sediments. (b) The Mesaoria Plain underlain by Upper Miocene to Pliostocene sediments; and (c) The Troodos Igneous Complex with a core of Plutonic rocks surrounded by the Sheeted complex which in turn is surrounded by the Pillow Lava Series. The latter represents a volcanic pile of Mesozoic age and of tholeitic character which evolved in an oceanic environment in which the sialic crust was absent or very thin.

The Troodos Igneous Complex is mostly surrounded by calcareous sediments of Maestrichtian to Middle Miocene age. At the Igneous-sedimentary contact sporadic lenticles of dark brown sediments rich in iron and manganese are present. These are often associated with argillites and radiolarian cherts of Campanian age. At the southwestern part of the Troodos Igneous Complex allochthonous sediments are resting either on pillow lavas or on autochthonous sediments of Campanian age.

In Cyprus the massive sulphide orebodies are confined to the Troodos Pillow Lavas constituting an integral part of the volcanic succession. The sulphide orebodies occur in all the stratigraphic horizons in the lava sequence and it appears that they were formed by subaqueous solfataric activity during hiatuses in lava effusion.

2. The Kyrenia Range

The Kyrenia Range is considered as a segment of the outermost arc of the Alpine Chain representing a thrust zone which moved from the north. At the sole of the thrust there are erratic blocks of metamorphic rocks including chloritic schists, quartz-micaschists, garnetiferous mica-schists and epidote-schists all possibly of Devonian age (Ducloz 1964). The oldest sedimentary units outcropping along the Kyrenia Range are represented by Permo-Carboniferous sediments. These are fossiliferous massive limestone in places brecciated and recrystallized, varying in colour from dark brown through light brown to grey and white(Ducloz 1964); Knup and Kluyver (1968). These units occur as large blocks, some of mountain size and are described as olistoliths.

Stratigraphically the Kyrenia Range in upward succession consists of the Dhikomo, Sykhari, Hilarion, Lapithos and Kythrea Formations (Fig. 2-1). The Dhikomo Formation is of Triassic Age and it consists of thinly-bedded yellow to white micaceous marbles 18 to 90 metres thick. The Sykhari Formation includes dark to light grey massive to thickly bedded and frequently brecciated dolomitic limestone 220 to 300 metres thick and it is of Jurassic age(Ducloz (1964); Knup and Kluyver (1968)). The Hilarion Formation -Lower to Upper Cretoneous age, consists of light to dark grey massive or thickly bedded marbles about 200 metres thick (Ducloz (1965); Knup and Kluyver (1968))

The Lapithos Formation consists of thinly bedded light-grey and fine grained globigerinal limestones, in places slightly marly, with intercalations of thinly-bedded grey crystalline and partly silicified limestones. In this Formation there are intercalations of basaltic pillow lavas and flows. The thickness of the Lapithos Formation is about 310 metres and its age is Upper Cretaceous to Lower Miocene, Ducloz (1964). The Flanks of the Kyrenia Range are occupied by the Kythrea Formation consisting of alternating thin beds of fine to medium grained greywackes siltitones and marls, and a basal conglomerate. The thickness of the Kythrea Formation is about 4,000 metres and its age is Middle Miocene, (Ducloz (1964) Knup and Kluyver (1968)).

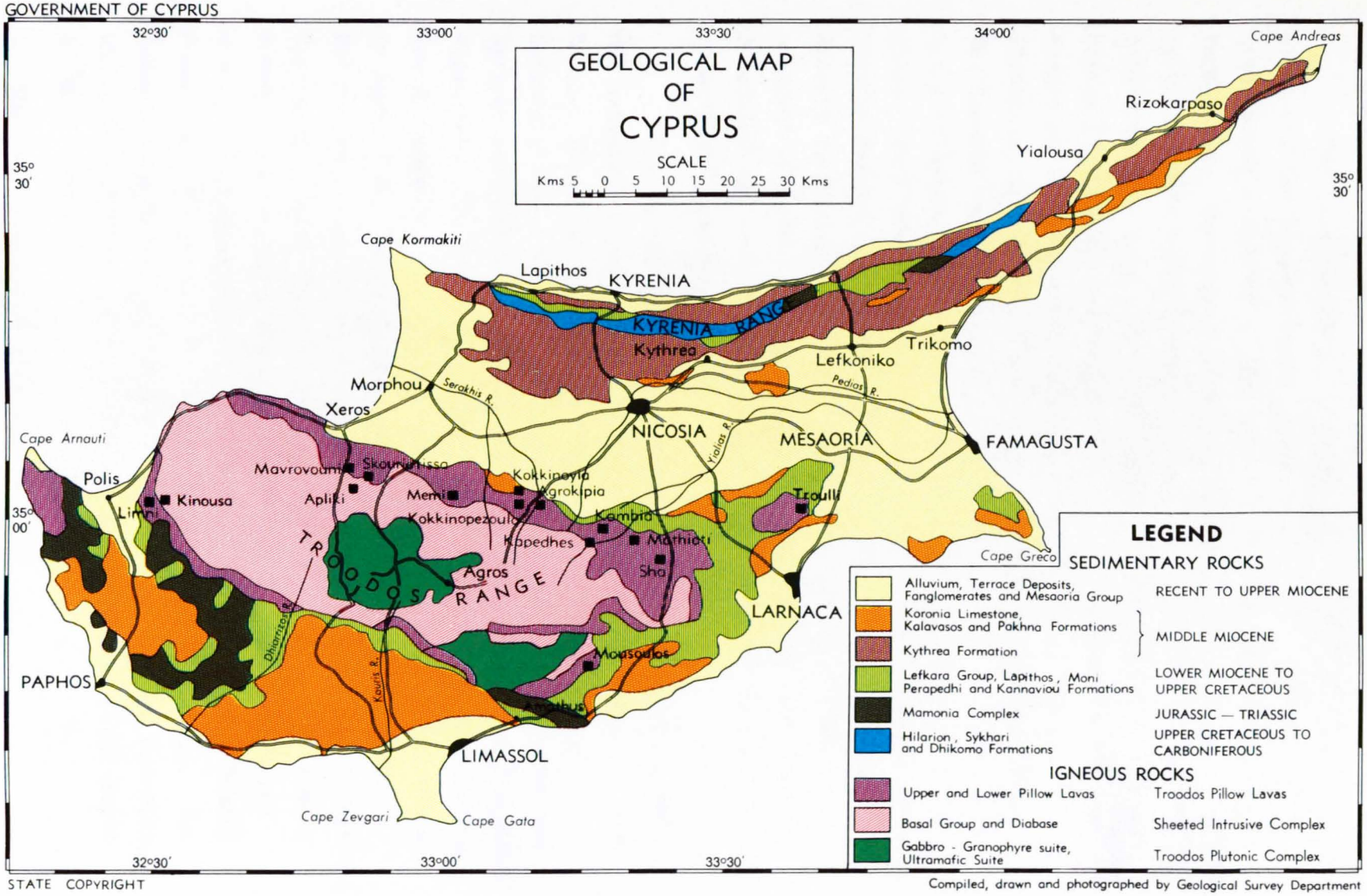


Fig. 2 - 1. Distribution of the principal sulphide orebodies (■) and their close relation to the Troodos Pillow Lavas.

3. The Mesaoria Plain

The Mesaoria Plain is bounded by the Kyrenia Range to the north and the Troodos Range to the south. It is underlain by underformed sediments of the Lapatza, Nicosia and Athalassa Formations. The Lapatza Formation includes gypsum beds and lenses up to 240 metres thick which are commonly interbedded with thinly bedded chalks, grey marls, grey green silty sandstones and marly limestones (Ducloz (1965); Knup and Kluyver (1968)). The age of the Lapatza Formation is Upper Middle Miocene to Lower Upper Miocene (S. Afrodisis, Cyprus Geological Survey, personal communication). The Nicosia Formation includes grey fossiliferous silty marls, marly siltstones, fine and coarse grained calcarenites and in places basal conglomerates and graywackes. The thickness of the Nicosia Formation is about 760 metres and its age is Upper Miocene to Pliocene (Ducloz 1965). The Athalassa Formation consists of medium to coarse grained calcarenites and silty fossiliferous marls 6 to 45 metres thick of Upper Miocene to Pliostocene age.(Ducloz 1965).

Two recent exploration boreholes for oil indicate that the basement of the Mesaoria Plain is made up of Troodos Pillow Lavas. The first of these boreholes was located south of Lefkonico (Fig. 2-1) and in downward succession intersected the Kythrea and Pakhna Formations, the Lefkara Group and the Perapedhi Formation. The total thickness of the sediments is 2,700 metres and are underlain by olivine basaltic Upper Pillow Lavas which in turn at the depth of 3,245 metres are underlain by Lower Pillow Lavas down to the final depth of 3,295 metres (A. Panayiotou Cyprus Geological Survey, personal communication). The second borehole is located 4 miles south of Nicosia and in downward succession intersected the sediments of the Nicosia and Pakhna Formations, the Lefkara Group and the Perapedhi Formation. The total thickness of the sediments is 2,050 metres being underlain by olivine basaltic Upper Pillow Lavas down to the final depth of 2,083 metres.

4. The Troodos Igneous Complex

The third and southernmost belt is occupied by the Troodos Massif which constitutes the main topographical and

geological feature of Cyprus. The Troodos massif has an elliptical shape with its long axis trending west-northwest (Figs. 2-1, 2-2). The massif covers little less than a third of the total area of Cyprus. The summit of the massif rises to a height of about 1890 metres and it is characterized by outcrops of ultrabasic plutonic rocks. For descriptive purposes the geologists of the Cyprus Geological Survey had divided the Troodos Igneous Complex into the following three broad units:-

(a) The Plutonic complex, (b) The Sheeted Complex and (c) The Troodos Pillow Lavas.(Wilson (1959), Bear (1960, 1963, 1965) Gass and Masson-Smith (1963)).

(a) The Troodos Plutonic Complex

The Troodos Plutonic Complex is represented by two main outcrops, the Troodos area proper and the Limassol Forest. (Fig, 2-2). The first exposure covers an area of 210 square kilometres and its core consists of dunite, bastite-serpentine, enstantite-olivinite, harzburgite, wherlite and olivine gabbro, with subordinate anorthosites, pyroxenites and gabbro-pegmatites, (Wilson (1959);Bear (1965)). The dunites contain lenses of economic chromite deposits whereas the serpentine contains large economic deposits of chrysotile asbestos. The outer part of the Troodos Plutonic Complex, in the Troodos area, comprises various types of gabbro, as well as diorite trondjhemite and quartz porphyry. In most places the various rock types have a random distribution with contacts that vary from sharp to gradational, near vertical to near horizontal interfingering to faulted (Bear 1965).

The second large exposure of Plutonic rocks occurs in the Limassol Forest. The plutonic rocks here form an elongated east-west trending mass consisting of a variety of rock types mainly peridotites, olivinites, pyroxenites and gabbros (Pantazis (1967) Lapierre (1966). The contacts between the above mentioned rock types are generally gradational although the exact original relationship is difficult to determine because of the complex structures.

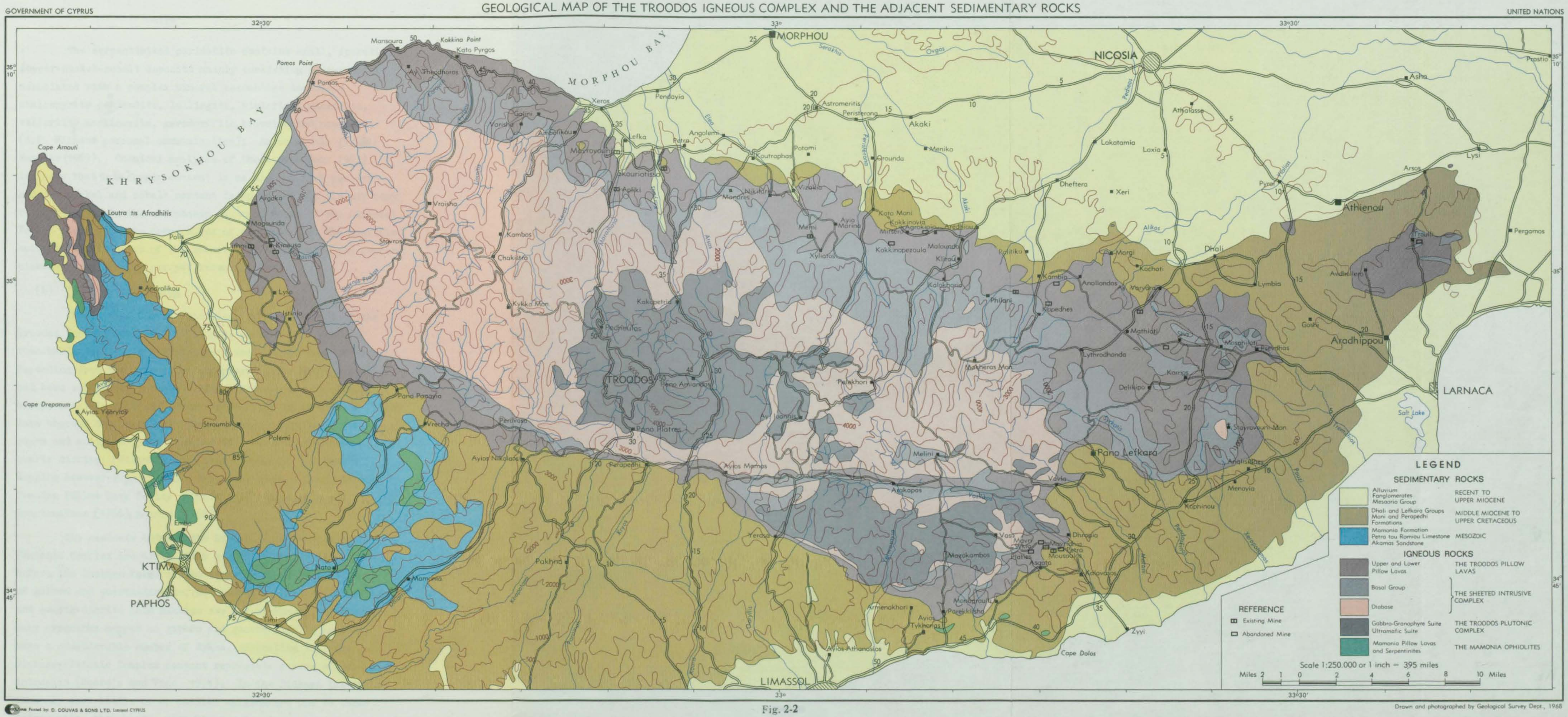

GOVERNMENT OF CYPRUS
GEOLOGICAL MAP OF THE TROODOS IGNEOUS COMPLEX AND THE ADJACENT SEDIMENTARY ROCKS
UNITED NATIONS
MORPHOU
NICOSIA
TROODOS
LIMASSOL
LARNACA
KTIMA
PAPHOS
MORPHOU BAY
KHRYSOKHOU BAY
Cape Arnauti
Cape Drepanum
Cape Dolos
LEGEND
SEDIMENTARY ROCKS
Alluvium
Fanglomerates
Mesaoria Group
RECENT TO UPPER MIOCENE
Dhali and Lefkara Groups
Moni and Perapedhi Formations
MIDDLE MIOCENE TO UPPER CRETACEOUS
Mamonia Formation
Petra tou Romiou Limestone
Akamas Sandstone
MESOZOIC
IGNEOUS ROCKS
Upper and Lower Pillow Lavas
THE TROODOS PILLOW LAVAS
Basal Group
Diabase
THE SHEETED INTRUSIVE COMPLEX
Gabbro-Granophyre Suite
Ultramafic Suite
THE TROODOS PLUTONIC COMPLEX
Mamonia Pillow Lavas and Serpentinites
THE MAMONIA OPHIOLITES
REFERENCE
Existing Mine
Abandoned Mine
Scale 1:250.000 or 1 inch = 3.95 miles
Miles 2 1 0 2 4 6 8 10 Miles
Printed by: D. COUVAS & SONS LTD. Limassol CYPRUS
Drawn and photographed by Geological Survey Dept., 1968

Fig. 2-2

The serpentinized peridotite contains small, sporadic, copper-nickel-cobalt deposits mainly consisting of pyrrhotite associated with a complex mineral assemblage including chalcopyrite pentlandite, lollingite, violarite, niccolite, valleriite mackinawite, gersdorffite, bravoite and oregonite (A.P. Milman personal communication); Autun et al. (1966); Ramdohr (1969). Chemical analyses of these ores (Bear 1963) indicate that their copper content is as high as 13.9 per cent and the nickel and cobalt content is up to 1.1 and 0.3 per cent respectively. In the ultrabasic plutonic rocks of the Limassol Forest there are many occurrences of chromite, but the possible economic significance of the occurrences of chromite and copper-nickel-cobalt ores is not yet known.

(b) The Sheeted Complex

The Sheeted Complex occupies the greater part of the Troodos Igneous Complex. It is made up of a dyke swarm of remarkable density, containing very small proportion of screens. Depending upon the type of screen present, the Sheeted Complex had been subdivided into two units: the upper unit, the Basal Group, consists of 90 to 100 per cent dykes in screens of Pillow lava whereas the lower unit, the Diabase, consists of dyke swarm and multiple dykes intruded into screens of gabbro or quartz diorite; (Wilson (1959); Bear (1960, 1965)). Recent mapping however suggests that the Basal Group belongs to the Troodos Pillow Lava Series (Pantazis (1967); Searle and Constantinou (1968); Searle (1968)) .

The contacts between the Diabase and the underlying Plutonic Complex are irregularly gradational. As mentioned before, the Diabase forms a dyke swarm intrusive into screens of gabbro and quartz-diorite, but intrusive contacts of gabbro and quartz-diorite into Diabase are not uncommon. Furthermore many exposures mapped as gabbro and quartz-diorite actually have a considerable number of dykes, suggesting that the Diabase-Plutonic Complex contact represents a zone of multiple intrusion (Moore's and Vine 1971). In the Diabase the dykes commonly show little or no chilled margins, are one to three metres wide, they have a variable trend and are generally steeply

inclined. Available chemical analyses of rocks of the Sheeted Complex compiled by Moores and Vine (1971) indicate that these rocks have a moderate to high SiO_2 and low K_2O content.

In the Diabase, sulphide mineralization is very common but no economic orebody has been found yet. The sulphide mineralization in the Diabase is restricted to inter-dyke contacts and intensely brecciated and sheared fault zones. The mineralization is in the form of narrow sulphide veins filling fractures or cementing the diabase fragments. The veins consist mainly of Pyrite often associated with quartz. Chalcopyrite and various secondary copper minerals including covellite, digenite and cuprite were found in many places. Not infrequently oxidation of the sulphides to limonite, produced extensive outcrops of limonitic staining in the Diabase. In these oxidized zones very often there are veins of maghemite associated with quartz and remnants of Pyrite.

(c) The Troodos Pillow Lavas

The outer periphery of the Troodos Igneous Complex is occupied by the Troodos Pilllow Lavas. Volcanic rocks similar to the Troodos Pillow Lavas cover also considerable part of the large inliers at Troulli in the east and Akamas Penisula in the extreme west of Cyprus (Fig. 2-2). The Troodos Pillow Lavas had been accumulated by submarine volcanism that took place probably by fissure eruptions during the Mesozoic. Detailed studies of the stratigraphy, the field relationships, petrography and chemistry of the Troodos Pillow Lavas are found in the Memoirs, Bulletins, Annual Reports and many unpublished reports of the Cyprus Geological Survey. Detailed studies of the petrography and geochemistry of the Troodos Pillow Lavas are presently in progress in some English and French Universities.

In the publications of the Cyprus Geological Survey the Troodos Pillow Lavas had been subdivided in upward succession into Basal Group (B.G.) Lower Pillow Lavas (L.P.L.) and the Upper Pillow Lavas (U.P.L.). The main criteria for this subdivision were the proportion of dykes to pillows, the observed petrological and mineralogical differences in the lavas of the three horizons and local unconformable contacts between

these lava horizons.

i. The Basal Group

The Basal Group has a thickness ranging from 280 to 450 metres and consists of Pillow Lavas cut by numerous closely-spaced feeder dykes to lavas of higher stratigraphic horizons. The proportion of dykes generally exceeds the proportion of lavas but in some rare outcrops the opposite has been observed. The lack of intercalated sediments in the Basal Group or at its contact with the overlying Lower Pillow Lava makes the conclusive determination of its age difficult.

The lower part of the Basal Group consists of blue-grey lavas which had suffered low-grade metamorphism and vary in composition from quartz-keratophyres and chlorite-actinolite rocks to epidosites (Bear 1958). The upper part of the Basal Group consists mainly of silicified and chloritized lava impregnated with fine grained pyrite. Pyrite veins filling fractures are very common and are often associated with quartz. Because of hydrothermal alteration, the primary petrological characteristics of the upper part of the Basal Group had been obliterated. Block faulting brought to the surface extensive outcrops of the upper part of the Basal Group. These outcrops have a brown colour produced by the oxidation of the sulphides to limonite. Deep mining operations and extensive drilling around the known sulphide orebodies, as well as extensive exploration drilling by the Mining Companies and the Cyprus Geological Survey away from the known orebodies, indicate that hydrothermally altered and slightly mineralized Basal Group underlies the Lower and/or Upper Pillow Lavas in many parts of the island.

ii. The Lower Pillows Lavas (L.P.L.)

The Lower Pillow Lavas have a maximum thickness of about 380 metres and include basaltic and less commonly andesitic Pillow Lavas cut by basaltic feeder dykes to the Upper Pillow Lavas. The contacts of the Lower Pillow Lavas with the Basal Group are generally faulted. Block faulting and tilting of the Basal Group before the extrusion of the Lower Pillow Lavas had produced local unconformable contacts between the two lava horizons.

The most common minerals of the Lower Pillow Lavas are the plagioclase, pyroxene and magnetite in decreasing order of abundance, associated with variable proportions of glassy mesostasis. Celadonite, argillic and zeolite alterations as well as amygdales of milky chalcedony and colloform opal are common in the Lower Pillow Lavas. Available chemical data suggest that the Lower Pillow Lavas are characterized by high silica low potash and variable amounts of other elements (Moores and Vine (1971).

The age of extrusion of the Lower Pillow Lavas was difficult to determine because of lack of sediments in the lavas of this horizon. Recent detailed mapping has shown the occurrence of local thin layers of ochreous sediments between the Lower Pillow Lavas and the overlying Upper Pillow Lavas. In most of these ochreous layers micropalaeontological investigations failed to detect any microfossils. During drilling in a prospect around the Kambia village 24 kilometres south of Nicosia (Fig. 2-2) the drill-hole MR 35/66 intersected a layer of brown ochre 50 cms thick. This layer marks the contact of the Lower with the Upper Pillow Lavas at the depth of 142 metres (Constantinou 1966). Micropalaeontological investigations detected the foraminifer Thomassinella aegyptia; the above foraminifer was described by Omara (1956) in Cenomanian Sediments from the Sinai Peninsula. (M. Mantis Cyprus Geological Survey personal communication). The occurrence of the ochreous sedimentary layer suggests that in the Kambia area there was a pause in volcanicity after the extrusion of the Lower Pillow Lavas and that the latter probably were extruded during or before the Cenomanian.

iii. <u>The Upper Pillow Lavas</u>

The Upper Pillow Lavas generally form the margin of the Troodos Igneous Complex and have a maximum thickness of about 620 metres. They include olivine basalts limburgites, picrite basalts, and basalts mostly with well formed pillow structure and subordinate hyaloclastites, autobrecciated pillows, intrusives and non-pillowed flows and sills. Plagioclase, pyroxene and magnetite are the main primary minerals of the Upper Pillow Lavas and are associated with variable proportions of glassy

mesostasis. Montmorillonite, chlorophaeite and zeolites particularly analcite are common alteration products in the Upper Pillow Lavas. Most of the olivine is altered to iron hydroxides or iron stained calcite. Published analyses of rocks from the Upper Pillow Lavas indicate that they generally have a low SiO_2 content and low to high alkalis. Compared with the Lower Pillow Lavas most rocks of the Upper Pillow Lava are lower in silica and higher in alkalis (Moores and Vine 1971).

In the Upper Pillow Lava there are sporadic thin layers of waterlain volcanic sediments, comprising alternating layers of ochreous material lithic tuff and tuffaceous grit (See chapters 4 and 5). Micropalaeontological investigations failed to identify any microfossils that could determine the age of extrusion of the Upper Pillow Lavas. The latter however are overlain by the sediments of the Perapedhi Formation of Campanian age (Allen 1966) suggesting that the Upper Pillow Lavas had been extruded during or before the Campanian.

5. The Sedimentary Rocks Surrounding the Troodos Igneous Complex

The Troodos Igneous Complex is surrounded by sedimentary rocks of Campanian to Lower Miocene age (Fig. 2-1). The base of this sedimentary succession is occupied by the Perapedhi Formation of Campanian age, which consists of dark-brown shales and mudstones rich in iron and manganese (locally termed umbers) occasionally associated with red and pink shales radiolation cherts and argillites. The Perapedhi umber in many cases overlies unconformably fresh or weathered Upper Pillow Lavas. The field characteristics of the Perapedhi Umber and its mineralogical and chemical composition will be described in chapters 3, 4, and 5, whereas its genetic relationship with the sulphide ores and the pillow lavas will be discussed in chapter 6.

The Perapedhi Formation is overlain conformably by the calcareous sediments of the Lefkara Group In areas where the Perapedhi Formation is missing the sediments of the Lefkara Group overlie unconformably the pillow lavas. The Lefkara Group in upward succession comprises marls of Maestrictian to Paleocene age chalks and cherts of Palaeocene to Eocene age, massive chalks and limestones of marls and calcarenite of Lower

Miocene age (Table 4-1). The Lefkara Group is overlain by the calcareous sediments of the Pakhna Formation comprising marls, chalks, gypsum, calcarenite and reef limestone of Middle-Miocene age (Table 4-1).

At the southwestern flank of the Troodos Igneous Complex allochthonous sediments (the Mammonia Complex) are resting either on the Troodos Pillow Lavas or on autochthonous sediments (the Kannaviou Formation) of Campanian age. The allochthonous sediments include blocks of reef limestone, sandstones, shales and cherts as well as lava and serpentine. The autochthonous sediments comprise micaceous sandstones, bands of tuffaceous sandstones, as well as mudstones (S. Afrodisis Cyprus Geological Survey personal communication).

6. Stratigraphic Position of the Cyprus Sulphide Ores

As it is illustrated in figures 2-1 and 2-2 the Cyprus sulphide ores are confined to the Troodos Pillow Lava series. Orebodies occur in all horizons of the lava sequence constituting an integral part of the volcanic succession. The close genetic relationship of the sulphide ores to the volcanism of the Troodos Pillow Lavas was noted by all the geologists who have studied the Cyprus sulphide ores, but the age of emplacement of the individual deposits, their stratigraphic position in the lava sequence and their detailed relationship with the surrounding lavas were for a long time controversial aspects. The lack of detailed maps in most of the orebodies, the beyond recognition hydrothermal alteration of the lavas underlying most of them and complications of their original geological setting brought about by post mineralization faulting and in many cases by tilting were the main reasons for the above controversies.

A controversial aspect was whether the sulphide mineralization in Cyprus is pre or post-Perapedhi Formation. Cullis and Edge (1922) relying mainly on the study of the Skouriotissa orebody which is overlain by sedimentary rocks, concluded that the mineralization is post-Perapedhi whereas Lespineux and de Magnee (1935), Jarrel (1947) and Ingham (1959), advocated a pre-Perapedhi age for this orebody. Mousoulos (1957) and Gordon-Smith (1963) suggested a post-Perapedhi age for the mineralization in the

Kalavasos area whereas Pantazis (1967) prefers a pre-Perapedhi age for the mineralization, in the same area. Bear (1963) concluded that the sulphide mineralization in Cyprus postdates the Perapedhi Formation.

Previous workers recognized that sulphide orebodies occur at all levels of the pillow lavas and it was considered that the sulphide ores were emplaced during a single event, at the waning stages of the Troodos Pillow Lavas volcanism. The size, shape and grade of the individual orebodies was considered to depend largely on the position of the orebody within the lava sequence, the nature of the hostrock and the presence of faulting. Thus the large and copper-rich orebodies were considered to occur in the Upper Pillow Lavas whereas the orebodies which occur in the Lower Pillow Lavas have more irregular shape and size, and are of lower grade because they are diluted by dykes and sills contained in these lavas. (Bear (1963); Vokes (1964)).

Wolff (1964) produced evidence suggesting that the Agrokipia orebody was emplaced before the extrusion of the Upper Pillow Lavas and concluded that in Cyprus there were two periods of sulphide mineralization. Vokes (1966a) concurs with the suggestion of two periods of sulphide mineralization in Cyprus. Recent detailed mapping produced unequivocal evidence suggesting that many large and copper-rich orebodies were emplaced before the extrusion of the Upper Pillow Lavas. Many orebodies are overlain conformably by unmineralized Upper Pillow Lavas and in some of them between the massive ore and the overlying Upper Pillow Lavas is interposed a thin layer of ochreous sediment suggesting a time interval between the emplacement of these orebodies and the extrusion of the Upper Pillow Lavas (Chapters 4, 5). Furthermore many orebodies overlain by U.P.L. contain unmineralized dykes identical in composition and texture with the typical feeder dykes to the Upper Pillow Lavas. However beyond the establishment of a pre - Upper Pillow Lava age for these orebodies it is still difficult to determine conclusively their exact stratigraphic position in the lava sequence.

CHAPTER III

THE SKOURIOTISSA MINING AREA

A. INTRODUCTION

1. Location and History

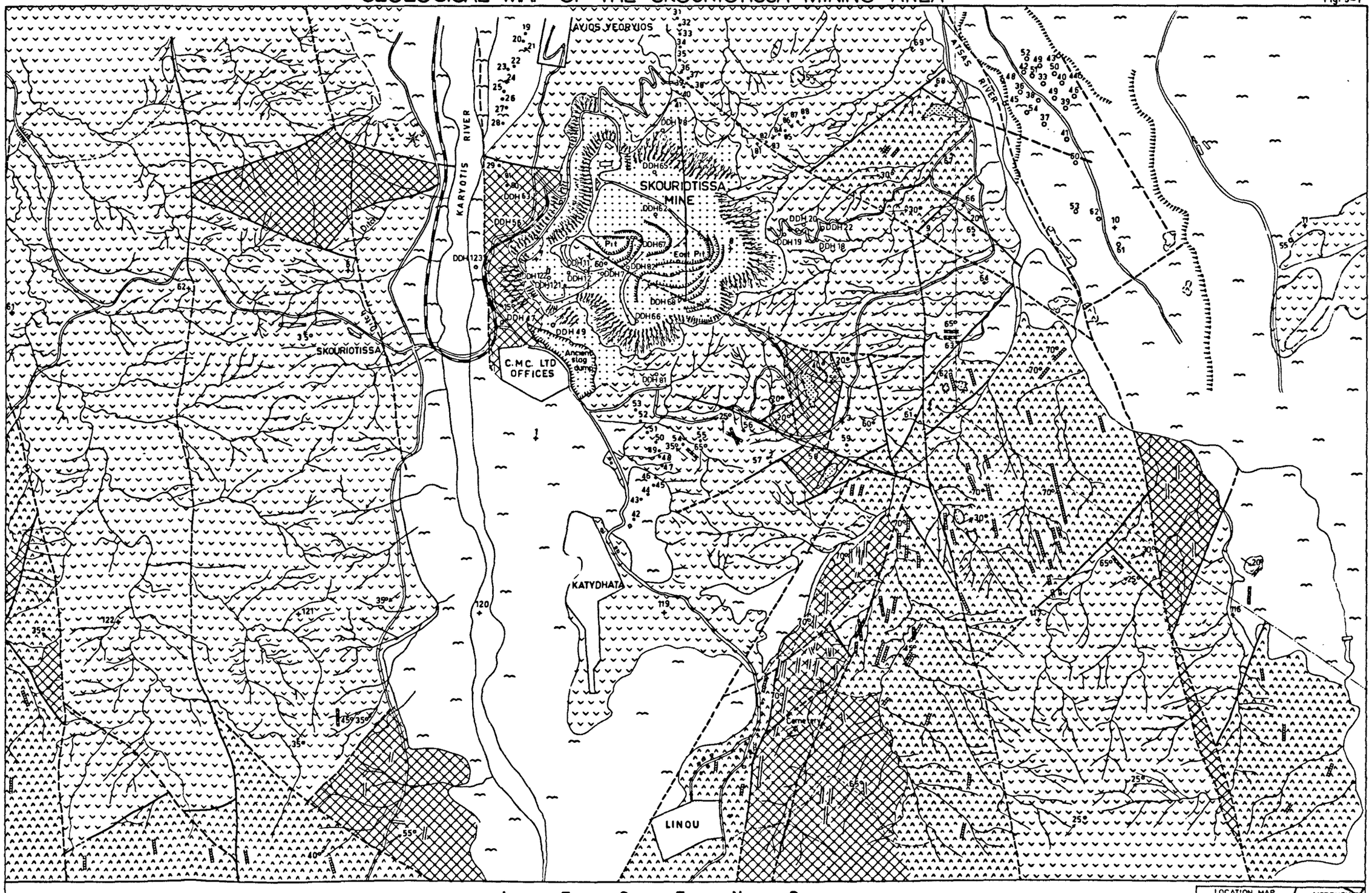
The Skouriotissa mining area is situated approximately 6 kilometres inland from Morphou Bay and 2 kilometres South-Southeast of Lefka. It is about 60 kilometres West-Southwest of Nicosia along the main road between Nicosia and the Marathasa District. The position of the Skouriotissa Mining Area relative to the Apliki and Mavrovouni orebodies is shown in Fig. 3-1.

It is known that the Skouriotissa orebody, after which the mining area is named, was the most important mine of the Greek kingdom of Soli, the port of which was located about 4 kilometreswest of the present port of Xeros. The intensity of the ancient mining and smelting activities can be judged by the large accumulation of slag a short distance southwest of the mine. Comparison of the composition of the slag from here with those of other mining areas in Cyprus suggests that the ore was successively worked by the Prephoenicians, Phoenicians, Greeks and by the Romans. There is no record of mining activity in the area between Roman times and the beginning of this century.

Cullis and Edge (1922) report that, in the years prior to 1913, several people took out prospecting permits, but it was not until C.G. Gunther examined the area in 1913 that serious prospecting was done. After a detailed investigation, Gunther obtained a special prospecting permit and began drilling in 1914. The outbreak of war interrupted the drilling for four years, although by the end of 1920, 47 churn drill holes had been completed. In 1915 a 50-year Mining Lease, for an area of one square mile, was granted to C.G. Gunther, Seely W. Mudd and Philip Wiseman, and in the following year they formed the Cyprus Mines Corporation (C.M.C.), a private company which was incorporated in New York. During the war considerable amount of underground development work was completed. In 1929 the company mining lease was extended to an area of 5.67 square miles.

GEOLOGICAL MAP OF THE SKOURIOTISSA MINING AREA

Fig. 3-1



L E G E N D

SEDIMENTARY ROCKS

- Recent alluvium, gravels, soils intensely cultivated
- Marls with thin cover of reef limestone

TROODOS VOLCANIC ROCKS

- Upper pillow lava
- Grey-green lower pillow lava
- Iron stained altered lava with jasper, upper part of Basal Group
- Gossan

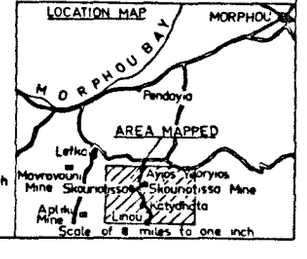
MINOR INTRUSIVES

- Dyke of upper lava type
- Dyke of lower lava type
- Undifferentiated dyke in brown lava and basal group

C O N V E N T I O N A L S I G N S

- Fault
- Inferred fault
- Geological boundary, nature unknown
- 20° Direction and amount of dip of pillowed lava
- 60 UNDP drill-hole
- DDH 47 C.M.C drill-hole
- 34 Station of geochemical sample
- Mine dump
- Mine bench
- Ancient slag dump
- Geophysically surveyed area, 1967
- 121 Principal point of aerial photograph
- Slope
- Road
- Mine railway
- Principal footpath

LOCATION MAP



Scale

Feet 1000 0 1000 2000 3000 4000 5000 Feet

Metres 100 0 100 500 1000 1500 Metres

From the 47 churn drill holes which were drilled intermittently between 1914 and 1920, and the extensive concurrent underground development work, the total tonnage of the ore was estimated to exceed 6-million tons. Over half of this tonnage was mined by underground methods between 1921-1940. Owing to the special characteristics of the ore and the footwall (see following sections) various methods had been used, some of them especially developed to cope with these characteristics of the ore.

After the war period, during which the mining of cupriferous pyrites was suspended the mining operations of C.M.C. were concentrated on the Mavrovouni orebody, (Fig.2-2) which was richer in copper and more amenable to beneficiation than the Skouriotissa ore. At the Skouriotissa orebody, where mining operations resumed in 1963, an open pit method was used for the extraction of the remaining 2.5 million tons of ore.

2. Previous work

Much has been written on the Skouriotissa Mining area, but most papers deal primarily with the geology and origin of the Skouriotissa orebody: the first geological account given by Cullis and Edge (1922) was based on information obtained from the first 47 drill holes and the early underground development. This was followed by a more detailed paper by Lespineux and de Magnee (1935) who made a combined field and laboratory study of the Skouriotissa ore. The Skouriotissa orebody was discussed by Jarrel (1947) in a confidential report to C.M.C. and a more detailed account was given by Bruce (1948). Further description of the general geology of the Skouriotissa orebody has since been given by Ingham (1959), and a compilation of the published information was given by Bear (1963).

In 1962 two C.M.C. geologists, Callaghan and Pilkington, initiated surface mapping of the whole C.M.C. Mining district on a scale 1:5000 and, at the same time, they carried out systematic diamond core drilling, beneath and adjacent to the Skouriotissa orebody. The resultant information, plus the data collected were published by Callaghan (1965).

Late in 1967 G.J. Govett and Th. Pantazis undertook a

detailed geochemical investigation of the lavas in the vicinity of the orebody and the former, together with the writer, sampled the ore, lavas and sediments exposed in the open pit. A preliminary report of the results obtained was given by Govett (1969).

3. Present investigation

In thespring of 1968 the writer began systematic sampling and detailed mapping of the pit, on a scale 1:1000, using the mine plans of the C.M.C. as a base map. The mining operations were very well advanced when the mapping was completed. (Fig.3-2) and the contact of the orebody with the underlying volcanic rocks was exposed down to great depths. Although a geological map of the surrounding area was available, the rock classification used by C.M.C. geologists was completely different from that used by the Cyprus Geological Survey. Thus the mapping was extended outwards, on a scale of approximately 1:10000, by using aerial photographs of the Geological Survey. Originally it was intended to map westwards for 2 kilometres so as to include the Aplikí and Mavrovouni orebodies, the latter being the biggest in Cyprus. A study of these ores was considered essential to a general understanding of the Cyprus sulphide deposits but, because of inter-communal troubles on the island at the time, their mapping had to be abandoned.

In addition to mapping, cores from about twenty selected diamond drill holes in and around the Skouriotissa orebody were logged and sampled. Unfortunately much additional drilling information was not available to the writer. Using the information obtained from the detailed mapping and data compiled by Cullis and Edge (1922) as well as the drilling information of the early 47 churn drill holes the isometric projection illustrated in figure 3-3 was constructed.

B. GEOLOGY OF THE SKOURIOTISSA AREA

1. General statement

Figure 3-1 shows that most of the Skouriotissa area is covered by Pre-Upper Cretaceous volcanic rocks. These can be divided into three, well-defined groups: The upper part of the Basal Group (B.G.), the Lower Pillow Lavas (L.P.L.) and the Upper Pillow Lavas (U.P.L.), (Table 3-1). The oldest of these rocks occur in the south while the younger Pillow lava predominate in the centre and the north.

The small patches of post-Middle Miocene sedimentary rocks, exposed in the north and north-west, are probably remnants of once continuous cover that has since been largely eroded away. These sediments consist mainly of clay-marls and marls capped by a thin reef limestone horizon. Similar sediments are found above the umbers that overlie the Skouriotissa orebody.

The general topography of the area is smooth to undulating, with elevations ranging between 150 and 275 metres above sea level. Differential weathering of the lower two groups of Pillow lavas and the many dykes they certain, results in a rugged topography in the southern region. This is in contrast with the more even weathering and less pronounced relief in the dyke-free Upper Pillow Lavas in the north. The most prominent feature in the whole area is Phoucasa Hill standing about 400 metres high and made up of basaltic lavas, massive sulphide ore, ochre and umber, argillites, marls and capped by reef limestone.

2. Upper Part of Basal Group (Brown Lavas)

The Basal Group is the oldest exposed rock in the area and is made up of a highly variable proportions of vesicular pillow lavas and dykes, the latter being feeder conduits for the younger Pillow lavas. Small outcrops of the Basal Group rocks exist in the central region, on the upthrown sides of block faults, but they are confined mainly to the South near Linou village. To the South of the area these rocks become the dominant lithology.

These lavas are generally brown due to the oxidation of iron sulphide impregnations and fracture fillings to limonite. They

Table 3-1. The stratigraphic succession in the Skouriotissa Mining area.

	LITHOLOGY	FORMATION	AGE	MAXIMUM THICKNESS (in metres)
SEDIMENTARY ROCKS	Reef limestone	KORONIA LIMESTONE	UPPER MIDDLE MIOCENE	37
	Marls and chalky marls	PAKHNA	MIDDLE MIOCENE	24
	Thick bedded chalks, chalks and marly chalks interbedded with chert, pink marl.	LEFKARA GROUP	LOWER MIOCENE TO UPPER CRETACEOUS (MAESTRICHTIAN)	Absent
	Umbers and manganiferous shales grading up into brown and pink argillites	PERAPEDHI	CAMPANIAN (UPPER CRETACEOUS)	12
	Bedded grey green clayey tuffs	OCHRE GROUP	UPPER CRETACEOUS?	9
	Bedded brown and orange yellow ochre with graded banding			
	Red hematitic ochre (rich in sulphide with graded banding)			
	Bedded chert with sulphide			
	Massive sulphide interbedded with ochre			
	Massive iron and copper sulphide	MINERALIZATION	UPPER CRETACEOUS?	52
VOLCANIC ROCKS	Olivine basalts with well developed pillow structure	UPPER PILLOW LAVAS (U.P.L.)	UPPER CRETACEOUS?	290
	Grey green basaltic pillow lavas with green celadonite	LOWER PILLOW LAVAS (L.P.L.)	UPPER CRETACEOUS?	91
	Sillicified and chloritized pillow lavas and dykes containing veins and disseminations of sulphides. Commonly iron stained due to oxidation of sulphide to limonide	UPPER PART OF BASAL GROUP (B.G.)	?	366

often contain red jasper, both as fracture filling veins and as nodules in cavities; also, in places, they are extremely hard and resistant to weathering and erosion as a result of severe silicification.

The dykes have a meridional strike and dip steeply westwards, whereas the pillow lavas of the Basal Group dip gently to the northeast parallel to the L.P.L. The dykes have undergone alteration identical with those of the pillow lavas. Drilling data suggest that there is a subsurface extension of the Basal Group rocks, under the northern part of the area.

The primary petrographic character of the Basal Group lavas has been obliterated both by hydrothermal alteration and by supergene alteration, associated with near-surface oxidation of their iron sulphide minerals to limonite. Drilling data indicate that the hydrothermally altered Basal Group extends to depths of more than 700 metres and contains erratically distributed sulphide mineralization that tends to decrease with depth. Epidote is rather rare and sporadic on the surface, but it increases and is quite common at depth. Both minerals tend to fill fractures and cavities, or they are disseminated in the altered lavas. Silicification is intense and its intensity remains constant with depth, whereas chlorite in general tends to increase in depth.

Thin-section studies show that the original texture of the poorly crystalline lavas was destroyed, whereas ghost microporphyritic textures are relatively common. In the microporphyritic lavas the plagioclase and pyroxene are pseudomorphed by quartz, while the glassy matrix is altered to chlorite and chalcedony. Quartz and chlorite fill vesicles and fractures; limonite, often with spheroidal and collomorphic texture, is abundant.

3. Lower Pillow Lavas (L.P.L.)

The Lower Pillow Lavas are mostly exposed at the southeastern and southwestern parts of the area. Westwards beyond the area the Lower Pillow Lavas outcrop almost continuously up to the Apliki orebody. They are dark grey-green on a fresh surface

but weather to a characteristic khaki colour. Pillow structures are very well developed, and the individual pillows are separated with black glassy selvages. The L.P.L. have a basaltic composition, with vitreous and microporphyritic texture. Laths and microlites of plagioglase constitute most of the crystalline material, followed in abundance by pyroxene and magnetite.

Earthy, green celadonite is abundant, and fills fractures and vesicles in the pillows. Many of the vesicles are lined with chalcedony and zeolites. Rare chalcedonic silica is also found in the glassy matrix Limonite staining is very widespread, and there are isolated patches of relatively strong gossanization, associated with silicification of the lava around, and abundant red Jasper.

The abundant basic dykes in the L.P.L. were intruded in two periods. The early dykes trending north north-eastwards have a steep westerly dip, and show the same field and petrographic features as the surrounding pillows. The later dykes intersecting the early ones have a north, northwesterly trend. They are also darker in colour, more basic in composition and petrographically are similar to the olivine basaltic Upper Pillow Lavas which were extruded after the L.P.L. It is certain that the younger dykes feed the overlying Upper Pillow Lavas.

4. Upper Pillow Lavas (U.P.L.)

The Upper Pillow Lavas are the youngest and most widespread volcanic rocks in the Skouriotissa area. The thickness of these lavas generally increases towards the north, and drilling suggests that their maximum thickness is about 290 metres. The Upper Pillow Lavas surround and underlie the Skouriotissa orebody, and extend westwards up to the Mavrovouni orebody Fig. 3-1. The lavas are cut by rare sills and dykes, the latter trending north - northwest, more or less parallel to the second generation of dykes cutting the Lower Pillow Lavas.

The Upper Pillow Lavas have a very well defined pillow structure; the diameter of the pillows ranges from 30 cms 1:5 metre and in some rare cases it is up to 3 metres. The well developed glassy selvages around the pillows have a characteristic green colour.

Weathering causes the lavas to vary in colour from grey through pale-grey to grey-pink.

The lavas are highly vesicular, particularly near the margins of the pillows. The vesicles are filled with secondary calcite or zeolites (mostly analcite). Fracturing in a variety of patterns is very common, and calcite often fills these fractures as well. Brown iron-stained calcite, or amorphous iron oxide pseudomorphs after olivine, observable with unaided eye, are common in these lavas.

The textures of the basaltic lavas can in general be related to both the size of the individual pillow and the distance from the pillow centre. The small pillows and the outer parts of large pillows have a vitreous texture, and are composed of up to 95 per cent of glassy matrix. The central part of large pillows, have a microporphyritic texture and lower proportion of glass to crystals. Vesicularity increases in glassy lavas. All these obesrvations are consistent with the cooling of the lava being at a slower rate in the larger pillows.

The most common minerals in the Upper Pillow Lavas and included dykes are plagioclase, pyroxene, olivine and magnetite. In the glassy lavas, the plagioclass mostly occurs as lath-like microphenocrysts whereas in the microporphyritic lavas, it mainly occurs as microlites; much of the plagioclase is altered to greenish cryptocrystalline montmorillonite and the presence of compositional zoning is often revealed through differential alteration across zone boundaries. Augite, the second most common mineral, forms subhedral grains scattered in the glassy mesostasis. The pyroxene is partly altered to a greenish substance probably cryptocrystalline chlorite.

Olivine phenocrysts and microphenocrysts are very common in these lavas and tend to form "olivine nodules". They are largely altered to dark chocolate brown, amorphous iron oxide and, to less extent, to iron stained calcite. The glassy lavas contain rare, fine-grained skeletal crystals of magnetitic. The glassy mesostasis altered to dark brown to light green chlorophacite and montmorillonite. Zeolites, mainly analcite, are common in fractures and vesicles.

Several X-ray diffraction analyses of fresh olivine basaltic lavas from inside and outside the pit were made to complement the optical investigations, (Table 10-2). These analyses indicate that:

(i) Plagioclase is the predominant primary mineral followed by pyroxene.

(ii) Montmorillonite is invariably present in considerable amounts.

(iii) Chlorite, which is often reported as a common alteration product of the glassy matrix of these lavas, is absent.

(iv) No other clay minerals are present.

(v) The glassy selvages around the pillows mostly consist of montmorillonite.

5. Structure

The tectonic pattern in the Skouriotissa area is one of tilted fault blocks, and small horst and graben structures bounded by normal gravity faults. The tilting of the lavas ranges from 25° to 35° and within each major fault block it is remarkably constant in both direction and magnitude. As it can be seen on figure 3-1 most of the contacts between the different rock units are faulted, and this has been confirmed by drilling information. Faulting uplifted and exposed mineralized blocks, and it appears that faulting postdates the mineralization in the Skouriotissa area.

The strikes of major fault sets in order of decreasing age are 320°, 020°, 040°, 060°, 300° and 350°. This fault pattern is typical of the structural pattern seen in the other mining areas in Cyprus. It is probable that certain fault sets are complementary and therefore of the same age, and also that many faults have had repeated movements along them. In general the lack of sediments makes the study and dating of fault movements rather difficult.

6. Summary

Most of the area is covered with volcanic rocks that are divisable into, the Upper part of the Basal Group, Lower

Pillow Lavas and Upper Pillow Lavas. Generally, the older volcanics are more abundant in the south with only uplifted blocks exposed in the central and northern parts where the younger olivine basalts predominate.

The Basal Group and the Lower Pillow Lavas are characterised by high proportion of dykes. There is a marked change in the trend of the two generations of dykes in the Lower Pillow Lavas, as well as in their petrological composition.

The Basal Group is extensively mineralized with iron sulphides, and the mineralization was associated with silicification chloritization and in depth epidotization of the lavas. Because of the alteration their original petrological character is obliterated. Oxidation of the sulphides has imparted a brown discolouration to the rocks of this group.

The Lower Pillow Lavas are rich in green celadonite and are mineralized in some parts. The olivine basaltic Upper Pillow Lavas have similar field and petrographic features both inside and away from the Skouriotissa Pit. Field and Laboratory data suggest that they are unmineralized and are not hydrothermally altered.

Inasmuch as the area suffered intense block faulting, tectonically it is less disturbed than the other mining areas in Cyprus. The tectonic pattern is one of tilted fault blocks and small horst and graben structures bounded by normal gravity faults.

C. GEOLOGY OF THE SKOURIOTISSA OREBODY

1. General Statement

The geological setting of the orebody and its relation to the surrounding volcanic rocks and the overlying sedimentary rocks is shown in the isometric projection, shown in (Fig. 3-3). This projection covers the whole orebody except for small areas at its eastern and western extremities. The western orebody (Sections A, B, C and D) is downthrown relative to the eastern orebody, (sections E, F and G) by a fault that trends approximately north-south, and dips steeply to the west.

The sedimentary sequence overlying conformably the orebody in upward succession includes the Ochre Group, the Perapedhi Formation, the Palna Formation and the Koronia Limestone. The orebody is underlain conformably by olivine basaltic U.P.L. similar in composition and texture to the olivine-basaltic U.P.L. described in the previous section. Knife-edge contacts between the ore and the underlying lavas are common. Faulted contacts brought about by post mineralization movements are also common.

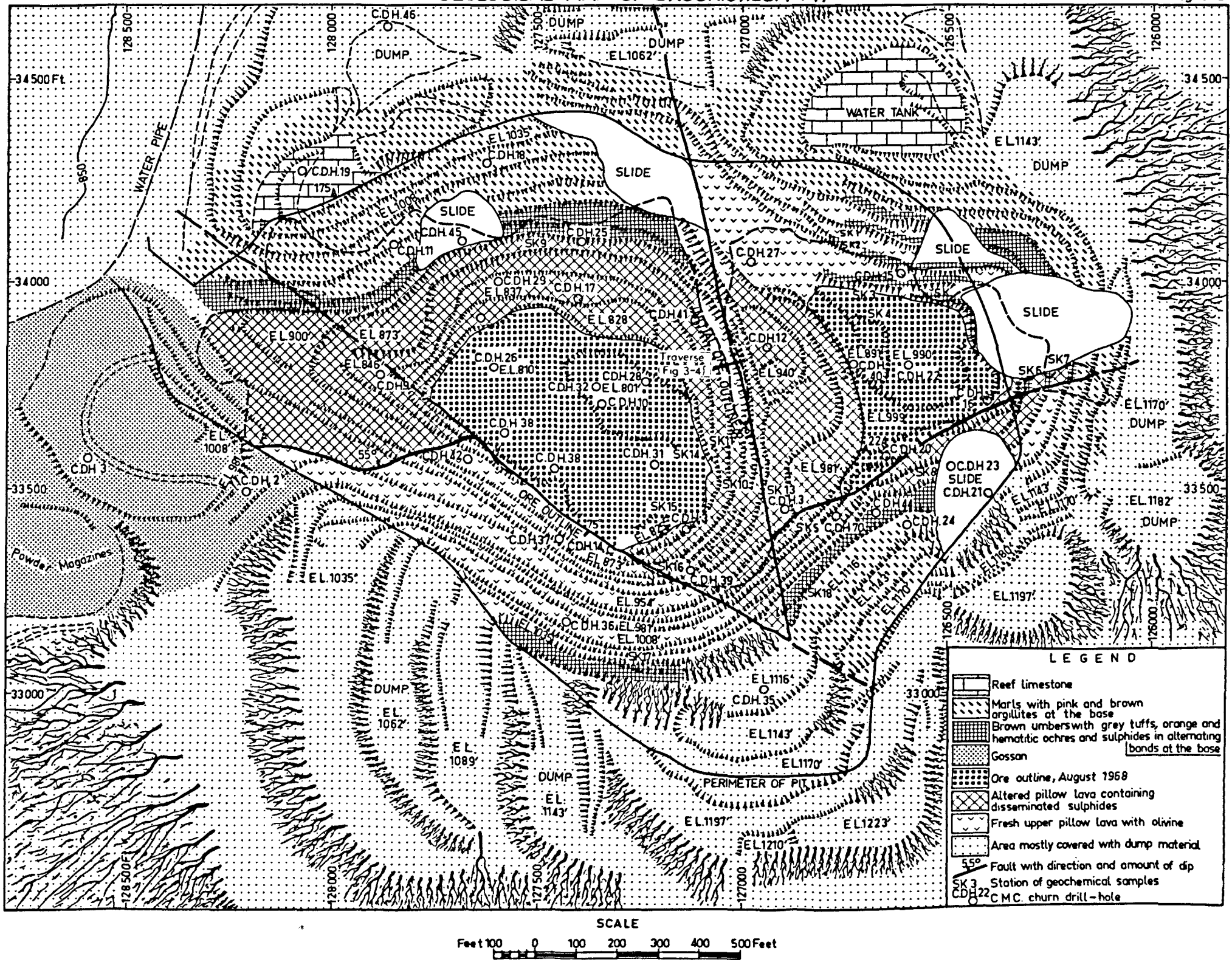
2. Koronia Limestone and Palna Formation

A detailed stratigraphic section through the orebody is shown in (Table 3-1), it indicates that the top of the sedimentary succession, overlying the orebody consists of reef limestone of Upper Middle Miocene age. Its thickness varies from several to 42 metres; it has its maximum thickness in the central and southern part of the orebody, but it thins towards the north. It is a massive, coarse grained and fossiliferous limestone of pale yellowish colour. Well rounded pebbles of gabbro and other igneous rocks, of the Troodos Igneous Complex, were reported by Cullis and Edge (1922) to occur in this limestone.

The reef limestone, is underlain conformably by the Pakhna Formation which is Middle Miocene in age. The top of this formation consists of well-bedded, chalky marls grading down into marls at the base. The maximum thickness of the marls, was 25 metres and were very well exposed on the northern and

GEOLOGICAL MAP OF SKOURIOTISSA PIT

Fig. 3-2



northeastern slopes of the Phoukasa Hill. From the drill hole logs it is difficult to distinguish, the lower part of this Formation from the top of the argillites of the underlying Perapedhi Formation.

3. Perapedhi Formation

The Pakhna Formation lies disconformably upon the Perapedhi Formation of Campanian (Upper Cretaceous) age. Here there is a hiatus in sedimentation extending from Lower Miocene down to Upper Cretaceous. In the Tamassos and Kalavassos mining areas this gap is represented by the sediments of the Lefkara Group. The Perapedhi Formation consists of argillites at the top which grade down through brown argillites to brown umber at the base.

(a) Argillites

The argillites consist of about 6 metres of soft, sticky sediments that commonly display post-depositional slump structures. Recent sliding since the uncovering of the pit has been widespread (Fig. 3-2). The brown and pink colour of the argillites are probably due to variations in their iron and manganese contents. A partial analysis of brown argillite given in table (3-2), indicates that its iron and manganese are considerably lower than the iron and manganese content of the umber. One X-ray diffraction analysis of the same sample showed the brown argillite to consist of a mixture of montmorillonite and illite (the former predominating) plus quartz and subordinate amounts of goethite.

(b) Umber

i. Field characteristics and chemical composition

The umbers are easily distinguishable from the sediments above and below by their striking dark brown colour. Their lateral extent was difficult to ascertain in the present investigation, because it was obscured by the extensive mining operations. However, there is unanimous agreement in all the published work on the orebody that the umber extends well beyond the margins of the orebody, and that it lies between the volcanic rocks and the marls.

Table 3-2. *Partial major element analyses of umber and ochre and **Atomic absorption spectrophotometer analyses for Cu, Zn, Ni and Co in umber, ochre and sulphide ore from Skouriotissa

Sample No.	Location	Description	Al_2O_3 %	MnO_2 %	Fe_2O_3 %	Cu ppm	Zn ppm	Ni ppm	Co ppm
UMBER									
SK 29	Level 1008 ft, Coords:-126445, 33910 m	Dark brown umber	2.80	13 6	43 6	-	-	-	-
SK 31	" " " " "	" " "	3 87	21.0	40 0	-	-	-	-
SK/7/2	Level. 1116 ft., Coords: -126400, 33950 m.	Brown urgillite umber	14 80	3.87	11.9	-	-	-	-
SK?	Skouriotissa	After Ingham (1959)	-	8 28	53 43	-	-	-	-
SK?	"	After Bear (1963)	5 90	18 07	51.78	-	-	-	-
SK/9/11	Level. 945 ft, Coords: -127475, 34155 m.	Dark brown umber	-	-	-	832	1000	387	292
" " 12	" " " " "	" " "	-	-	-	1248	920	320	265
" " 13	" " " " "	" " "	-	-	-	3708	980	265	265
SKP/7/83	Level 1018 ft., Coords: -126438, 34048 m	" " "	-	-	-	1288	213	266	130
" " 84	" " " " "	" " "	-	-	-	832	380	275	275
" " 85	" " " " "	" " "	-	-	-	960	480	345	220
" " 86	" " " " "	" " "	-	-	-	1020	460	312	205
" " 87	" " " " "	" " "	-	-	-	1120	460	308	230
" " 88	Samples every two feet " " " "	" " "	-	-	-	1168	420	368	155
" " 89	" " " " "	" " "	-	-	-	1000	500	362	245
" " 90	" " " " "	" " "	-	-	-	916	460	362	235
" " 91	" " " " "	" " "	-	-	-	832	400	342	200
" " 92	Top of section " "	" " "	-	-	-	500	192	47	75
					Means:	1186	528	304	215
Ratios: Cu : Zn = 2.2, Ni : Co = 1.4, Cu : Co = 5.5									
OCHRE									
SK	Skouriotissa	After Ingham (1959)	nd	nd	68 60	-	-	-	-
SK	"	After Ingham (1959)	4 5	0 22	71.70	-	-	-	-
SK 27c	Level: 1008 ft., Coords:-126445, 33910 m.	Brown, yellow ochre	1.73	1.28	62 20	-	-	-	-
SK 27d	" " " " "	Dark brown ochre	2 38	1.79	49 40	-	-	-	-
SK 3	" "	Orange yellow ochre	2.19	0.60	78. 00	3905	1210	55	146
SK/4/3	Level: 990 ft., Coords: -126665, 33 900 m.	Red hematitic ochre	0.62	0.06	54. 30	28000	268	24	204
SK/9/3	Level. 945 ft, Coords: -127475, 34155 m.	Brown yellow ochre	-	-	-	14580	106	6	178
SK/9/6	" " " " "	" " "	-	-	-	11 680	560	20	151
SK/9/8	" " " " "	" " "	-	-	-	2268	213	31	49
SK/9/9	" " " " "	" " "	-	-	-	14960	45	165	320
SK G 6	Level: 1008 ft., Coords: -126460, 34026 m	" " "	-	-	-	121	55	37	160
SK G 7	" " " " "	" " "	-	-	-	129	58	37	300
SKG 8	" " " " "	" " "	-	-	-	175	59	40	380
SKG 9	" " " " "	" " "	-	-	-	167	73	42	260
SKP/6/74	Level 846 ft., Coords: -127894, 33818 m.	" " "	-	-	-	3788	1400	66	215
SKP/6/75	" " " " "	" " "	-	-	-	26680	640	33	185
SKG/2/3A	Level: 1062 ft, Coords: -127062, 33148 m.	Red hematitic ochre	-	-	-	13200	235	25	127
" " 3B	" " " " "	" " "	-	-	-	10000	184	21	125
" " 3C	" " " " "	" " "	-	-	-	16400	380	50	136
" " 4A	" " " " "	" " "	-	-	-	26400	116	25	243
" " 4B	" " " " "	" " "	-	-	-	25360	152	31	370
					Means:	11636	338	42	209
Ratios: Cu : Zn = 34.4, Ni : Co = 0.2, Cu : Co = 55.7									
ORE									
SKP/1/12	Level: 855 ft, Coords. -127754, 33963 m.	Massive sulphide ore	-	-	-	11440	99	6	250
SKP/2/13	Level 885 ft, Coords. -127290, 34100 m.	" " "	-	-	-	11110	49	12	250
" " 15	" " " " "	" " "	-	-	-	13740	57	6	205
" " 21	" " " " "	" " "	-	-	-	21440	45	6	360
" " 22	" " " " "	" " "	-	-	-	77440	176	44	685
SKP/4/54	Level 875 ft, Coords: -127037, 33756 m.	" " "	-	-	-	3048	960	44	610
SKP/6/81	Level: 1008 ft, Coords -126533, 34012 m.	" " "	-	-	-	7880	220	22	290
SKP/8/93	Level 999 ft, Coords -126455, 33721 m.	" " "	-	-	-	28320	740	29	105
" " 94	" " " " "	" " "	-	-	-	9200	4320	29	145
SK/14/29	Level: 810 ft, Coords -127396, 33840 m.	" " "	-	-	-	26640	808	44	400
SKS	Western orebody	After Searle (1965)	-	-	-	13300	2700	20	1200
SKS	" "	After Searle (1965)	-	-	-	4900	550	20	280
					Means:	21026	747	24	330
Ratios: Cu : Zn = 28.1, Ni · Co = 0.07, Cu : Co = 63.7									

* Analyst, Pure Geochemistry Department, Imperial College

** Analyst, Chemical Laboratory of the Cyprus Geological Survey

The umbers are massive to poorly-bedded rocks which have a chestnut to chocolate brown more rarely lighter brown colour; they are homogeneous, extremely fine grained, exceptionally light, soft, relatively friable and brake with a conchoidal fracture.

Chemically the umbers consist of varying proportions of iron and manganese oxides, silica and alumina. Partial chemical analyses indicate that in the umber the MnO_2 content exhibits a wide variation but is persistently high. Although the MnO_2 content of the umber at Skouriotissa varies considerably the lowest figure for MnO_2 in Table 3-2 is ten times higher than the lowest figure for MnO_2 given by Jarrel (1947) who reported that " .... in ten samples termed umber from the Skouriotissa Mine analysed by the Assay Office MnO_2 varies between 0.47 and 13.5 per cent .....". It appears that the lowest of the MnO_2 values given by Jarrel represent analyses of samples of ochre which underlie the umber and which contain very low manganese; it seems likely that the above author failed to distinguish between umber and ochre.

Storrs (1930) reported that weathering of umber at Skouriotissa produced concretions of manganese oxide containing very high manganese. Fragments of such concretions were very common in zones of denuded umber, but were also spread over the nearby pillow lavas on the eastern slopes of Phoucasa Hill.

A number of samples of umber from the Skouriotissa orebody were analysed for Cu, Zn, Ni and Co by the Chemical Laboratory of the Cyprus Geological Survey using a Perkin Elmer Model 290 E Atomic Absorption Spectrophotometer, and following the analytical procedure described by Govett and Pantazis (1971). The results of these analyses are shown in Table 3-2 and indicate that:

(a) Copper, Zinc, Nickel and Cobalt are generally high in the umber, and

(b) The ratios of Cu:Zn and Ni:Co are higher than one.

ii. Mineralogy

The physical characteristics of the umber made the preparation of thin and polished sections extremely difficult.

Various impregnation techniques were tested, but only one proved to be satisfactory (see Appendix A), and a few polished sections had been prepared.

At low magnifications the umber is seen to consist of massive, structureless material having a low reflectivity. At high magnifications rounded and elliptical areas of slightly higher reflectivity and relief are observed, scattered through the dark massive matrix. These high reflectivity areas constitute small proportion of the volume of the rock, show distinct red brown internal reflections and they probably represent areas of poorly crystalline goethite.

Minute crystals of goethite and more rarely of maghemite were seen scattered through the dark matrix. These vary considerably, both in size and form, but all have angular crystal outlines displaying indentations and projections that are probably due to corrosion. Planar faces are extremely rare (Plate 3-35).

Rare fragments of pyrite occurring in the matrix are mostly highly fractured and corroded. Plate 3-34 shows pyrite fragments in which fractures and zones of corrosion are filled with iron oxides. The similarity of the observed crystal forms of iron oxides and pyrite plus the observed replacement of pyrite by iron oxides suggest that the crystalline iron oxides most probably represent products of in situ oxidation of pyrite.

X-ray diffraction analyses of umber (Table 6-1) indicate that it is poorly crystalline. All the analyses showed only weak peaks for goethite; no quartz or clay minerals were detected. Although the manganese content in the umber is considerably high, the optical study and the X-ray diffraction analyses did not detect any manganese mineral(s) (see chapter 6).

One sample of umber collected from the eastern orebody was investigated for microfossils by Dr. M. Muir. In this sample were observed several leaf cuticles derived from land plants and some spores, probably from the same source; all these proved to be unidentifiable because of bacterial attack. In the same specimen were observed several large and many small pieces of mucillaginus tissue almost certainly algal in origin. (Dr. M. Muir, Department of Micropalaeontology, Imperial College, Personal communication).

4. Ochre Group

Ochre Group has been adopted by the writer as a general term to cover the sediments lying between the umber and the orebody. Table 3-1 indicates that the Ochre Group includes:

(a) The well bedded grey-green clayey tuffs,

(b) The well bedded, brown yellow ochre with rare sulphide layers,

(c) The well bedded red hematitic ochre with common bands and disseminations of sulphide.

(d) The bedded cherts with bands and disseminations of sulphide, and

(e) Massive sulphides interlyered with ochre.

The base of the Ochre Formation follows irregularities on the top of the orebody, and where it extends beyond the ore boundaries over the nearby lavas it also fills irregularities on the top of the lavas. The ochre is generally restricted to the vicinity of the orebody; yellow ochre however was mined from an isolated outcrop close to Ayios Yeorghios village (Fig. 3-1). The general distribution of the Ochre Formation in the pit is shown in fig. 3-2. At the northeastern face of the eastern orebody the ochre is clearly overlain unconformably by the umbers, since the bedding of the clayey tuffs and ochres dips 30° to the southeast beneath flat lying umbers (Plate 3-2). Yet at the northern face of the western pit the ochre is overlain conformably by the umber. (Plate 3-3).

(a) Grey-green tuffs

The thickness of these sediments ranges from 10 cms to several metres, their maximum thickness being at the exposure shown in Plate 3-2. Here they overlie red-yellow ochre; the contact of the yellow ochre with the tuff is gradational with fragments of the former intimately mixed with the latter, up to 3 metres from the contact.

The tuffs are well stratified and invariably display graded bedding, sliding and discolouration through percolating surface water is common along bedding planes. X-ray diffraction analyses of clayey tuffs indicate variable mineral assemblages from bed to bed, but within a single graded bed the mineralogical

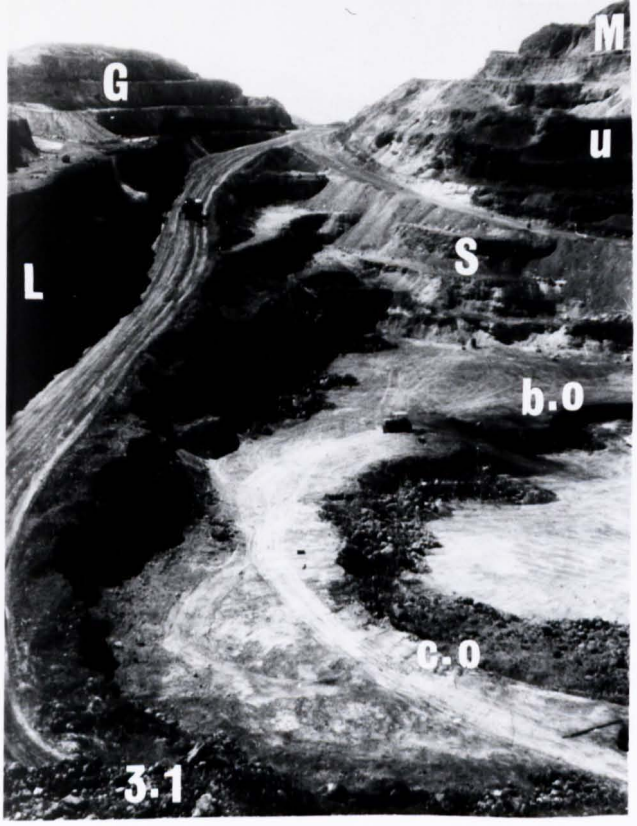
Plate 3-1. Western Skouriotissa pit looking northwest. Foreground entrance of the pit, massive gossan (G) marly chalks (M) and umber (U). Road is parallel to the 300° trending fault with unmineralized olivine basaltic U.P.L. (L) on the left and massive sulphide ore on the right. Note the location of the fragmented massive ore (b.o) and of the hard compact ore (c.o) at the 810 foot level as well as the location of the layer of native sulphur (S) at the 915 foot level.

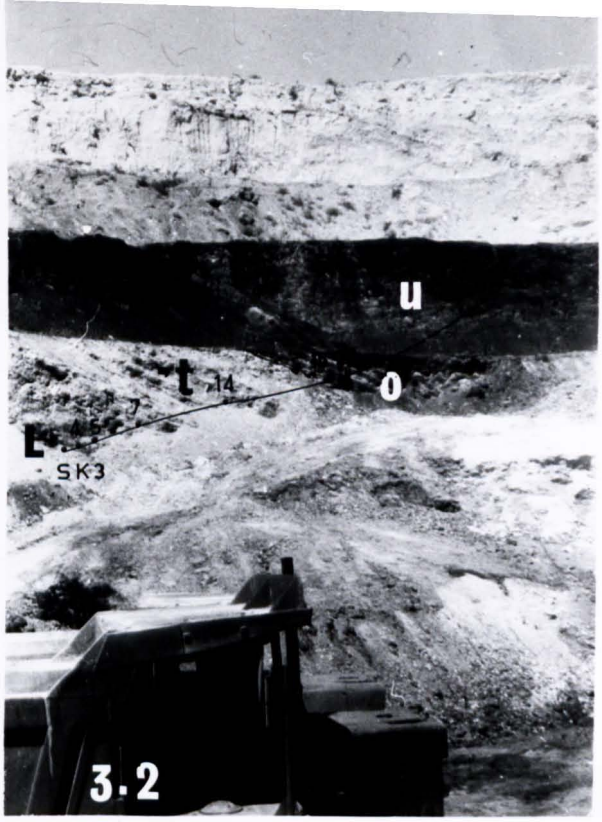
Plate 3-2. Eastern Skouriotissa pit looking northeast. It shows in upward succession unmineralized olivine basaltic U.P.L. (L), well bedded clayey tuffs (t), well bedded ochre (o), Umber (U), marly chalks and reef limestone (white). Note the angular unconformity between the ochre (o) and the flat lying umber (U).

Plate 3-3. Western Skouriotissa Pit looking north. Massive sulphide (grey) interbedded with ochre (brown) overlain by well bedded ochre (brown) in turn overlain conformably by massive umber (dark brown).

Plate 3-4. Close up photograph of the well bedded ochre shown in Plate 3-2. Note the colour variation in the bands of ochre and the occurrence of a layer of massive sulphide (band indicated by the handle of the hammer) interbedded with ochre.

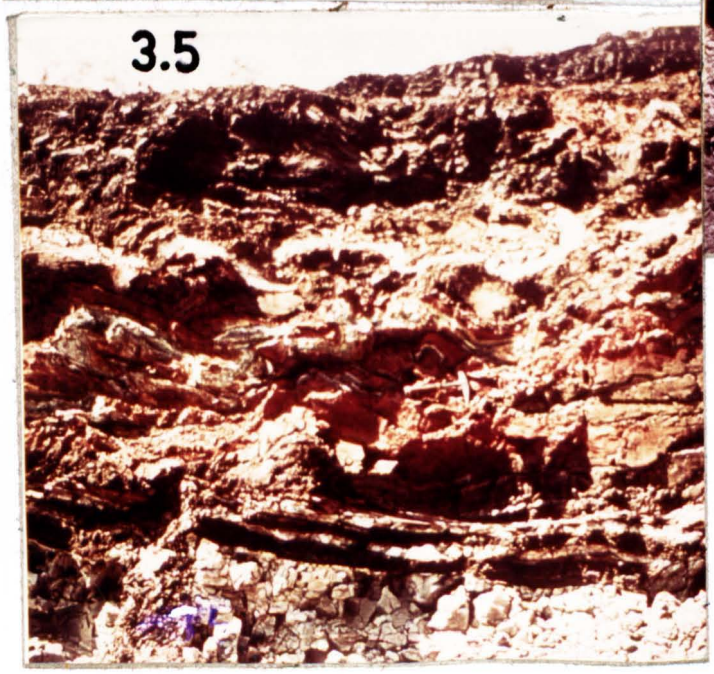
Plate 3-5. Slump structures in both the well bedded ochre and the interbedded sulphide (area indicated by hammer)


G
M
u
L
S
b.o
c.o
3.1


u
t
14
o
L
SK3
3.2


3.3
SK9/11
SK9/9
SK9/8
SK9/6
SK9/3


SK 27
SK 24
SK 23
SK 22
3.4


3.5

composition is constistent and only the grain size changes. Some beds consist entirely of montmorillonite whereas others are made up of montmorillonite and quartz.

(b) Brown yellow ochre

The clayey tuffs at the exposure, shown in plate 3-2 are overlain by a zone of alternating beds of brown and orange yellow ochre, clayey-tuffs and massive sulphide. The plates 3-2, 3-4 show this exposure in which the well defined bedding and the sharp conformable contacts between the alternating beds are obvious. Post depositional slumping has apparently affected the beds of sulphides, ochre and clayey tuffs.

In the individual beds of ochre well defined delicate banding consisting of alternating bands in all shades from dark brown to yellow (Plate 3-4) is common. This colour banding is characteristic of the ochre around the whole orebody.

Several partial analyses of ochre were carried out for the writer by the Pure Geochemistry Department, Imperial College (Dr. J.R. Butler Personal communication). These analyses (Table 3-2) indicate that the manganese content in the ochre is persistently low and generally varies antipathetically with that of iron. In the same table are shown A.A.S. analyses of ochre for copper, zinc, nickel and cobalt which were carried out by the Chemical Laboratory of the Cyprus Geological Survey. These analyses indicate that:

(a) In the ochre copper is high and decreases rapidly away from the top of the orebody; a similar trend is recognisable in zinc.

(b) The nickel content in the ochre is very low compared with that of the umber whereas the cobalt content of the ochre is higher than that of the umber.

The colour variation in the banded ochre is a striking feature both in the field (Plate 3-4) and in hand specimens (Plate 3-6) and it was thought to be due to a variation in chemical composition. Manganese content was suspected to be the controlling factor and the dark brown colour was attributed to high manganese. However, partial analyses of a dark-brown band (SK27d table 3-2) and a brown-yellow band (SK27c table 3-2) from the hand specimen shown in plate 3-6 showed that in the two bands the difference in

manganese content is hardly enough to account for these colour contrasts.

Subsequent examination of polished sections from the specimen shown in plate 3-6 showed that the fine banding represents graded banding and that the colour variation in the bands is due to variation in grain size and degree of crystallinity of the material (Plates 3-12, 3-13, 3-19). Thus the dark brown bands consist of an homogeneous mixture of fine grained and poorly-crystalline iron oxides while the brown-yellow bands consist of coarser grained and well crystalline iron oxides scattered in a matrix of poorly-crystalline iron oxides.

By electron probe investigations it was found that in the dark bands, the manganese is evenly distributed through the iron oxide matrix, and no detectable manganese minerals are present. In the light bands, anhedral unidentified manganese mineral(s) are intimately mixed with iron oxides, (Part II Plates 6-1, 6-2, 6-3).

X-ray diffraction analyses of ochre (Table 6-1) showed that the light bands consist mostly of well crystalline goethite mixed with variable proportions of quartz. In the case of the red-yellow ochre at the bottom of the succession (SK3 Table 6-1) the crystalline goethite constitutes about 85 per cent of the crystalline material. In the brown ochre in addition to goethite and quartz, illite is present and tends to increase in the lighter bands. Montmorillonite was found only in a band of sticky, dark pink ochre, where it was mixed with quartz and goethite. A specimen of brown ochre was also investigated for microfossils by Dr. Muir in the previously mentioned department. A considerable amount of bituminous material was present but there were no indications of terrestrial material.

(c) Red Hematitic Ochre

The red hematitic ochre is best developed in the centre of the eastern orebody, at or close to the top of the ore. It consists of regularly repeating bands of sulphides, sulphide-rich ochre and sulphide-poor ochre. The plates 3-8 and 3-9 show hand specimens of red hematitic ochre which contain fine bands of sulphide in which the coarse grained pyrite is restricted to the base of each band thus resulting in a type of graded bedding.

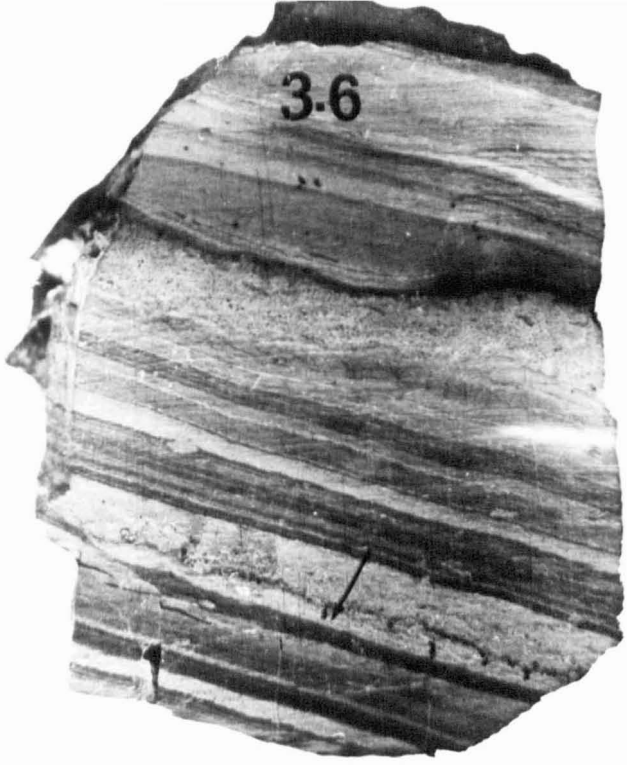
Plate 3-6. Hand specimen of ochre showing well defined colour banding consisting of alternating bands in all shades from dark brown to yellow brown (natural size).

Plate 3-7. Hand specimen of chert with randomly distributed patches (left) and veins of sulphide (natural size).

Plates 3-8, 3-9. Hand specimen of banded red hematitic ochre, with fine bands of sulphide (points indicated by arrow) in which coarse grained pyrite is restricted to the base of each sulphide band (natural size).

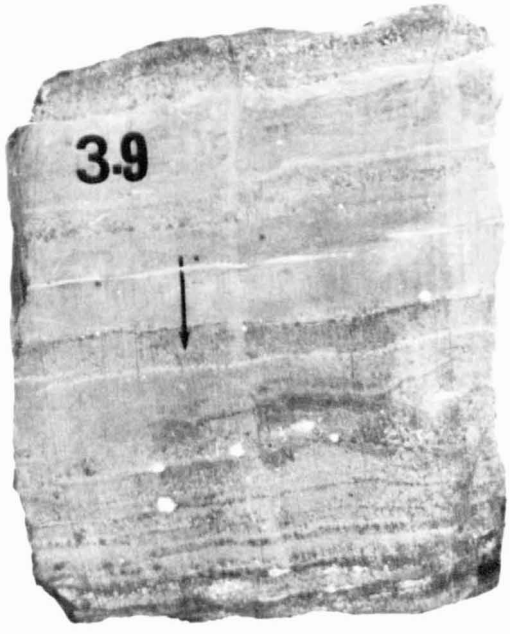
Plate 3-10. Hand specimen of slightly leached lava underlying massive sulphide ore. Note that the vesicular structure of the lava is preserved (natural size).

Plate 3-11. Hand specimen of intensely leached lava in sharp contact with massive sulphide ore (natural size).

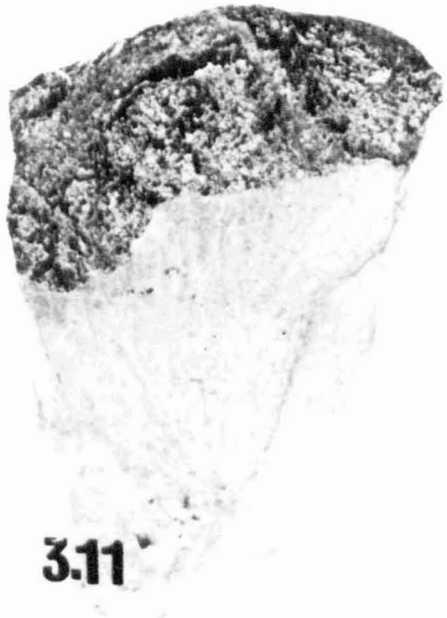

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In polished sections the sulphide bands are seen to consist of aggregates of highly fractured and corroded pyrite, in a matrix of well to poorly crystalline goethite. The pyrite fractures are often filled with maghemite. (Plates 3.14, 3.15, 3.17 and 3.18). The red ochre consists of bands of well crystalline maghemite enclosing isolated areas of goethite and rare quartz, alternating with bands of goethite containing zones of maghemite (Plate 3.16). Remnants of intensely corroded pyrite are scattered throughout, but quartz is more common in the goethite bands.

Covellite is the most common sulphide after pyrite in the red ochres. It is highly porous and very often is intergrown with digenite. The covellite and digenite tend to concentrate along the contacts of the sulphide rich bands, with the bands of red ochre.

(d) Cherts with sulphides

The cherts are very well exposed overlying massive ore in the central face, and conformably overlying altered lavas at the southern face of the eastern orebody. Over the ore their base consists of massive red to pink quartz cementing individual fragments of brecciated ore. The cherts higher up are generally well bedded and finely banded. The banding is due either to variation in mineralogical composition (regularly repeating bands of sulphide, sulphide with quartz, quartz with rare sulphide) or to variation in colour from grey, grey-green, pink, brown to hematitic red.

Thin sections show that the variation in colour of the fine bands is due to the degree of dispersion of iron oxides in the silica. The silica is mainly cryptocrystalline except for rare chalcedony confined mostly to the vicinity of sulphide bands or near the pyrite grains which are scattered in the silica bands. (Plates 3-20, 3-21).

Pyrite is the most common sulphide in the cherts and exhibits characteristic corrosion patterns. Plates 3.22 and 3.23 show rounded aggregates of pyrite having slightly corroded outer zones, followed inwards by zones of intense corrosion in

Plate 3-12. Polished section of the area indicated by arrow in Plate 3-6, showing contact between a dark brown and a light-brown band of ochre. The dark brown band (left) consists exclusively of fine grained and poorly crystalline goethite whereas the light brown band consists of fragments of well crystalline goethite scattered in a matrix of fine grained and poorly crystalline goethite.

PPL scale bar = 150 microns

Plate 3-13. Centre of the light brown band shown in Plate 3-12. Fragments of well crystalline goethite (grey) varying greatly in size and form are scattered in a matrix of poorly crystalline goethite (dark grey).

PPL scale bar = 150 microns

Plates 3-14, 3-15. Intensely fractured and corroded pyrite embedded in a matrix of goethite. Fractures and zones of corrosion in pyrite are filled with well crystalline goethite and/or maghemite.

PPL scale bar = 150 microns

Plate 3-16. Euhedral (left) and corroded pyrite scattered in a matrix of poorly and well crystalline goethite.

PPL scale bar = 800 microns

Plates 3-17, 3-18. Fractured and corroded pyrite scattered in a matrix of poorly and well-crystalline goethite. Fractures and zones of corrosion in pyrite are filled with well-crystalline goethite and/or maghemite.

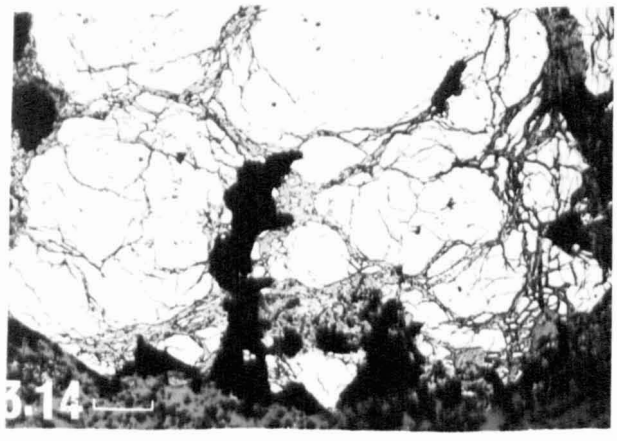
PPL scale bar = 150 microns

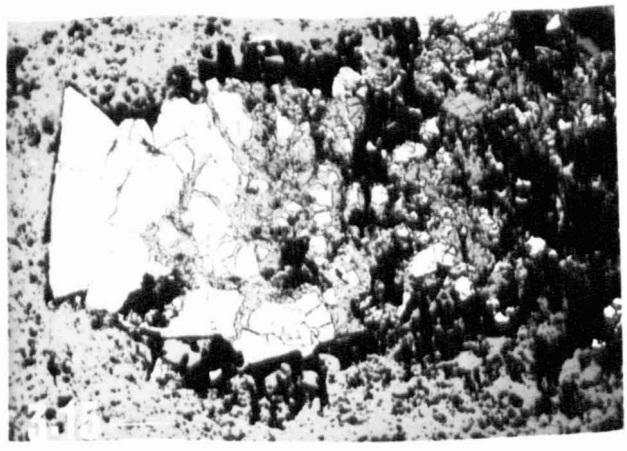
Plate 3-19. An area of the light brown band shown in plate 3-12, showing well crystalline goethite exhibiting framboidal texture.

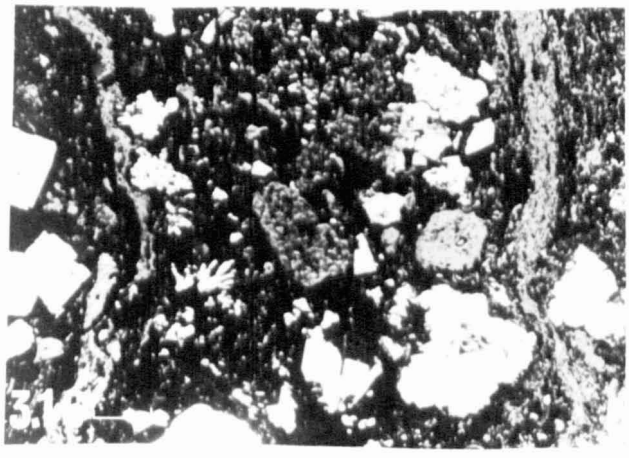
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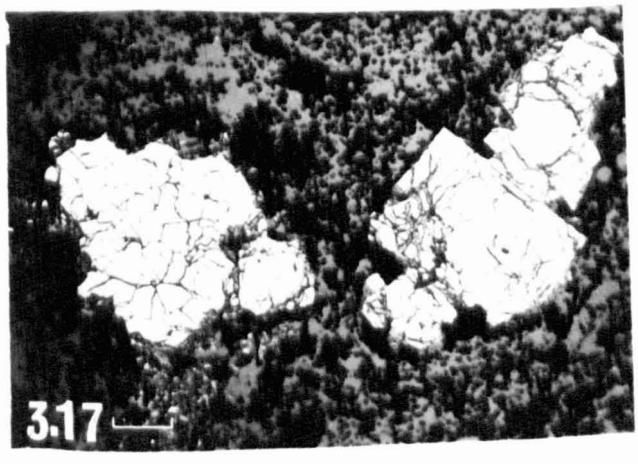

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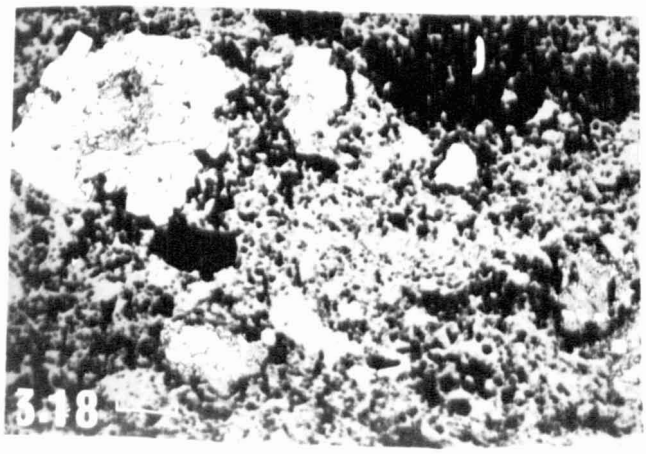

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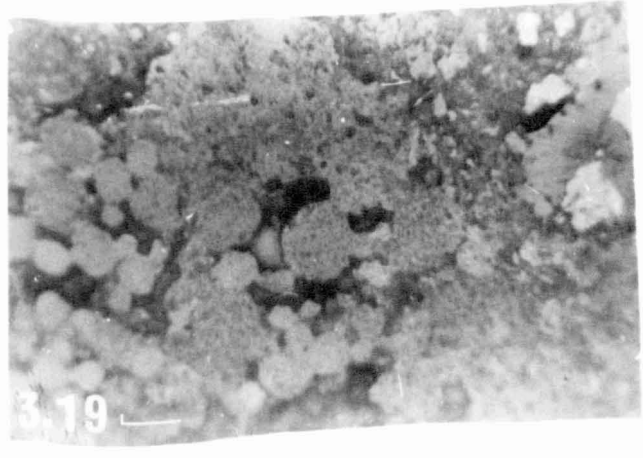

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which the remnants of pyrite have a feathery texture. The central zones of the aggregates are less corroded but highly fractured; the fractures exhibit a characteristic radiating pattern. Not infrequently corrosion of the cores of anhedral pyrite produced characteristic atoll textures whereas euhedral pyrite is relatively unaffected. (Plates 3-24, 3-25, 3-26 and 3-27).

Covellite, the next most abundant sulphide, occurs in the form of rims around chalcopyrite, or as discrete crystals characterized by high microporosity. Chalcopyrite and less commonly digenite and idaite were observed in the bands rich in sulphide.

(e) Massive sulphide interlayered with ochre

Interlayering of massive sulphide and yellow ochre, overlain by ochre and umber, is very well exposed at the northern face of the western orebody (Plate 3.3, fig. 3-2). The layers of massive sulphide consist of blocks of solid sulphide, encased in a matrix of soft friable sulphide. The solid blocks are more abundant and bigger at the bottom of each layer to give a type of graded bedding. The contacts of the layers of ochre and sulphide are conformable and sharp, and no veins of sulphide cut across the ochre. Post depositional slumping had affected the layers, of sulphides and ochre.

At the base of the exposure shown in plate 3-3 the mineralogy of the sulphide layers is similar to that of the main orebody and will be discussed later. Towards the top of this exposure the sulphide layers consist mainly of sandy friable ore which contain rare and small blocks of solid sulphide. The friable ore consists mostly of fractured and intensely corroded unzoned pyrite (Plates 3-28, 3-29, 3-30, 3-31). Remnants of corroded zoned pyrite are very rare and indicate that corrosion follows the contacts of growth zones (Plate 3-32). In some cases only the central part of the pyrite is corroded and atoll textures are produced (Plate 3-33). Deep corrosion embayments of various configurations are shown in plate 3-30; in some cases the original crystal outline of the fractured and corroded pyrite is well preserved (plate 3-29).

Plates 3-20, 3-21. Thin sections of finely banded chert. From left to right it shows a band of cryptocrystalline silica stained with iron oxide; a sulphide rich band; a band of chalcedonic silica (white) with pyrite scattered in it; a sulphide rich band; and a band of cryptocrystalline silica stained with iron oxides.

PPL scales bar = 2mms.

Plates 3-22, 3-23. Fractured and corroded pyrite (white) scattered in silica (black).

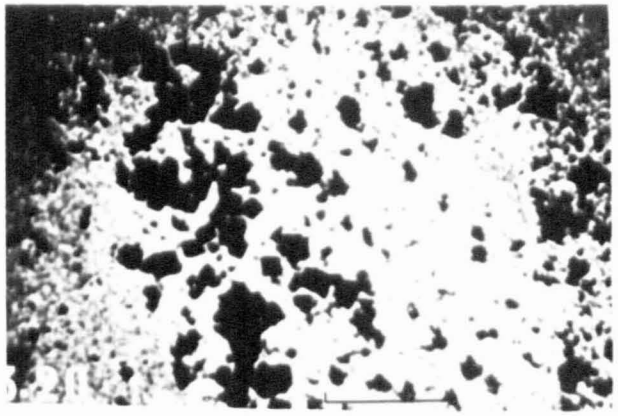
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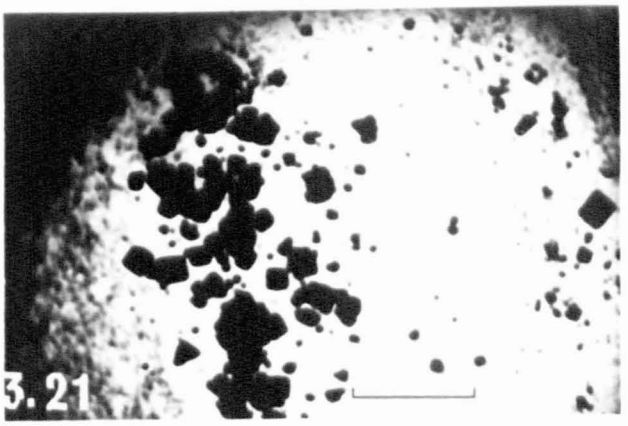
Plate 3-24. Euhedral as well as fractured and corroded pyrite scattered in silica (black).

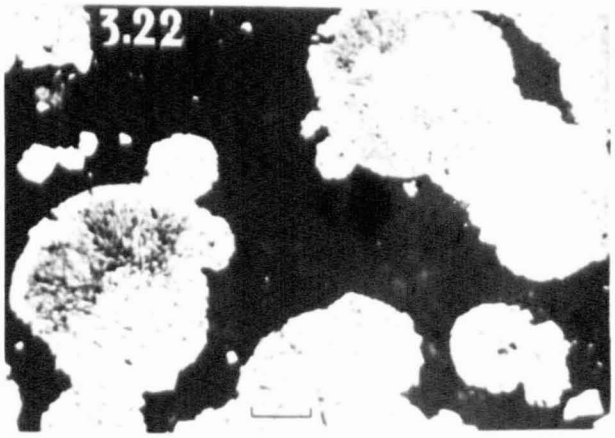
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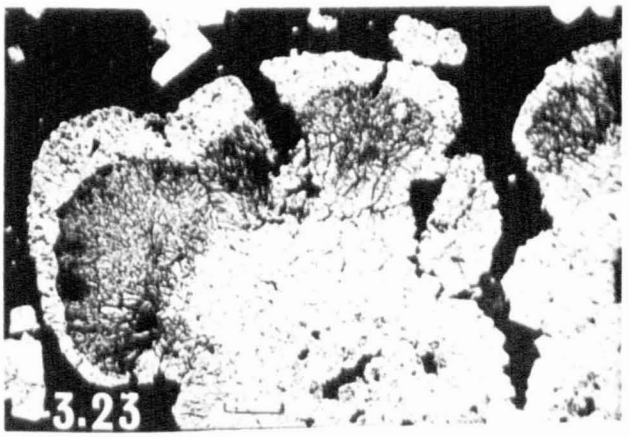
Plates 3-25, 3-26, 3-27. Intensely corroded pyrite scattered in silica. In some cases atoll textures are produced by corrosion of the central part of pyrite.

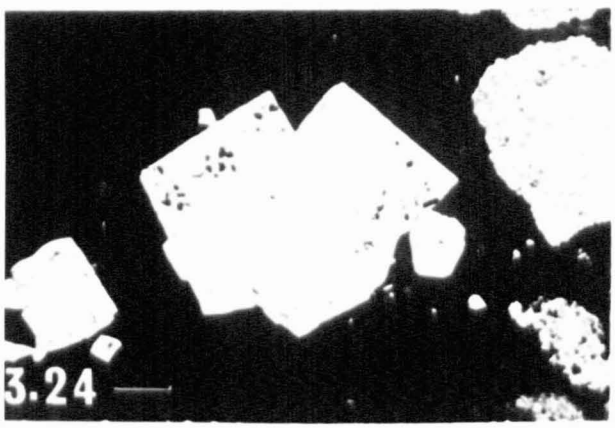
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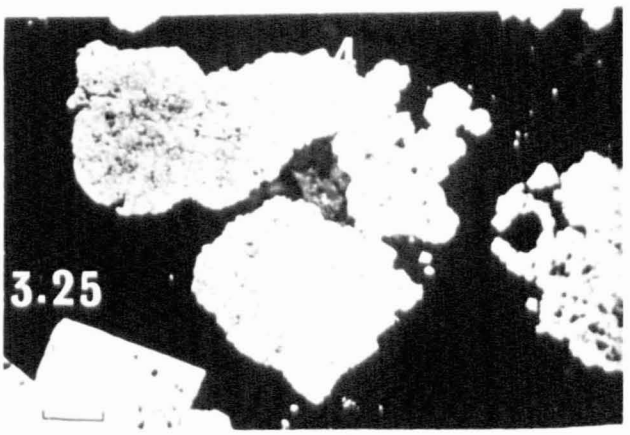


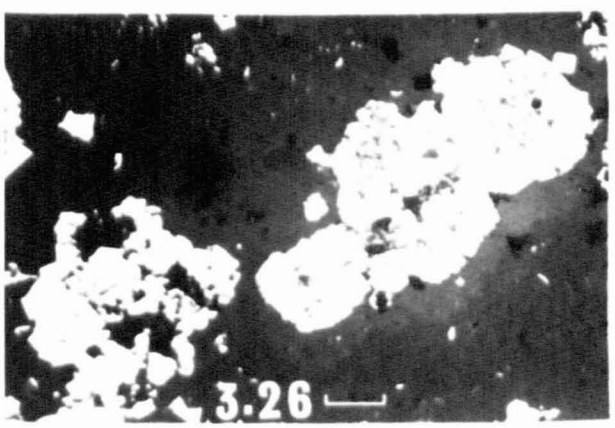

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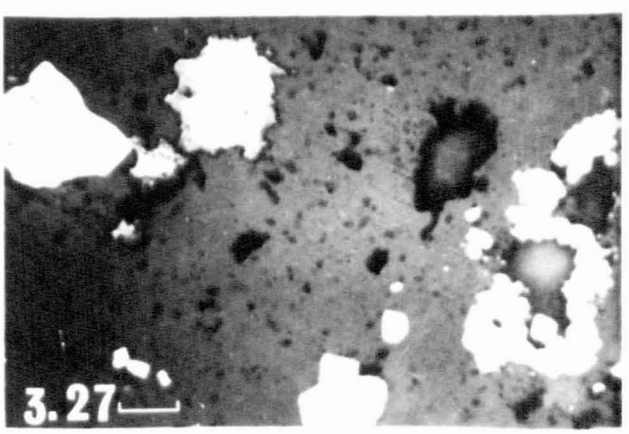

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Plates 3-28, 3-29. Friable massive ore interlayered with ochre, consisting of intensely fractured and corroded pyrite. Black areas represent empty space.

PPL scales bar = 150 microns

Plates 3-30, 3-31. Friable massive ore interlayered with ochre. Pyrite with deep corrosion embayments of various configurations. Black areas represent empty space.

PPL scales bar = 150 microns

Plate 3-32. Fractured and corroded zoned and unzoned pyrite in massive friable ore interbedded with ochre. Note that in the zoned pyrite corrosion proceeds along contacts of growth zones.

PPL scale bar = 150 microns

Plate 3-33. Atoll textures of pyrite produced by the corrosion of central parts of pyrite aggregates. Black areas represent empty space.

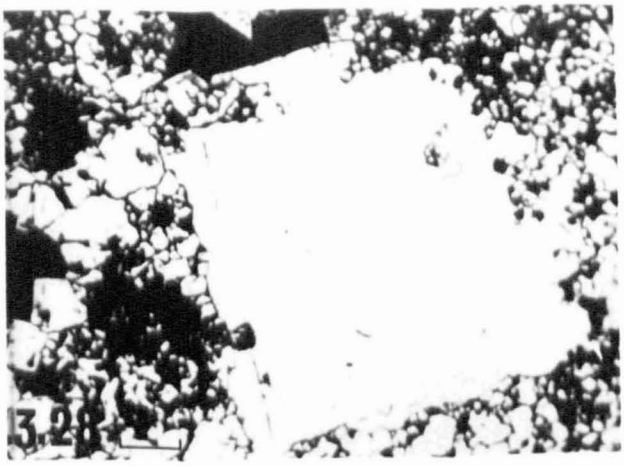
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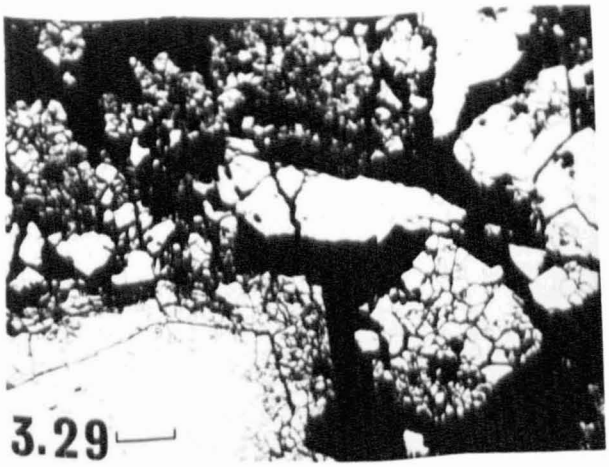
Plate 3-34. Fractured pyrite (white point indicated by arrow) scattered in umber (black) and mostly replaced by well crystalline goethite and/or maghemite.

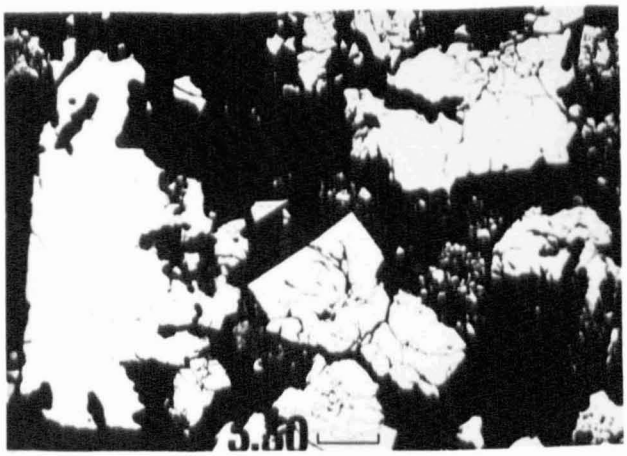
Oil immersion, scale bar = 50 microns

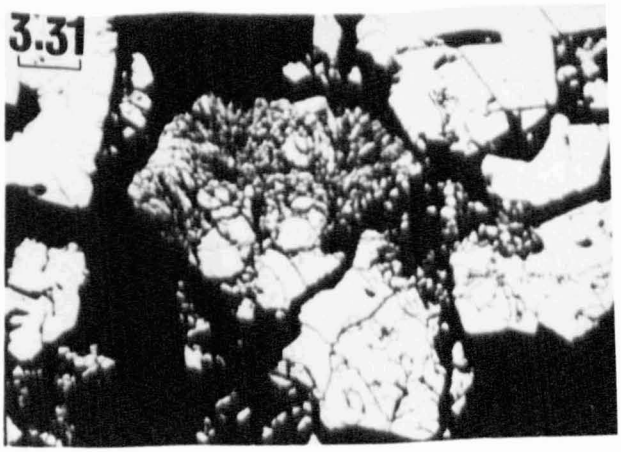
Plate 3-35. Irregular grains of well crystalline goethite (grey) scattered in a matrix of poorly crystalline goethite of umber.

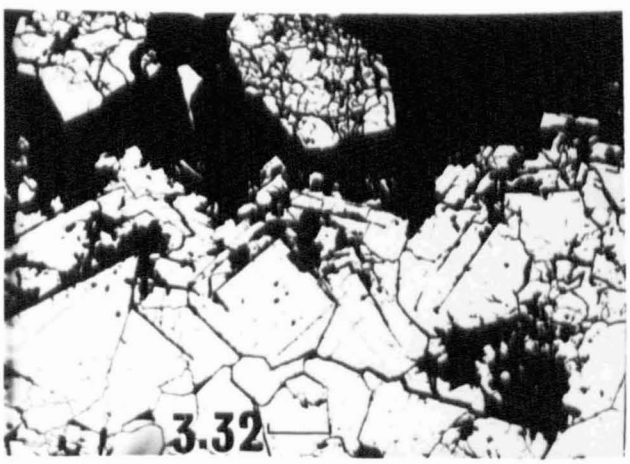
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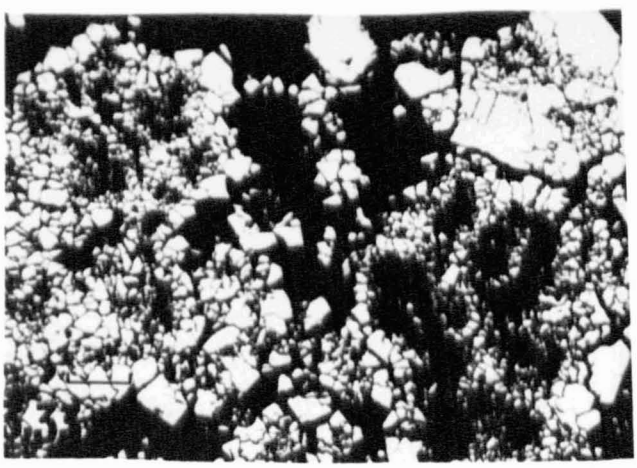

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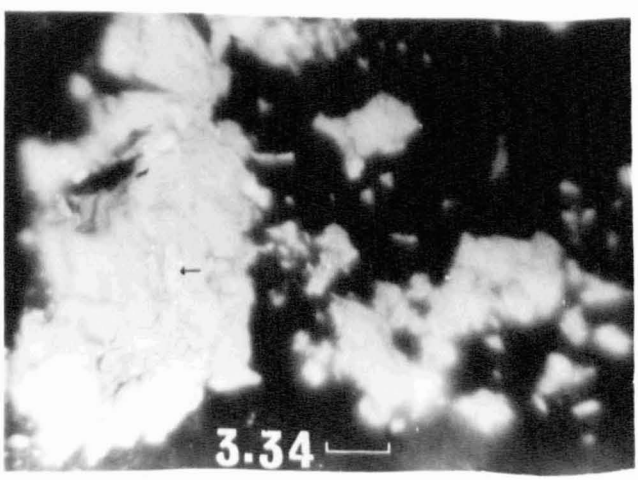

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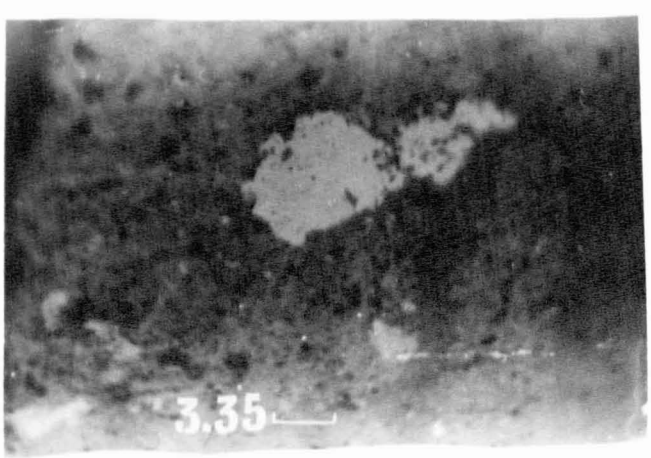

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3.34


3.35

The small solid sulphide blocks consist mainly of pyrite and small amounts of chalcopyrite and other copper sulphides. These blocks are fractured and porous. Along the fractures only remnants of corroded unzoned pyrite are present whereas away from the fractures zoned pyrite is also present. Small chalcopyrite crystals partly replaced by covellite and less commonly by chalcocite and bornite are common away from the fractures. Very small crystals of sphalerite mostly mixed with pyrrhotite were seen along the grain boundaries of pyrite and between growth zones in pyrite.

5. Contacts of the orebody with the surrounding volcanic rocks

The isometric projection of figure 3-3 shows that most parts of the orebody are in non-faulted contact with the underlying basaltic lavas. The boundaries of the mineralization, are very well defined along both, the normal and the faulted contacts.

To the north the contact of the orebody with the fresh olivine basaltic lavas is sharp. This is illustrated by the drop in sulphur content from 45 per cent to zero over a distance less than two centimetres. Towards the central part, particularly at the western orebody, massive ore is in sharp contact with badly altered and disintegraded lava (Plate 3-11) containing rare disseminated sulphide. The altered lavas grade laterally and downwards, into fresh basaltic lavas.

Of the faulted contacts the most conspicuous is that along the post Miocene 350° trending fault (Figs 3-2, 3-3). This is a normal fault dipping 50° to the west, and had downthrown the western orebody, relative to the eastern orebody, by more than 35 metres; the western orebody constitutes about 75 per cent of the total ore.

The footwall of this fault is occupied by two distinctly different types of lava. Dark grey-green, intensely brecciated lavas which are mineralized and hydrothermally altered outcop at the southern part of the footwall which is affected by a 300° and 060° trending intersecting faults (Fig. 3.2). At the northern part of the footwall there is an occurrence of unmineralized olivine basaltic Upper Pillow Lavas which in some places had been leached probably by supergene solutions, Detailed

sampling at various levels indicates that along the 350° trending fault the two types of lava are persistently present down to low depths.

The southern contact between the massive ore of the western orebody and the unmineralized olivine basaltic lavas is marked by the 300° trending fault (Fig. 3-2, Plate 3-1) which dips steeply to the north northwest. Extensive ancient workings had obscured the geology at the intersection of this fault with the 350° trending fault. The fault plane is occupied by a zone 70 centimetres wide which consists of rounded and polished fragments of unmineralized basaltic lava embedded in a matrix of grey, hematitic clayey fault gouge. The footwall consists of unmineralized olivine basaltic Upper Pillow Lavas which display a very well developed pillow structure. Drilling data indicate that the unmineralized olivine basaltic lavas are about 300 metres thick and are underlain by mineralized and hydrothermally altered lavas.

The southern contact of the eastern orebody with altered and unaltered pillow lavas is marked by the 060° trending fault (Fig. 2-2). This is a normal fault and dips steeply to the north-northwest. This fault postdates the mineralization but the available information was insufficient to establish the age relationship of this fault with the overlying sediments. The geology along this fault was complicated by the extensive ancient and modern underground workings. At the intersection of this fault with the 350° trending fault the foot wall consists of altered pillow lavas whereas away from this intersection the footwall consists of unmineralized olivine basaltic pillow lavas. The contact of the two types of lava was obscured by the extensive underground workings and subsequent subsidence.

At the southwestern part of the western orebody a portion of the orebody is offset by a 060° trending fault. The displaced ore is in contact with unmineralized olivine basaltic lavas, but the geology in this area is obscured by dumps. The displaced ore was exposed to the surface and oxidized to massive gossan (Fig. 3-2, Plate 3-1).

6. Summary

The Skouriotissa orebody lies under a thick cover of sedimentary rocks the upper part of which is occupied by massive

fossiliferous limestone. The latter is underlain by marls and chalky marls of the Pakhna Formation which are inturn underlain by argillites and umber of the Perapedhi Formation. The Perapedhi umber in some place rests unconformably on well bedded ochre of the Ochre Group.

The Perapedhi umber at the Skouriotissa orebody has a chocolate-brown colour and is generally massive or poorly-bedded. It is very fine grained and consists of variable proportions of iron and manganese oxides and alumina. It is high in copper, zinc, nickel and cobalt; the copperishigher than zinc and nickel is higher than cobalt. The umber contains small amounts of goethite scattered in a matrix of amorphous to poorly-crystalline hydroxides. No manganese minerals have been detected in the umber but it contains traces of fractured and corroded pyrite partly replaced by goethite and maghemite.

The umber contains leaf cuticles and spores from land plants suggesting a probable contribution of a nearby landmass to the formation of umber. The contribution of land material to the umber probably accounts for their high nickel and manganese because the surrounding olivine basaltic U.P.L. are high in nickel and manganese (Govett 1969). The presence of bacterial and algal organisms in the umber suggests a relatively shallow water of deposition as algal do not live below the zone of penetration of light.

The Ochre Group includes a variety of rock types all bedded and characterized by graded banding. The most common rock is the ochre with colours varying from dark-brown through brown-yellow to red hematitic. The ochre overlies unconformably both the massive ore and the adjacent volcanics. It is fine grained and consists mostly of iron oxides and variable proportions of alumina. Manganese is invariably low in the ochre but tends to increase towards its top. Copper is very high at the base of the ochre near its contact with the massive ore, decreasing substantially at the top of the ochre with a similar trend recognizable in zinc. Nickel is low, cobalt is high and the ratio of Ni:Co is less than one. The ochre is generally well crystalline, consisting mainly of goethite and quartz and minor

amounts of illite.

Grey-clayey tuff is a common rock-type of the Ochre-Group. It is interbedded with ochre and it was not observed in direct contact with massive ore. It consists of bands of montmorillonite and bands of montmorillonite and quartz. Well bedded chert with common colour banding overlie conformably the massive ore in the centre of the eastern orebody. It consists mainly of cryptocrystalline silica stained with variable amounts of iron hydroxides.

In the Skouriotissa orebody bands of sulphide are found interbedded with ochre and chert. The frequency of these bands decreases considerably away from the top of the orebody. Away from the ore zone the sulphide bands which are interbedded with ochre consist only of intensely corroded pyrite whereas in the vicinity of the orebody the sulphide bands which are interbedded with ochre and chert in addition to corroded pyrite contain subordinate amounts of copper sulphides.

The orebody is conformable with the surface of the volcanics. Both normal and faulted contacts of the ore with the surrounding volcanics are sharp. Barren volcanics succeed massive ore over distances of less than two centimetres. All the faults in this orebody postdate the mineralization since they displace the ore. The maximum displacement is across the 350° trending fault which dismembered the orebody into two separate orebodies. The other faults govern the general configuration of the orebody.

D. THE OREBODY

1. Form Size and Tonnage

The general form of the orebody and the configuration of its base are shown in the isometric projection of the Fig. 3.3 Ore fills a shallow basin at the top of the basaltic lavas, and the orebody resembles a flat lying concavo-convex elliptical lense having an east-west major axis. The slightly concave upper surface is partly due to the extensive ancient mining activity.

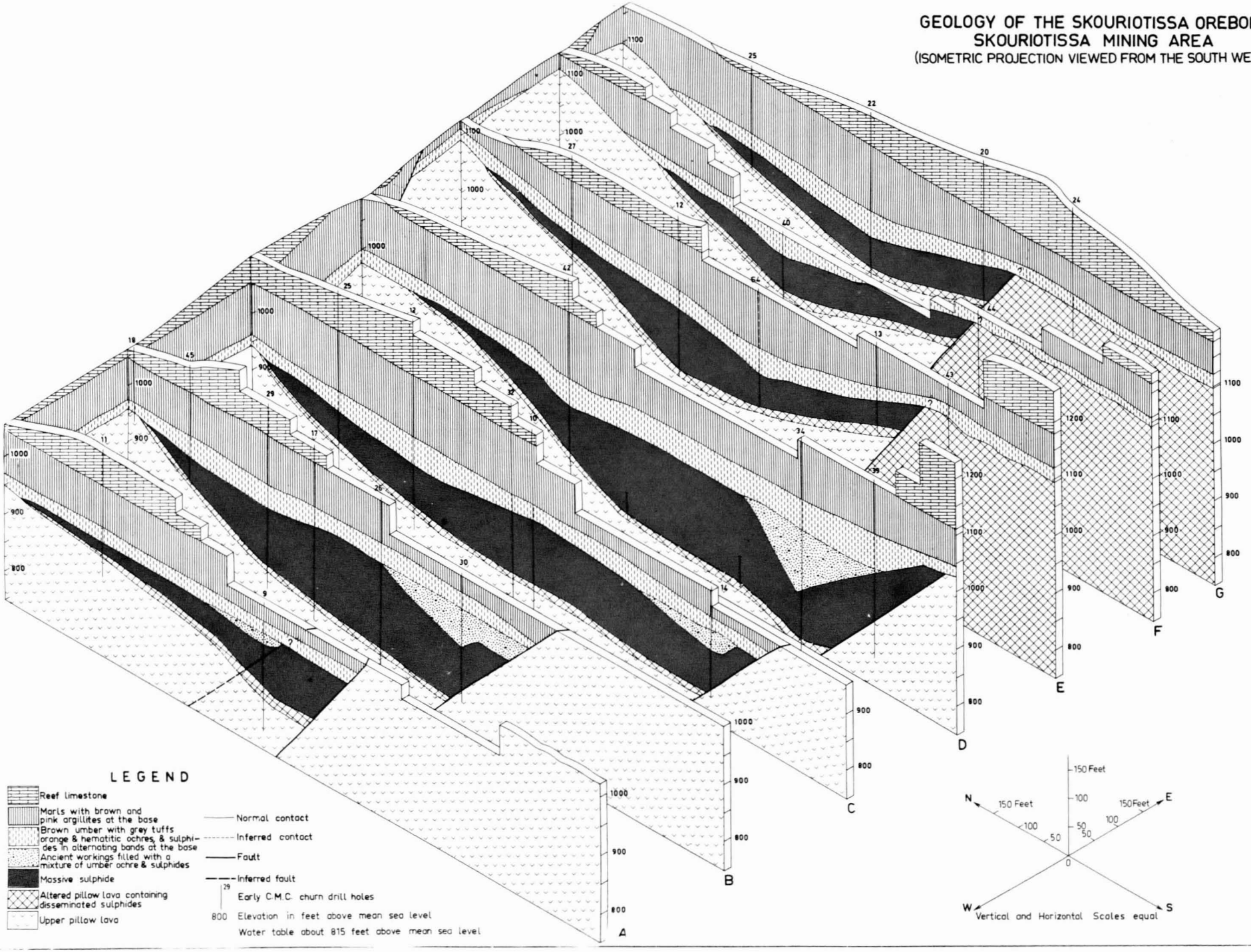
The orebody is 671 metres long, 213 metres wide and ranges in thickness from [illegible] metres to 52 metres. Callaghan (1965) estimated that the orebody was originally 1219 metres long and 518 metres wide but had "shrunken" to its present size through erosion. From the 47 churn drill holes which were drilled intermittently between 1914 and 1920, and the extensive concurrent underground development work, the total tonnage of the ore was estimated to exceed **six million tons.**

2. Field and Macroscopic characteristics of the ore

The orebody consists entirely of massive sulphide ore of two distinctive structural types. The first (most common) type has a conglomeratic appearance, and a dark grey colour, while the second, type has a light-yellow colour and is hard and compact. Gradational contacts and well advanced mining of the ore made the mapping of the distribution of the two types difficult; nevertheless there is a tendency for the hard compact ore to be concentrated in the eastern and southeastern zones of the western orebody (Plate 3.1).

The conglomeratic ore consists of blocks of solid sulphide encased in a matrix of gritty sugary sulphides: there is a wide variation in the proportions of these two components. There are narrow zones in the eastern orebody consisting entirely of sugary pyrite (Plate 3.37); these zones invariably underlie red hematitic ochre. In both orebodies, zones in which the sugary matrix makes up 75 per cent of the volume of the ore are very common. The sugary matrix is very porous, friable, and crumbles when squeezed between the fingers. The solid sulphide blocks

GEOLOGY OF THE SKOURIOTISSA OREBODY
SKOURIOTISSA MINING AREA
(ISOMETRIC PROJECTION VIEWED FROM THE SOUTH WEST)



are angular subangular and rounded and have a variable size. The solid sulphide blocks are generally very porous (Plates 3-36, 3-38, 3-40) and very often they have a "pumicious" appearance.

Hand specimens of conglomeratic ore show cavities to be both isolated and interconnected. Not infrequently small voids coalesce forming narrow elongated fracture-like cavities. (Plate 3-39). The cavities in size from less than one millimetre to several centimetres and their morphology vary greatly although there is no definite pattern in their distribution. The large cavities are lined with euhedral pyrite which is mostly corroded to give a honeycomb texture. Interstitial chalcopyrite is common as are secondary copper sulphides and sulphates, quartz, gypsum, and iron sulphates.

Collomorphic banding is a striking characteristic of this conglomeratic ore and has been reported by all the geologists who worked on this orebody. The bands of collomorphic pyrite are either straight, slightly curved, or scalloped, traversing through the solid blocks (Plate 3-38). Closed or partly open oval structures, widely varying in diameter, are common in the central part of the solid blocks (Plate 3-38).

In the past the collomorphic banding was attributed to alternating bands of different mineralogical proportions of pyrite, marcasite, chalcopyrite, and chalcocite (see section on ore mineralogy). Detailed examination of many hand specimens showed that collomorphic banding is a reflectivity effect related to the total porosity of each band (Plates 3-36, 3-38).

A transitional zone between the solid sulphide and the sugary matrix can be seen in some hand specimens. This has a structure identicalwith the conglomeratic ore, but on a smaller scale; it consists of fine breccia fragments encased in a soft matrix. This zone is highly porous and has a dark grey colour.

The hard compact ore consists of large blocks of hard solid sulphide separated by fractures up to five centimetres wide; these fractures are commonly filled with soft friable pyrite. The hard compact ore has a bright yellow colour and is less porous than the conglomeratic ore.

Plate 3-36. Hand specimen of solid sulphide block. Dark grey colour represents areas of high porosity whereas grey-white colour represents areas of low porosity. (natural size)

Plate 3-37. Hand specimen of sandy friable massive ore from the sulphide ore-red hematitic ochre contact (natural size).

Plate 3-38. Polished hand specimen of solid sulphide block. Colloform bands represent zones of high porosity (natural size).

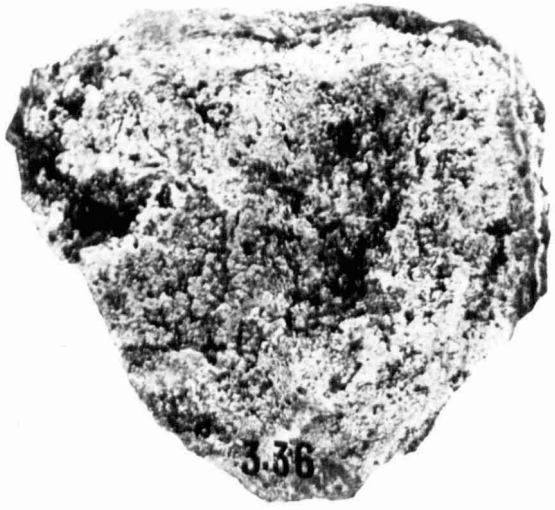
Plate 3-39. Hand specimen of hard compact ore containing randomly distributed cavities of various shapes and sizes (natural size).

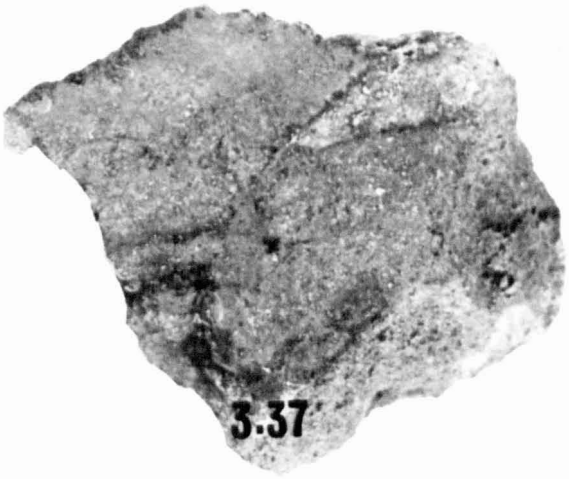
Plate 3-40. Finely fragmented massive ore with small fragments of solid sulphide blocks (centre) in a matrix of friable ore (natural size).

Plate 3-41. Hand specimen of mineralized and hydrothermally altered lava, with veins of sulphide filling fractures in it (natural size).

Plate 3-42. Hand specimen of massive chalcopyrite with rare cubes of pyrite scattered in it (natural size).

Plate 3-43. Hand specimen of massive chalcopyrite (grey) and covellite (black) after chalcopyrite (natural size).

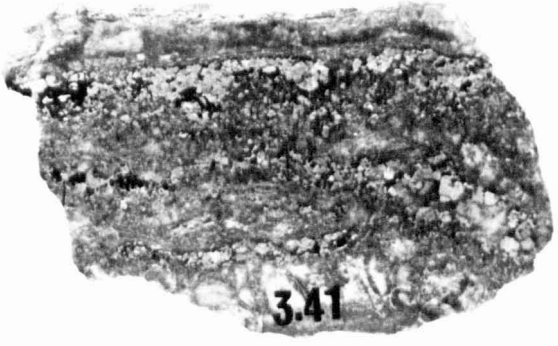

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In the hard compact ore the cavities are lined with clusters of pyrite cubes and pyritohedra, commonly displaying twinning and striated faces. This type of ore generally has a higher reflectivity than the first type, and collomorphic banding is absent from the upper levels down to at least the 810-foot level. The ore consists almost entirely of pyrite. Interstitial chalcopyrite is apparently absent but chalcopyrite, often associated with covellite, forms thin coatings on the pyrite along fractures in the ore. Coatings of the same minerals, are common on the crystal faces of pyrite which lines the cavities.

3. Major Element Chemistry of the ore

The orebody consists entirely of iron, copper and sulphur with minor amounts of silica, alumina and zinc. Only one analysis (Table 3-3) of the ore from this orebody is available and this represents a composite sample of 10.000 tons taken from the footwall at the western part of the western orebody; Cullis and Edge (1922) considered that the figures of their analysis were not representative of the ore in general, and suggested that in that analysis the sulphur was slightly high and the copper distinctly low.

Table 3-3. Analysis of a bulk sample near the footwall at the western part of the western Skouriotissa Orebody (after Cullis and Edge 1922).

Fe	44.47%	
S	50.90%	
Cu	1.36%	
SiO2	0.81%	
Al_2O_3	0.71%	Only traces of Precious
CaO	0.22%	metals were found.
MgO	0.16%	
Mn	0.01%	
As	0.018	
Pb	Trace	
Zn	Trace	
Cd	Trace	
Undetermined	1.342%	
	100.000%	

As it will be shown later the area from which the sample was taken is near the gossan where the ore was affected considerably by the acid waters produced during the gossan formation. This analysis, however, is very important because the figures for the combined impurities MgO, CaO, Al_2O_3 and SiO_2 total only 1.9 per cent. This is interesting when considering that the ore is in contact with lavas in which these oxides constitute more than 85 per cent of their weight. The same analysis indicates that As, Mn and Ti are very low.

Copper is very erratically distributed throughout the orebody; copper values range from 0.3 to 12 per cent even through a single hand specimen. Copper is generally higher in the conglomeratic ore.

At the top of the eastern orebody just under the ochre, fragments of ore with chalcopyrite in very high proportions, are associated with fragments of ore with very little chalcopyrite. At the triangular intersection of the 350° and 300° trending faults, near the top of the orebody, there is a zone containing exceptionally high copper. The ore consists mainly of coarse grained pyrite with well developed cubes, with face length up to 4 centimetres; these were the largest pyrite crystals found in Cyprus by the writer. Twinning and striated faces are very common in this pyrite which is coated and mixed with massive chalcopyrite and covellite (Plates 3-42, 3-43).

4. Trace Elements in the Ore.

Twelve grap samples taken from different parts of the orebody were analysed with Atomic Absorption spectrophotometer and colorimetric methods by the Chemical Laboratory of the Cyprus Geological Survey for Cu, Zn, Ni and Co. The results of these analyses are shown in Table 3-2 and indicate that:

a. The Copper content of the ore is high and shows a wide variation in the different parts of the orebody. The mean value of copper for the 10 A.A.S. analyses is 2.1 per cent and is in approximate agreement with the value of 2.35% per cent given by Bruce (1948) as the average copper content of the Skouriotissa ore.

b. Zinc is generally low and it also shows a wide range of values. The mean value for the 10 A.A.S. analyses is 747 ppm and the ratio of Cu:Zn is about 29.

c. Nickel is anomalously low compared to the surrounding volcanics which contain more than 180 ppm nickel (Govett 1969).

d. Cobalt is very high and it is characterised by a sporadic distribution. Its mean value is 330 ppm and the ratio Ni:Co is as low as 0.07.

The general distribution of these metals at the contact of the ore with the lavas, as well as in the lavas was investigated by G.J. Govett and the writer. Figure 4-4 shows the elemental profiles and it is clear that:

i. In the lavas copper declines to background and below background levels within few feet from the contact.

ii. At the contact zinc increases 10 to 20 fold its value in the ore.

iii. Nickel increases from its very low values in the ore to very high values at and beyond the contact.

iv. Cobalt declines substantially away from the contact but maintains anomalously high values over the entire section.

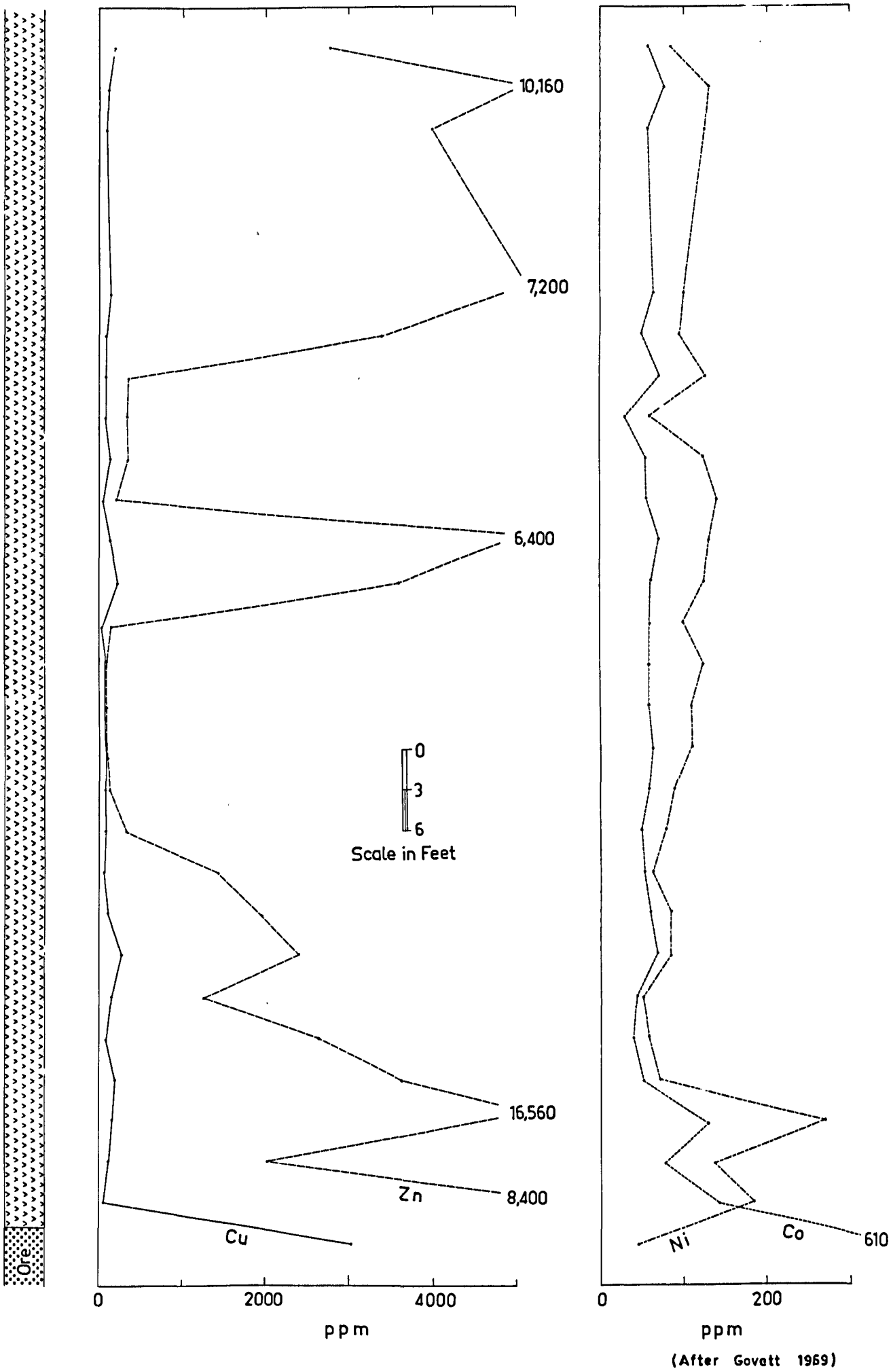
5. Ore Mineralogy

a. Opening statement

As mentioned before the Skouriotissa orebody consists almost entirely of iron and copper sulphides. The primary mineral assemblage is simple. The most predominant mineral is pyrite, followed by chalcopyrite and minor amounts of sphalerite. Pyrrhotite occurs in some parts of the orebody, and to simplify the description, it is included in the primary minerals. Its position in the paragenetic sequence will be discussed in Part II. The same treatment is given to the very rare marcasite.

The secondary mineral assemblage is more complex and includes covellite, neodigenite permanent blue covellite, idaite, tenorite, paramelaconite, chalcocite bornite, delafossite and

Fig. 3-4. Trace element distribution in massive ore and adjacent olivine basaltic Upper Pillow Lavas. (For location of traverse see Fig. 3-2.)



(After Govett 1969)

mackinawite in decreasing order of abundance.

Although the mineral assemblage is basically simple the forms and textures of the minerals, particularly of pyrite, show a great variation which is in part due to secondary processes.

b. Pyrite

Pyrite constitutes 70 to 96% per cent by volume of the ore and exists in a wide variety of textures and forms. Three paragenetic pyrite types have been recognised.

The first type designated pyrite I is euhedral to subhedral and most commonly zoned. This is the most common pyrite type in the hard compact ore, while in the conglomeratic ore its proportion varies greatly, in many cases pyrite I being less than 30 per cent of the total pyrite.

In polished sections this pyrite is distinguished from the other two types by its higher reflectivity and relief and lower microporosity (Plates 3-50, 3.53 and 3.60). These three properties are most likely interrelated. Most of pyrite I is isotropic, but distinctly anisotropic pyrite is also present.

Electrolytic etching, revealed some very interesting microstructures in the zoned pyrite. Generally similar microstructures of pyrite were described by Read (1968) in the Rio Tinto ores. A summary of the main features is given below but their possible genetic significance will be discussed in part II.

In the zoned pyrite, the central parts of the grains consist of euhedral zones whereas the grain boundaries are mostly irregular and often serrated. Usually the grain boundary irregularities, appear to be related to the succession of euhedral growth zones (Plate 3.44).

There is a tendency for the euhedral zones in the central parts of the crystals to be continuous but in the outer parts particularly in large grains, the zones are discontinuous. Such discontinuities are a result either of truncation by another zoned crystal, or by a non zoned crystal (Plates 3.45, 3.46, 3.47, 3.48).

Idiomorphic crystals are relatively rare, are mainly

Plate 3-44. Euhedral zoned pyrite I intersected by a band of fine grained pyrite III. The grain boundaries of the zoned pyrite are irregular (point indicated by arrow). Specimen electrolytically etched.

PPL scale bar = 2 mms

Plate 3-45. Euhedral zoned Pyrite I, truncated by unhedral pyrite II or zoned pyrite I. At bottom right the zoned Pyrite I is intersected by a band of fine grained pyrite III. Specimen electrolytically etched.

PPL scale bar = 2 mms

Plate 3-46. Euhedral zoned pyrite I often truncated by unhedral pyrite II or zoned pyrite I. Specimen electrolytically etched.

PPL scale bar = 800 microns

Plate 3-47. Euhedral zoned pyrite I often truncated by zoned pyrite I (point indicated by lower arrow). At point indicated by upper arrow collomorphic pyrite is sandwiched between euhedral zones with octahedral habit. Specimen electrolytically etched.

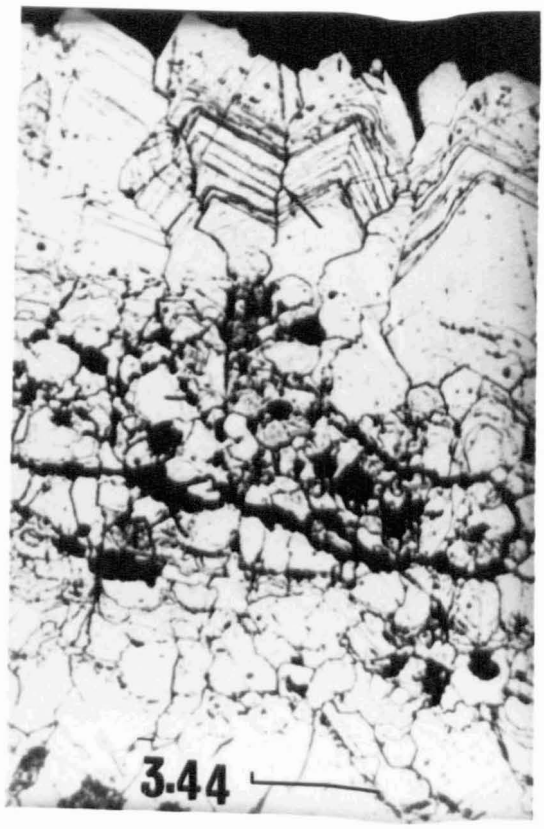
PPL scale bar = 500 microns

Plate 3-48. Idiomorphic zoned pyrite I with anhedral pyrite enclosed between some growth zones. Specimen electrolytically etched.

PPL scale bar = 800 microns

Plate 3-49. Idiomorphic zoned pyrite I fractured and corroded. Fractures are filled with later pyrite. Specimen electrolytically etched.

PPL scale bar = 800 microns



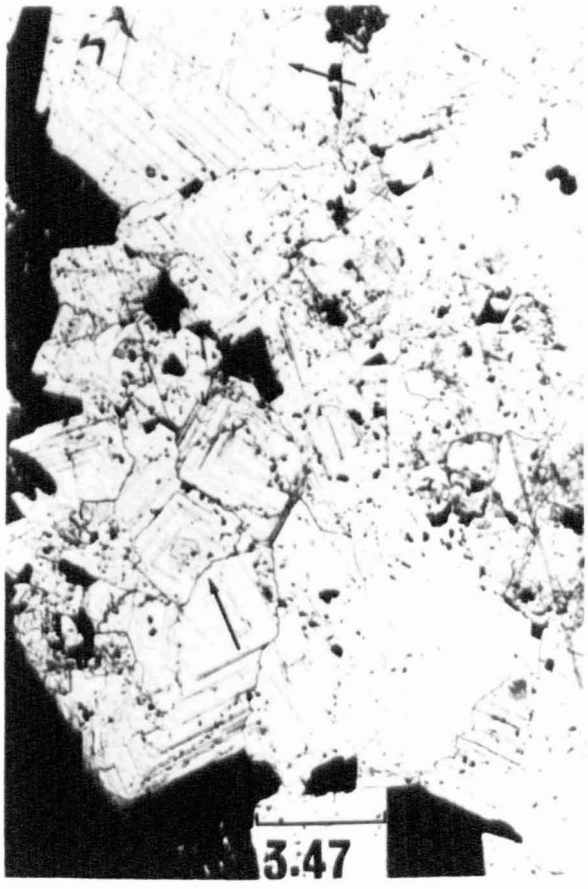
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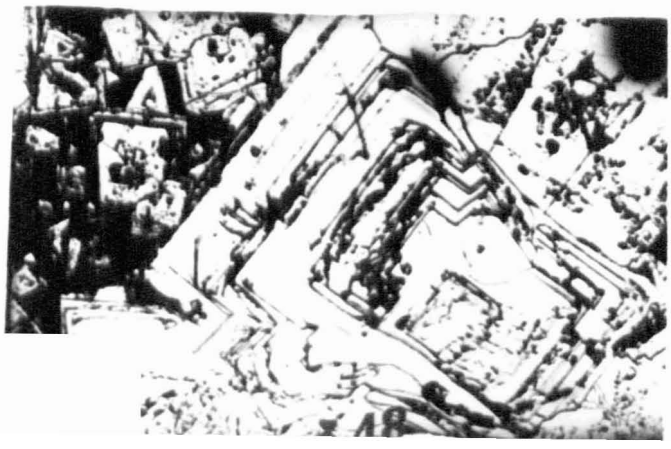
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3.49

concetrated around cavities and often are not zoned. Some zones of large grains are commonly locally fractured or have a corroded outer boundary. The fractures are filled with later pyrite (Plate 3.49). The corroded zones are succeeded by later euhedral zones having the same orientation as the earlier ones. In some large idiomorphic grains small pyrite crystals are enclosed in some zones (Plate 3.48).

In many crystals zone relationships indicate that during growth the pyrite alternated from cubic to octahedral habit (Plates 3.47, 3.54). Even more commonly, euhedral zones are succeeded by zones with a collomorphic microstructure, superimposed on which are other euhedral zones. (Plate 3.54).

A common feature is the apparent variation in the width of single euhedral growth zone. In small grains and in the central parts of larger grains the euhedral zones tend to be more narrow and regularlyspaced whereas in the outer parts where the zones are irregularly spaced and their width is more variable.

The grain size of the zoned pyrite is variable but commonly in the hard compact ore there are isolated areas having uniform grain size.

The possibility of variation in chemical composition from zone to zone was investigated with electron probe microanalyser. No copper or zinc rich zones were detected but very commonly lines of minute grains of chalcopyrite and sphalerite several microns across were seen between individual zones. In some rare cases the outer boundary of a zone is "coated" by discrete grains with rounded "external" boundaries. These grains have been surrounded by pyrite during the growth of a later zone.

The second type of pyrite termed Pyrite II has lower reflectivity and relief than the pyrite I, and is unzoned (Plate 3.53). It is difficult to estimate the amount of this type of pyrite but it shows a general tendency to be more common in areas where the porosity increases.

Pyrite II shows a wide variation of grain size and shape; individual grains are anhedral to subhedral and grain boundaries are generally smooth and commonly curved. Elongated and embayed

Plates 3-50, 3-51. Euhedral pyrite I surrounded with collomorphic pyrite associated with high porosity.

PPL scale bar = 150 microns

Plate 3-52. Simple and composite spheres of collomorphic pyrite separated by zones of pyrite I. The core of the large sphere exhibits cellular texture.

PPL scale bar = 150 microns

Plate 3-53. Pyrite I (high relief and high reflectivity) replaced by pyrite II (low relief and low reflectivity). Orbicular textures of collomorphic pyrite are associated with high porosity.

PPL scale bar = 150 microns

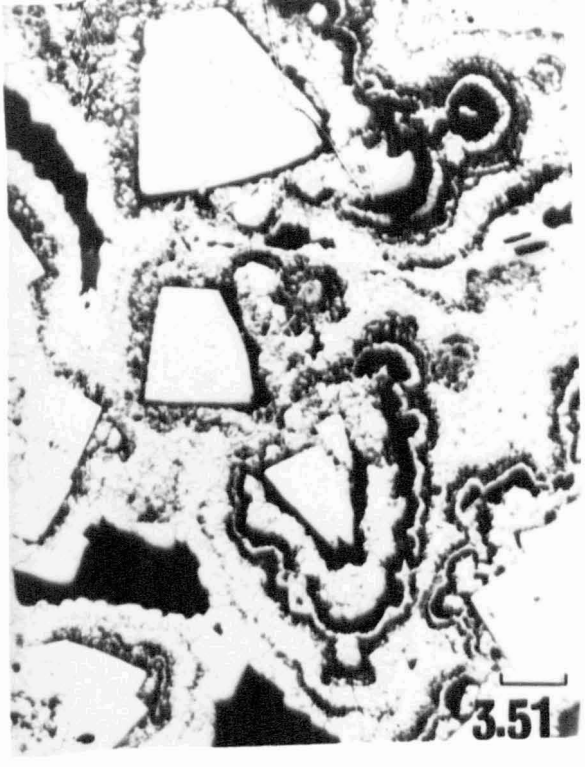
Plate 3-54. Idiomorphic zoned pyrite I, during the growth of which zones with cubic habit alternated with zones with octahedral habit; between some growth zones is sandwiched collomorphic pyrite. Specimen electrolytically etched.

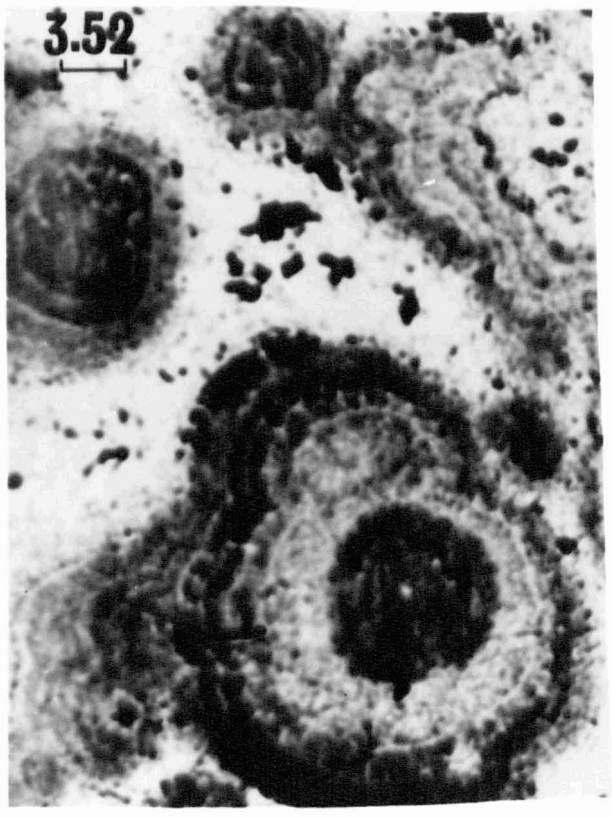
PPL scale bar = 150 microns

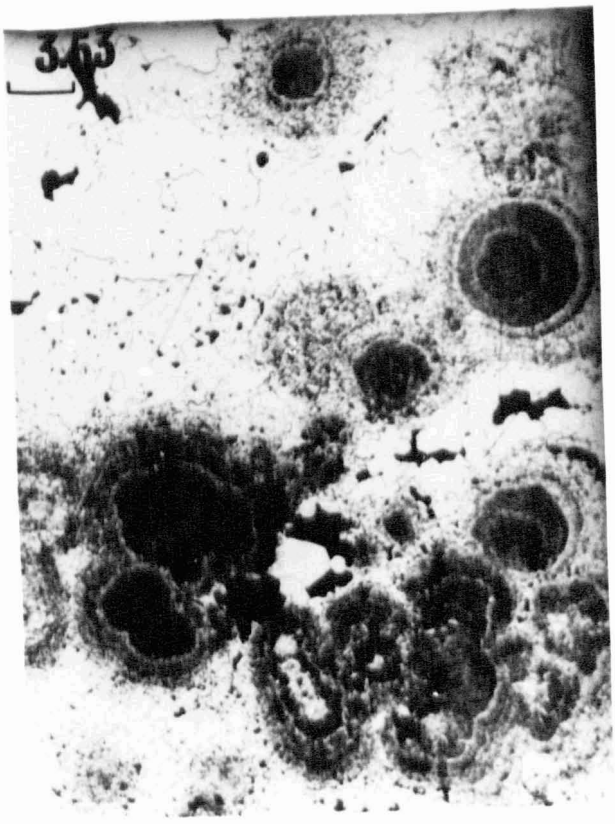
Plate 3-55. Collomorphic pyrite (white) in contact with collomorphic silica (dark grey) which contains remnants of corroded pyrite.

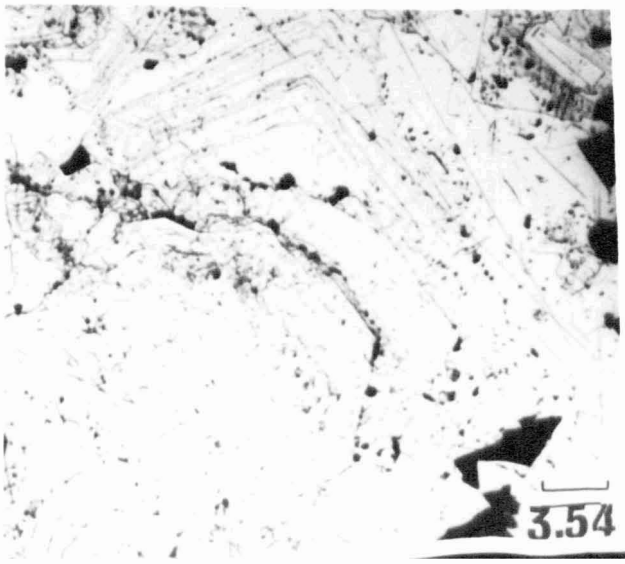
PPL scale bar = 150 microns

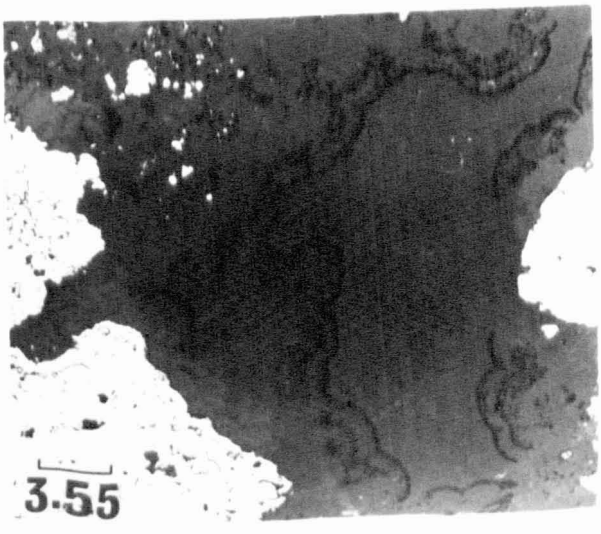

3.50


3.51


3.52


3.53


3.54


3.55

crystals are common. In unetched surfaces isolated areas of pyrite I in pyrite II suggest that the latter is the invading phase (Plates 3.53, 3.60). This interpretation is reinforced by observations of etched surfaces where pyrite II commonly truncates zones of pyrites(Plates 3.44, 3.45).

The third type of pyrite, Pyrite III, is characterized by low relief and reflectivity which are due to high microporosity. These properties render this pyrite quite distinctive. In hand specimens of conglomeratic ore the pyrite III is present in the form of colloform bands.

The most simple form of collomorphic pyrite in two dimensional view is a circle. These range in diameter from several microns up to few millimetres, and show a considerable variation in their internal structure. Commonly the core is homogeneous and is surrounded by concentric layers of pyrite to give an orbicular texture (Plate 3.53). Very often the core of the sphere exhibits a cellular texture (Plates 3.52, 3.53) in which euhedral outlines in the individual polygonal cells are discernible. Isolated spheres with radiating internal structures are abundant (Plate 3.53). Less common are spheres with framboidal texture.

In many cases individual spheres join together to form clusters of spheres that result in composite collomorphic structures possessing a variety of configurations. Clusters of spheres are separated from others by narrow "bridges" of pyrite I (Plate 3.52). Frequently pyrite I is surrounded by closed collomorphic structures (Plates 3.50, 3.51) and vice versa. Individual spheres often join together to form a colloform band up to several centimetres long which is sandwiched between pyrite I and II. Such bands may be continuous or discontinuous (Plates 3.56, 3.57, 3.58, 3.60). The bands mostly have a scalloped structure and in rare cases form more or less straight lines.

Plates 3.44, 3.45 show another form of collomorphic pyrite. It consists of bands truncating pyrite I and II. Internally these bands consist of aggregates of fine grained pyrite with a more or less uniform grain size and with a wide

Plates 3-56, 3-57. Continuous band of collomorphic pyrite produced by the joining of individual spheres of collomorphic pyrite. The band truncates euhedral zoned pyrite I and their contact is irregular. Specimen electrolytically etched.

PPL scale bar = 800 microns

Plate 3-58. Discontinuous band of collomorphic pyrite intersecting euhedral zoned pyrite I. Individual spheres of this band are separated with zones of pyrite I. Specimen electrolytically etched.

PPL scale bar = 800 microns

Plate 3-59. Intensely corroded pyrite associated with silica. Sphereoidal form of pyrite is common.

PPL scale bar = 300 microns

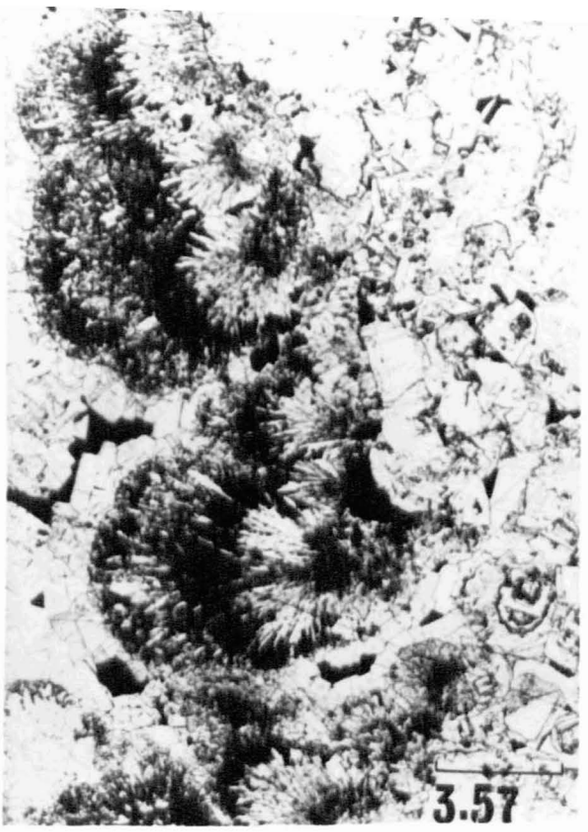
Plate 3-60. Pyrite I (high relief and high reflectivity), Partly replaced by pyrite II and both intersected by a band of collomorphic pyrite.

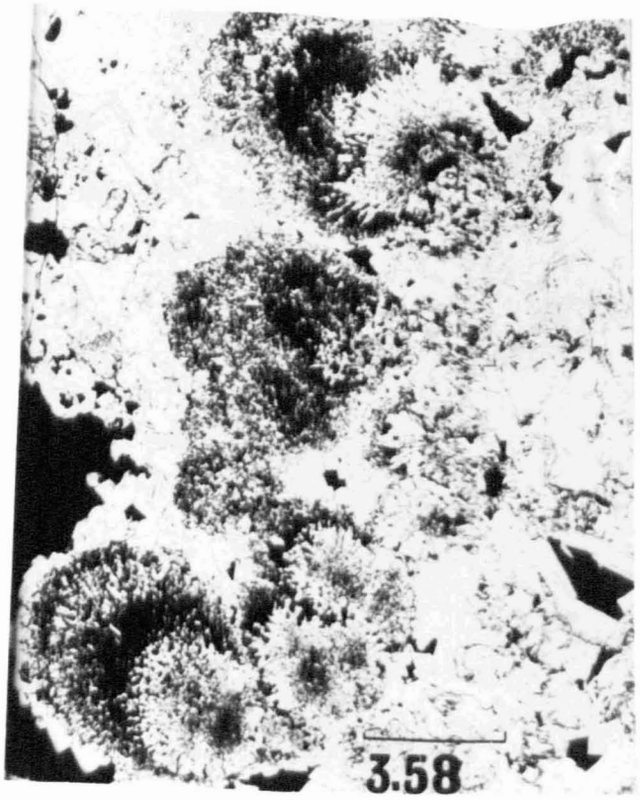
PPL scale bar = 800 microns

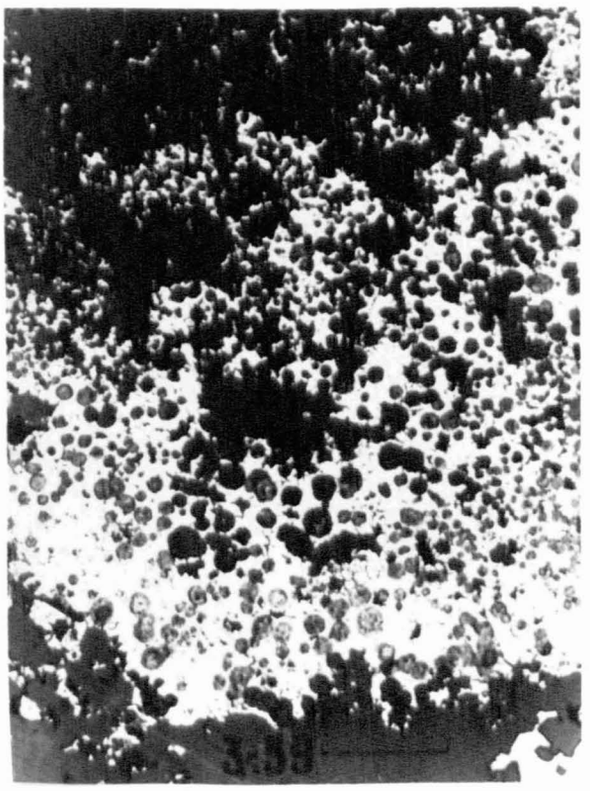
Plate 3-61. Band of collomorphic pyrite intersecting pyrite I.

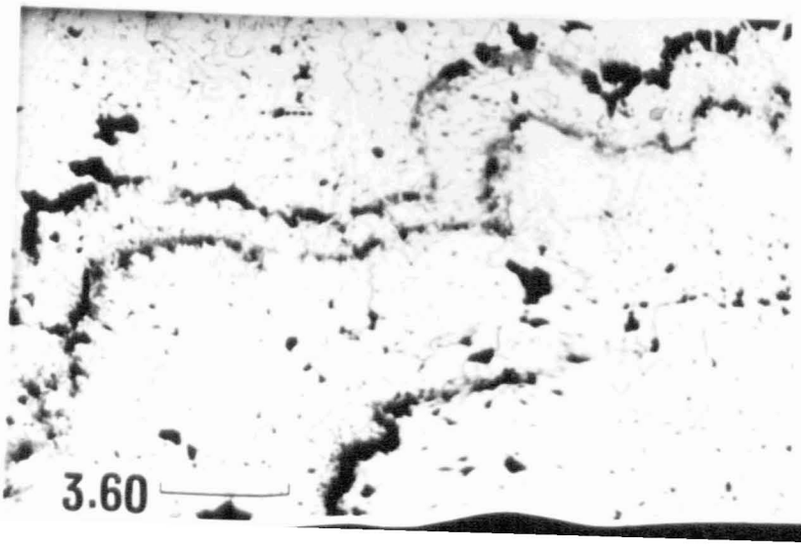
PPL scale bar = 800 microns

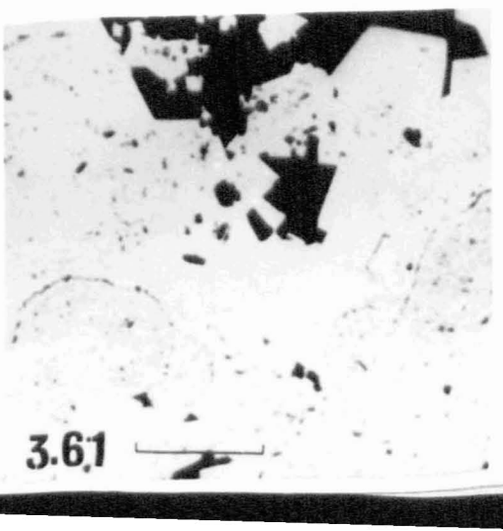

3.56


3.57


3.58


3.59


3.60


3.61

variation in grain shape. These aggregates may form isolated patches in pyrite I or may form continuous bands extending 1 cm across.

Pyrite III invariably truncates pyrite I and in many cases project. into it which stongly suggests that the pyrite III is later than the pyrite I.

c. Chalcopyrite

Chalcopyrite is the second most common mineral after pyrite, and its distribution follows roughly the distribution pattern of copper. It generally tends to be more abundant at the top of the orebody, and in the conglomeratic ore. In localized areas of the orebody where the copper content ranges from 1 to 12 per cent the main copper mineral is chalcopyrite.

Three distinctive modes of occurrence of chalcopyrite can be recognized.

i. Fine anhedral chalcopyrite grains several microns across, occur either as inclusions between separate growth zones and along the grain boundaries of pyrite I. The small size of the grain makes their separation from the pyrite extremely difficult. It is difficult to determine the contribution of this chalcopyrite to the overall copper content of the ore but it would not exceed 0.6 per cent.

ii. Interstitial chalcopyrite, occupying the interstices between pyrite grains or filling cavities in the ore, constitutes the main volume of the chalcopyrite in this orebody. In areas where the chalcopyrite is highly concentrated, it cements coarse euhedral and mostly unzoned pyrite. Part of the pyrite in these areas is intensely corroded with fragments of corroded pyrite enclosed in the chalcopyrite (Plates 3.62, 3.63, 3.65, 3.66). This chalcopyrite forms granular anhedral aggregates in which the grains have a variable form and size. The grain boundaries are smoothed and curved (Plate 3.63). Etching of the interstitial chalcopyrite revealed that in the latter simple and repeated twinning are very common. The interstitial chalcopyrite is often rimmed and veined by covellite (Plate 3.62).

Plate 3-62. Chalcopyrite (cpy) filling cavities in pyrite and partly altered to covellite (cv).

PPL scale bar = 150 microns

Plate 3-63. Subhedral and anhedral chalcopyrite (cpy) filling cavities in pyrite (white) and partly altered to covellite (cv).

PPL scale bar = 150 microns

Plate 3-64. Intensely fragmented pyrite (white) cemented with chalcopyrite (grey) associated with silica (dark grey).

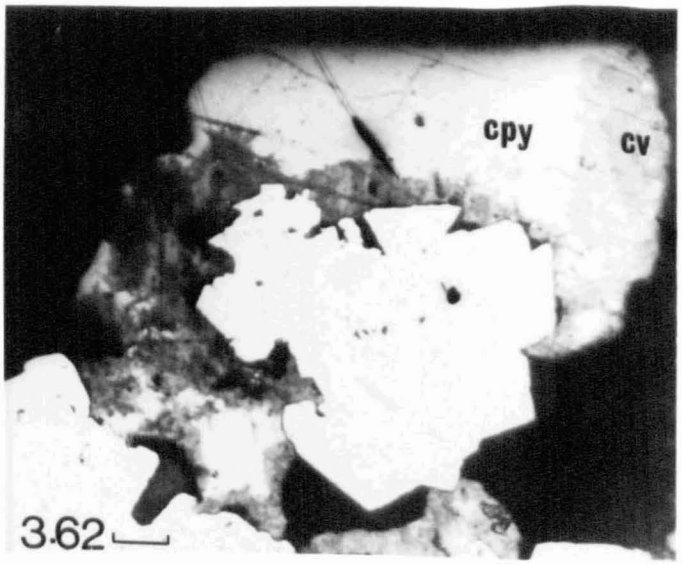
PPL scale bar = 400 microns

Plate 3-65. Chalcopyrite (cpy) filling cavities (black) in pyrite and partly altered to covellite (grey).

PPL scale bar = 150 microns

Plate 3-66. Chalcopyrite (cpy) cementing euhedral pyrite, and partly altered to covellite (grey).

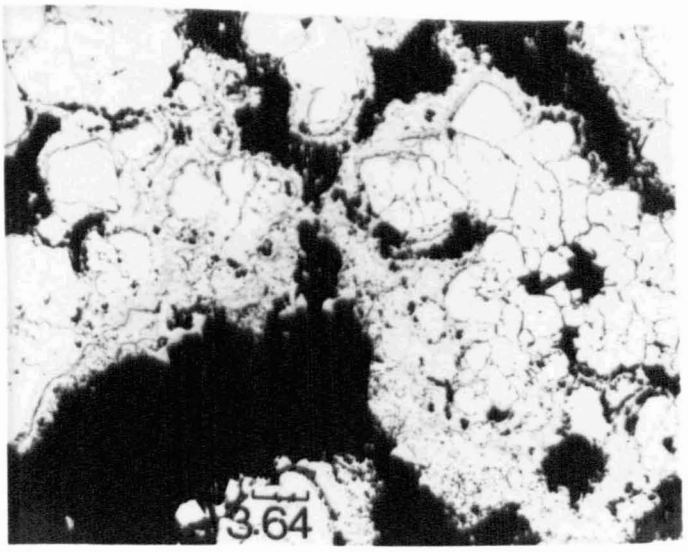
PPL scale bar = 300 microns

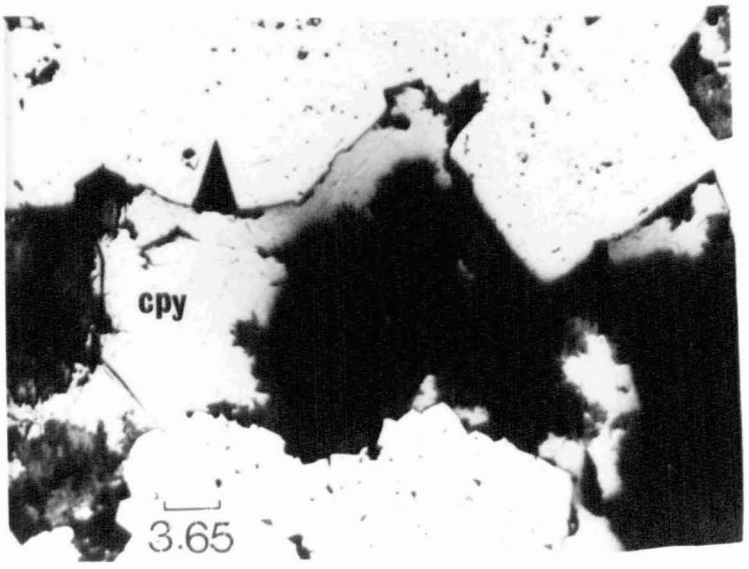


3.62

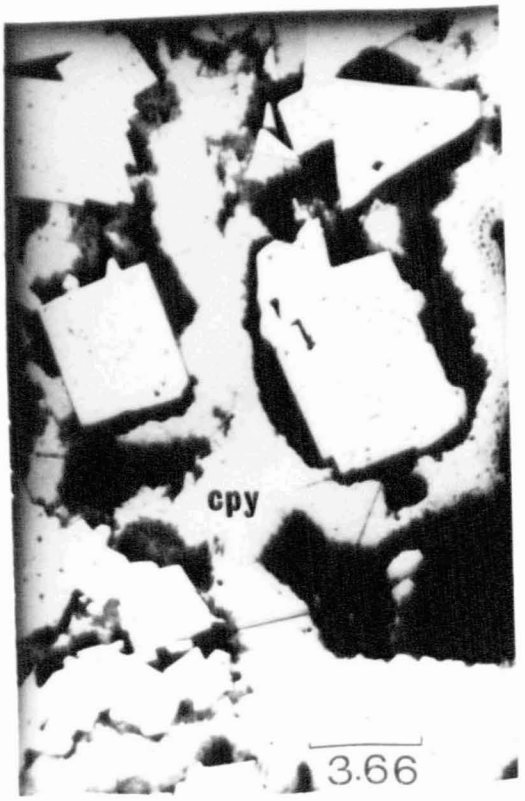


3.63


3.64



3.65



3.66

Not infrequently the interstitial chalcopyrite fills the empty spaces between the bands of collomorphic pyrite (Plate 3.55). At the top of the eastern orebody near its contact with the overlying ochre, interstitial chalcopyrite appears to have invaded and replaced intensely fractured pyrite (Plate 3.64).

The third type of chalcopyrite is intergrown with sphalerite and less commonly with pyrrhotite, and tends to be more common at the upper parts of the orebody and in the conglomeratic ore.

d. Sphalerite Pyrrhotite and marcasite

Sphalerite is present in this orebody in only minor amounts. It shows an erratic distribution but there is a tendency for it to increase both at the top of the orebody and in the conglomeratic ore. Two textural types of sphalerite are present:

i. Small anhedral grains of sphalerite in lines between growth zones of pyrite I similar to chalcopyrite. This type of sphalerite is found throughout the orebody.

ii. The second type, which is restricted to the top of the orebody and to the fragmental ore, is more abundant than the first type. It mostly fills interstices in the pyrite, and often truncates the zoned pyrite. In many cases the sphalerite infills the cavities between collomorphic pyrite and Pyrite I (Plate 3.63). Sphalerite crystals vary from anhedral to euhedral and the grain size ranges from a few microns to a few millimetres. Inclusions of pyrite, chalcopyrite and pyrrhotite are common in this sphalerite. In some cases the pyrite inclusions in the sphalerite form euhedral outlines (Plate 3.70). The grain boundary relationships of pyrite and sphalerite are complicated; in a single polished section sphalerite projects into pyrite and vice versa. Sphalerite pyrrhotite-chalcopyrite textural relationships are shown in plates 3.68, 3.71.

Pyrrhotite is rare and is generally restricted to the conglomeratic ore at the top of the orebody; in the hard compact ore it is very rare. It mostly fills cavities in pyrite I (Plate 3.69) or is mixed with chalcopyrite and sphalerite. Most of the

Plate 3-67. Elongated tabular and prismatic paramelaconsite (grey) filling cavities in pyrite (white).

PPL scale bar = 100 microns

Plate 3-68. Sphalerite (dark grey), associated with pyrrhotite (grey) filling cavities in pyrite.

PPL scale bar = 100 microns

Plate 3-69. Pyrrhotite (white grey) associated with chalcopyrite (point indicated by arrow) filling a cavity in pyrite.

PPL scale bar = 100 microns

Plate 3-70. Sphalerite (dark grey) filling cavities in pyrite (white) and containing fine fragments of pyrite.

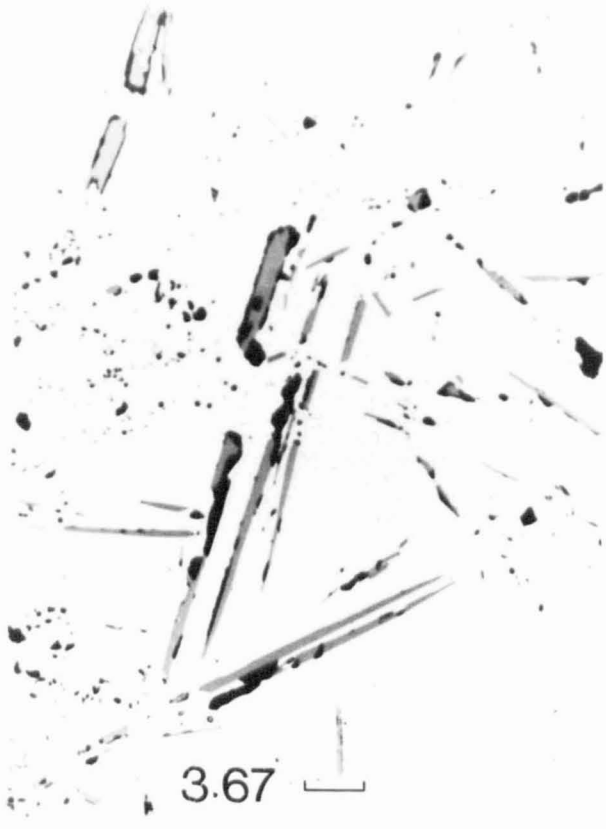
PPL scale bar = 200 microns

Plate 3-71. Sphalerite (grey) and pyrrhotite (white-grey) filling cavities in pyrite (white).

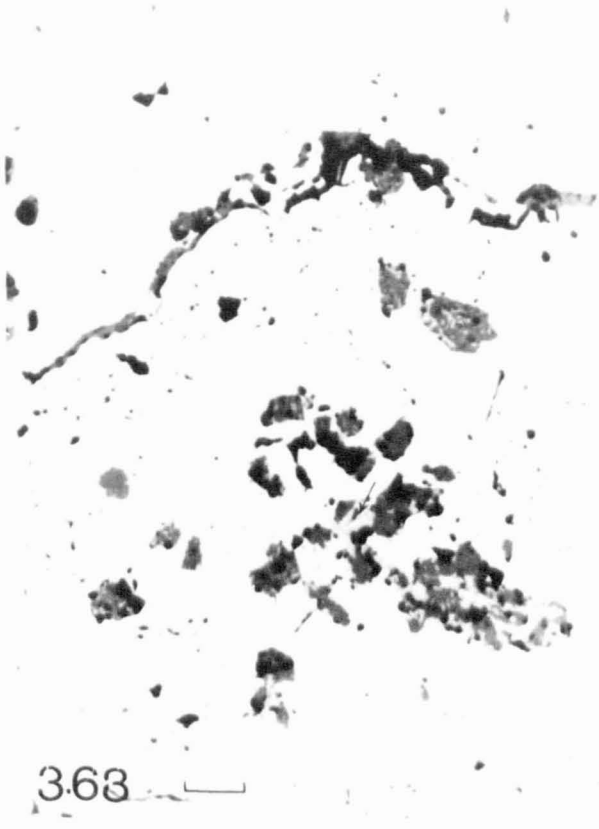
PPL scale bar = 100 microns

Plate 3-72. Digenite (grey) with remnants of chalcopyrite (white grey) in it.

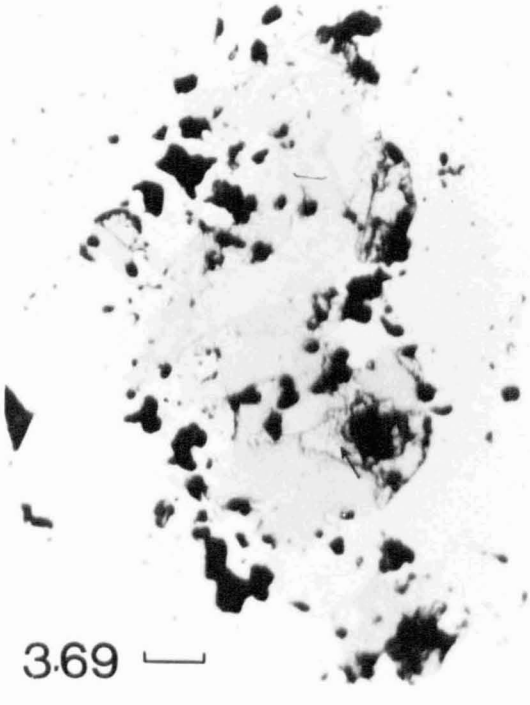
PPL scale bar = 150 microns



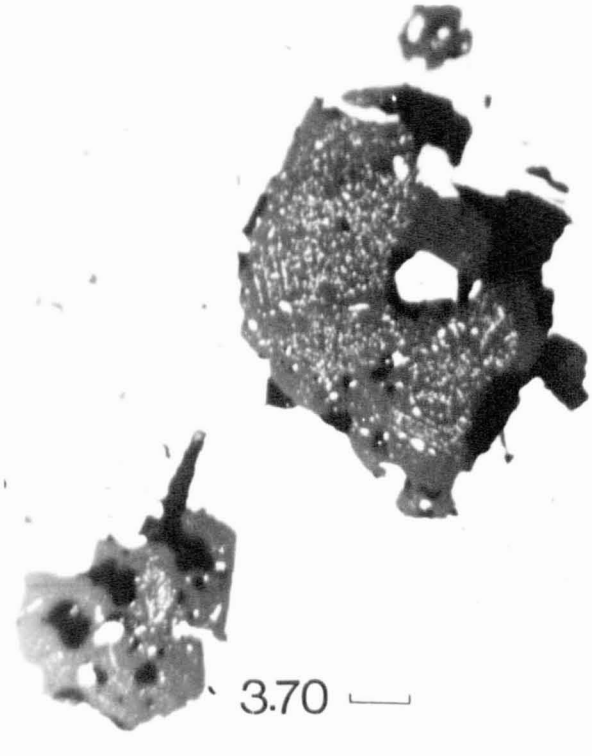
3.67



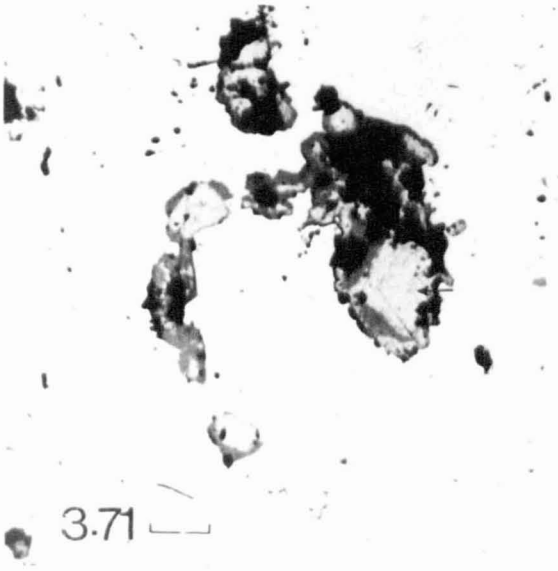
3.68



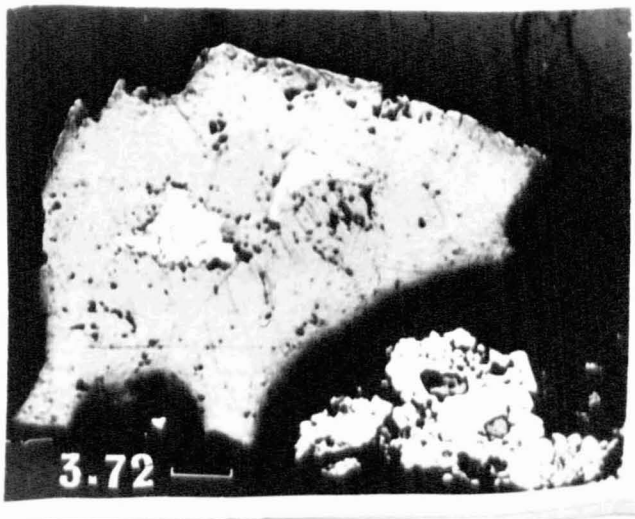
3.69



3.70



3.71



3.72

pyrrhotite grains are less than 15 microns in diameter.

Marcasite has been reported as one of the major minerals in this orebody. According to Bear (1963 p. 53),...."The sandy matrix of the conglomeratic ore contained more marcasite than the solid blocks. ..... Much of the pyrite and marcasite crystallized in small cubes less than a millimetre in diameter. Colloform structures are also very common and consist of delicately banded material comprising, pyrite marcasite and chalcocite". Hutchinson (1965) stated .... "Fine void colloform structures with delicate banding are common. The colloform banding usually consists of alternating layers of pyrite (Melnicovite), marcasite and chalcopyrite, but sphalerite bands are occasionally present ....."

During the present investigation 50 polished sections of samples of all ore types from all parts of the orebody have been examined. Only one specimen from ore interbedded with ochre contains marcasite which occurs along fractures and intersects bands of collomorphic pyrite. This agrees with the observations of Lespineux and De Magnee (1935 p. 109) who stated ..... "L' etude en luminiere polarisee d'une série d' echantillons polis, n'a cependant pas permis de trouver trace de marcassite .....".

c. Secondary copper minerals

i. Covellite is far the most predominant secondary copper sulphide and occurs in the hematitic ochres and cherts, but is also abundant down to the lowest levels of the orebody. Much of the covellite form rims around chalcopyrite or replaces it along fractures. When the chalcopyrite has been completely replaced by covellite the latter is characterized by high microporosity. The covellite fills interstices in pyrite. It is difficult to ascertain whether is an in situ alteration product of chalcopyrite, or was deposited as covellite from secondary solutions during the oxidation of the top of the ore.

Examination of the covellite under an oil immersion objective lens showed that it is commonly associated with and permanent blue covellite (blaubleiblender covellite). The permanent blue covellite appears to be more common in specimens which contain digenite and/or chalcocite.

neodigenite and chalcocite are present. Ramdohr (1969) suggested that the anomalous covellite is due to small amounts of chalcocite in the covellite.

ii. Digenite is very common and made distinctive by its blue colour and isotropy. It occurs in the hematitic ochre and chert intimately associated with covellite but is more common at the top of the eastern orebody, particularly when the ore is mixed with quartz. Plate 3.72 shows a grain of digenite with remnants of chalcopyrite in it, suggesting that the former probably formed through alteration of the latter.

iii. Idaite has not been reported before in Cyprus. Valleriite is supposed to be a common mineral in the Skouriotissa orebody but was not found during the present investigation. It is possible that idaite was mistaken in the past for valleriite since their modes of occurrence and optical properties are very similar.

Idaite was found to be a very common mineral in specimens consisting of a mixture of pyrite and quartz after pyrite from the top of the eastern orebody. In polished sections it is distinguished from bornite by its lighter colour (orange brown) and from chalcopyrite by its darker colour. It shows a high reflection, pleochroism and has a very high anisotropy (Plates 3.75, 3.76, 3.78, 3.79).

According to Ramdohr (1969) idaite was described by many writers in the past, but was first identified by Frenzel (1959) who found that its X-ray powder diffraction pattern was identical to that given by Lombard and Merwin (1937) for the synthetic Cu_5FeS_6. He named the mineral after the Ida mine Khan South-West Africa where it occurs as lamellae intergrown with bornite, often together with fine spindles of chalcopyrite.

Since then, this mineral has aroused the interest of many geologists and has been reported from many parts of the world e.g. Argentina (Brodtkorb 1961) 10 localities in Japan, Takeuchi and Nambu 1961), Norway (Krause 1965) and India, (Rao 1965).

Considerable controvery exists in the literature regarding the formula of idaite. Eliseev (1960) (quoted by Yund 1963).

Plate 3-73. Chalcopyrite (cpy) replaced by idaite (id) in turn replaced by covellite (cv).

PPL scale bar = 300 microns

Plate 3-74. Chalcopyrite (cpy) replaced by idaite in turn replaced by covellite (point indicated by white arrow). At point indicated by black arrow sphalerite in chalcopyrite.

PPL scale bar = 300 microns

Plate 3-75. Large anhedral crystal of idaite embedded in silica.

PPL scale bar = 600 microns

Plate 3-76. Idaite (white grey), partly altered to covellite (grey). At the centre of idaite a fragment of remnant chalcopyrite.

PPL scale bar = 200 microns

Plate 3-77. Chalcopyrite (cpy) replaced by idaite (id) in turn replaced by covellite (cv). At bottom right bornite (bn) replaced by digenite (nd) in turn replaced by covellite (cv). At point indicated by white arrow contact between digenite and covellite.

PPL scale bar = 400 microns

Plate 3-78. High anisotropy of the idaite shown in plate 3-55. Nickols crossed.

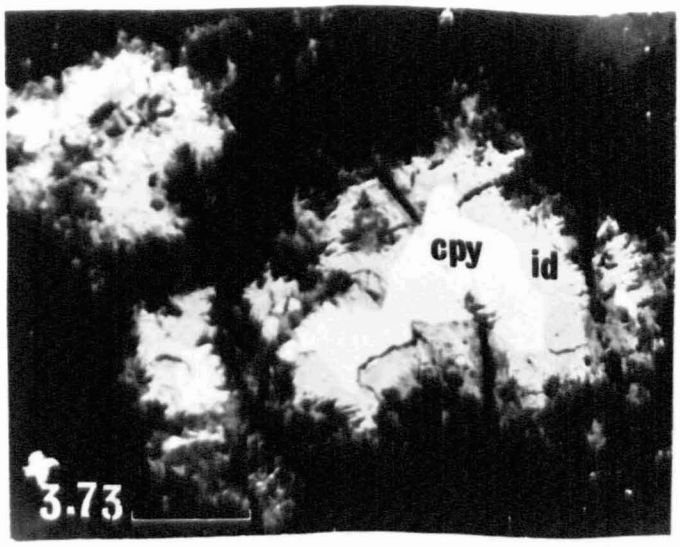
Scale bar = 600 microns

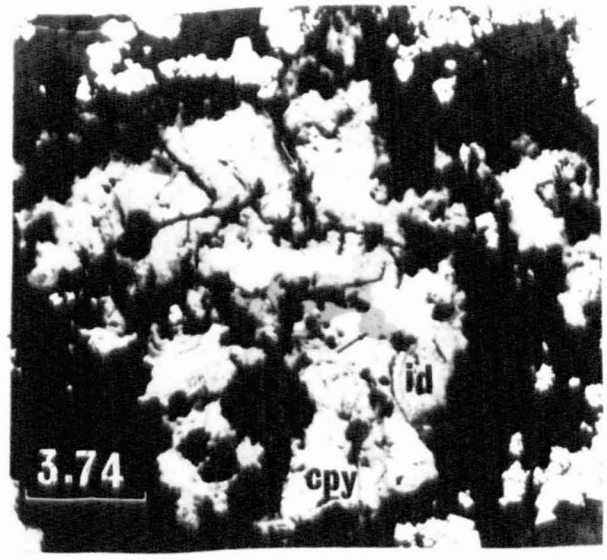
Plate 3-79. High anisotropy of the idaite shown in plate 3-76. Nickols crossed.

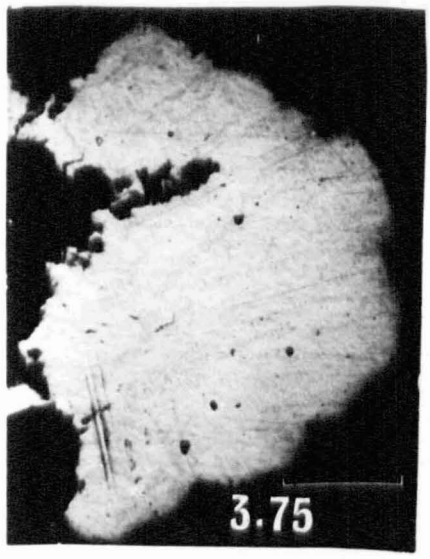
Scale bar = 200 microns

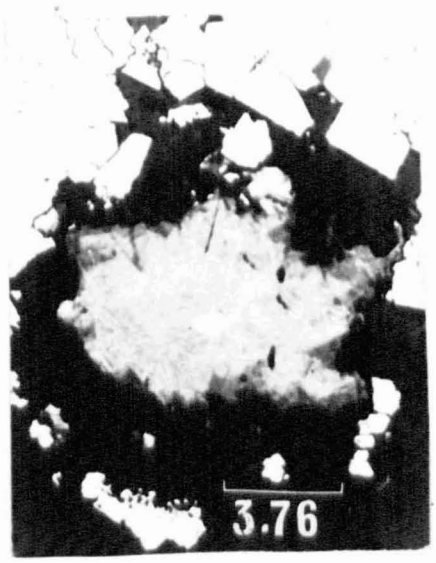
Plate 3-80. Chalcopyrite (white) replaced by idaite (white grey) in turn replaced by covellite (grey).

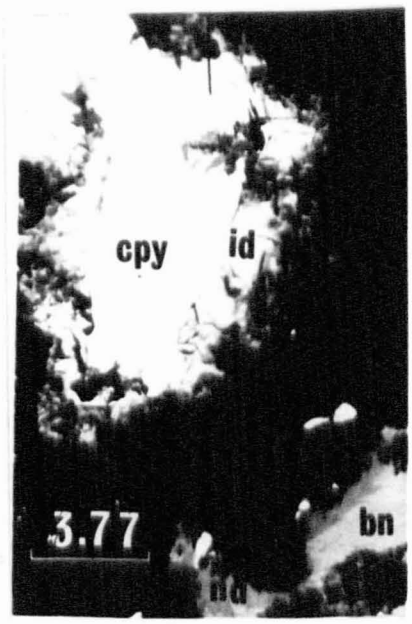
PPL scale bar = 300 microns


cpy
id
3.73

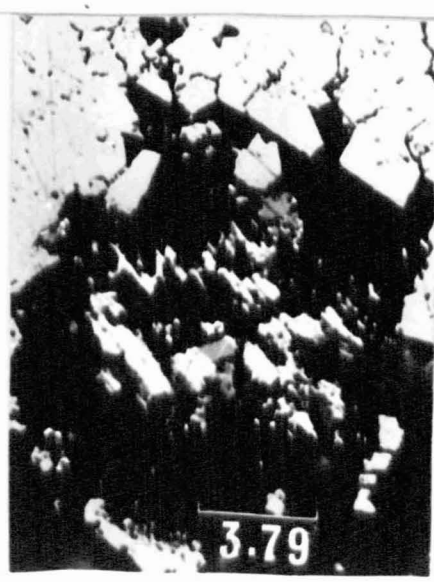

id
3.74
cpy


3.75


3.76


cpy
id
3.77
bn


3.78


3.79


3.80

suggested that the amount of Fe is very low in the given formula Cu_5FeS_6 and a mineral with such formula theoretically can not exist. Yund (1963) using high purity elements synthesized idaite and gave the spacings and intensities of the X-ray lines, which are not in full agreement with those given by Frenzel, and he suggested the formula Cu 3.38 Fe 0.62 S4 for this mineral. Levy (1965) using electron microprobe established the formula of idaite as Cu_3FeS_4. He concluded that chemically at least idaite can be considered as the pole of a series with formula Cu_2 (Cu Sn/Fe S_4) of which normal stannite is the other pole while yellow stannites and orange bornites are intermediate members.

All the literature reports idaite to be intimately associated with bornite and is considered to be the first product of decomposition of bornite. Ramdoh (1969) reported that idaite is often connected with newly formed limonite and permanent blue and normal covellites, and that very often idaite changes to covellite.

In the Skouriotissa orebody idaite is not associated with bornite. It forms discrete anhedral grains up to one millimetre in size, that are invariably rimed with covellites (Plates 3.75, 3.76). These grains in most cases exhibit complex parquet twinning. (Plates 3.78, 3.79). Commonly idaite appears to be a direct alteration product of chalcopyrite since it forms rims around it and fills fractures in it. (Plates 3.73, 3.74).
Idaite - chalcopyrite contacts are in most cases sharp and well defined (Plates 3.73, 3.77). The idaite is commonly altered to covellite, the latter riming the former and filling fractures in it with very common interfingering of covellite in idaite.

It is worth mentioning that in one specimen a chalcopyrite grain rimmed in turn by idaite and covellite, was situated near a bornite grain, which was rimed in turn by digenite and a mixture of permanent blue and normal covellite. The contact of the individual rims was sharp and well defined (Plates 3.77, 3.80).

Quantitative electron probe microanalyses of idaite from one polished section, were carried out independantly by P. Suddaby and G.M. Steed of the Geology Department, Imperial College; the

former used Geoscan and the B.M. - I.C. - N.P.L. computer programs for the calculation of corrections, whereas the latter used the Microscan I and the Alpha correction method (Kelly unpublished data). The results of these analyses plus the X-ray powder diffraction data of the Skouriotissa idaite are shown in Tables 3-4a and 3-4b.

Table 3-4a: X-ray data for idaite from Skouriotissa ore (1) compared with data for synthetic idaite (2) given by Yund (1963) and natural idaite from Ida Mine (3) given by Frenzel (1959)

(1)		(2)		(3)	
I	d	I	d	I	d
10	3.45			VW	3.45
25	3.26	25	3.27	MW	3.27
100	3.14	100	3.139	St	3.14
80	2.81	80	2.823	St	2.82
65	1.89	65	1.89	St	1.89
50	1.85	65	1.85	St	1.85
40	1.577	30	1.565	St	1.56
30	1.577				
10	1.2[illegible]	10	1.32		
15	1.204		1.20	St	1.20

Table 3-4b: Electron Probe Analyses of idaite from the Skouriotissa orebody using Geoscan (1) and Microscan I (2,3) compared with analyses of idaite (4,5,6,7) given by Levy (1965) and analyses expected for idaite with the formula Cu_5FeS_6 (8) and Cu_3FeS_4 (9). Calculation of formula for the analyses (1, 2, 3) is based on one Fe atom.

Wt%	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Cu	50.7	51.7	49.4	50.6	50.3	50.3	48.2	56.1	50.9
S	35.7	32.7	32.9	34.1	34.4	34.7	35.2	34.0	34.2
Fe	14.6	14.7	13.9	14.2	15.9	15.5	14.7	9.9	14.9
Total	101.0	99.1	96.2	98.9	100.6	100.5	98.1	100.0	100.0

Formulae (1) $Cu_{3.04}Fe_1S_{4.25}$ (2) $Cu_{3.09}Fe_1S_{3.88}$ (3) $Cu_3Fe_1S_4$

Table 3-4c: X-ray data for Paramelaconite from the Skouriotissa ore (1) compared with Paramelaconite data (2) given by Ramdohr (1969).

(1)		(2)	
(I)	d	(I)	d
100	2.50	100	2.49
50	2.03	50	2.05
70	1.59	70	1.575
40	1.48	40	1.449

The figures in these tables indicate that the spacings of the X-ray lines of the idaite from Skouriotissa are in good agreement with those given by Frenzel (op. cit) but the formula calculated from the results of the analyses for one Fe atom, is different from that hitherto accepted, but is in very good agreement with the formula established by Levy (1965).

iv. Paramelaconite CuO is common in this orebody but appears to be restricted to the hard compact ore, in the vicinity of the intersection of the 350° and 300° trending faults. It forms clusters of elongated tabular crystals and less commonly shows prismatic crystals randomly distributed in the pyrite (Plate 3.67), the crystal shapes are controlled, by the shapes of interstices they fill. The paramelaconite has a grey white blue colour, and distinct reflection pleochroism and inisotropy, particularly in the elongated crystals.

The optical properties of paramelaconite are similar to those of tenorite (CuO) and originally was concluded by the writer that only tenorite was present. However an X-ray diffraction powder photograph gave a pattern similar to that of the paramelaconite given by Frondel and compiled by Ramdohr (1969) (Table 3-4c). Because:(a) Paramelaconite is metastable at room temperature, and is commonly replaced by tenorite (Ramdohr 1967), (b) the optical properties of tenorite and paramelaconite are very similar and (c) only two grains have been analysed by X-ray diffraction, it is probable that tenorite is also present in the Skouriotissa orebody.

v. Other Minerals: Chalcocite has been reported as being abundant in this orebody and to be partly responsible for the collomorphic banding of the ore. The present investigation revealed that present only in minor amounts and is distributed throughout the entire orebody.

Bornite is very rare and it is found in many parts of the orebody. As mentioned before, it occurs in contact with neodigenite or chalcocite but is not associated with idaite.

Mackinawite is very rare and was found associated with copper sulphides, in the sulphide-quartz areas at the top of the

eastern orebody. Typically its reflection pleochroism is high and its anisotropy enormous. Rare delafossite ($CuFeO_2$) was founed in the ore in the vicinity of the intersection of the 350° and 300° trending faults.

7. Summary

The Skouriotissa orebody occurs within a saucer-shaped depression on the surface of the olivine basaltic U.P.L.

In the field the conglomeratic ore that consists of fragments of solid sulphide in a matrix of soft friable sulphide, is readily distinguishable from the hard, compact and fractured ore. The conglomeratic ore tends to concentrate in the eastern orebody and in the western part of the western orebody whereas the compact ore is confined to the eastern part of the western orebody (Plate 3-1).

The conglomeratic ore is characterized by collomorphic banding, which is absent from the hard compact ore. This banding is due to differences in macro and micro-porosity and reflectivity in the individual bands, and not to differences in mineralogical composition. The ore as a whole is highly porous, and the total porosity increases substantially in the conglomeratic ore.

The ore mostly consists of S, Fe and Cu with minor amounts of Zn, SiO_2, CaO, Al_2O_3 MgO, MnO, TiO_2. Copper and Zinc are erratically distibuted in the orebody; the copper is generally higher in the conglomeratic ore compared to the compact ore; The cobalt content is high and it is erratically distributed while Ni is very low; The Cu:Zn ratio is high whereas the Ni:Co ratio is anomalously low. In the basaltic lavas adjacent to the ore copper is lower than the background value whereas zinc and nickel are much higher; Cobalt decreases considerably from ore to lavas but it is higher than background.

Pyrite is the dominant mineral in this orebody and was divided into three major textural types. Pyrite I, the earliest type is euhedral to subhedral and is mostly zoned. The zoning indicates a complicated history of growth and dissolution. Pyrite I generally is optically isotropic and

has the highest reflectivity and relief of the pyrite types.

Pyrite II is mostly anhedral, with smooth curved grain boundaries. Its reflectivity and relief are intermediate between pyrite I and III;. it truncates the zoning of pyrite I and is considered to be later than pyrite I.

Pyrite III (collomorphic pyrite) is confined to the conglomeratic ore. Its reflectivity and polishing hardness are lower than those of the other two pyrite types, and its colour in plane polarized light commonly is light brown. It is highly microporous and very commonly natural differential decomposition reveals the internal structure without having to resort to etching. It shows striking structural similarities with the Melnikovite pyrite described by Ramdohr (1969). Pyrite III truncates the previous two types and is considered to be the latest pyrite in the Skouriotissa orebody.

Chalcopyrite is the second most common mineral and can likewise be classified into three textural types. The first occurs as small inclusions within pyrite I and constitutes minor proportion of the total chalcopyrite. The bulk of the chalcopyrite is made up by the second type which occupies interstices between pyrite grains and fills cavities in the ore. The third type is associated with pyrite III and is accompanied by shpalerite and pyrrhotite which occur in minor amounts. Mutual intergrowths of sphalerite pyrrhotite and chalcopyrite are common but confined only to the conglomeratic ore. Contrary to previous reports marcasite is extremely rare.

Covellite is the most common secondary copper sulphide. Permanent blue covellite, digenite, paramelakonite, tenorite mackinawite, and delafossite have been reported for the first time in the Skouriotissa orebody. Small amounts of chalcocite and bornite have been confirmed. Idaite was identified for the first time in Cyprus, and it is possibly the first occurrence in the world where it is a direct alteration product of chalcopyrite rather than of bornite. It is very well crystalline and electron probe investigation revealed a formula Cu_3FeS_4 for idaite and not Cu_5FeS_6 as it was previously accepted. This is in agreement with the formula proposed by Levy (1965) for idaite.

E. OXIDATION PRODUCTS OF THE ORE AND WALLROCK ALTERATIONS

1. Opening Statement

The southwestern end of the orebody was faulted and brought to the surface and had been oxidized to massive gossan. Much of the acid water produced during the oxidation of the ore percolated through the unoxidized orebody which, in this area, was well above the water table. Such acid waters, considerably affected the mineralogy and textures of the ore; pyrite was intensely leached, and iron and copper sulphades plus secondary copper sulphides were deposited. It is worth mentioning that at the 810 feet level in the vicinity of the gossan the ore has a conglomeratic structure whereas away from the gossan the ore is hard and compact.

At the contact of the ore with the underlying volcanic rocks the descending acid solutions probably had undergone dramatic chemical changes through their reaction with the olivine basaltic lavas. As a result the lavas were altered and a number of unique products precipitated. These products were mined in the 1940s but a short compilation of the available information is included in this section because the writer considered them as important for the completeness of the geological setting of the Skouriotissa orebody.

2. Gossan and Native Sulphur.

The oxidation of the exposed massive ore, formed a spectacular massive gossan, which attracted the ancient and modern prospectors. The first C.M.C. drill holes were sunk on this gossan and drilling data indicate that the supergene oxidation extends to a minimum of 85 and as much as 145 metres below the surface.

The upper part of the gossan consists mainly of solid masses of jarosite of considerable extent, through which are scattered patches of limonite and white spongy silica. The intensity of oxidation decreases with depth, where remnant pyrite, mixed with secondary copper sulphides and varying amounts of native copper are encountered. The zone of oxidation in this part of the orebody is succeeded in depth by stockwork-type mineralization consisting of veins and disseminations of pyrite in silicified, chloritized and variably epidotized lavas.

In the vicinity of the gossan, at the 915-foot level, a layer of native sulphur was found below the massive ore and along its interface with the basaltic lavas (Plate 3.1). The sulphur was reported to occur in considerable quantities and to be of good quality. Assays indicate that it contained up to 87 per cent sulphur and high values of silver and gold, the silver content being six times that of gold. (Ag 2.02 oz and Au 0.33 oz per ton). Cullis and Edge (1922) reported that the impurities of the native sulphur comprised mainly the basic iron sulphates fibroferrite ($fe_2O_3.2\ SO_3.10H_2O$) and copiapite ($2Fe_2O_35SO_3\ 18H_2O$). Lespineaux found a layer of sulphates between the massive ore and the layer of native sulphur, and he despatched specimens to Melon and Donnay (1935) for mineralogical investigations who, in addition to the above sulphates, identified gypsum, jarosite, destinezite (Sulphate and Ferric phosphate) and cyprusite ($7\ Fe_2O_3.\ Al_2O_3\ 10SO_3\ 14H_2O$).

Although the persistent association of all these sulphates with the native sulphur has been mentioned in all the later references to this orebody, Hutchinson (1965) in his discussion on the origin of the Cyprus sulphide ores, ignored them and considered the native sulphur to be a product of primary deposition.

3. Devil's Mud

A horizontal layer of ore with unique physical and chemical characteristics was found between the layer of native sulphur with sulphates, and the massive sulphide ore; it was also found beyond the domains of native sulphur (intercalated) between the volcanic rocks and the massive sulphide ore. Isolated patches of this ore were found fringing the orebody and forming veins along fault planes. The thickness of this material ranged from 15 cms to 2 metres and it covered an area of approximately 10 acres.

This ore is very light, weighing only 75 lbs per cubic foot in place (55 lbs per cubic foot after mining), and it has a dry, soft, friable, sponge-like texture. Because it becomes liquid slime when pressed between the fingers, and is highly corrosive, it has been named Devil's Mud by the local miners.

The Devil's Mud contains 15-18 per cent water, is highly acid and contains about 18 per cent soluble salts (mostly iron sulphates). It also contains considerable amount of silica, and titrates 1.32 to 2.5 per cent free sulphuric acid . It was mined for its high gold and silver content (Table 3-5). In some gold- and silver-rich samples the selenium content was reported to be as high as 3 per cent, whereas sporadic thin bands of galena were found in the layer of Devil's Mud.

Table 3-5. Analysis of high-grade Devil's Mud.

(After Rose 1934)

Au	9.2	ozs per short dry ton
Ag	15.0	" " " " "
Moisture	18.5%	
Soluble salts	13.5%	
SiO_2	39.03%	this equals 57.4% on dry insoluble material
$Fe_2(SO_4)3$	9.6%	
$FeSO_4$	0.2%	
Free H_2SO_4	1.52%	

Rose (1934) by comparing the silver and gold contents of the Skouriotissa sulphide ore and the Devil's Mud, and assuming that (a) the metals in the mud were derived from the oxidation of sulphide ore and (b) the ore that was oxidized was no richer in these metals than the orebody as a whole, estimated that for each ton of Devil's mud ore formed, about 100 tons of sulphide ore must have been oxidized. He concluded that for the total tonnage of Devil's Mud in this orebody at least 100 feet of sulphide ore must have been oxidized. Callaghan (1965) probably had this calculation in mind when stating that the orebody had ..... "Shrunken to its present size .....".

4. Leaching and "sulphation" of the ore

The chemical composition of the Devil's mud and the type of alteration of the underlying lavas, both suggest that this part of the ore was affected by acid, sulphated ground waters. The percolation of such solutions down through the orebody resembles the artificial heap and dump leaching of cupriferous

sulphide ores that has been practised for long time at Rio Tinto and many other places throughout the world.

Most of the Skouriotissa orebody can be imagined as a natural ore heap, protected from oxidation by the capping of overlying sediments. The leaching was evidently most intense at the western end of the orebody because (a) it was connected to outcropping ore which is much more permeable than the overlying sediments, covering the rest of the orebody and (b) the percolating waters were charged with strong, acid, ferric sulphate solutions, produced during the oxidation of the outcropping ore.

The overlying sediments to the east probably restricted the percolation of groundwater through the ore thus it would be expected that leaching effects and supergene changes would progressively decrease in intensity from west to east. Associated with the leaching process, was the development of an assemblage of iron and copper sulphates, very common throughout the orebody. Melanterite and fibroferrite are the most common sulphates, and brochanthite and chalcanthite the dominant copper sulphates.

5. Supergene Wallrock Alteration

There has been widespread reaction between the acid ground waters and the basaltic lavas surrounding and underlying the Skouriotissa orebody, but the resulting alteration varies considerably in intensity in the different parts of the orebody. At the higher levels the altered lavas have a whitish pale-grey colour and the pillow and vesicular structures are more on less preserved (Plate 3-10). Some vesicles and fractures are lined with prismatic quartz, whereas scaly gypsum is scattered through the altered lava.

At the lower levels, particularly towards the central part of the western orebody, the lavas were intensely altered. Their pillow structure is obliterated and they are highly decomposed and disintegrated. These changes extend downwards for up to several metres where the altered lavas pass into fresh basaltic lavas (Fig. 3-3). The contact of the ore with the intensely altered lavas is very sharp (Plate 3-11). The sulphur content diminishes abruptly from over 40 to less than 2 per cent over distances less than two centimetres.

The pyrite of the ore at the contact with the altered lava has been intensely leached and replaced by quartz which was probably liberated from the altered lava in contact with it (Plates 3-85, 3-86, 3-87, 3-88).

X-ray diffraction analyses of the intensely altered lavas, indicate a very complicated mineral assemblage, including hydrated sulphates of iron and magnesium, quartz, and clay minerals.

6. Hypogene Wallrock Alteration

In contrast with the other sulphide orebodies in Cyprus, the Skouriotissa orebody has no recognizable stockwork zone under the massive ore. This was pointed out by some of the earlier investigators e.g. Bruce (1948) who stated that "... there are no recognizable roots of feed channels ...". However during the present investigation hydrothermally altered lavas were found, in the footwall of the 350° trending fault in the area which lies between the intersections of this fault with the 300° trending fault and the 060°/ trending fault of the eastern orebody (Fig. 3.2). These lavas have a dark grey green colour, are highly brecciated, and pillow structures are only rarely discernible. They are intensely silicified and chloritized and fractures in the lava are filled with sulphides, quartz and rare red jasper. At the higher benches of this part of the orebody, the hydrothermally altered lavas are overlain by pale-grey lavas which have a well preserved pillow structure, contain no or very little sulphide, had undergone extensive supergene leaching and are overlain by the sediments of the Perapedhi Formation. Macroscopically these lavas appear to be different from the underlying hydrothermally altered lavas and similar to the surrounding olivine basaltic lavas but the extensive alteration of the lavas makes it difficult to prove this suggestion.

In the zone of hydrothermally altered lavas the mineralization is represented by sulphide veins, which fill fractures in the lavas, and by fine grained pyrite which is disseminated in the mineralized lavas. The sulphide veins consist mainly of pyrite associated with chalcopyrite, covellite, and minor amounts of sphalerite delafossite, paramelaconite and tenorite. The pyrite in the sulphide veins is coarse grained,

Plate 3-81. Coarse grained pyrite (black) associated with quartz, filling fracture in hydrothermally altered lava (left and right). The lava is impregnated with fine grained pyrite (black).

PPL scale bar = 400 microns

Plate 3-81. Hydrothermally altered lava impregnated with fine grained pyrite (black). Plagioclase and pyroxene in the lava have been replaced by quartz (white).

PPL scale bar = 250 microns

Plates 3-83, 3-84. Intensely corroded pyrite (black) replaced by quartz and chalcedony (white).

PPL scale bar = 400 microns

Plates 3-85, 3-86. Intensely leached pyrite (black) replaced by quartz (white).

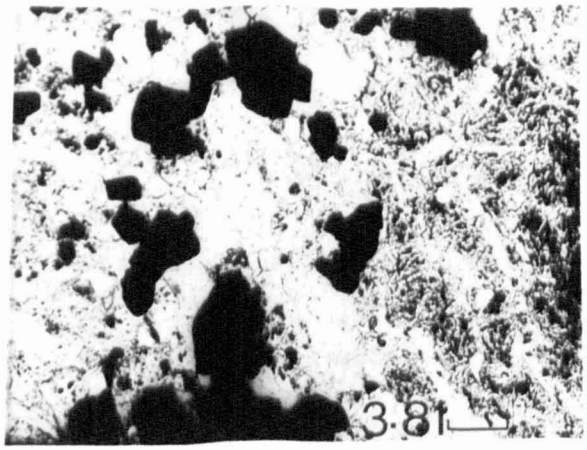
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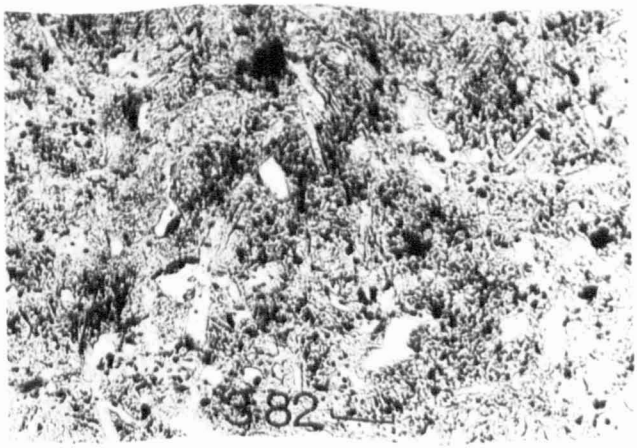
Plate 3-87. Intensely leached pyrite (black) replaced by quartz. Nickols crossed.

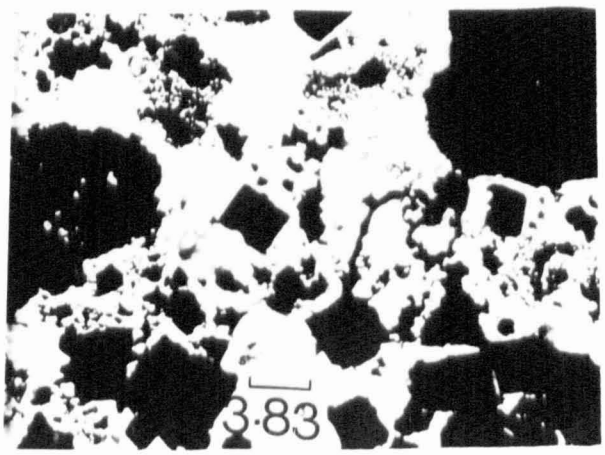
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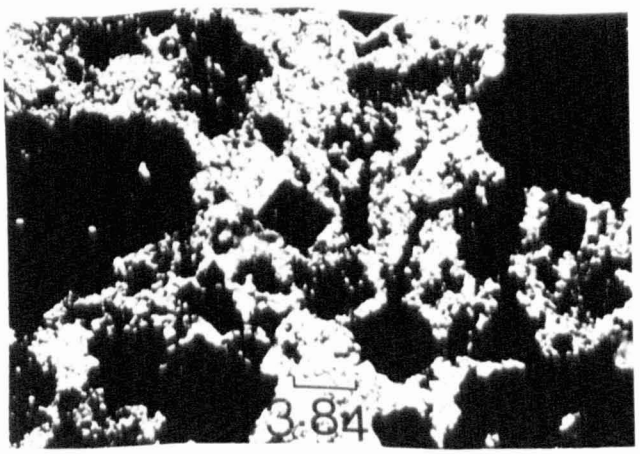
Plate 3-88. Intensely leached pyrite (black) replaced by quartz (white).

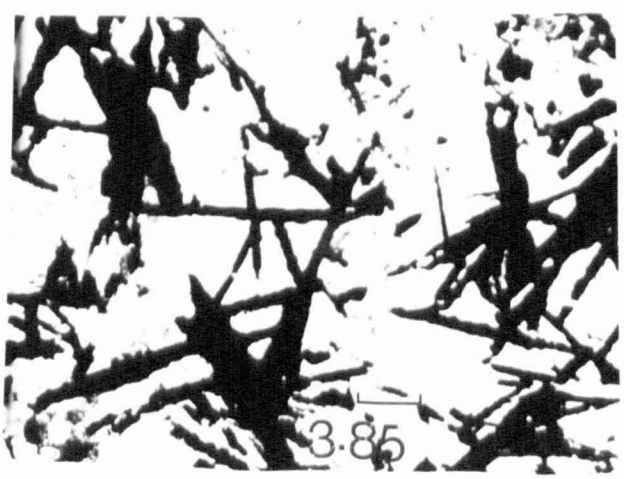
PPL scale bar = 400 microns


3·81

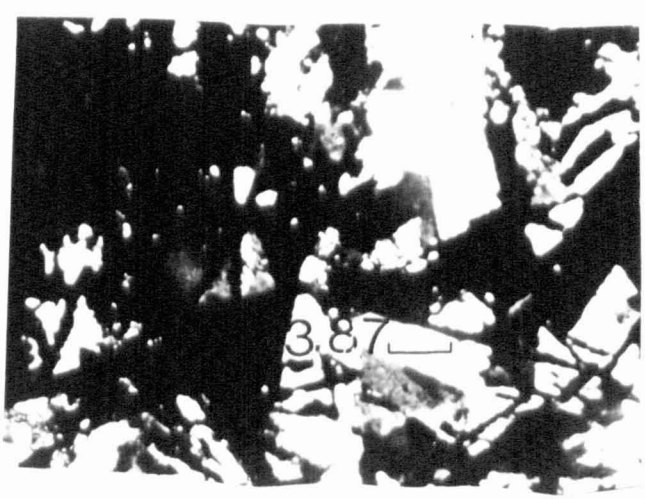

3·82

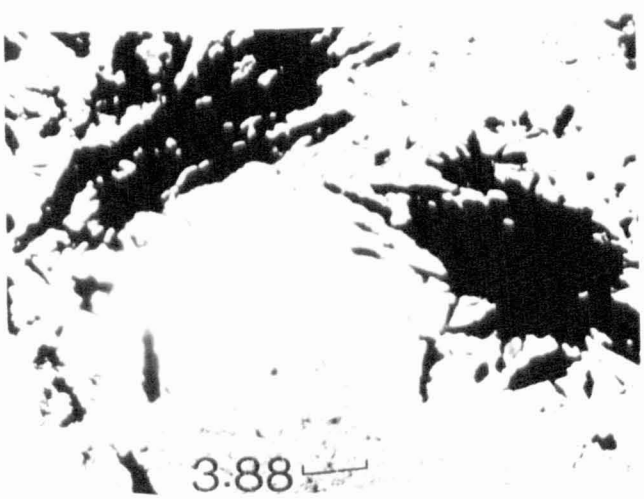

3·83


3·84


3·85


3·86


3·87


3·88

unzoned and less commonly zoned; it is intensely corroded and replaced by chalcedony and quartz (Plates 3.83, 3.84). The chalcedony commonly has a spherulitic texture with syneresis cracks, and contains remnants of replaced pyrite. Moving away from the fractures towards the lava the amount and grain size of pyrite decrease abruptly. (Plate 3.81). A striking feature is that away from the fractures or other open spaces no chalcopyrite or sphalerite or other copper mineral was observed impregnating the lava. Even in samples which are ramified with veins of chalcopyrite not a grain of the latter was observed impregnating the lava.

The mineralized lavas are impregnated with fine grained unzoned pyrite. The weakly mineralized lavas contain about as much fine grained pyrite as the unaltered lavas contain magnetite (Plate 3-82), and they are highly chloritized. The chlorite is a chamositic variety and is poorly crystalline and mixed with chalcedony. It is restricted to the glassy mesostasis of the altered lava, while the plagioclase and pyroxene have been replaced by quartz (Plates 3-81, 3-82).

X-ray diffraction analyses of samples of hydrothermally altered lava Table 10-1 and Table 10-2 indicate that:

(a) Quartz predominates in all the specimens followed in abundance by pyrite and chlorite.

(b) There is a noticeable antipathetic relationship between pyrite and chlorite.

(c) Minor amounts of illite, kaolinite and palygosrkite are present in the hydrothermally altered lavas whereas montmorillonite is absent from all the samples analysed.

The type of alteration in this zone is identicalwith the alteration found in the stockwork zone underlying most of the Cyprus orebodies (Chapters 4 and 5). Callaghan (1965) relying on information he obtained from the extensive drilling beneath and around this orebody concluded that ".,.,.. Mineral forming constituents moved upwards through a chimney of quartz, chlorite altered lava to the contact surface where precipitation took place .....". As Callaghan did not mention the location of "the chimney of quartzchlorite altered lava" the writer communicated

with him and was assured that its location is the zone discussed above.

As mentioned before, at the southwestern end of the orebody, the gossan is underlain by low grade fracture filling mineralization in hydrothermally altered lava; as the leached outcrops extend to the west up to the C.M.C. offices (Fig. 3-1) and are underlain by the above type of mineralization, most probably this area represents another zone through which mineralizing solutions had access to the surface.

7. Summary

The Skouriotissa orebody mostly lies above the water table. Most part of the orebody was protected from the supergene processes by the overlying impermeable sedimentary cover. Block faulting and erosion, however, brought to the surface the southwestern end of the orebody and has been oxidized to massive gossan probably under semi-arid climatic conditions.

Strong acidic, ferric sulphate carrying solutions, produced during the oxidation of the outcropping ore, percolated through and around the sulphide ore. As they descended they leached and sulphated the massive ore, and the intensity of the alteration decreases away from the gossan.

Near the gossan, at the lava-ore interface the leaching solutions reacted with the lava to produce a complex mineral assemblage, including native sulphur as well as iron and copper sulphates. Metals such as Ag. Au, Se, Pb, present only in trace amounts in the oxidized protore were greatly concentrated in this zone. The lavas at the interface with the ore were intensely decomposed and disintegrated.

Material from a zone, recognized in the field as hydrothermally altered lava, was further investigated in the laboratory. The alteration appears to have a marked resemblance to the alteration found in the stockwork zone in the other Cyprus sulphide deposits and the altered zone is considered to represent the possible channels through which the mineralizing constituents had access to the surface.

CHAPTER IV

THE TAMASSOS MINING AREA

A INTRODUCTION

1. Location And History

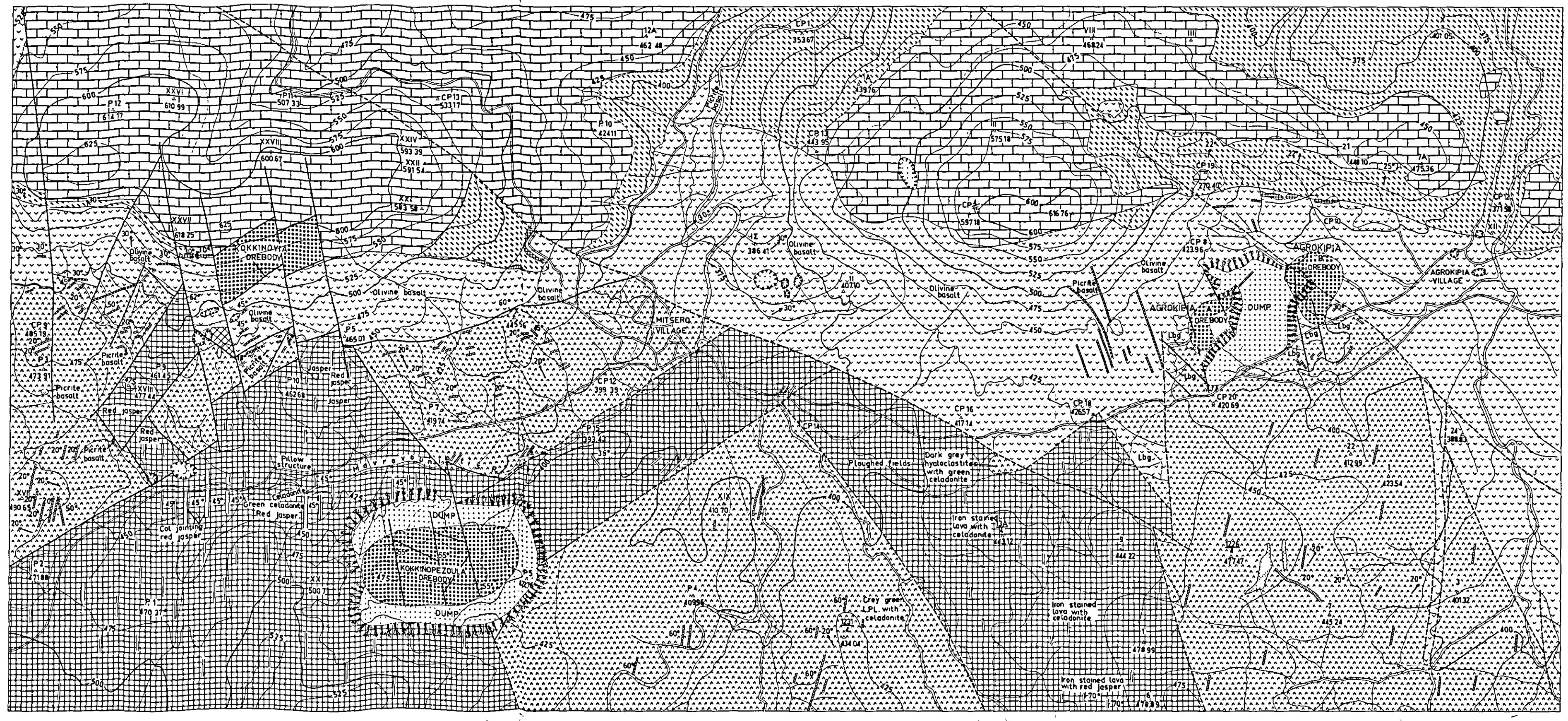
The Tamassos Mining area, measuring approximately 6 by 3 kilometres, is situated 25 road-kilometres Southwest of Nicosia. In this area are located the Kokkinopezoula, Agrokipia "A" (opencast), Agrokipia "B" (underground) and Kokkinoyia orebodies. The Tamassos Mining area covers part of the Tamassos Mining Lease held by the Hellenic Mining Company (Helco) since 1937. In this Mining Lease are included the Memi mine to the west of the Tamassos area, and the Kambia, Kapedhes, Mathiatis North and the Sha mines all situated to the east of the area (Figs. 2-1, 2-2).

The Mining Lease is named after Tamassos which was the administrative centre of one of the oldest Greek kingdoms in Cyprus. This centre was located close to the present village of Politiko, approximately halfway between this area and the Mathiatis N. mine. Reference to this Kingdom as a copper producer is found in Homer's Iliad. The large accumulations of slag scattered throughout the Tamassos area (Fig. 4-1) testify to extensive ancient mining and smelting activities. The slag compositions suggest that the orebodies in the area had been worked by Prephoenicians and Phoenicians before the Greeks as well as by the Romans after them. No mining occurred between 395 A.D. and the first decades of this century.

In the 1930's mining operations were resumed when the Hellenic Company of Chemical Products and Manures mined the gossans overlying some of the sulphide orebodies in the area for their gold and silver. In 1948 the above company changed to Hellenic Mining Company (Helco) and in 1951 the Kokkinopezoula and Agrokipia A orebodies were discovered The Agrokipia A was worked intermittently between 1952 and 1960 and the Kokkinopezoula was worked between 1953 and 1966. In 1966 the Agrokipia B orebody was discovered and part of the ore was mined between 1958 and 1964. Finally in 1962 the Kokkinoyia

GEOLOGICAL MAP OF THE TAMASOS MINING AREA

Fig. 4–1



LEGEND

SEDIMENTARY ROCKS

- Reef limestone (Upper miocene)
- Chalks, marly chalks and marls (Oligocene to middle miocene)
- Brown umbers and argillites

VOLCANIC ROCKS

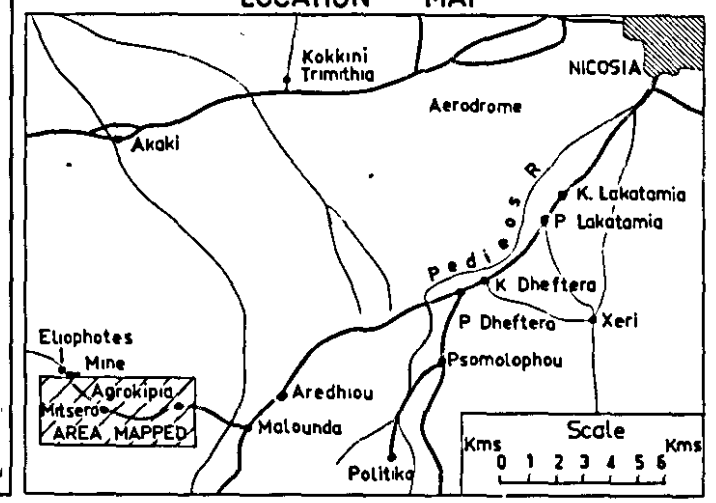
- Upper pillow lava consisting mainly of olivine basalts
- Lbg — Upper pillow lava (Limburgites)
- Grey green lower pillow lava
- Brown iron stained, silicified lavas in places with jasper and celadonite
- Argillised lava with disseminated pyrite
- Approximate underground boundary of the orebodies mainly based on borehole data
- Gossan

- Undifferentiated iron stained dykes
- Dykes feeding lower pillow lava
- Dykes feeding upper pillow lava

CONVENTIONAL SIGNS

- →24° Dip of sediments
- →24° Direction and amount of dip of pillow lava and lava flows
- Normal contact
- Gradational or inferred contact
- Major fault
- Major fault, inferred
- Ancient slag
- Dump
- Open cast pits
- Road
- Truck and path
- River
- —450— Contours in metres
- X, △ Triangulation points

LOCATION MAP



orebody was discovered and mining of its ore was expected to start by the end of 1971.

2. Previous Work and Present Investigation

Cullis and Edge (1922) gave a brief account of the geology of this area under the heading "Mitsero and Agrokipia Prospects", but from their description of the slag dumps and the gossans it is obvious that they refer only to the Kokkinoyia prospect. They suggested that it was possible that the lavas which are beneath the sedimentary cover might contain an orebody and, indeed, drilling 40 years later proved that their conclusions were correct.

The Cyprus Geological Survey refers to the mines in this area in Memoir 3 in which Bear (1960) compiled the geological information obtained from drilling and underground mining; he compiled also information about the tonnage of the different orebodies and production figures. Kattamis (1962) in a University thesis (in French) investigated the temperature of crystallization of pyrite and sphalerite in the Agrokipia and Kokkinopezoula orebodies, using the electrical conductivity of pyrite and the iron content in sphalerite as geothermometer.

Gordon-Smith (1963) in a private report to Helco and later in a Ph.D. thesis (1968) gave a general description of the geology of the mines of the area. Wolff (1964) in a Ph.D. thesis (in German) gave a general descriptive account of the sulphide mineralization in Cyprus, with special reference to the Kokkinopezoula and Agrokipia orebodies. No geological map for any of the orebodies or their environs accompanied any of the previous works, apart from the early reconnaissance map of Bear (1960).

Early in 1964 Searle and Panayiotou undertook a detailed geological mapping of the pit of the Agrokipia A on a scale of 1:500; later they extended the mapping outside the pit into the surrounding area on a scale of 1:1000. Searle and Panayiotou also carried out a detailed study of the data from drill holes, through the Agrokipia A and B orebodies. The results of their work appeared in a U.N. report, Searle (1965). Govett and Pantazis undertook detailed geochemical investigation of the

mineralized lavas exposed in the open pit of Agrokipia A, extending their sampling outside the pit into the surrounding lavas. A preliminary report on the results of this investigation was submitted by Govett (1969) but a detailed geochemical investigation of this area is still in progress (Govett personal communication).

Early in 1968 the writer undertook the mapping of the Tamassos mining area on a scale of 1:5000 using as base map a topographical map provided by Helco. The Kokkinopezoula open pit and the area around the Kokkinoyia orebody were mapped on the scales of 1:500 and 1:1000 respectively. In addition to the mapping the writer had access to relog all the boreholes through the Kokkinoyia orebody and a considerable number of drill-holes through the Agrokipia A and B orebodies. Samples of both lava and ore from a number of boreholes through the various orebodies were taken for detailed laboratory investigation. The principal geological features of the Tamassos mining area were given in a U.N. report (Searle and Constantinou 1968).

B. THE GEOLOGY OF THE TAMASSOS MINING AREA

1. General Statement

The Southern and central part of the Tamassos area is covered with volcanic rocks whereas its northern part is occupied by sedimentary rocks. The oldest exposed rocks in the area are the lavas of the Basal Group, which have a characteristic brown colour and contain a high proportion of dykes with a consistent north-south trend. The Basal Group is overlain unconformably by the Lower Pillow Lavas consisting of grey green basaltic Pillow Lavas and dykes commonly associated with green celadonite. At the contact of the Basal Group with the Lower Pillow Lavas are located the Kokkinopezoula orebody and the Mathiatis Agrokipia prospect. The latter is situated a few hundred metres south of the southeastern corner of the mapped area.

The Lower Pillow Lavas are overlain by the Upper Pillow Lavas consisting mainly of well pillowed olivine basalts and sporadic patches of limburgites and picrite basalts. The olivine basaltic Upper Pillow Lavas overlie conformably the Kokkinoyia,

Agrokipia A and Agrokipia B orebodies; Sedimentary rocks including Perapedhi umbers of Campanian age and calcareous sediments of Maestrichtian to Upper Middle Miocene age are resting unconformably on the olivine basaltic Upper Pillow Lavas.

The Tamassos area is characterized by a generally smooth and undulating topography, with elevations ranging from 400 to 500 metres. The highest points in the area occur at the Kryatis Hill and the Koroni scarp both capped with massive reef limestone and separated by a deep valley of the northerly flowing Mitsero river.

2. The Basal Group

The Basal Group tends to be concentrated at the South-western part of the area, and around the Kokkinopezoula orebody. Isolated outcrops of Basal Group also occur in other parts of the area (Fig. 4-1) in faulted contact with the Lower Pillow Lavas and in some rare cases with Upper Pillow Lavas. In this area intense faulting generally obscured the original relationship between the B.G. and the L.P.L. but beyond it, near the Mathiatis (Agrokipia) prospect, Searle (in Searle and Constantinou 1968) reported that the Lower Pillow Lavas are resting unconformably on the Basal Group.

The Basal Group contains a high proportion of dykes trending consistently to the north and dipping 45° to 65° to the east. These dykes are 2 to 8 metres wide, are highly vesicular and exhibit well-defined columnar jointing; in areas where the proportion of pillows increases the lavas contain rare green celadonite. Both the Pillow Lavas and the dykes are characterized by a widespread brown colouration brought about by oxidation of sulphide to limonite. The sulphides form veins along fractures and are also disseminated in the Pillow Lavas and dykes. Both the pillow lavas and dykes are silicified and chloritized and contain abundant red jasper in the form of thin veins and small nodules. The primary petrological characteristics of the Basal Group had been destroyed by the hydrothermal alteration and the alteration associated with the oxidation of sulphides to limonite.

3. Lower Pillow Lavas

The outcrops of Lower Pillow Lava are concentrated at the southcentral, the southeastern and the western parts of the area and around Mitsero village (Fig. 4-1). The L.P.L. are mostly in faulted contact with the B.G. and U.P.L. and only in the vicinity of the Kokkinoyia orebody they are in normal contact with olivine-basaltic U.P.L. and a plug of Picrite basalt. The Lower Pillow Lavas consist of dark grey-green basaltic lavas with irregularly sized pillows, containing abundant green celadonite. At the western part of the area they contain common amygdales of milky chalcedony and colloform opal as well as a variety of zeolites. The L.P.L. are generally unmineralized but some of its outcrops contain isolated patches of gossan.

The Lower Pillow Lavas contain a considerable number of dykes and sills. Many of these dykes have similar composition and are contemporaneous with the enclosing lavas and are commonly intersected by later olivine-basaltic and rare picrite basaltic dykes. In the Lower Pillows Lavas there are also sporadic small patches of picrite basalt (Fig. 4-1). To the west of the Kokkinoyia orebody (Fig. 4-1) olivine-basaltic dykes are traceable continuously through the L.P.L. into the overlying olivine basaltic U.P.L.; also to the south of the above orebody picrite-basaltic dykes are traceable continuously through the L.P.L. into a plug of picrite basalt with rare Pillow structure, grading upwards into olivine basaltic U.P.L.

4. Upper Pillow Lavas.

The Upper Pillow Lavas in this area form a continuous outcrop between the previously described volcanic rocks and the sedimentary rocks. These lavas have a distinctive pale pinkish-grey colouration, they generally consist of uniformly sized pillows and contain rare contemporaneous intrusions. At the base of the Upper Pillow Lavas there are sporadic patches of glassy limburgites and picrite basalt with rare pillow structure; both the limburgites and the picrite basalts are overlain by olivine basaltic pillow lavas which constitute the bulk of the Upper Pillow Lavas. In the field the U.P.L. commonly are seen to contain chocolate-brown pseudomorphs often olivine; in some

outcrops along the valley of the Mitsero river they contain fresh phenocrysts of olivine up to two centimetres long. Well developed analcite crystals filling vesicles are very common in the olivine basaltic U.P.L. of the area. In the western part of the area were found isolated beds of intervolcanic sediments half a metre thick and traceable for three metres. These beds consist of coarse grained waterlain lithic tuff with graded bedding, suggesting possible short pauses in volcanicity, during the outpouring of the U.P.L.

As mentioned before olivine basaltic Upper Pillow Lavas rest conformably on the Kokkinoyia, the Agrokipia B and part of the Agrokipia A orebodies. Drilling data indicate that low grade sulphide mineralization extends well beyond the limits of these orebodies and is covered by unmineralized olivine basaltic Upper Pillow Lavas; in some drill-holes the thickness of the U.P.L. is more than 300 metres.

5. Sedimentary Rocks

The base of the sedimentary rocks in the area is occupied by the Perapedhi Formation (Table 4-1) consisting of dark brown chocolate umber, brown argillites and sporadic brown cherts; at Kryatis Hill structureless dark brown umber overlies unconformably weathered and brecciated olivine basaltic lavas with some umber infiltrating down in the lava up to 6 metres away form the umber-lava contact. At the western part of the area around the Koroni scarp, umber outcrops are more common and are seen to overlie unconformably brecciated and weathered U.P.L. Drilling through and around the Kokkinoyia orebody indicates a lateral extension of the umber under the sedimentary cover, varying in thickness from 1 to 10 metres.

The Perapedhi Formation is overlain by the sediments of the Lefkara Group, the lower part of which consists of pink marl containing abundant lenticles of pink and green chert, whereas the upper part of this Formation consists of whitish to creamy marly chalk, and bands of marl. The chalks are very well bedded with their bedding planes generally dipping 20° to 30° to the NNE, but on the flanks of Kryatis Hill bedding attains a dip ranging between 50° and 60°; this steepening seems to be due to

Table 4-1. The stratigraphic succession in the Tamassos Mining area.

	LITHOLOGY	FORMATION	AGE	MAXIMUM THICKNESS (in metres)
SEDIMENTARY ROCKS	Reef limestone	KORONIA LIMESTONE	UPPER MIDDLE MIOCENE	55
	Marls, calcarenite, whitish and creamy marly chalk, calcareous shales	PAKHNA	MIDDLE AND LOWER MIDDLE MIOCENE	85
	Whitish to creamy marly chalk, with bands of marl, pink marl and chert.	LEFKARA GROUP	LOWER MIOCENE TO UPPER CRETACEOUS	70
	Umber, argillites	PERAPEDHI	MAESTRICHTIAN (UPPER CRETACEOUS)	10
VOLCANIC ROCKS WITH INTERCALATED MASSIVE SULPHIDE OREBODIES	Olivine basalts, basalts, picrite basalts, and limburgites	UPPER PILLOW LAVAS (U.P.L.)	PRE-MAESTRICHIAN (UPPER CRETACEOUS)	610
	KOKKINOYIA, AGROKIPIA A and B, MATHIATIS NORTH KOKKINOPEZOULA ? Massive sulphide orebodies	MINERALIZATION	CRETACEOUS ?	80-100?
	Grey-green basaltic and andesitic lavas with green celadonite	LOWER PILLOW LAVAS (L.P.L.)	?	?
	KOKKINOPEZOULA orebody? MATHIATIS (Agrokipia) prospect	MINERALIZATION	?	?
	Brown iron stained, silicified lavas in places with jasper and celadonite	UPPER PART OF BASAL GROUP ?	?	?

dragging along the Agrokipia Fault. (Searle 1965). The Lefkara Group is overlain unconformably by the Pakhna Formation, the base of which consists of calcareous shale, red marl and chalk, followed upwards by creamy marly chalk calcarenite and chalky marl. The top of the sedimentary succession in the area is occupied by the Koronia limestone; which is a massive and fragmentary reef limestone. The reef limestone at Kryatis Hill rests directly on the lavas whereas at Koroni Hill it overlies the umber of the Perapedhi Formation and the chalks of the Lefkara Group; finally at Kottaphi Hill the reef limestone rests on the upper part of the Pakhna Formation. (Mantis 1967).

6. Structure

The Tamassos mining area appears to represent a N - S uplifted block, some 7 kilometres long which is bounded by two Parallel N-S faults both beyond the mapped area. The first occurs to the east of Agrokipia village and the second to the east of Kato Moni village. The vertical displacement along these faults is about 250 and 300 metres respectively (Searle and Constantinou 1968). The general structural pattern within this area is one of block faulting, often associated with tilting, resulting in small horst and graben tectonics. The tilting of the lavas ranges between 20° and 40° and in each major fault block the dip is consistent in its direction and amount. The attitude of the pillow lavas in most cases was deduced from the direction and amount of dip of the sills existing in them. There are two prominent faults in this area running parallel and striking approximately 290° and dipping 50° to the NE (Fig, 4-1); both of them are normal faults and displace the Upper Middle Miocene sedimentary rocks. The vertical displacement along the western 290°/fault trending is 75 to 100 metres, whereas the vertical displacement along the eastern 290°/fault trending passing through the Agrokipia B orebody is about 200 metres (Searle 1965).

The fault pattern in this area in general is similar to that found in the Skouriotissa area. The major fault directions in order of relative age are 320°, 020°, 040°, 060°, 290°, and 350° with some uncertainty about the relative age of the last two fault directions. As mentioned in the previous chapter it is possible

that certain fault directions are complementary to others and therefore are of the same age.

7. Summary

The oldest exposed rock in the Tamassos area is the Basal Group which is mainly concentrated in the southern part of the area. It consists of brown hydrothermally altered and slightly mineralized lavas and dykes, the latter trending consistently to the north and dipping to the east. The Basal Group is overlain unconformably by the dark grey-green basaltic Lower Pillow Lavas with common green celadonite. At the contact of the Basal Group with the L.P.L. is located the Kokkinopezoula orebody. The Lower Pillow Lavas contain a considerable number of contemporaneous dykes which are intersected by later olivine-basaltic and picrite-basaltic dykes representing feeder dykes to the overlying Upper Pillow Lavas.

The Upper Pillow Lavas consist mainly of olivine basaltic pillow lavas with some sporadic patches of limburgite and picrite basalt at their base. In this area there are indications of short pauses in volcanicity during the accumulation of the Upper Pillow Lavas. The Upper Pillow Lavas rest conformably on the Agrokipia A and B and the Kokkinoyia orebodies as well as on low grade mineralization extending beyond the limits of the above orebodies.

The Perapedhi Formation consisting of umber, brown chert and argillites rests unconformably on the Upper Pillow Lavas and is overlain in upward succession by the calcareous sediments of the Lefkara Group and the Pakhna Formation. The top of the sedimentary succession is occupied by the Koronia reef limestone. In this area most of the contacts of the rocks of the three lava horizons are faulted. Tectonic movements represented by block faulting and tilting started after the extrusion of the Basal Group lavas and continued at least until the Upper Miocene. The structural pattern in this area is generally similar to that of the Skouriotissa mining area.

C. GEOLOGY OF THE OREBODIES OF THE TAMASSOS MINING AREA

1. General Statement

As mentioned before the Tamassos Mining Area contains the Kokkinopezoula, the Kokkinoyia and the Agrokipia A and B orebodies. These orebodies are confined to the Pillow Lavas and occur in different stratigraphic horizons in the lava sequence. Block faulting and subsequent erosion of the lavas brought to the surface the Kokkinopezoula and parts of the Agrokipia A and the Kokkinoyia orebodies. Oxidation of the exposed sulphide ore resulted in extensive and brilliantly coloured massive gossans consisting mainly of jarosite, limonite and patches of white spongy silica. The Agrokipia B orebody is hidden under a thick cover of olivine basaltic upper pillow lavas and is devoid of any surface expression.

The elevations above sea level of the top of the orebodies which occur in the Tamassos Mining Area and the Tamassos Mining Lease are given in Table 4-2. The figures of this table represent the elevations of the top of the orebodies as they were discovered and do not consider the parts of the orebodies which were oxidized to gossans or were exploited by the Ancients.

Table 4-2 Elevations of the top of the orebodies in the Tamassos Mining Lease

OREBODY	ELEVATION (in metres) above sealevel
Kokkinopezoula	435
Agrokipia A	420
Agrokipia B	295
Kokkinoyia	415
Mathiatis N	353
Memi	411
Kambia	435
Kapedhes	497
Sha (opencast)	350
Sha (underground)	325

The size of the orebodies of the Tamassos area is variable and their respective tonnage ranges from less than one million

tons to over 4 million tons. They contain massive, medium and low grade ores exhibiting a characteristic vertical zoning. In the orebodies of this area, copper and zinc exhibit a very wide variation; this variation is common also in different parts of the individual orebodies. All orebodies in this area contain unmineralized dykes similar in composition and texture to the feeder dykes of the Upper Pillow Lavas.

2. The Kokkinopezoula Orebody

a. General Information

The Kokkinopezoula orebody was exposed to the surface and its upper part was oxidized to a massive gossan 10 to 45 metres thick. The contact of the gossan with the underlying sulphide ore is sharp and horizontal (Fig. 4.3). The gossan consists of massive yellow jarosite, limonite and spongy white silica; the latter is in some cases veined with native sulphur. The gossan contained appreciable amounts of gold and silver and was partly mined during the period 1937-1940.

The existence of a pyritic orebody under the gossan was discovered in 1950-1951 after a 170 millivolts self-potential anomaly was tested by drilling. The drilling results were further tested by underground investigations and in 1953 mining of the orebody commenced by underground methods. In 1957 and after the extraction of 90,000 tons of ore the Hellenic Mining Company decided to extract the rest of the ore by opencast method. By 1966, when the mine closed, about $5\frac{1}{2}$ million tons of ore had been mined. The resultant open pit (Fig. 4.2) has an elliptical shape with an E-W long axis measuring 600 metres and a N-S short axis measuring 300 metres.

b. Geology of the Kokkinopezoula Pit

At the northeastern and southeastern parts of the pit the upper benches are occupied by unmineralized dark grey green Lower Pillow Lavas with common green celadonite. (Fig. 4-2) The outcrop of L.P.L. appears to continue under the cover of dumps beyond the pit where it is in faulted contact with a patch of Upper Pillow Lavas and with Basal Group (Fig. 4-1). At the northcentral and western part of the pit, the top benches are

GEOLOGICAL MAP OF KOKKINOPEZOULA PIT-TAMASOS MINING AREA

Fig. 4-2

LEGEND

- Gossan
- L.P.L. with celadonite Weakly altered lavas
- Low grade ore in intensely propylitized and silicified lava
- Stumped material
- Premineralization weakly altered dykes
- Premineralization intensely altered dykes
- Post mineralization fresh basaltic dykes
- 55° Strike and dip of fault
- Normal contact
- КП 4 Borehole

- 18700 Meters
- 18600
- 18500
- 18400
- 18300
- 18200 Meters
- +3700
- +3600
- +3500
- +3400 Meters

КП 21, КП 18, КП 15, КП 16, КП 19, КП 14, КП 28, КП 22, КП 17, КП 30, КП 20, КП 26, КП 17, КП 27, КП 1, КП 7, КП 9, КП 29, КП 5, КП 3, КП 23, КП 10, КП 11, КП 6, КП 8, КП 4, КП 2

350°F

PERIMETER OF PIT

SCALE 1:1500

Meters 25 0 25 50 75 100 Meters

covered with a weak gossan consisting of limonite and patches of jarosite. The gossan is underlain by pale-grey, hydrothermally altered lavas containing veins and disseminations of pyrite; the contact between the two is sharp. Sporadic patches of weak gossan also occur in the upper benches of the eastern part of the pit.

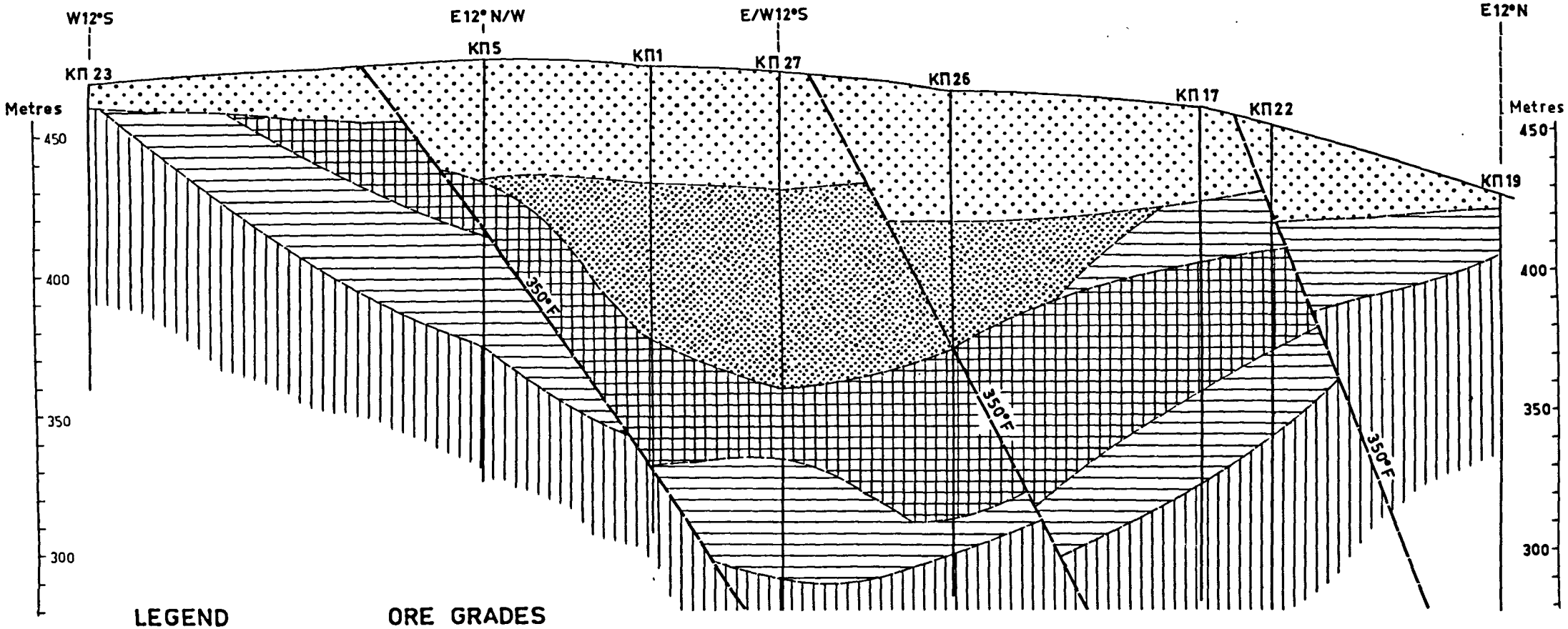
The rest of the pit is occupied by mineralized and hydrothermally brecciated lavas and lavas with preserved pillow structure. At the upper levels of the pit the mineralized lavas have a brown colour due to the oxidation of sulphide to limonite (Fig. 4-2 Plate 4-3). The brown lavas are easily distinguishable from the pale-grey unweathered mineralized lavas that occupy the larger area of the pit (Plates 4-1, 4-2, 4-3, 4-5).

Three parallel normal faults were traced in the pit; they strike about 350° and dip 55° to the east. Drilling data suggest that the vertical displacement along these faults tends to decrease towards the east (Fig. 4-3). The most eastern of these faults is traceable northwards and southwards outside the pit (Fig. 4-1); the records of the company indicate that the ore which is on the downthrown side of this fault is higher in copper. Bear (1960) suggested that this is premineralization fault and that the high copper content in the ore on its downthrown side was the result of a late copper-rich period of mineralization during which this fault acted as channelways for the mineralizing solutions. Field and drilling data, however, indicate that this fault displaces the ore, therefore it postdates the mineralization.

A characteristic feature of the pit is the high proportion of dykes found in it. Many of these dykes have a N-S trend and dip steeply to the east. These dykes are mineralized and had undergone similar hydrothermal alteration and generally contain the same amount of sulphide with the adjacent pillow lavas. X-ray diffraction analyses (Table 10-2) indicate that these dykes are intensely silicified and chloritized and contain minor amounts of pyrite and Kaolinite. Hand specimens examination shows pyrite generally decreasing from the edges of the dykes towards their centre.

The N-S trending dykes are commonly truncated by later olivine basaltic dykes with a variable trend (Fig. 4-2, Plates 4-1, 4-2, 4-3). These dykes occur at all the levels of the pit

Fig. 4-3



LEGEND

Gossan

КП7 No. of borehole

Inferred contact

Inferred fault

ORE GRADES

% S

>30

20-30

10-20

< 10

SCALE Horizontal 1:2000
Vertical 1:2000

SECTION A-A'

KOKKINOPEZOULA PIT - TAMASOS MINING AREA

Plate 4-1. Kokkinopezoula Pit looking southwest; showing mining operations and mineralized dykes (point indicated by arrow) intersecting mineralized and hydrothermally altered lavas (Pale grey). At the southern side of the pit the upper benches are occupied by slightly altered brown lavas (dark grey).

Plate 4-2. Kokkinopezoula pit looking southwest; showing the end of mining operations. The lowest part of the pit is occupied by water. Note that the colour contrast between the unmineralized basaltic dykes and the mineralized lavas is less obvious after the former had been exposed for a few years.

4.1



4.2



Plate 4-3. Kokkinopezoula pit looking northeast; upper benches occupied by slightly mineralized brown lavas (dark grey) underlain by intensely mineralized and hydrothermally altered lavas (pale grey) which are intersected by unmineralized basaltic dykes (point indicated by arrow).

Plate 4-4. Kokkinopezoula pit looking north. Slightly mineralized and hydrothermally altered lava with rare pillow structure.

Plate 4-5. Kokkinopezoula pit looking west. Brecciated lavas intensely mineralized and hydrothermally altered.

Plate 4-6. Kokkinopezoula pit. Mineralized and hydrothermally altered pillow lava. Fractures in the pillow are filled with veins of sulphide and quartz whereas the lava is impregnated with fine grained pyrite.

Plate 4-7. Kokkinopezoula. Close up photograph of a mineralized pillow showing veins of sulphide filling fractures in the pillow. Note the sharp contact between the lava and the sulphide veins (point indicated by arrow).

Plate 4-8. Kokkinopezoula pit looking south. Unmineralized basaltic dyke chilled (point indicated by arrow) against brecciated and mineralized lavas. Note the ill-defined columnar joining in the dyke.

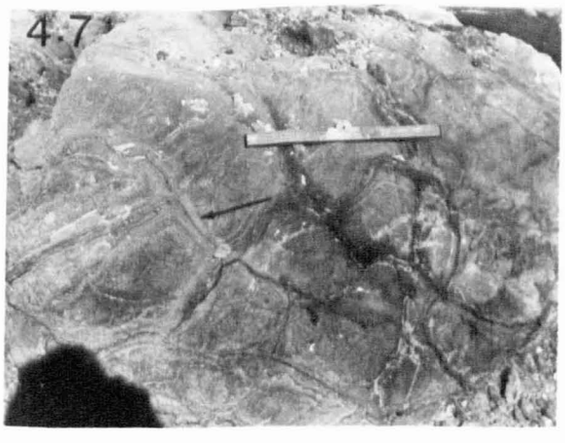
Plate 4-9. Kokkinopezoula pit looking northeast. Unmineralized basaltic dyke 10 cms. thick intersecting slightly mineralized dykes and pillow lavas. At the point indicated by arrow the dyke truncates a vein of sulphide with red jasper.

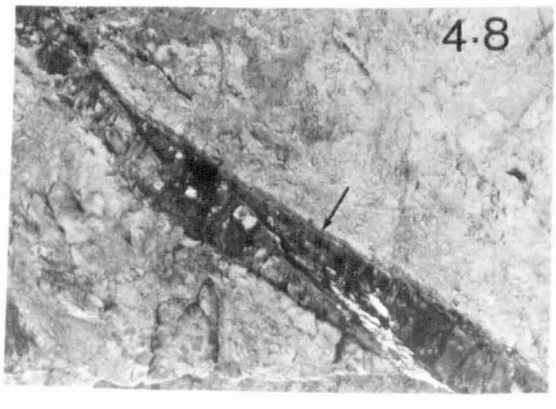

4.3


4.4


4.5


4.6


4.7


4.8


4.9

and on newly exposed bench faces their dark grey-green almost black colour contrasts markedly with the pale-grey to whitish colour of the hydrothermally altered lavas (plates 4-1, 4-3, 4-8, 4-9). After exposure these dykes alter rapidly through the action of acid surface waters produced from the oxidation of sulphides in the pit (Compare Plates 4-1 and 4-2).

These dykes have a markedly sinuous character so that very often a single intrusive has the features of a dyke and sill (Fig. 4-2 Plate 4-1). Branching, pinching and swelling along the strike is also common in these dykes. Some dykes are traceable for 30 metres and their thickness ranges between 10 cms and 2 metres. The thick dykes exhibit well defined columnar jointing which becomes less well defined as the thickness of the dykes decreases. The dykes are in sharp contact with the mineralized and hydrothermally altered lavas and dykes, and are chilled against them (Plate 4-8).

Plagioclase is the most common mineral followed in abundance by pyroxene olivine and magnetite. The pyrogenic minerals are associated with variable proportions of glassy mesostasis. The plagioclase is partly altered to montmorillonite whereas the pyroxene is partly altered to cryptocrystalline chlorite. Most of the olivine is altered to chocolate-brown amorphous iron oxides, whereas the mesostasis altered to a mixture of montmorillonite and chlorophacite X-ray diffraction analyses indicate that the products of alteration in the unmineralized olivine basaltic dykes are distinctly different (Table 10.2) from the products of hydrothermal alteration in the mineralized lavas and the N-S trending dykes.

Field relationships, mineralogical data and the type of alteration suggest that the olivine basaltic dykes postdate the emplacement of the Kokkinopezoula orebody. Optical studies of polished sections of samples of low grade ore in contact with olivine basaltic dykes indicate that these dykes produced no noticeable thermal effects on the sulphide veins and on the pyrite impregnating the lava.

c. <u>The Orebody.</u>

The Kokkinopezoula orebody has a lenticular form plunging gently to the east and its long E-W axis measures about 350 metres. The orebody consists mainly of medium to low grade pyritic ore

and only its upper part consists of massive ore with sulphur content over 40 per cent. Most of the massive ore oxidized to massive gossan and only the stockwork of the original orebody is left. The ore generally exhibits a vertical zoning and its sulphur content gradually decreases with depth (Fig. 4-3). The copper content of the ore is generally less than 0.5 per cent and, as mentioned before, only the ore on the downthrown side of the most eastern 350° trending fault contains more than 0.5 per cent copper.

In the Kokkinopezoula orebody the mineralization is mainly represented by sulphide veins which fill fractures in the lava and cement the lava fragments. The sulphide veins are 2 mms to 20 cms wide and their frequency decreases with depth. In the zones with descernible pillow structure the individual pillows are surrounded with pyrite associated with quartz and to a lesser extent with red jasper. The pillows are ramified by a network of sulphide veins which fill fractures in the pillows (Plates 4-4, 4-6, 4-7). Small proportion of sulphide is represented by fine grained pyrite disseminated in the lava fragments and pillows. The amount of disseminated pyrite diminishes away from the fractures.

The sulphide veins consist mostly of pyrite and minor amounts of chalcopyrite and sphalerite. In electrolytically etched polished sections the sulphide veins appear to consist of pyrite I and pyrite II the second being the most common. The pyrite I has a high relief and high reflectivity (Plates 4-10, 4-11) and in some cases has an internal euhedral zoned structure (Plate 4-12). The pyrite II has low relief and low reflectivity due to high microporosity (Plates 4-10, 4-11). The mutual grain boundaries of the two types of pyrite suggest that Pyrite I was invaded and replaced by pyrite II.

Red jasper is very common in the Kokkinopezoula orebody. It is found as nodules of variable size and as veins of variable width. Frequently the nodules of red jasper contain coarse cubic and pyritohendral pyrite with striated faces and prismatic quartz. In polished sections the red jasper appears to be later than pyrite. Remnants of intensely corroded pyrite are common in the jasper

Plate 4-10. Kokkinopezoula ore. Pyrite I with high relief and reflectivity replaced by Pyrite II with lower relief and reflectivity; note that Pyrite II has higher microporosity.

PPL scale bar = 1.2 mm

Plate 4-11. Kokkinopezoula ore. Large crystal of euhedral Pyrite I partly replaced by Pyrite II.

PPL scale bar = 1.2 mm

Plate 4-12. Kokkinopezoula ore. Electrolytically etched Pyrite I with euhedral zoned structure.

PPL scale bar = 1.2 mm

Plate 4-13. Kokkinopezoula ore. Remnants of intensely corroded pyrite embedded in red jasper.

PPL scale bar = 1 mm

Plate 4-14. Kokkinopezoula ore. Polished section etched with HF, showing red jasper containing remnants of corroded pyrite. Note that the euhedral and subhedral quartz contains no pyrite.

PPL scale bar = 1 mm

Plate 4-15. Agrokipia A ore. Contact of hydrothermally altered lava (black) impregnated with Pyrite (white), with vein of quartz (grey) and pyrite (white).

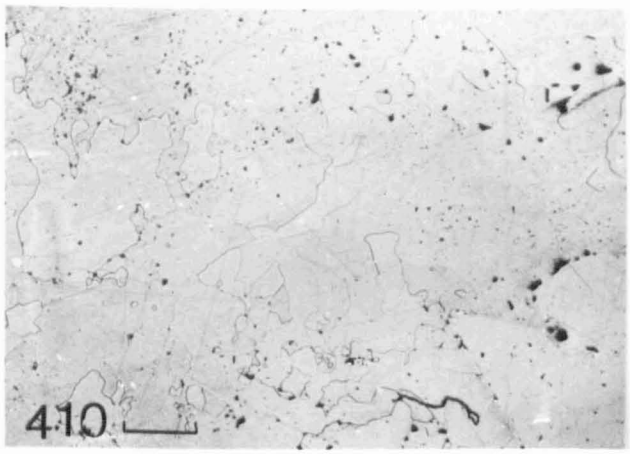
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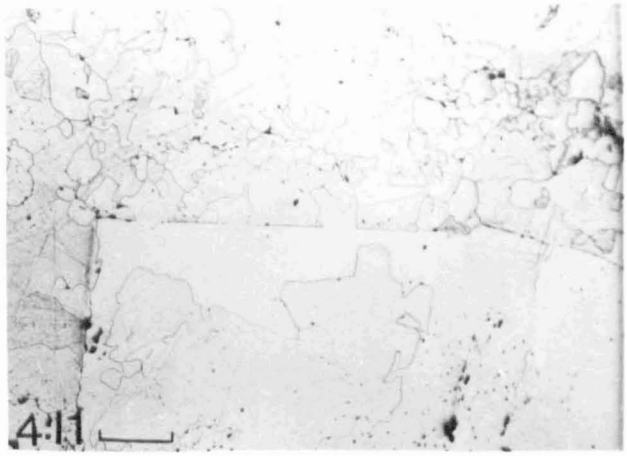
Plate 4-16. Agrokipia ore. Contact of mineralized lava (left top corner) with a vein of massive sulphide filling fracture in the lava.

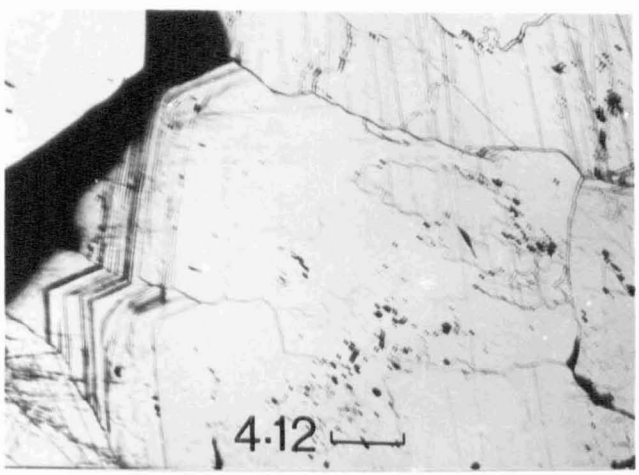
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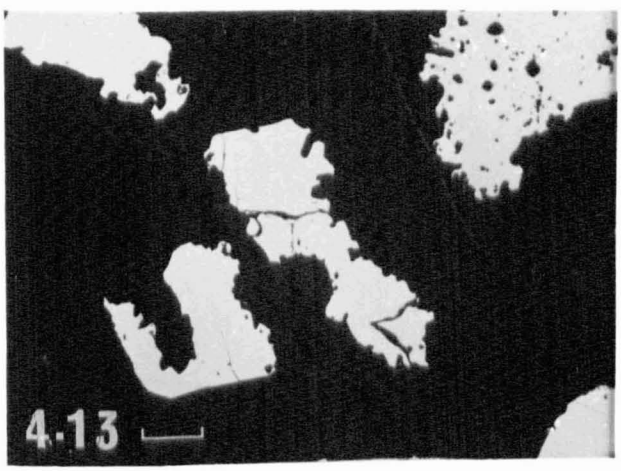
Plate 4-17. Agrokipia A ore. Electrolytically etched polished section showing the centre of a massive sulphide vein consisting mostly of zoned and unzoned Pyrite I.

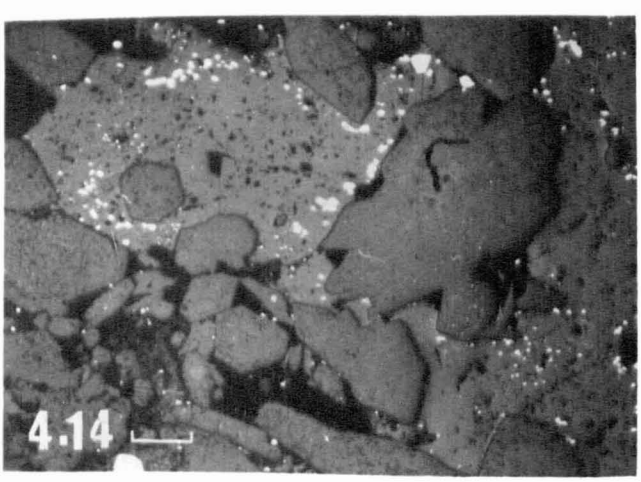
PPL scale bar = 480 microns

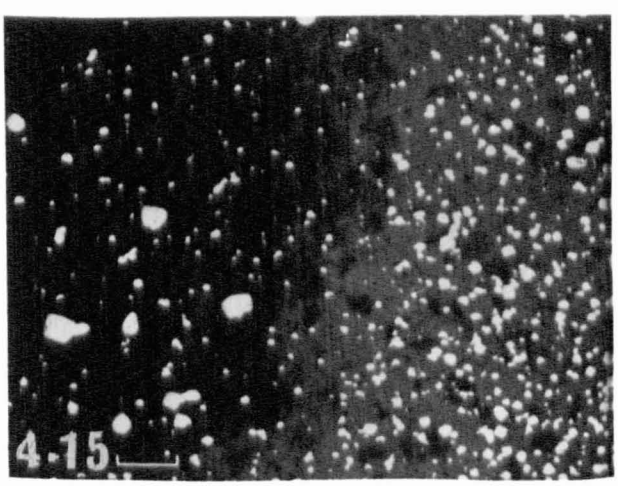

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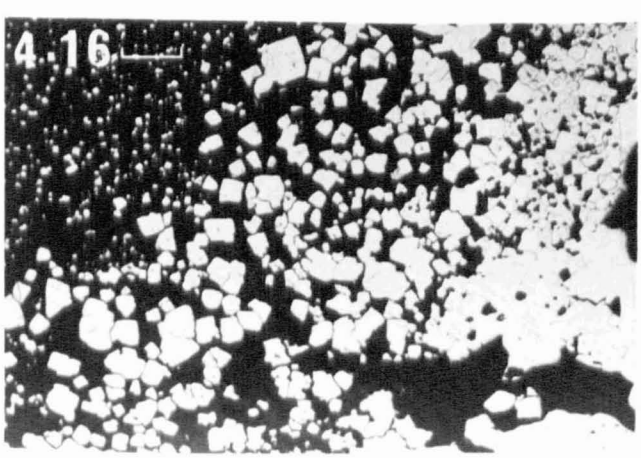

4.11


4.12


4.13


4.14


4.15


4.16


4.17

(Plate 4-13). In polished sections etched with HF the jasper, in addition to the remnant pyrite, contains subhedral to euhedral grains of quartz devoid of any pyrite inclusions (Plate 4-14).

The sulphide mineralization was associated with extensive hydrothermal alteration of the host lavas and dykes. This alteration consists of silicification, chloritization and to a lesser extent argillization. Quartz generally replaces the plagioclase and pyroxene of the mineralized lava. Chlorite is restricted to the glassy mesostasis and is intimately mixed with chalcedony. Epidote is erratically distributed and tends to increase at the deeper parts of the pit. X-ray diffraction analyses of hydrothermally altered lava and dyke indicate the presence of minor amount of illite whereas montmorillonite was not detected (Table 10-2).

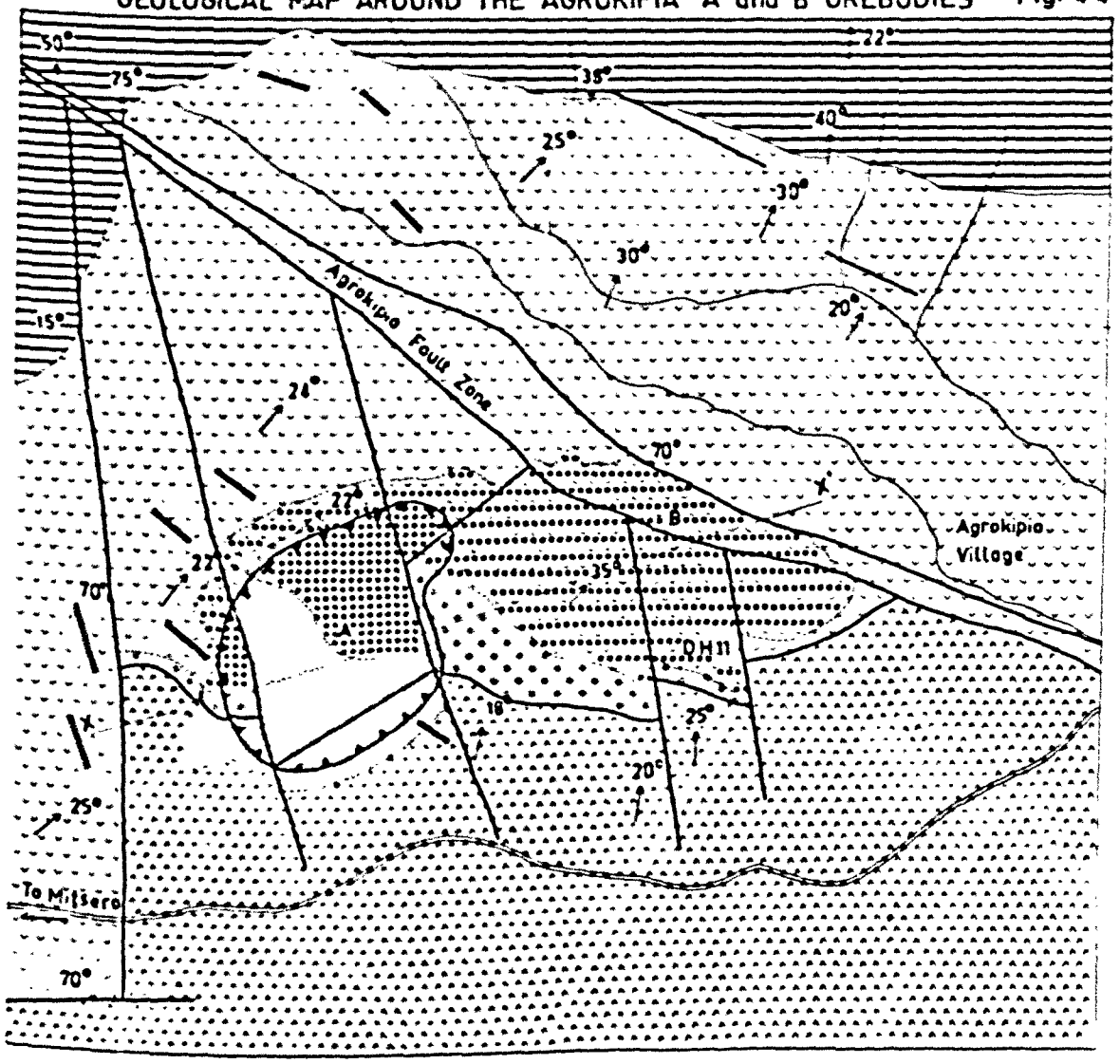
3. The Agrokipia A Orebody

(a) General Geology of the Open Pit.

The Agrokipia A orebody appears to occur in an uplifted block, bounded by two parallel 350° trending faults dipping steeply in opposite directions (Fig. 4-4). As a result of this uplift and subsequent erosion of the lavas which most likely covered originally the orebody, the southern part of the ore was exposed and oxidized to gossan; the gossan was firstly mined in 1936 for its gold and silver content. The rest of the gossan was removed after 1952 during stripping operations carried out as part of the pit development. Remnant gossan overlying low grade ore and containing an ancient gallery (Plate 4-29) is still exposed at the south southeastern part of the pit (Fig. 4-4).

The vertical displacement of the western 350° trending fault is about 35 metres Searle (1965). The downthrown side of this fault is occupied by Lower Pillow Lavas which cover the western part of the pit. The L.P.L. consist of pillows with very irregular size and shape; the pillows range from elongated and flattened sausage-like to rounded "lava balls" 4 metres in diameter and exhibit radiating fracturing (Plates 4-18, 4-19). The lavas are highly vesicular; most vesicles are empty but some of them are filled with celadonite and zeolites.

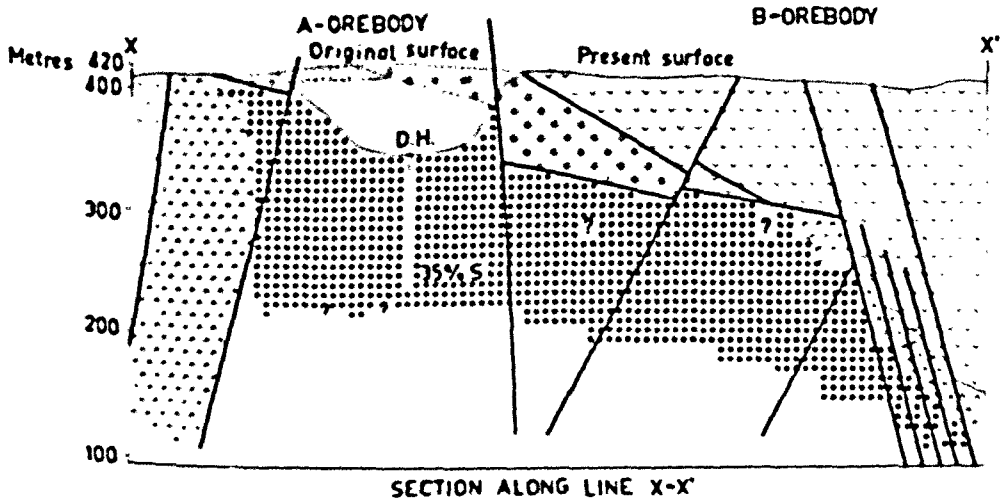
GEOLOGICAL MAP AROUND THE AGROKIPIA "A" and "B" OREBODIES Fig. 4-4



Sediments
Upper pillow lavas
Basalt flow at base of UPL
Lower pillow lavas
Cossan
Mineralization bellow lava cover
Exposed Mineralization
Dykes
Opencast pit

SCALE
Metres 100 0 100 200 Metres

Fig. 4-4a



SECTION ALONG LINE X-X'

After Searle,(in Searle and Constantinou 1968)

Plate 4-18. Agrokipia pit looking west. Large rounded unmineralized Lower Pillow Lavas with characteristic radiating fracturing, overlain by elongated and sausage-like pillows.

Plate 4-19. Agrokipia pit looking west. Unmineralized Lower Pillow Lavas with radiating fracturing overlain by a sill with columnar joining. Above the hammer is a patch of jarosite (white) produced by the oxidation of secondary pyrite.

Plate 4-20. Agrokipia pit looking north. Sharp contact of medium grade ore partly oxidized with unmineralized olivine basaltic Upper Pillow Lavas. The base of U.P.L. is occupied by a flow (point indicated by arrow) overlain by U.P.L. with well developed pillow structure.



4.18



4.19



4.20

The lavas are generally unmineralized but some veins or pockets of massive friable pyrite, partly oxidized to jarosite, were observed around the pillows (Plate 4-19). This was considered by Searle (in Searle and Constantinou 1968) as representing a mineralization - hostrock contact relationship with the mineralization projecting into the host rock. However the Lower Pillow Lavas in contact with the ore were brought to their present position by faulting after the emplacement of the orebody and are not hydrothermally altered. These sporadic pockets of massive pyrite are not interconnected and probably bear no relation to the emplacement of the main orebody.

At the northern part of the pit the lower benches are occupied by brecciated and hydrothermally altered lavas which contain small amounts of sulphide. The mineralized brecciated lava is mixed with limonite and jarosite and is overlain conformably by unmineralized olivine basaltic Upper Pillow Lavas. These lavas occupy the upper benches of the pit and their base consists of an olivine basaltic flow being in sharp contact with the underlying mineralized lava (Plate 4-20).

At the northwestern part of the pit the olivine basaltic Upper Pillow Lavas rest with a slight discordance on grey-green Lower Pillow Lavas. Along this contact, outside the pit, there is an intercalated layer of ochre containing 0.8 per cent copper; the thickness of the ochreous layer increases towards the pit, (Searle (1965). This ochreous layer probably is the equivalent of a sedimentary horizon recently exposed at the northeastern part of the pit. This horizon fills irregularities on the top of the mineralized lavas and is overlain by an unmineralized olivine basaltic flow about 5 metres thick.

Two unmineralized basaltic dykes outcrop in the ore zone; they have been reported by all the previous geologists who have studied the Agrokipia A orebody. At the southern part of the pit, one of these dykes is traceable through the ore zone into the gossan. Since exposure to the surface these dykes have undergone extensive supergene alteration by the acid surface waters.

(b) The Orebody

The northern part of the Agrokipia A orebody was covered with unmineralized olivine basaltic Upper Pillow Lavas. Drilling data indicate that the lava cover is 30 metres thick. The ore below this cover contains 30 per cent sulphur and 1.5 per cent copper. Sulphur and copper decrease gradually with depth and at 90 metres below the top of the orebody the sulphar and copper content is 10 per cent and 0.4per cent respectively. Drilling data also suggest that the upper few metres of the ore which was covered with gossan was rich in copper.

The copper-rich northern part of the orebody is only 65.000 tons; the main orebody is 700.000 tons and contain less than 30 per cent sulphur and less than 0.5 per cent copper. About 300.000 tons of ore were extracted during the period 1952-1960; Mining operations stopped at the 391 metre level where the sulphur content of the ore drops to less than 20 per cent. In the literature concerned with this orebody, the northern copper-rich part is thought to be a separate orebody. Thus, Bear (1960, 1963), reports on .. "two shallowly emplaced lenses in the finely vesicular basalts of the Upper Pillow Lavas..." Gordon Smith (1963) also reports on two orebodies separated by barren rock. Recent detailed mapping however suggests that the copper-rich ore is part of the main orebody, (Searle and Constantinou '1968).

The Agrokipia A orebody appears to represent the stockwork zone of an orebody, the massive top part of which has been oxidized and removed. The upper part of the stockwork consists of brecciated and mineralized lava; the lava fragments are cemented with sulphide associated with quartz (Plates 4-21, 4-22) and are impregnated with fine grained pyrite.

The lower part of the stockwork zone consists of mineralized pillow lavas. In the mineralized pillow lavas, veins of sulphide and quartz are replacing the glassy selvages of the unmineralized pillow lavas (compare Plate 4-24 with Plates 4-25 and 4-26). The fractures in the pillows are also filled with sulphides and quartz (Plates 4-23, 4-25, 4-26, 4-27). During the fracture filling process, the sulphide veins grow symmetrically from both sides of

Plate 4-21. Agrokipia Pit looking south. Brecciated and mineralized lavas occupying the upper benches at the southern side of the pit.

Plate 4-22. Agrokipia pit looking south. Close up photograph showing brecciated and mineralized lavas. The lava fragments vary greatly in size and form and are cemented with sulphide and silica.

Plate 4-23. Centre of the Agrokipia pit. Mineralized and hydrothermally altered lavas with well preserved pillow structure.

Plate 4-24. Typical unmineralized Lower Pillow Lavas in the Tamassos Mining Area.

Plates 4-25, 4-26. Centre of the Agrokipia pit. Mineralized and hydrothermally altered lavas with well preserved pillow structure. The pillows are surrounded with massive sulphide, and the fractures in the pillows are filled with veins of sulphide.

Plate 4-27. Close up photograph of the area shown in plate 4-26. Points indicated by the pen and arrow show cavity filling massive sulphide.

Plate 4-28. Centre of Agrokipia pit. Contact between brecciated and mineralized lavas (right) and mineralized lavas with well preserved pillow structure (centre and left).

Plate 4-29. Agrokipia pit looking east. Ancient gallery driven in gossan.

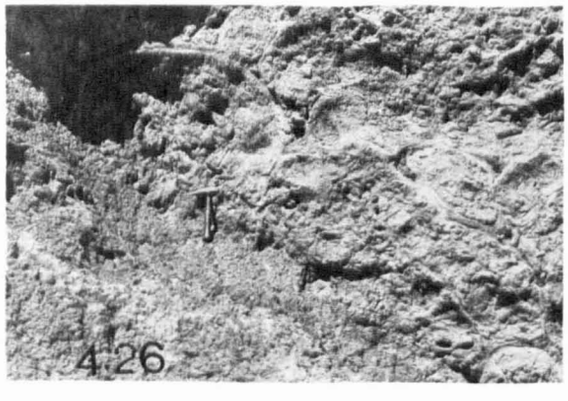

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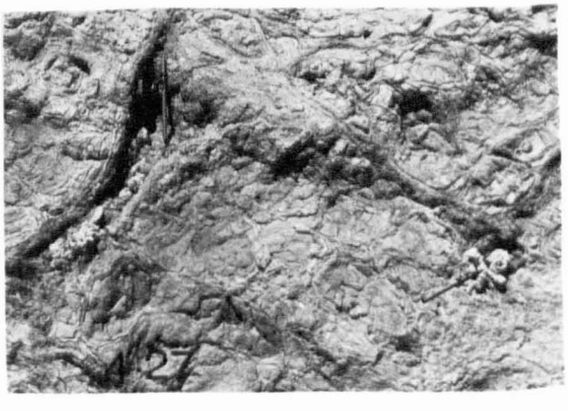

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4.28

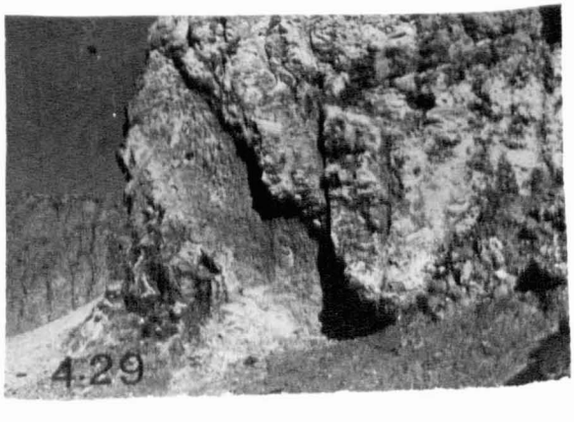

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4.27


4.28


4.29

the fracture. The grain size of pyrite increases inwards, in some cases abruptly producing crustification banding in a symmetrical manner. In the veins comb textures are common, and frequently at the centre of the veins where crystal ends meet, an interdigitated vaggy zone is formed. Since the opening of the pit the sulphide in the veins has been partly oxidized to limonite and/or jarosite. The oxidation took place symmetrically from the sides of the veins towards their centre (Plates 4-25 and 4-26).

In polished sections the sulphide veins around the pillows are seen to consist mostly of pyrite and minor amounts of chalcopyrite, sphalerite and pyrrhotite. Most of the pyrite is represented by euhedral pyrite I with or without internal growth zoning (Plates 4-17, 4-30). The Pyrite I is truncated by anhedral pyrite II characterized by low relief and low reflectivity (Plates 4-30, 4-31). The sulphide veins filling fractures in the pillows consist of euhedral and anhedral pyrite mixed with quartz (Plate 4-16). Outside the fractures the amount of pyrite decreases abruptly (Plate 4-16) and in the mineralized lava only fine anhedral disseminated pyrite occurs (Plate 4-15).

Chalcopyrite is rare in the veins and mostly occurs in cavities in pyrite (Plate 4-31) or forms minute inclusions in pyrite. Traces of pyrrhotite and sphalerite fill also cavities in pyrite.

The mineralized brecciated or pillowed lavas are hydrothermally altered. They had been silicified and chloritized and to a lesser extent argillized.

The distribution of the trace elements, Copper, Zinc, Nickel and Cobalt in the mineralized lavas was investigated by Govett and Pantazis. Figure 4-5c illustrates the distribution of the above elements along a continuous traverse in mineralized lavas (for location see fig. 4-4) and indicates that: (i) Zinc content is very low and is consistently lower than copper. It is probable that the very low zinc content resulted from leaching of this element by the acid surface water after the opening of the pit. (ii) Copper increases substantially towards the northern end of the traverse. (iii) Cobalt also increases towards the northern end of the traverse whereas nickel decreases towards this direction.

Plate 4-30. Agrokipia A ore. Centre of a sulphide vein filling fracture in mineralized pillow lava, consisting mostly of zoned and unzoned pyrite I, partly replaced by pyrite II (specimen electrolytically etched).

PPL scale bar = 1.6 mm

Plate 4-31. As in Plate 4-30. Note chalcopyrite (grey) in a large cavity in the centre of the Plate.

PPL scale bar = 1.6 mm

Plate 4-32. Agrokipia B ore. Unzoned pyrite I (white) and chalcopyrite (grey) which contains remnants of corroded pyrite. Note the considerable amount of cavities in the pyrite.

PPL scale bar = 1.2 mm

Plate 4-33. Agrokipia B ore. Polished section of a drillhole sample showing unzoned pyrite I cemented with chalcopyrite (cp) or sphalerite (Sl).

PPL scale bar = 480 microns

Plate 4-34. Agrokipia B ore. Massive chalcopyrite intersected by a vein of intensely fragmented chalcopyrite. A cavity in chalcopyrite is filled with sphalerite (Sl).

PPL scale bar = 516 microns

Plate 4-35. Agrokipia B ore. Sphalerite (grey) filling a cavity in chalcopyrite (white) and associated with tennantite (tnt) and bornite (bn). Fragmented chalcopyrite (top left) is partly altered to digenite (nd).

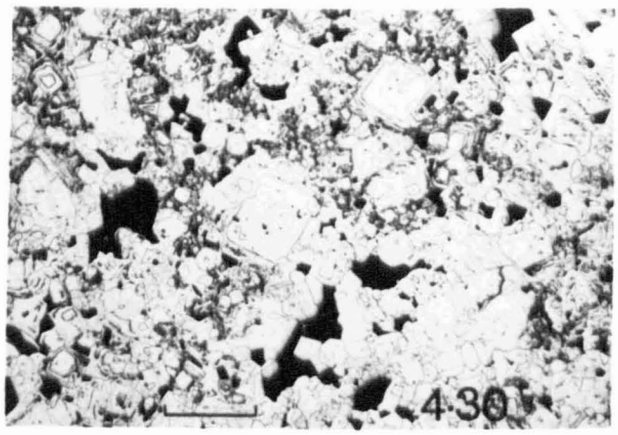
PPL scale bar = 100 microns

Plate 4-36. Agrokipia B ore. Late prismatic and bladed chalcopyrite grown on bornite (grey) which rims earlier chalcopyrite.

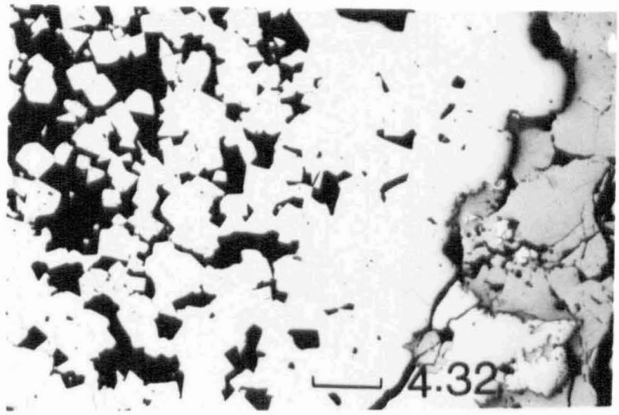
PPL scale bar = 187 microns

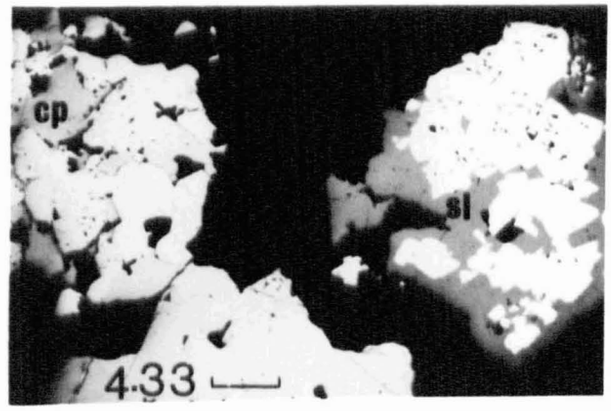
Plate 4-37. Agrokipia B ore. Late prismatic chalcopyrite grown on sphalerite which fills cavities in pyrite (Py).

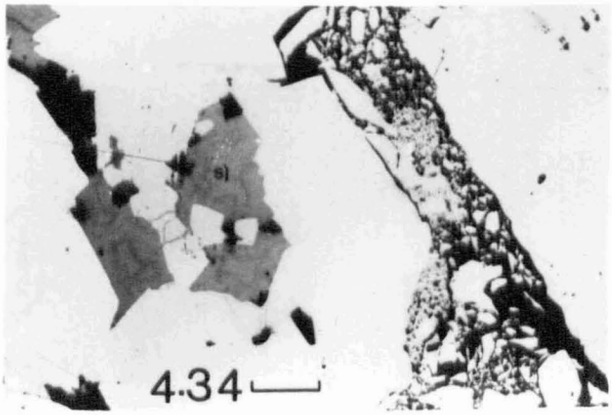
PPL scale bar = 180 microns

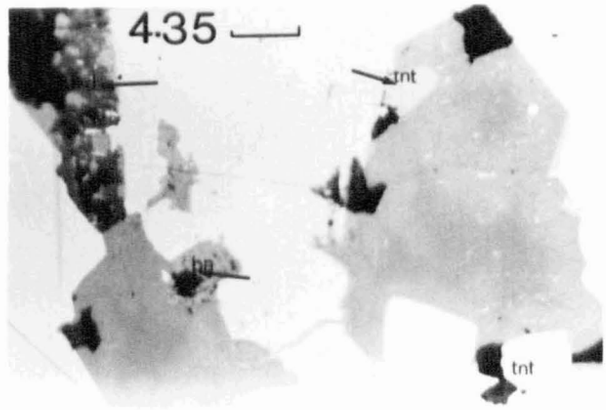

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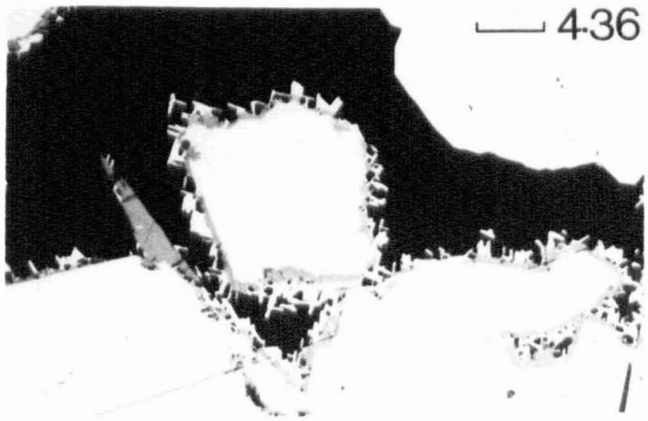

4.31

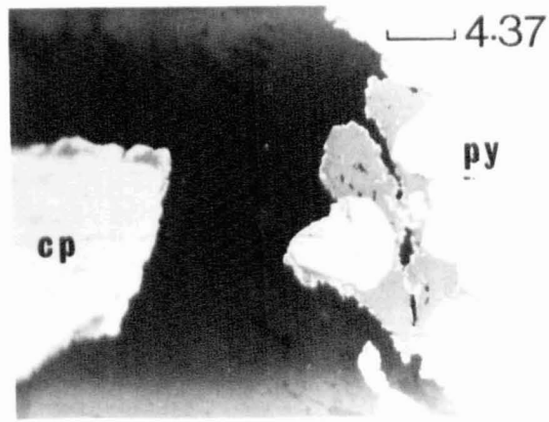

4.32


cp
sl
4.33


sl
4.34


4.35
tnt
tnt


4.36


4.37
py
cp

4. The Agrokipia B Orebody

(a) General Information

The Agrokipia B orebody is hidden under a cover of unmineralized olivine basaltic Upper Pillow Lavas 100 to 220 metres thick. The orebody was discovered in 1956 by drilling on a gravity anomaly. The mining records of the Hellenic Mining Company indicate that the ore reserves in this orebody are approximately $4\frac{1}{2}$ million tons. The massive ore tends to concentrate at the northern margins of the orebody; it is about 500.000 tons and it is high in copper and zinc. Part of the high grade ore was mined by underground methods during the period 1958 — 1964. The rest of the ore is of low grade and contains trace amounts of copper and zinc.

No underground map of the Agrokipia B orebody is available. The study of this orebody was based mainly on information obtained from the logging of the drill holes through it and on limited information from notes on the underground mine plans. Samples from a selected drill hole were used for detailed laboratory investigations. This drill hole in downward succession intersects olivine basaltic U.P.L. 140 metres thick and massive and low grade ore 154 metres thick (Fig. 5.4[a]). In addition to the drill hole samples hand specimens of ore, collected by Searle, were used for detailed investigation of the ore mineralogy.

The Agrokipia B orebody plunges to the north (Fig. 4.5c) and its outline resembles to an assymetrical pyramid in which two opposing sides are almost vertical. Searle (in Searle and Constantinou 1968) noting the exceptionally high zinc content in some parts of this orebody suggested that it was emplaced during an early period of zinc-rich mineralization which post-dates the extrusion of the B.G. and antedates the extrusion of the L.P.L.; thus the orebody is overlain by Lower Pillow Lavas (Fig. 4.4a). Detailed study of the drill hole samples indicates that this orebody is covered with olivine basaltic Upper Pillow Lavas. The contact of the ore with the overlying lavas is sharp and barren lava is succeeded by massive ore containing over 40 percent sulphur over a distance of several centimetres (Fig. 4.5a). X-ray diffraction analysis of lava in contact with massive ore from the drill hole shown in Fig. 4.5a indicates that the mineral assemblage of this lava

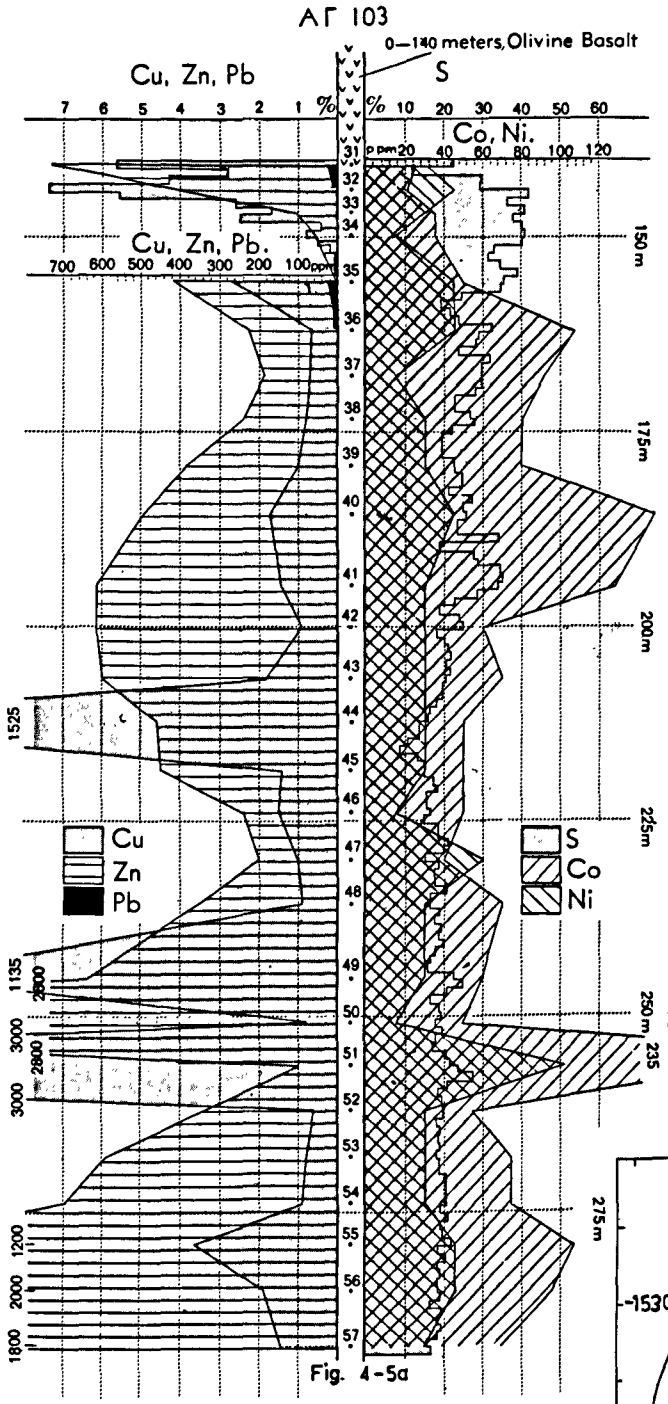


Fig. 4-5a

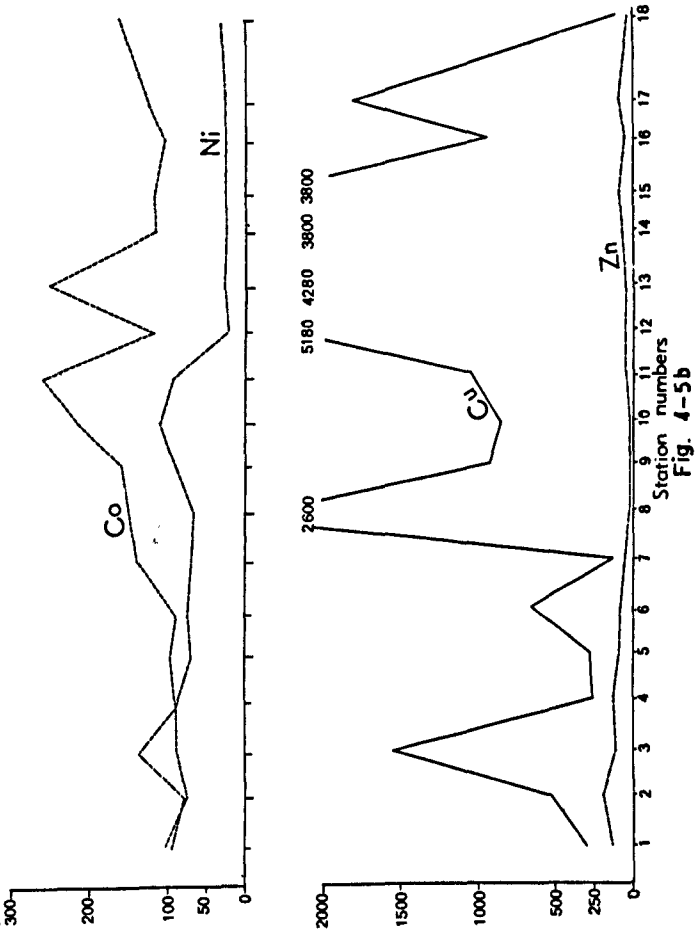


Fig. 4-5b

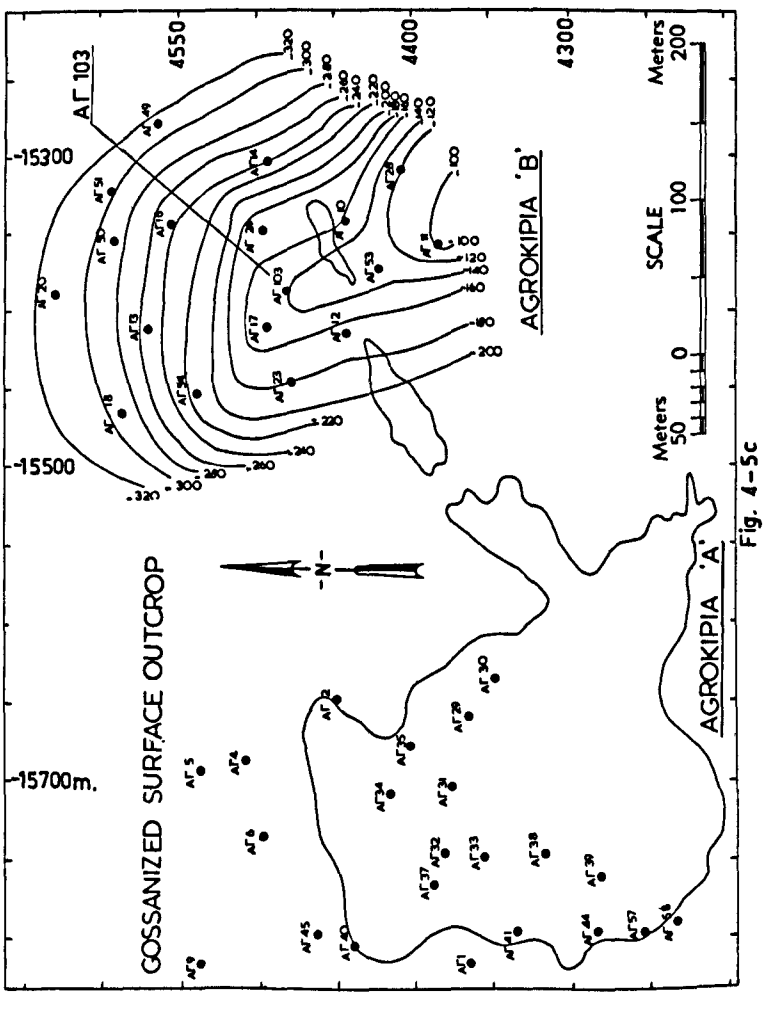


Fig. 4-5c

Fig. 4-5a. Major and trace element distribution along the (АГ 103) borehole (Agr."B") intersecting massive and low grade sulphide ore. (Sulphur and part of copper analyses every one meter.)

Fig. 4-5b. Trace element distribution along the traverse A-A (Fig. 4.4) in the stockwork zone at the Agrokipia "A" open pit. (After Govett 1969)

Fig. 4-5c. Location map showing:
(a) The relative position of boreholes over the "A" and "B" orebodies
(b) The subsurface contours in meters of the top of the "B" orebody (After Searle 1965)

is identical with the mineral assemblage of the unmineralized U.P.L. (Table 10.2). In the private files of the Hellenic Mining Company drillhole logs record "sheets of barren rock" in the orebody. The sheets of barren rock most probably represent unmineralized dykes.

The Agrokipia B orebody lies in the Agrokipia Fault zone (Fig. 4.4) probably represents a downthrown block of the Agrokipia A orebody. The Agrokipia A and B orebodies probably are connected in depth by a continuous zone of medium to low grade ore (Fig. 4.4a). Searle (1965) reports that during his underground vist to the mine, the most noticeable feature in this orebody was the intense faulting and the sudden change from lava to ore to propylite and back again. He also noted that lense shaped xenoliths of chalcopyrite and sphalerite with some Pyrite ore embedded in a sheared matrix of propylite with disseminated pyrite.

(b) Major And Minor Element Chemistry Of The Ore

A marked characteristic of this orebody is the high concentration of copper and zinc in the upper parts of the massive ore. A complete chemical analysis of massive high grade ore (Table 4.3) indicates that in addition to the high concentration of copper and zinc. The trace elements lead and cadmium are highly concentrated too compared with other sulphide orebodies in Cyprus. Chemical data compiled by Searle (in Searle and Constantinou 1968) indicate that copper and zinc exhibit a very wide variation not only in the various levels but also in different parts of a single level. (Table 4.4).

A series of samples taken from the drillhole AC.103 were analysed with Atomic Absorption Spectrophotometer by the Chemical Laboratory of the Cyprus Geological Survey for copper, zinc, nickel and cobalt. The results of these analyses are shown in fig. 4.5a and indicate that:-

(i) Copper is highly concentrated at the upper 9 metres of the massive ore and decreases abruptly in the lower part of the massive ore. The copper in the stockwork zone is present only in trace amounts.

Table 4.3. Chemical analyses of ore from the Agrokipia A (1) Kokkinopezoula (2) Akrokipia B (3) and Kokkinoyia (4) Orebodies.

	1*	2	3	4
	%	%	%	%
S	46.5	46.70	43.35	38.47
Fe	42.0	41.50	32.07	35.66
Cu	0.95	0.16	5.25	3.14
Pb	0.10	0.10	0.22	0.06
Zn	0.67	0.10	11.77	nil
Cd	nd	nd	0.05	
As	0.01	0.01	0.055	0.015
Cr	nd	nd		
Co	nd		nil	nil
Ni	nd		0.01	nil
Mn	nd		0.003	
Al_2O_3	1.50	1.50	1.14	6.71
CaO	0.30	0.10		0.56
MgO	0.10	0.10	0.39	2.35
Sn	"	"	0.001	
Sb	"	"	0.02	—
Bi	"	"	0.005	
Sc	"	nd	0.003	0.014
SiO_2	7.9	9.7	2.62	11.04
Ti	nd	nd	0.05	
P	0.10	0.01	0.005	—
F	0.005	0.005		—
Cl	0.006	0.004	0.04	—
Au**	(0.20)	Absent	0.0001.3	
Ag**	(13.0)	(.0)	0.0068.3	.40

* Data for (1) and (2) compiled from Wolff (1964)
Data for (2) and (3) provided by Hellenic Mining Company
** Au and Ag in gr/t

Table 4.4. Maximum and minimum assay values from selected levels of B-orebody. After Searle (in Searle and Constantinou (1968)).

Level	Size of orebody	Assay values				Number of samples	Remarks
		Per cent	S%	Cu%	Zn%		
246	25x15 metres	Max.	47	14.5	42.2	8	Lense
		Min.	33	0.5	Nil		
240	15x10 "	Max.	52	7.6	12.5	10	Two pockets
		Min.	41	1.0	Nil	2	
	12x5 "	Max.	41	5.1	53.2	2	
		Min.	33	1.8	Nil		
230	18x8 "	Max.	46	1.4	2.13	5	Lense
		Min.	39	0.1	Nil		
170	25x8 "	Max.	46	13.3	14.2	4	Lense
		Min.	42	2.4	5.0		
160	15x5 "	Max.	50	1.6	1.2	1	Small pocket
150	65x15 "	Max	51	10.4	Nil	19	Faulted lenses
		Min.	42	0.7	Nil		
132	15x5 "	Max.	50	9.6	21.2	5	Mixed sulphide lense
		Min.	39	3.0	1.9		

(ii) Zinc generally has a similar pattern of distribution with copper. In the stockwork, zinc is generally higher than copper and the ratio Cu:Zn is less than one.

(iii) Lead is concentrated at the top of the massive high grade ore and decreases abruptly in the massive pyritic ore. In the stockwork zone lead is persistently less than 25 ppm.

(iv) Cobalt tends to decrease in the massive copper-and rich-rich ore, whereas it increases considerably in the pyritic massive ore and in the stockwork zone.

(v) Nickel in the upper part of the massive ore tends to be higher than cobalt, whereas in the pyritic massive ore and in the stockwork zone it is considerably less than cobalt.

(c) Ore Mineralogy of the Massive Ore

The upper part of the massive ore which is rich in copper and zinc consists mainly of variable proportions of pyrite chalcopyrite and sphalerite and small amounts of bornite. Small amounts of chalcocite and traces of digenite, covellite tennantite and galena are also present. The last two minerals were not observed in the other investigated orebodies. The pyritic massive ore consists mostly of pyrite and minor amounts of chalcopyrite and sphalerite.

Euhedral Pyrite I, characterized by high reflectivity and high relief is the most common type of pyrite in the massive ore. It is generally unzoned (Plate 4.32) but in some cases pyrite I with internal zoned structure was observed (Plate 4.39). In the drillhole shown in figure 4.5a in the upper 6 metres of the ore there is rare collomorphic pyrite; this pyrite is characterized by low reflectivity and low relief and it replaces the Pyrite I. The pyrite aggregates contain many cavities, part of which is filled with quartz (Plate 4.38) chalcopyrite, and sphalerite (Plates 4.32, 4.33).

Most of the Chalcopyrite in this orebody occurs mainly as massive chalcopyrite or as interstitial material to other minerals. The massive chalcopyrite often contains isolated crystals of unzoned pyrite I and aggregates of sphalerite (Plates 4.34, 4.35). Not infrequently in the massive chalcopyrite there are veins of intensely fragmented and corroded chalcopyrite (Plate 4.34). The

Plate 4-38. Agrokipia B ore. Remnants of corroded unzoned pyrite I (white) cemented with quartz (dark grey) chalcopyrite (cp) sphalerite (grey) and bornite (point indicated by arrow). Note that sphalerite rims the chalcopyrite.

PPL scale bar = 1.2 mm

Plate 4-39. Agrokipia B ore. Zoned pyrite I with some contacts of growth zones marked with sphalerite (grey).

PPL scale bar = 250 microns

Plate 4-40. Agrokipia B ore. Intergrowths of chalcopyrite (cp) in sphalerite. Rare galena (gn) is associated with sphalerite.

PPL scale bar = 180 microns

Plate 4-41. Kokkinoyia ore. Remnants of unzoned pyrite I cemented with chalcopyrite (grey).

PPL scale bar = 1.6 mm

Plate 4-42. Kokkinoyia ore. Intensely corroded pyrite (white) cemented with chalcopyrite (grey).

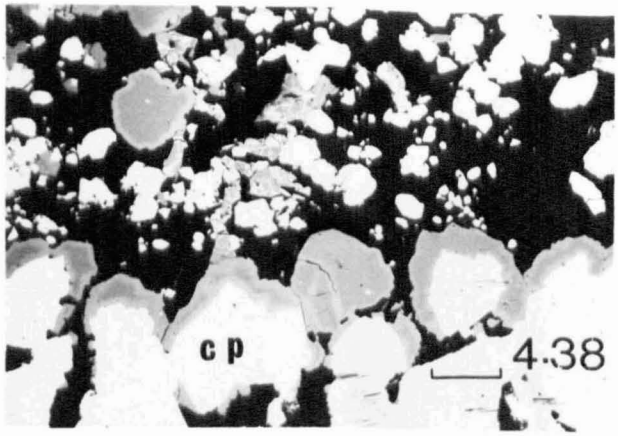
PPL scale bar = 1.2 mm

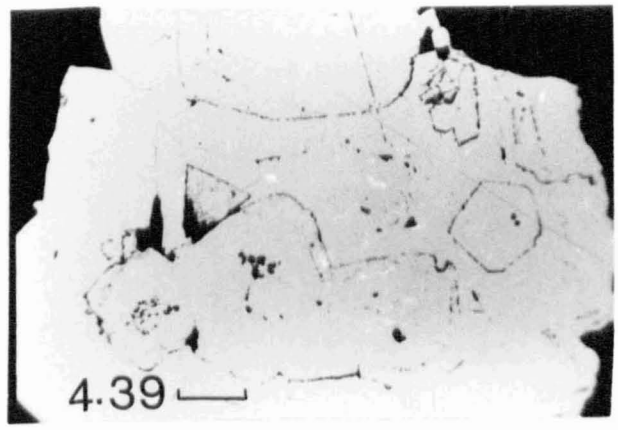
Plate 4-43. Kokkinoyia ore. Chalcopyrite (grey) filling part of the cavities in pyrite I.

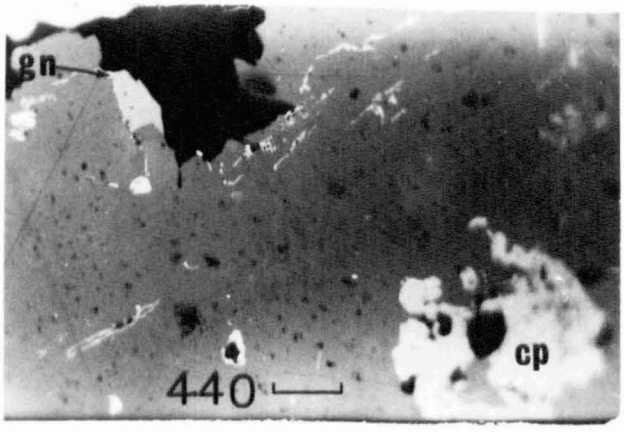
PPL scale bar = 1.6 mm

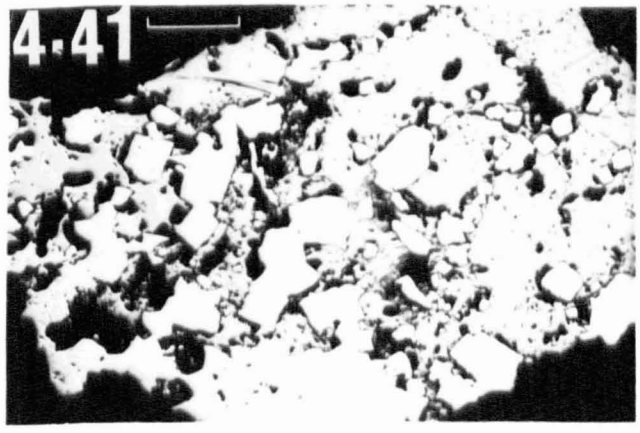
Plates 4-44, 4-45. Vryoidal (fungus like) textures produced by extreme corrosion of pyrite. Some of the cavities are filled with chalcopyrite (grey).

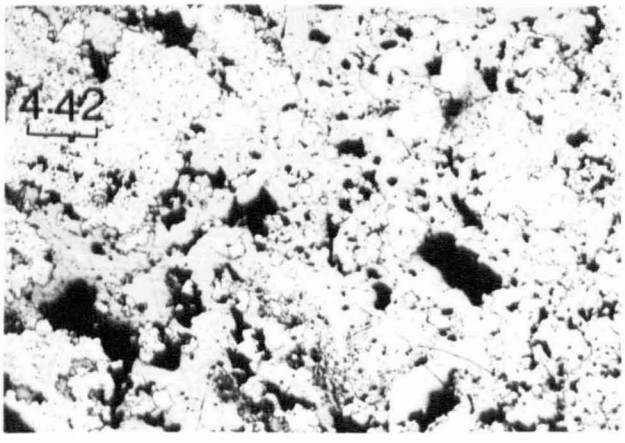
PPL scale bar = 1.2 mm

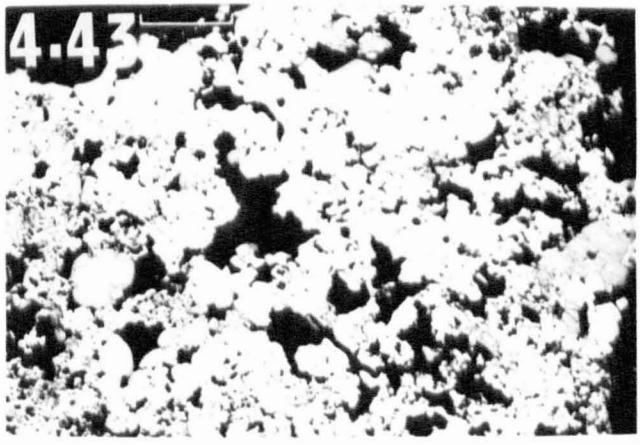

cp
4.38

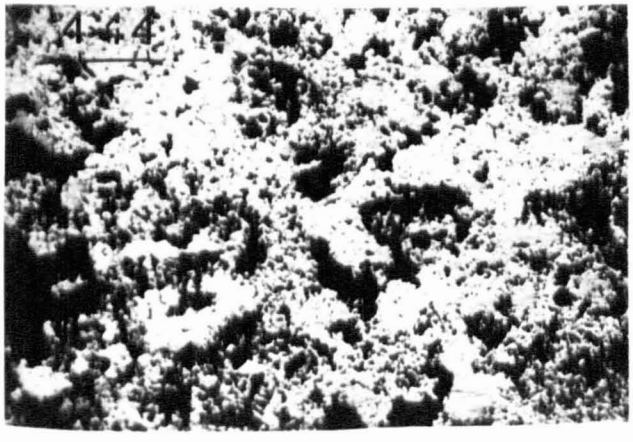

4.39

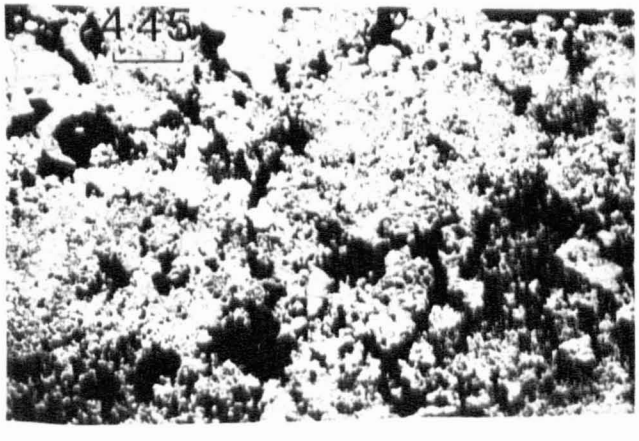

gn
cp
4.40


4.41


4.42


4.43


4.44


4.45

chalcopyrite fragments are cemented with quartz and/or bornite often associated with minor amounts of chalcocite digenite and covellite. The massive chalcopyrite is made up of subhedral and anhedral chalcopyrite crystals commonly exhibiting lamellar twinning.

The interstitial chalcopyrite fills part of the cavities in the aggregates of unzoned Pyrite I (Plates 4.32, 4.33). Small amounts of chalcopyrite are found as intergrowths in sphalerite (Plate 4.40) or as inclusion in Pyrite. In this orebody a very late generation of chalcopyrite was formed after the alteration of the massive and interstitial chalcopyrite to bornite. The late chalcopyrite forms prismatic and bladed crystals epitaxially grown on bornite which surrounds chalcopyrite and sphalerite (Plates 4.36, 4.37).

Similar to chalcopyrite most of the sphalerite present in the massive ore of this orebody is in the form of massive sphalerite or as interstitial material to pyrite and chalcopyrite. In the massive sphalerite are scattered remnants of corroded Pyrite I. The interstitial chalcopyrite fills cavities in pyrite (4.33) and chalcopyrite (Plates 4.43, 4.35). The sphalerite often forms rims around chalcopyrite grains (Plate 4.38) suggesting that part of the sphalerite is later than chalcopyrite. Minor amounts of sphalerite are found as intergrowths in chalcopyrite. Small amounts of sphalerite also occur as fine inclusions in pyrite; frequently the sphalerite inclusions are concentrated along contacts of frowth zones and along grain boundaries in pyrite (Plate 4.39).

Traces of galena associated with sphalerite (Plate 4.40) were observed only at the top of the massive ore. Traces of pale bluish-grey tennantite were found in the upper parts of the massive ore. Anhedral and subhedral tennantite is found in the chalcopyrite and sphalerite and less commonly along the grain boundaries of these two minerals (Plates 4.34, 4.35). The chemical composition of the tennantite in the Agrokipia B was investigated with electron probe and the results of this investigation are shown in Table 4.5.

Table 4.5. Electron probe analysis of tennantite from the upper part of the massive ore of the Agrokipia B orebody.

Element	Weight per cent	
Cu	42.4	
Fe	2.4	Ag not detected
Zn	5.4	Sb " "
S	28.8	
As	21.5	
Total	100.5	

Bornite is the most common secondary copper sulphide in this orebody. The bornite forms rims around chalcopyrite (Plate 4.36, 4.38) and less commonly around sphalerite (Plate 4.37) or fills fractures and cavities in chalcopyrite (Plate 4.35). Bornite also occurs in the veins of fragmented chalcopyrite and is associated with chalcocite, digenite and covellite (Plate 4.35).

The Lower parts of the massive ore consist mostly of unzoned Pyrite I and trace amounts of chalcopyrite and sphalerite. The last two minerals occur as anhedral inclusions in the pyrite.

(d) The Stockwork Zone

As indicated by drilling data, the massive ore is underlain by the stockwork zone which extends to considerable depth. Optical studies of drill hole samples suggest that in the stockwork the sulphide mineralization is represented by pyrite veins and disseminations. The pyrite in the veins is generally coarse grained and contains anhedral grains of chalcopyrite and less commonly sphalerite. The pyrite in the veins is corroded and is associated with quartz. The quartz appears to be later than pyrite and fills fractures and zones of corrosion in the pyrite. The pyrite impregnating the lava is generally fine grained subhedral to anhedral and is associated with quartz, chalcedony, chlorite and fine grained illite.

X-ray diffraction analyses of a series of samples from the stockwork zone (Table 10.2) indicate that:

(i) In the stockwork zone from top to bottom the mineral assemblage is the same and consists mainly of quartz, variable proportions of pyrite and chlorite, and minor amounts of illite.

(ii) There is a noticeable antipathetic distribution between pyrite and chlorite throughout the stockwork zone.

5. The Kokkinoyia Orebody

(a) General Information

The Kokkinoyia orebody is located under a cover of olivine basaltic Upper Pillow Lavas which varies in thickness from several metres to more than 200 metres. Part of this cover is overlain by sedimentary rocks (Fig. 4.7). Faulting, uplifting and subsequent erosion of the lavas, exposed the upthrown south-western part of the orebody which oxidized to massive gossan. The gossan attracted the ancient miners who extracted considerable proportion of the massive ore (Fig. 4.6); evidence of such activities is indicated by the large slag dumps around the orebody and ancient fillings. Caving troubles experienced during drilling and wood fragments recovered from drillholes suggest that the low to medium grade material which overlies the massive ore (Figs. 4.7, 4.7a) is ancient filling. This suggestion is further substantiated by the fact that in the sulphide orebodies of Cyprus the massive ore is never overlain by medium or low grade ore.

The massive gossan at the southwestern end of the orebody was mined in 1937 for its silver and gold content. Remnants of this gossan are still exposed in the small pit near the contact of the Lower Pillow Lavas with the Upper Pillow Lavas (Fig. 4.1). The gossan is underlain by hydrothermally altered lavas which contain veins and disseminations of pyrite.

In 1962 the Hellenic Mining Company undertook a systematic drilling programme searching for a possible extension of the mineralization beneath the lava cover. Over ninenty holes were drilled and resulted in the discovery of about one million tons of sulphide ore which contains over 30per cent sulphur and in average 1-5 percent copper. The Hellenic Mining Company recently had decided to mine the ore by underground methods and production was expected

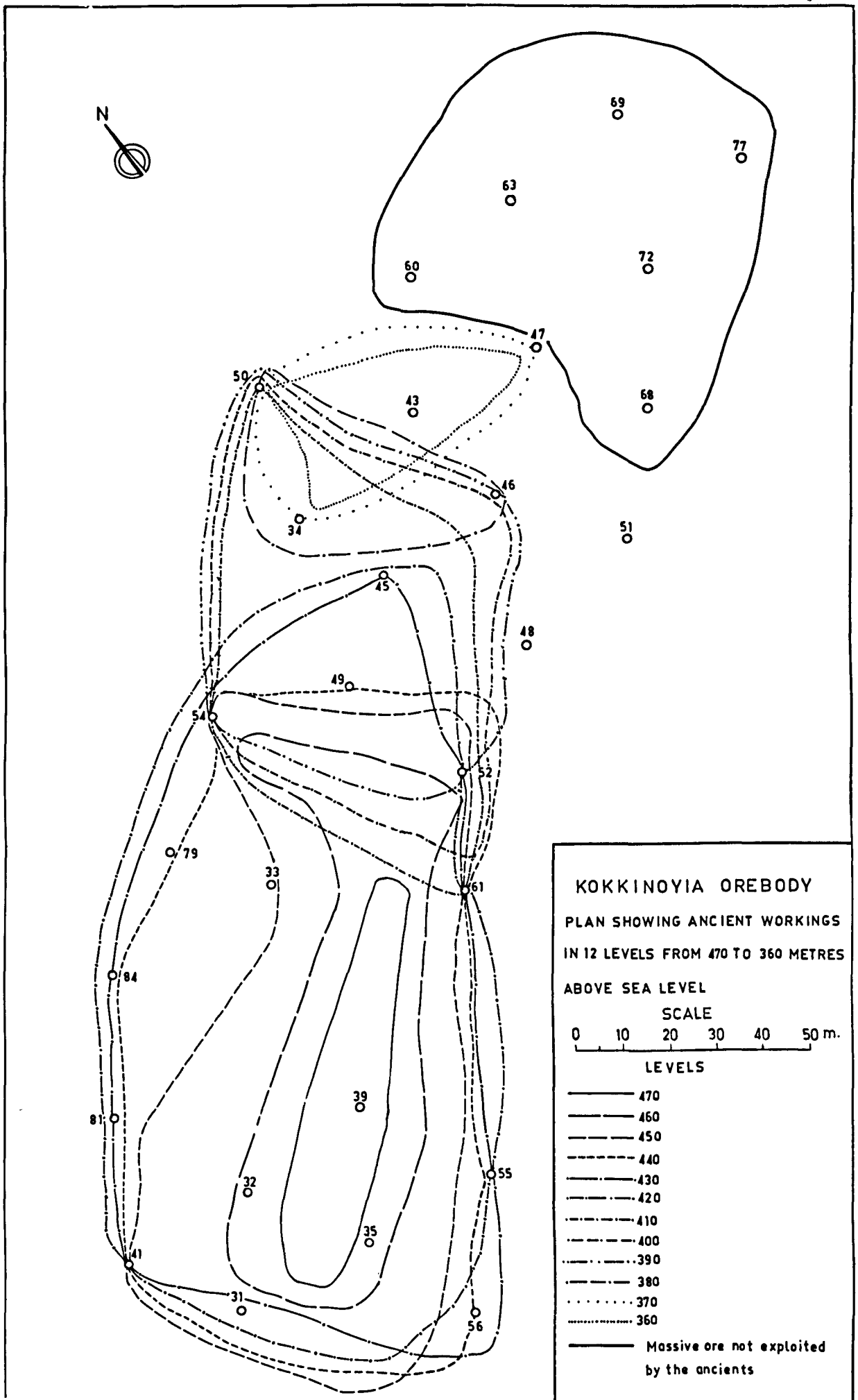

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56
KOKKINOYIA OREBODY
PLAN SHOWING ANCIENT WORKINGS
IN 12 LEVELS FROM 470 TO 360 METRES
ABOVE SEA LEVEL
SCALE
0 10 20 30 40 50 m.
LEVELS
470
460
450
440
430
420
410
400
390
380
370
360
Massive ore not exploited
by the ancients

Fig 4-7

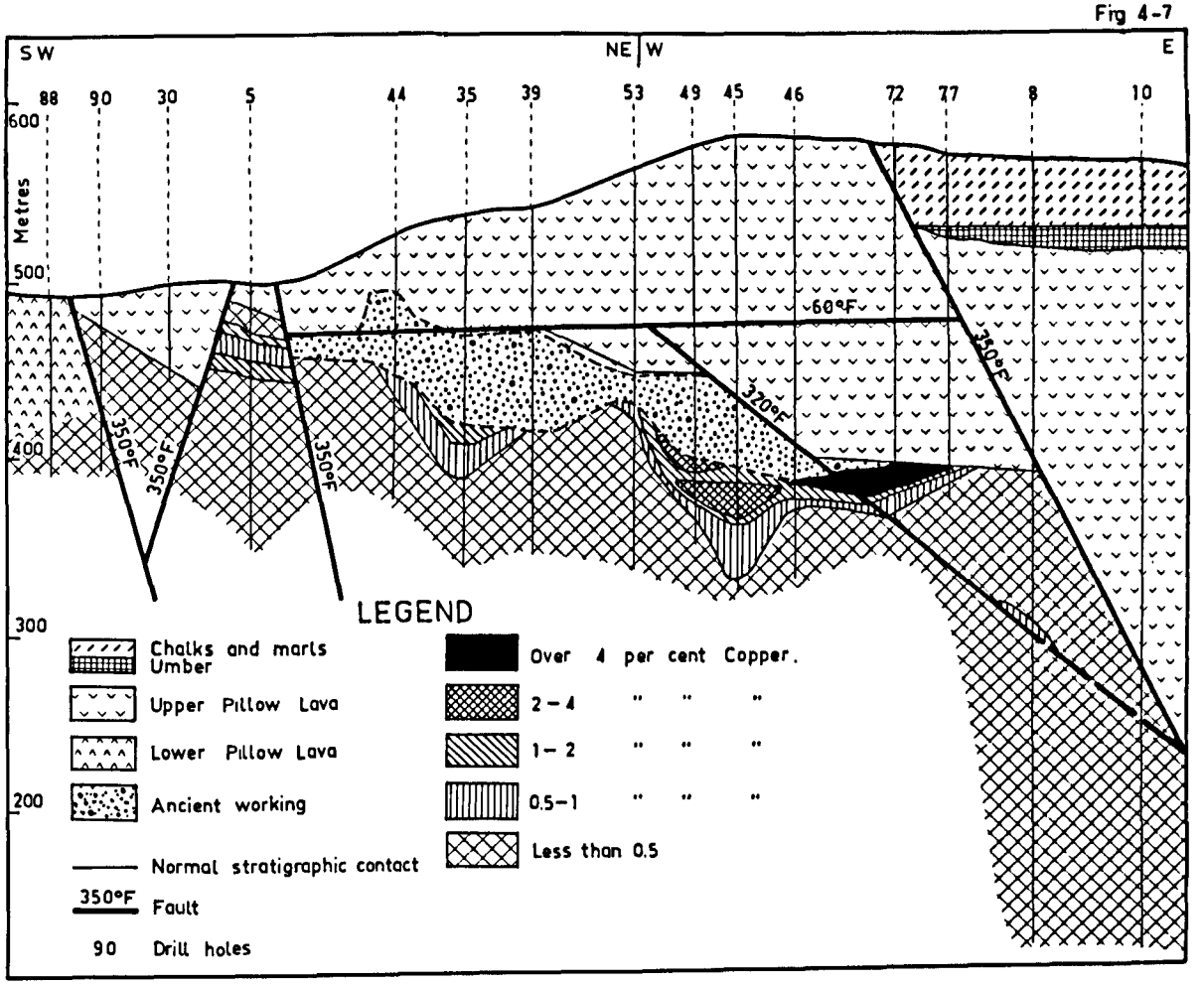
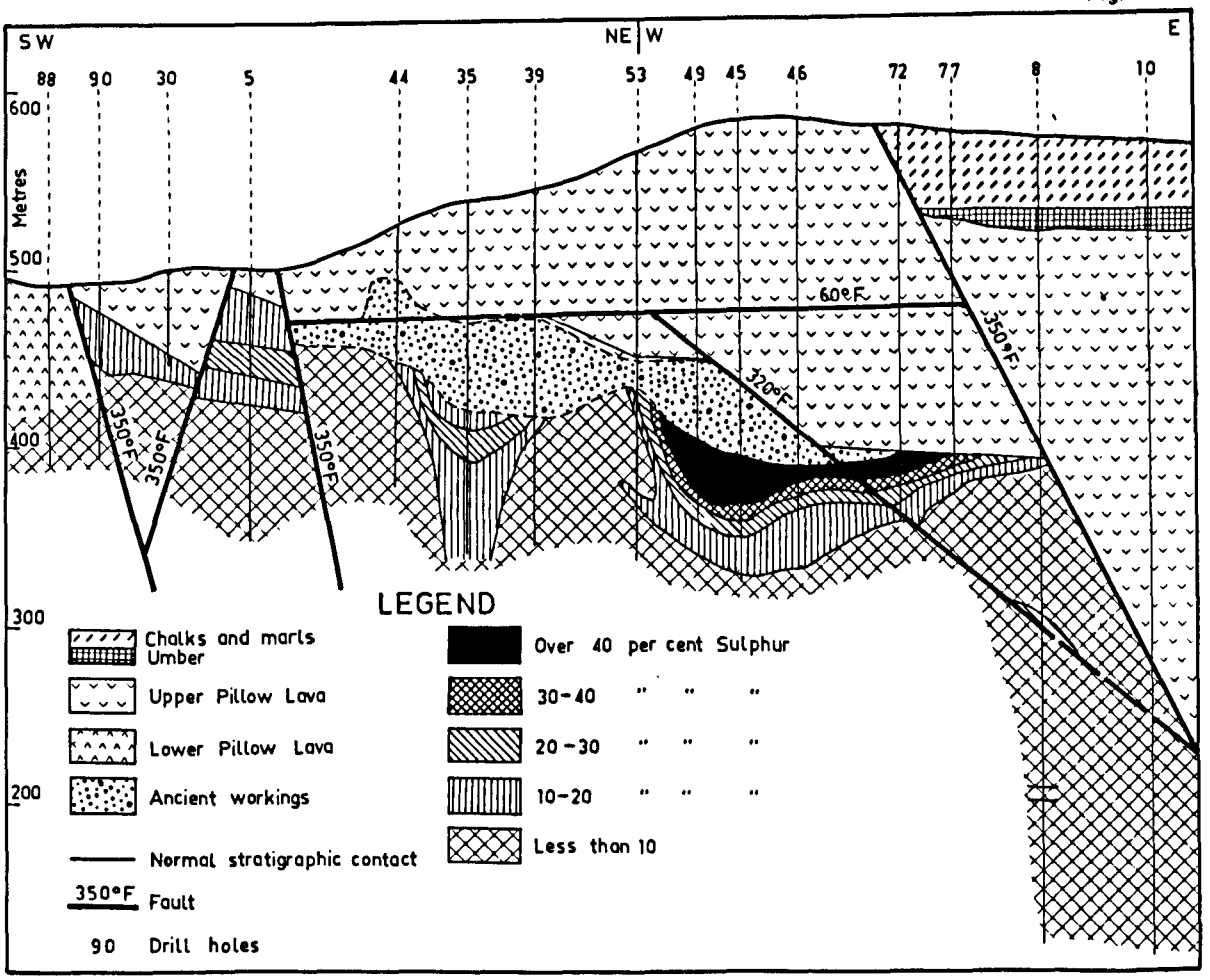


Fig. 4-7a



Geological sections through the Kokkinoyia orebody showing, (a) the extent of ancient workings, (b) the relationship between the sulphide ore and the overlying unmineralized olivine basaltic lava, (c) major fault pattern and (d) distribution of copper (Fig. 4-7) and sulphur (Fig. 4-7a) in the ore.

to start at the end of 1971.

For the present investigation the writer mapped the area around the orebody on the scale of 1:1000 using as base map a topographical map provided by the Hellenic Mining Company. The writer had also access to all data and samples of the exploration drillholes through and around the orebody. These drillholes were logged and samples from a number of selected drill-holes were made available to the writer by Helco, for detailed laboratory investigation.

(b) Geology of the Kokkinoyia Orebody

The only part of the orebody exposed on the surface occurs in the small Kokkinoyia pit which resulted from the mining of the massive gossan in 1937. In the pit the mineralization is represented by low grade ore in the form of sulphide veins and disseminations of pyrite in hydrothermally altered lavas. The low grade ore is overlain by unmineralized olivine basaltic Upper Pillow Lavas. The low grade ore - U.P.L. contact is sharp and dips about 35° to the north. The Lower Pillow Lavas exposed in the Kokkinoyia pit and the surrounded area are unmineralized. Uplifted blocks of weathered mineralized Basal Group containing abundant red jasper are exposed at the vicinity of the Kokkinoyia pit.

The hidden orebody has the appearance of a horst, bounded to the northwest and to the southeast by two parallel 060° trending faults. These two faults dip in opposite directions and downthrow the unmineralized U.P.L. which are in contact with the ore. The two 060° trending faults are truncated by two parallel normal faults which trend about 350°. The eastern 350° trending fault displaces the sedimentary rocks (Fig. 4.7). In the horst there are probably two parallel 320° trending faults downthrowing the ore and the overlying lavas to the northeast.

In most parts of the orebody the contact of the ore with the overlying U.P.L. was obscured by the extensive ancient workings. At the downthrown eastern part of the orebody which is devoid of ancient workings the U.P.L. rest conformably on massive ore. The contact is sharp and ore containing 45 to 50 percent sulphur is succeeded by barren lava over a very short distance (Fig. 4.8).

X-ray diffraction analyses of drill hole samples of lava in contact with massive ore, and away from the contact (table 10-2) indicate that the lavas consist mainly of plagioclase and montmorillonite and small amount of pyroxene. The X-ray diffraction pattern is generally similar to the pattern of the unmineralized olivine basaltic U.P.L. in the Tamassos and Skouriotissa area. In the private files of the Hellenic Mining Company the logs of some drill holes indicate that the Kokkinoyia orebody contains unmineralized dykes.

(c) Major and minor element chemistry of the Kokkinoyia Orebody.

A characteristic feature of the Kokkinoyia orebody is the vertical zoning of its ore. The top of the orebody consists of massive ore containing over 40per cent sulphur. The massive ore is underlain by a thin zone (the Zone B) consisting of an intimate mixture of sulphide, quartz and red jasper; the sulphur content in this zone ranges from 30 to 40per cent (Fig. 4.7a). The second zone is succeeded by the stockwork zone consisting of mineralized and hydrothermally altered lavas. The stockwork zone generally contains less than 30per cent sulphur and in its deeper parts the sulphur content is less than 10per cent (Fig. 4.7a).

At the upper parts of the massive ore copper is highly concentrated. The concentration of copper is more conspicuous in the eastern part of the orebody which is devoid of ancient workings. Copper values as high as 15per cent were recorded in drill holes intersecting this part of the orebody (Figs. 4.7, 4.8). In the lower parts of the massive ore copper decreases to less than 2 percent. The second zone of this orebody (the Zone B) consists of sulphide and silica and contains 1 to 2per cent copper whereas in the stockwork zone the copper content is less than one.

A series of samples of ore from three selected drill-holes were analysed for zinc, lead, nickel and cobalt with Atomic Absorption Spectrophotometer by the Chemical Laboratory of the Cyprus Geological Survey. The results of these analyses are shown in figure 4.8 and indicate that:-

(i) Zinc generally tends to concentrate in the massive ore whereas in the stockwork the zinc is very low.

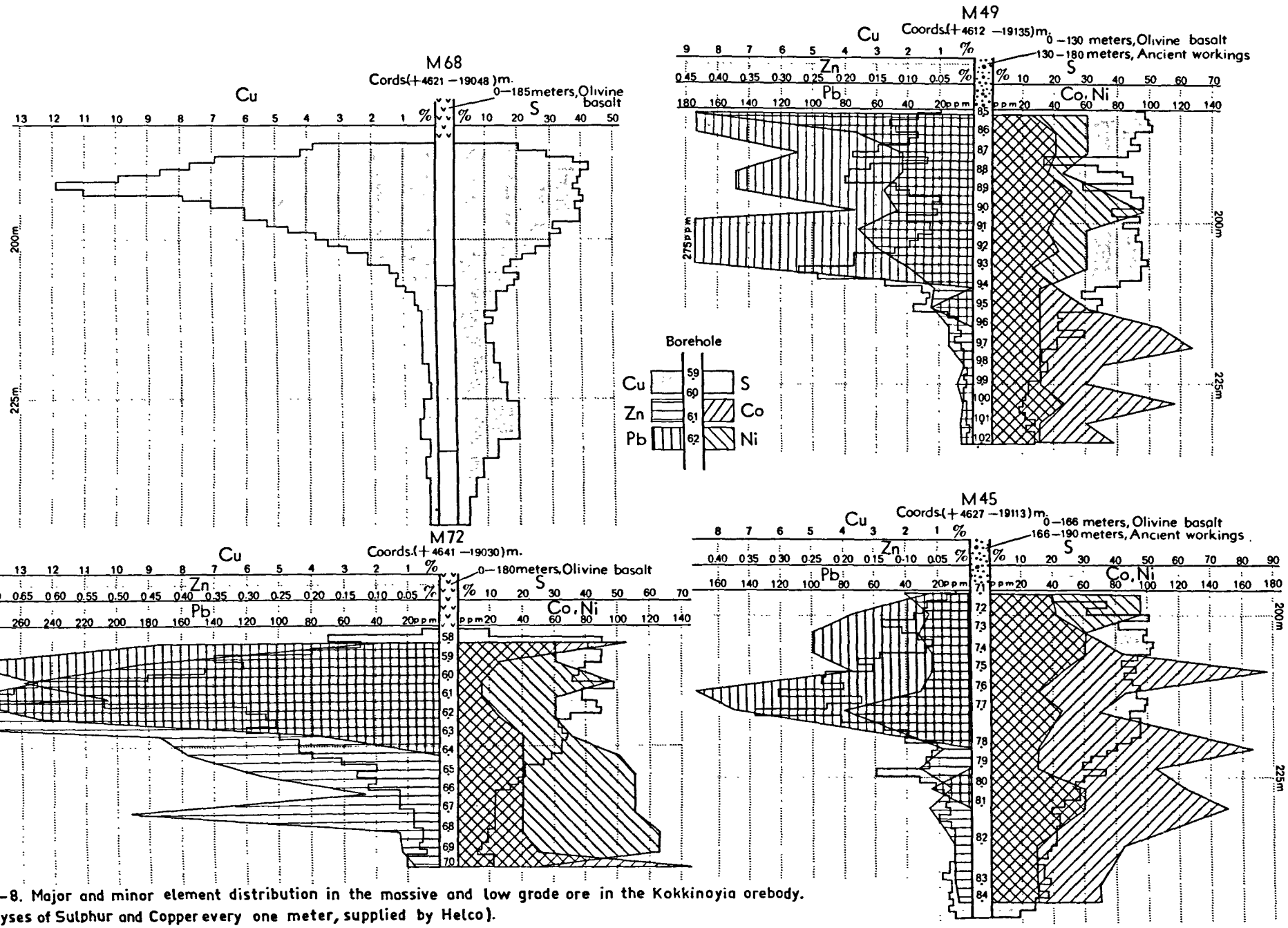


Fig. 4−8. Major and minor element distribution in the massive and low grade ore in the Kokkinoyia orebody. (Analyses of Sulphur and Copper every one meter, supplied by Helco).

(ii) Lead is sympathetically distributed with copper and tends to concentrate in the upper parts of the massive ore; it decreases abruptly to less than 25 p.p.m. in the lower parts of the massive ore, and in the stockwork zone.

(iii) Cobalt and nickel are erratically distributed in the different parts of the orebody. In the ore intersected by the drill hole M.72 the ratio Ni:Co is generally more than one except the first and the last samples in which this ratio is less than one. In the drill hole M.45 in the upper part of the massive ore the ratio Ni:Co is more than one whereas in the lower parts of the massive ore and in the stockwork zone this ratio is lower than one. Finally in the massive ore encountered in drill hole M.47 the ratio Ni:Co is generally more than one whereas in the stockwork this ratio is less than one.

(d) The Massive Ore

At the upper parts of the massive ore the ore is highly porous and frequently its total pore volume represents more than 50 per cent of the total volume of the ore as estimated from polished sections. The porosity decreases gradually with depth and at the lower parts of the massive ore the pore volume hardly exceeds 15 per cent of the total volume of the ore. Optical studies indicate that the porosity of the massive ore is secondary and resulted from the corrosion of pyrite. Most of the cavities are surrounded by corroded pyrite (Plates 4.41, 4.46, 4.47). The zones of high porosity are often seen to project into pyrite of low porosity; frequently remnants of corroded pyrite are observed in the resultant cavities (Plates 4.47, 4.48, 4.49, 4.50, 4.51). In some zones of extensive corrosion the ore has a characteristic vryoidal (fungus-like) texture (Plates 4.44, 4.45).

The mineral assemblage of the massive ore is relatively simple; the most predominant mineral is pyrite and is associated with variable proportions of chalcopyrite and minor amounts of marcasite and sphalerite. The secondary copper sulphides, bornite, digenite, chalcocite and covellite are present only in small amounts.

Plate 4-46. Kokkinoyia ore. Intensely corroded pyrite I, associated with collomorphic pyrite. Some cavities contain fragments of corroded pyrite which often are connected with the surrounding pyrite with narrow bridge.

PPL scale bar = 400 microns

Plate 4-47. Kokkinoyia ore. Collomorphic pyrite associated with high porosity. Cavities surrounded with corroded pyrite and containing remnants of corroded pyrite are common.

PPL scale bar = 125 microns

Plate 4-48. Kokkinoyia ore. Collomorphic texture produced by the alignemented of pores in pyrite; large cavities contain remnants of corroded pyrite and are surrounded by corroded pyrite.

PPL scale bar = 0.8 mm

Plate 4-49. Kokkinoyia ore. Collomorphic texture probably produced by the growth and interconnection of the pores of plate 4-48. Cavities again contain remnants of corroded pyrite and are surrounded by corroded pyrite.

PPL scale bar = 200 microns

Plate 4-50. Kokkinoyia ore. Collomorphic pyrite associated with high porosity. The latter seem to develop at the expense of pyrite I which has very low or no porosity.

PPL scale bar = 156 microns

Plate 4-51. Kokkinoyia ore. Collomorphic pyrite associated with zones of high porosity. The contact of the zones of high porosity with pyrite I is irregular.

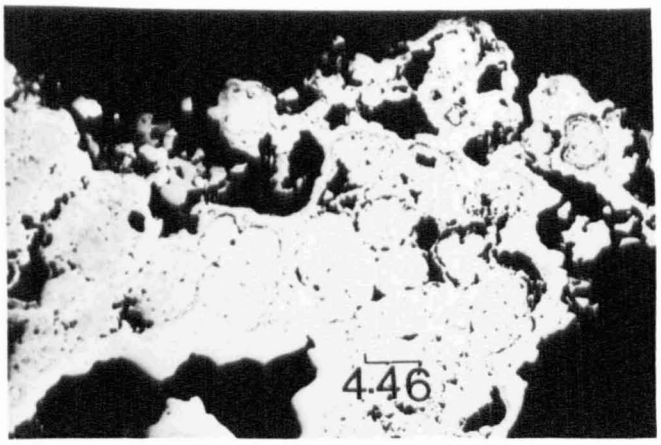
PPL scale bar = 97 microns

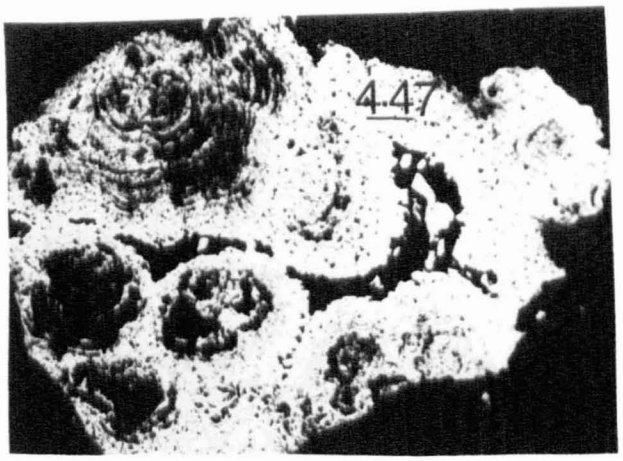
Plate 4-52. Kokkinoyia ore. Texture produced by intense corrosion of pyrite. Note that many isolated cavities contain fine fragments of pyrite.

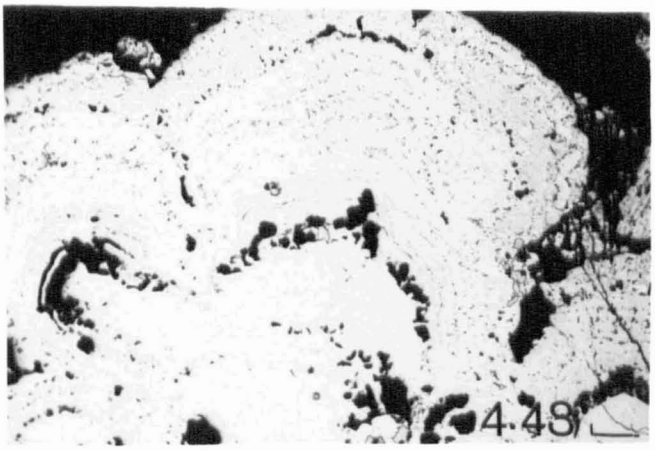
PPL scale bar = 0.8 mm

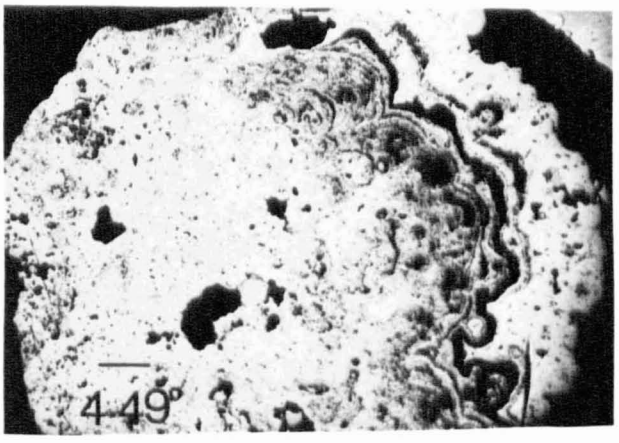
Plate 4-53. Kokkinoyia ore. Chalcopyrite grown in cavity and exhibiting simple (left) and lamellar (bottom) twinning. Niokols partly crossed.

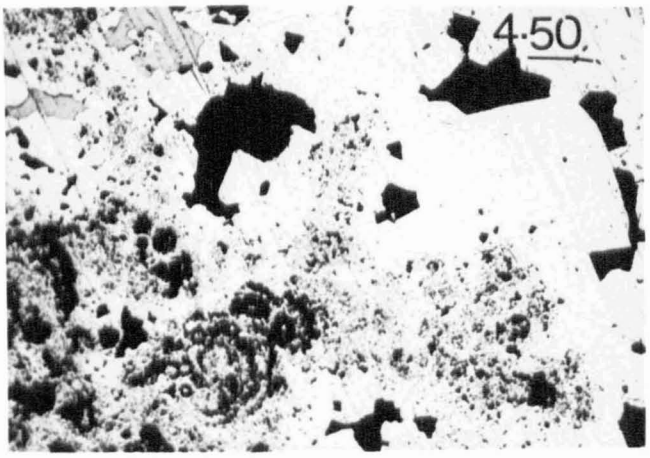
PPL scale bar = 150 microns

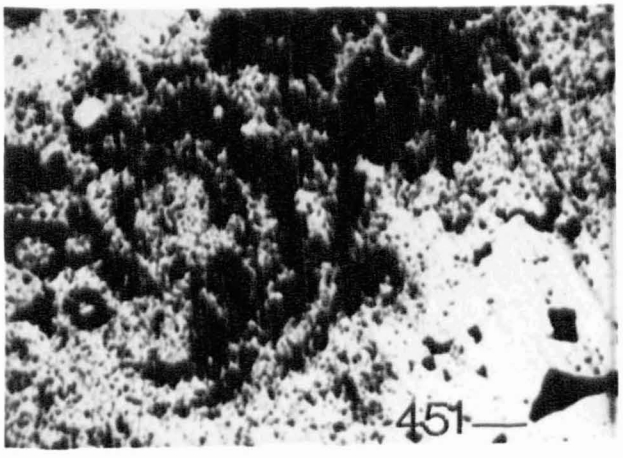

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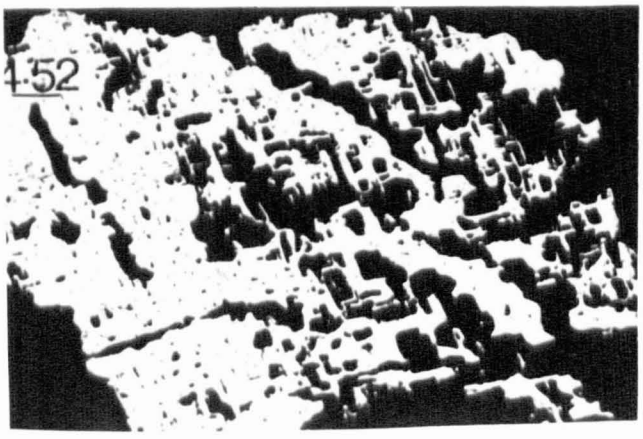

4.47

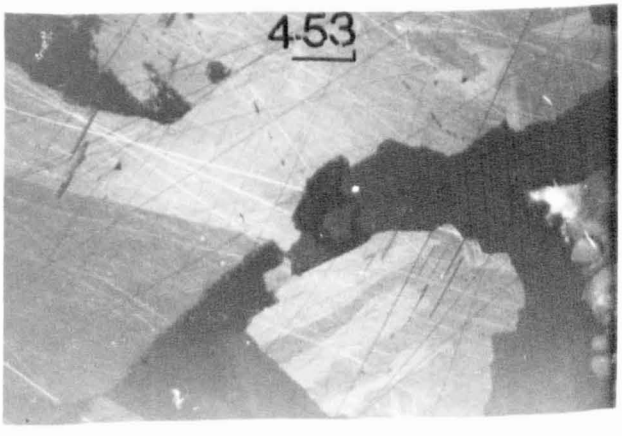

4.48


4.49


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451


4.52


4.53

Pyrite I with zoned internal structure is generally rare in the upper parts of the massive ore whereas it is more common in the lower parts of the massive ore. Highly corroded unzoned pyrite I is very common in the upper parts of the massive ore. Frequently the zones of corrosion and the cavities are filled with interstitial chalcopyrite. Collomorphic pyrite often associated with framboidal pyrite is common in the massive ore. The collomorphic pyrite is invariably associated with zones of high porosity and appears that it developed at the expense of pyrite I (Plates 4.46, 4.50, 4.51). Colloform textures appear to have been formed by gradual growth and interconnection of micropores in pyrite I (Compare Plate 4.46 with Plate 4.47, and plate 4.48 with plate 4.49). The probable processes involved will be discussed in part II.

Chalcopyrite is the most common mineral after pyrite and most of it occurs as interstitial material to pyrite. The drillholes M.68 and M.72 penetrated massive ore containing up to 12 and 15 per cent copper respectively (Fig. 4.8). In the private files of the Hellenic Mining Company the logs of these drill holes report that in the zones of high concentration of copper, the latter is in the form of black or blue-black sooty chalcocite. Optical study of polished sections of drill hole samples indicate that even in the zones of high copper concentration most of the copper is in the form of interstitial chalcopyrite and that chalcocite is present only in minor amounts.

The interstitial chalcopyrite fills part of the pores and cavities in pyrite (Plates 4.41, 4.42). Frequently in a single polished section, zones rich in interstitial chalcopyrite are found next to zones containing little interstitial chalcopyrite (Plates 4.42, 4.43). In zones rich in interstitial chalcopyrite often there is a considerable number of empty cavities (Plates 4.41, 4.42). The outlines of the empty cavities and the interstitial chalcopyrite are irregular. Remnants of corroded pyrite are common in interstitial chalcopyrite and are generally similar to remnants of corroded pyrite found in empty cavities (compare Plates 4.47 with plates 4.42). All these observations suggest that probably the interstitial chalcopyrite filled pre-existing cavities in pyrite.

The interstitial chalcopyrite commonly exhibits simple and lamellartwinning (Plate 4.53). The interstitial chalcopyrite decreases considerably at the lower parts of the massive ore. Throughout the massive ore a small proportion of chalcopyrite occurs in the form of small anhedral grains enclosed in pyrite I and less commonly in sphalerite.

Marcasite was observed throughout the massive ore of the Kokkinoyia orebody but tends to be more common at the upper parts of the massive ore.

Sphalerite tends to be more common in the massive ore which lies below the zones of high copper concentration. Most of the sphalerite occurs as interstitial material to pyrite. It generally fills cavities in pyrite I or in collomorphic pyrite and it is commonly seen to contain remnants of corroded pyrite. Small proportions of sphalerite occur in the form of small anhedral grains included in pyrite I.

The secondary copper sulphides, bornite chalcocite covellite and digenite are present only in small amounts and are restricted to the upper parts of the massive ore.

(e) The Zone B

The massive ore is underlain by the zone B which is generally thin and consists of medium grade ore mixed with silica. The sulphur content in this zone ranges between 30 and 40 cent whereas the copper content ranges between 1 and 2 cent. The silica in the zone B is represented by variable amounts of quartz chalcedony and red jasper.

In the zone B the predominant sulphide mineral is unzoned pyrite I being intensely corroded and replaced by quartz. Chalcopyrite is the second most common sulphide in the zone B. It mainly occurs in the form of interstitial material to pyrite and less commonly in the form of anhedral grains included in Pyrite I. A considerable proportion of chalcopyrite in the zone B is found scattered in the silica matrix. This chalcopyrite is corroded and the zones of corrosion are filled with silica.

Sphalerite is rare in the zone B and it occurs only in the form of small anhedral grains enclosed in the pyrite.

Collomorphic pyrite, marcasite and secondary copper sulphides were not observed in the zone B.

(f) The Stockwork Zone

The stockwork zone consists of low grade ore which generally contains less than 30per cent sulphur and less than one cent copper. In the deeper parts of the stockwork zone the sulphur decreases to less than 10per cent and the copper is present only in trace amounts. The mineralization is represented by sulphide veins and disseminations of pyrite in hydrothermally altered lavas. The sulphide veins consist of coarse grained pyrite partly corroded and replaced by quartz. The pyrite contains unhedral grains of chalcopyrite and less commonly sphalerite. The pyrite which impregnates the mineralized lava is generally fine grained and is partly corroded and replaced by quartz.

X-ray diffraction analyses of drill hole samples from the stockwork zone of the Kokkinoyia orebody (Table 10.2) indicate that the mineralized lavas in addition to pyrite contain abundant quartz. In the stockwork zone of the Kokkinoyia orebody illite tends to be more common than chlorite (the reverse to the other orebodies in Cyprus). An unidentified mixed-layer clay not detected in the other investigated orebodies is invariably present in the stockwork of the Kokkinoyia orebody.

6. Summary

The orebodies of the Tamassos Mining Area are restricted to the pillow lavas and occur in different stratigraphic horizons in the lava sequence. Thus the Kokkinopezoula orebody is located between the Basal Group and the Lower Pillow Lavas whereas the Kokkinoyia, Agrokipia A and Agrokipia B orebodies occur below the Upper Pillow Lavas.

In the Kokkinoyia and Agrokipia B orebodies the unmineralized Upper Pillow Lavas are resting on massive ore whereas in the Agrokipia A orebody these lavas overlie low grade or medium grade ore. All the orebodies of the Tamassos area contain unmineralized olivine basaltic dykes which probably represent feeder dykes to the Upper Pillow Lavas. The U.P.L. represent

submarine lava flows and as they rest directly on the sulphide ore of the Kokkinoyia, Agrokipia A and Agrokipia B orebodies most likely these orebodies were exposed on the sea floor during the extrusion of the U.P.L. At the Agrokipia B and Kokkinoyia orebodies, the U.P.L. which rest on the conspicuously enriched in copper and/or in zinc massive ore show no signs of alteration through leaching. Field evidence indicates that the basaltic lavas in Cyprus are very sensitive to the subaerial leaching processes. Thus it appears that the copper and/or zinc enrichment of these massive ores took place under submarine conditions and before the extrusion of the Upper Pillow Lavas.

After correction for postmineralization faulting the Kokkinoyia and Kokkinopezoula orebodies have a saucer-shaped form and they exhibit a characteristic vertical zoning. The upper part of these orebodies consists of massive ore (in the Kokkinopezoula orebody most of the massive ore is oxidized to gossans) which contains more than 40 percent sulphur. Massive ore occurs also in the Agrokipia B orebody whereas it is lacking in the Agrokipia A orebody. The massive ore is underlain by the zone B (well developed only in the Kokkinoyia orebody) which contains 30 to 40 per cent sulphur. Zone B is in turn underlain by the stockwork zone that contains less than 30 per cent sulphur.

In the Kokkinoyia orebody the massive ore particularly its upper parts contain high copper. In the Agrokipia B orebody the Upper parts of the massive ore contain high copper and zinc whereas the lower part of the massive ore contain only traces of copper and zinc. In the Kokkinopezoula orebody the massive ore generally contains less than 0.5 per cent copper.

The massive ore of the Kokkinoyia orebody consists mainly of pyrite (zoned and unzoned pyrite I, collomorphic and framboidal pyrite) chalcopyrite (mostly as interstitial material to pyrite) marcasite and sphalerite in decreasing order of abundance. In the Agrokipia B orebody the upper parts of the massive ore consist of pyrite (mostly unzoned pyrite I and rare collomorphic pyrite) and variable proportions of chalcopyrite (massive and/or interstitial material to pyrite) and sphalerite (massive, or interstitial material to pyrite and chalcopyrite) as well as minor amounts of

tennantite and galena (not detected in the other investigated orebodies). The pyritic massive ore of the Agrokipa B and the Kokkinopezoula orebodies mostly consists of pyrite and rare chalcopyrite and sphalerite.

In the Kokkinoyia orebody the zone B is generally thin and consists of an intimate mixture of sulphide, quartz and red jasper. The copper content of this zone ranges between 1 and 2 percent. The predominant sulphide mineral is unzoned pyrite I which is corroded and partly replaced by quartz. Chalcopyrite is common as interstitial material to pyrite and less commonly is scattered in the silica matrix.

The lower parts of the orebodies of the Tamassos area are occupied by the stockwork zone. This zone is represented by low grade ore consisting of sulphide veins and disseminations of pyrite in hydrothermally altered lavas; the latter are either brecciated or with discernible pillow structure. Many N-S trending dykes in the stockwork zone of the Kokkinopezoula orebody are mineralized as well as hydrothermally altered. The copper content of the stockwork zone in the four orebodies of the Tamassos area is generally the same and it is invariably less than 0.5 percent.

In the stockwork zone the sulphide veins fill fractures in the lavas or heal brecciated lavas. These veins consist of pyrite and minor amounts of chalcopyrite and sphalerite. The mineralized lava is impregnated with fine grained pyrite whereas no chalcopyrite or sphalerite were found as disseminations in the lavas. The mineralized lavas in the stockwork zone had been hydrothermally altered. Quartz is the predominant product of hydrothermal alteration followed in order of abundance by chlorite and illite. In the stockwork zone of the Kokkinoyia orebody illite is more common than chlorite. In the stockwork zone of the same orebody a mixed-layer clay is invariably present but its identification was not possible.

D. THE MATHIATI NORTH OREBODY

1. Introduction

The Mathiatis North orebody is located one kilometre north of Mathiatis village and approximately 28 kilometres south of Nicosia. The slag dumps in the vicinity of the mine testify to the ancient mining and smelting activity in this orebody. No mining activity is known to have been carried out in this orebody from the first centuries A.D. until the 1930's when C.M.C. worked the gossan overlying part of the orebody for its gold and silver content. The C.M.C. records indicate that in 1937 a shaft, sunk through the gossan, intersected massive pyritic ore; further underground investigations followed on three levels but these investigations were interrupted by the outbreak of the last World War.

Prospecting was resumed in 1947 with a gravity survey of the area around the orebody, followed up by drilling on a gravity anomaly. The drilling continued intermittently until 1957 and proved that the outline of a gravity anomaly coincided with the limits of the Mathiatis N. orebody. Drilling data and underground development work indicate that the total tonnage of this orebody is approximately 3 million tons. The ore is pyritic and in average it contains 33 per cent sulphur and 0.24per cent copper. In 1964 the prospect was acquired by the Hellenic Mining Company which in 1965 started stripping operations for opencast mining of the ore.

The first account of the geology of the Mathiatis orebody was given by Jarrel (1947) who investigated the massive gossan which was largely worked out during the 1930's. He also described the relation of the orebody to the surrounding volcanic rocks. The geology of the area around this orebody was described by Gass (1960); he gave a short account of the early investigations in this orebody and compiled data on the tonnage and grade of the ore.

The Sha-Mathiatis area was mapped again using aerial photographs by Searle and Panayiotou on a scale of 1:10000. They prepared a U.N. report describing the field geology of the area with special emphasis on the geology of the Mathiatis N. and Sha

orebodies,(Searle and Panayiotou 1968). Govett and Pantazis carried out a detailed geochemical investigation of the pillow lavas and gossan remnants in the pit and extended some traverses outside the open pit into the surrounding Pillow Lavas. The results of this investigation were given in a U.N. report by Govett (1969).

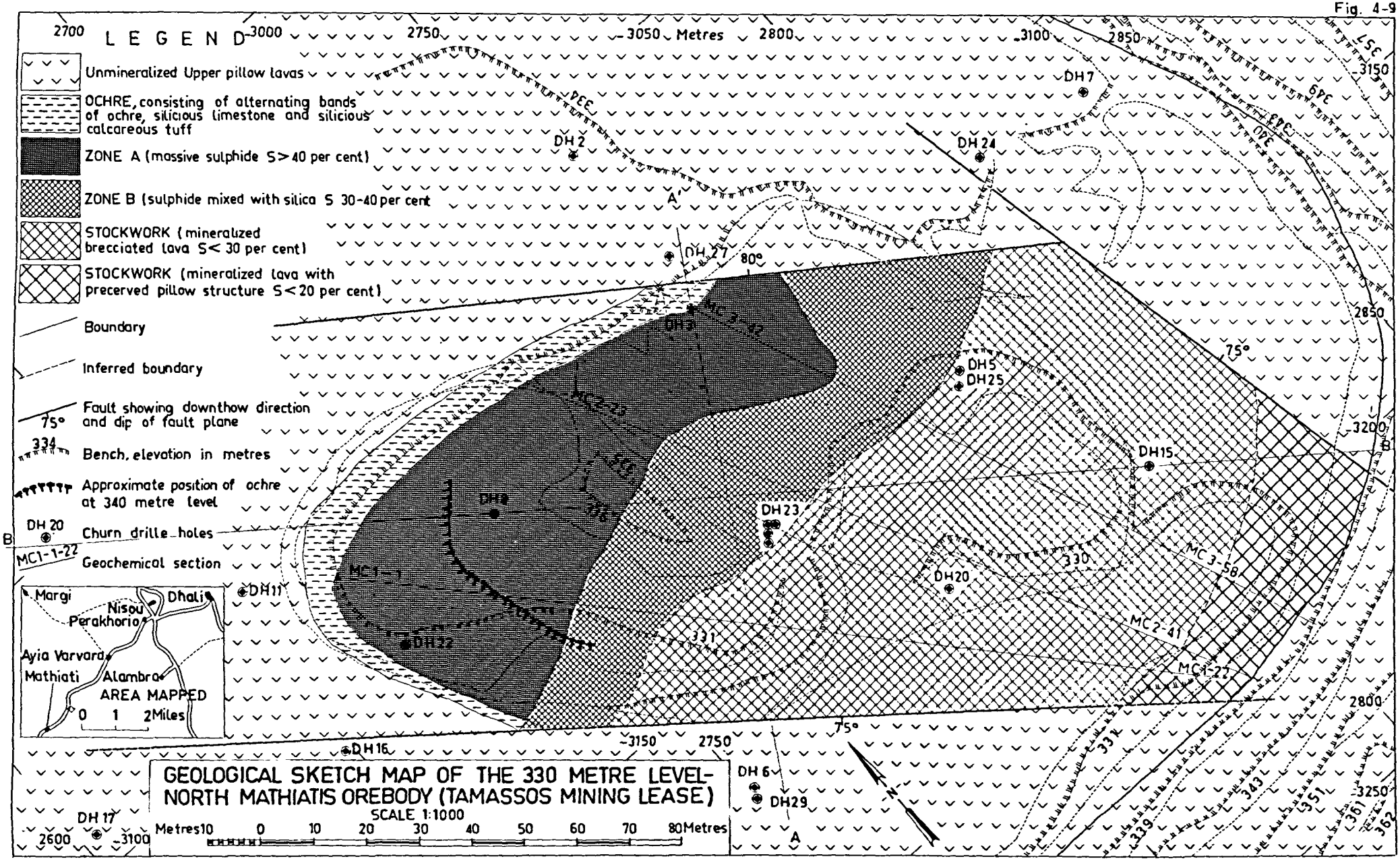
Lundberg (U.N. Associate Geologist) followed up the early stages of the mining operations in the orebody; late in 1967 when the mining operations went down to the 335 and 330 meter levels the writer was assigned to continue the above work. The 330 metre level was mapped and sampled on a scale of 1:500 using as base map the mine plans kindly provided by the Hellenic Mining Company. The surface observations as well as drilling data and the assay results of the early C.M.C. investigations (all accessible through the Cyprus Geological Survey) were used for the construction of geological sections through the orebody.

2. The Surrounding Rocks.

The Mathiatis orebody is surrounded with unmineralized olivine basaltic Upper Pillow Lavas (Fig. 4.9). In the open pit the benches below the 340 metre level are occupied by grey-green lavas with large and generally irregular pillows, whereas the benches above the 340 metre level are occupied by pale-grey to pink lavas with small and generally uniform pillows. At the northern and the northwestern part of the pit the contact of the grey-green and pale-grey lavas is marked with sills 4 metres thick and exhibiting well developed columnar jointing (Plate 4.55).

The lavas are generally vesicular and have a vitreous texture. Plagioclase and less common pyroxene are the principal minerals and are scattered in variable proportions of glassy matrix. The plagioclase is generally altered to montmorillonite whereas the pyroxene is commonly rimmed with chlorite. The olivine is generally altered to iron oxides. The glassy matrix is altered to a mixture of montmorillonite and chlorophaeite. The lavas are characteristically rich in zeolites particularly analcite. The zeolites fill fractures and vesicles in the lava, and frequently the zeolite veins are truncated by veins of later calcite.

Fig. 4-9


LEGEND
Unmineralized Upper pillow lavas
OCHRE, consisting of alternating bands of ochre, silicious limestone and silicious calcareous tuff
ZONE A (massive sulphide S>40 per cent)
ZONE B (sulphide mixed with silica S 30-40 per cent
STOCKWORK (mineralized brecciated lava S< 30 per cent)
STOCKWORK (mineralized lava with precerved pillow structure S<20 per cent)
Boundary
Inferred boundary
Fault showing downthow direction and dip of fault plane
Bench, elevation in metres
Approximate position of ochre at 340 metre level
Churn drille holes
Geochemical section
Margi
Nisou
Dhali
Perakhorio
Ayia Varvara
Mathiati
Alambra
AREA MAPPED
0 1 2Miles
GEOLOGICAL SKETCH MAP OF THE 330 METRE LEVEL- NORTH MATHIATIS OREBODY (TAMASSOS MINING LEASE)
SCALE 1:1000
Metres10 0 10 20 30 40 50 60 70 80Metres
Metres
DH 2
DH 3
DH 4
DH 5
DH 6
DH 7
DH 8
DH 11
DH 15
DH 16
DH 17
DH 20
DH 22
DH 23
DH 24
DH 25
DH 27
DH 29
MC1-1-22
MC1-1
MC2-23
MC2-41
MC3-58
MC4-27
A
A'
B
B'
N

Faulting, uplifting and subsequent erosion exposed the southeastern part of the orebody (Fig. 4.10) Oxidation of the sulphide ore produced massive gossan which consists mainly of massive jarosite, limonite and patches of white spongy silica. The gossan was worked by C.M.C. in the 1930's for its gold and silver content (Plate 4.54). Sporadic patches of transported massive gossan consisting mostly of jarosite were found on the top of the Upper Pillow Lavas. These patches of gossan tend to fill irregularities on the lava surface, and their deposition was associated with leaching of the underlying lavas.

At the northwestern part of the pit the unmineralized Upper Pillow Lavas are overlain by Perapedhi umber which in turn is overlain by alluvium up to 10 metres thick. The umber is generally massive, fine grained, and has a dark brown to chocolate brown colour. Samples of Perapedhi umber from inside the pit and from an outcrop north of the pit along the Ayia Varvara-Mathiatis road (Fig. 4.9) were analysed with Atomic Absorption Spectrophotometer for copper, zinc, nickel and cobalt by the Chemical Laboratory of the Cyprus Geological Survey. The results of these analyses are shown in Table 4.6 and indicate that the umber from both inside and outside the pit is high in copper, zinc, nickel and cobalt and that the ratios Cu:Zn and Ni:Co are higher than one.

Table 4.6. Atomic Absorption Spectrophotometer analyses of Cu, Zn, Ni and Co in ochre * (1-5), Umber ** in the Pit (6-9) and Umber *** outside the pit (10-12).

Element	OCHRE					PERA PEDHI UMBER						
ppm	1	2	3	4	5	6	7	8	9	10	11	12
Cu	520	216	50	400	800	1220	1000	400	840	760	720	720
Zn	1320	860	2160	280	800	300	380	860	400	360	400	220
Ni	39	19	30	22	51	200	245	240	210	250	240	200
Co	17	15	12	12	30	128	137	133	111	125	96	129
Means	Cu 397 Zn 1084 Ni 32 Co 17					Cu 809 Zn 417 Ni 226 Co 123						

* Samples taken from the 330 metres level (Fig. 4.9)
** " " " " 340 " " Coordinates N 2538m E-2988m
*** " " " outside the pit coordinates N 2305m E-3067m

3. The Ochre Group overlying the Mathiatis Orebody

At the northwestern part of the Mathiatis orebody between the massive ore and the overlying unmineralized Upper Pillow Lavas is interposed a sedimentary layer 3 to 8 metres thick (Figs. 4.9,

Plate 4-54. Mathiatis pit looking south. Showing pit produced from the mining of the gossan overlying the sulphide ore for its gold and silver content. At point indicated by arrow the sulphide ore was encountered.

Plate 4-55. Mathiatis pit looking north. Olivine basaltic flow exhibiting well developed columnar joining and marking the contact between grey-green and pale-grey Upper Pillow Lavas.

Plate 4-56. Mathiatis pit looking southeast. Southern contact of the orebody (left) with unmineralized Upper Pillow Lavas (right) marked by a steeply dipping 300° trending fault.

Plate 4-57. Mathiatis pit looking north. Contact of silicious calcareous tuff (upper half) with massive friable sulphide ore containing rare blocks of solid sulphide. Selenite gypsum and iron staining are common at the contact (point indicated by arrow).

Plate 4-57a. Mathiatis pit looking east. Conglomeratic massive ore underlain by lampy massive ore.

Plate 4-58. Hand specimen showing contact (point indicated by arrow) between ochre with ill-defined colour banding and massive sulphide.

Plate 4-59. Hand specimen of solid sulphide block from the ochre-sulphide ore contact. Note that the cavities in the block are filled with ochre.

Plate 4-60. Hand specimen of massive ore from the top of the orebody. The sulphide is veined with secondary selenite gypsum (white).

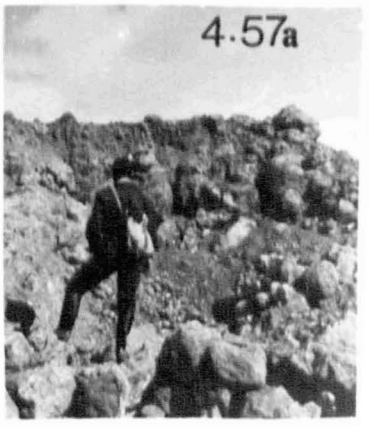
Plate 4-61. Hand specimen of silicious limestone mixed with goethite (dark grey).

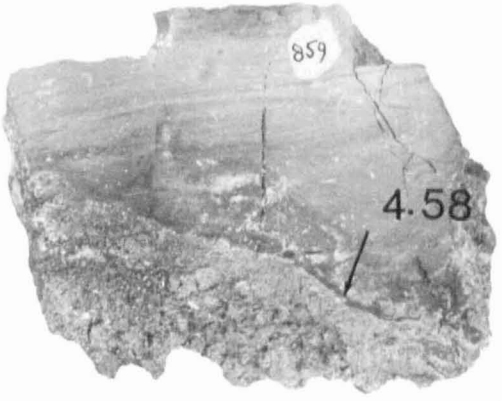

4.54


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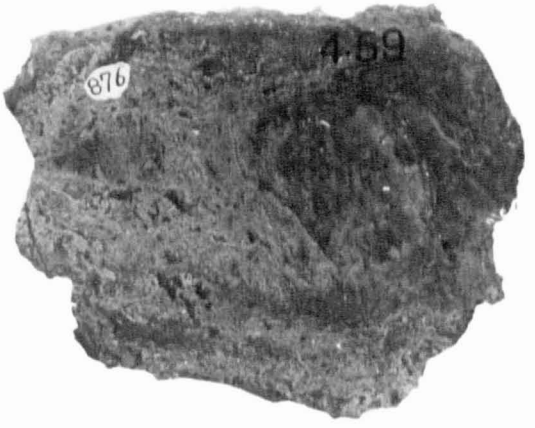

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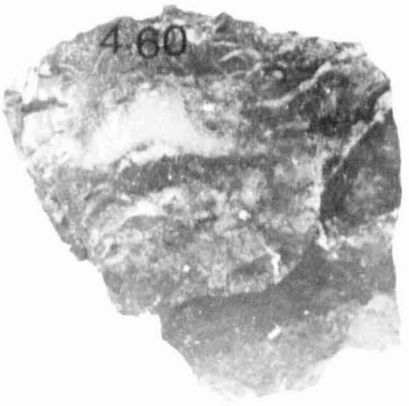

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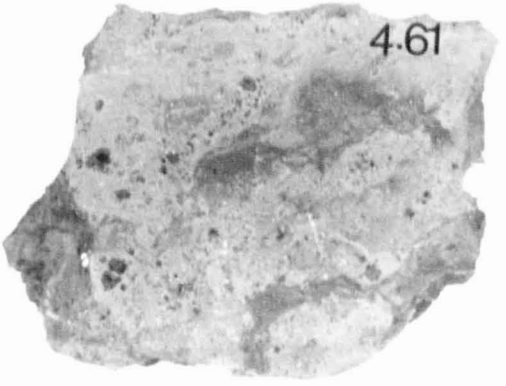


4.58



4.59


4.60


4.61

4.10). This sedimentary layer consists of alternating beds of brown-yellow ochre, silicious limestone, and silicious calcareous tuff. All these rock types occur in direct contact with massive ore at different parts of the orebody. Jarrel (1947) reports that the ochre was overlying the gossan at the eastern part of the orebody.

(a) The brown-yellow ochre

The brown-yellow ochre is the most common rock type in the Ochre Group and is in direct contact with the massive ore in most parts of the orebody. The contact of the massive ore with the brown ochre is gradational. At this contact the brown-yellow ochre predominates and contains only rare solid sulphide blocks. Away from this contact towards the massive ore the sulphide increases regularly at the expense of the ochre to such an extent that at 5 metres from the contact only rare sporadic patches of ochre are scattered in the massive ore. In hand specimens the contact of the solid-sulphide blocks with the ochre is either sharp (Plate 4.58) or gradational (Plate 4.59). In polished sections however even the sharp contact shown in plate 4.58 is seen to be gradational (Plate 4.65).

The brown-yellow ochre is very fine grained and is bedded or massive; not infrequently it exhibits ill-defined banding which consists of alternating thin bands of dark brown, brown and brown-yellow ochre (Plate 4.58). Frequently the ochre and the sulphide in contact with it are ramified with veins of later selenite gypsum (Plates 4.58, 4.60). X-ray diffraction analyses indicate that the ochre consists mostly of goethite and minor amounts of pyrite and quartz (Table 6.1).

Samples of ochre taken from the 330 metre level were analysed with Atomic Absorption Spectrophotometer by the Chemical Laboratory of the Cyprus Geological Survey, for Copper, Zinc, Nickel and Cobalt. The results of these analyses are shown in Table 4.6 and indicate that:

(i) copper is erratically distributed in the ochre and is generally lower than in the umber;

(ii) zinc is also erratically distributed in the ochre but is generally much higher than in the umber; and

(iii) nickel and cobalt are generally low in the ochre and are conspicuously lower than in the umber.

Detailed optical studies suggest that the goethite of the ochre is replacing the pyrite. The replacement of pyrite by goethite appears to be initiated along fractures, grain boundaries and contacts of growth zones (Plates 4.63, 4.64, 4.66). Unzoned pyrite appears to be more resistant to replacement and corroded remnants of such pyrite are found scattered in the ochre (Plates 4.65, 4.66). The amount of remnant pyrite in the ochre decreases abruptly towards the ochre. (Plate 4.65). Frequently fractures or zones of corrosion in pyrite are filled with maghemite but the latter was not observed in the ochre away from pyrite.

(b) The silicious limestone

The silicious limestone in some parts of the 330 and 335 metres levels is in direct contact with the massive ore, but more commonly is interbedded with the brown-yellow ochre and the silicious calcareous tuff. The contact of the silicious limestone and the massive ore is sharp with barren limestone succeeding massive ore over a distance of one centimetre. In hand specimens the silicious limestone is massive, intimately mixed with goethite and is ramified with veins of gypsum (Plate 4.61). The limestone is porous and most of the cavities are filled with goethite which often has well developed boxwork textures (Plate 4.61).

X-ray diffraction analyses (Table 6.1) indicate that the silicious limestone consists mainly of calcite and variable proportions of quartz, goethite and traces of siderite. In thin sections the calcite very often exhibits a characteristic zoned internal structure. The individual zones are separated by a layer of iron oxide possibly goethite (Plate 4.62). Frequently between the calcite crystals there are isolated grains of goethite or maghemite with cubic form, which was probably produced by the oxidation of pyrite cubes (Plate 4.62). One thin section of silicious limestone was treated with potassium ferrocyanide ($K_4Fe(CN)_6 3 H_2O$) and only prussian blue colour was produced suggesting that all the iron in the calcite is in the ferric state.

Plate 4-62. Thin section of silicious limestone showing zoned calcite mixed with quartz. Between the growth zones of coecite there are zones of iron oxide (black) iron oxides are also included in quartz. Cubes or aggregates of cubes consisting of goethite and/or maghemite are common (centre and bottom right) in the limestone.

PPL scale bar = 130 microns.

Plate 4-63. Replacement of pyrite (white) by poorly crystalline goethite (black). Note that replacement follows grain boundaries and contacts of growth zones. Remnants of corroded pyrite are common in the goethite.

PPL scale bar = 480 microns

Plate 4-64. Pyrite replaced by poorly crystalline goethite (black). Fractures in pyrite and interstices between grain boundaries are filled with well crystalline goethite and maghemite (grey).

PPL scale bar = 180 microns.

Plate 4-65. Polished section of the point indicated by arrow in Plate 4-58). The contact between ochre (left) and sulphide is gradational.

PPL scale bar = 400 microns

Plate 4-66. Remnants of intensely corroded pyrite (white) scattered in a matrix of poorly crystalline goethite (black).

PPL scale bar = 1 mm

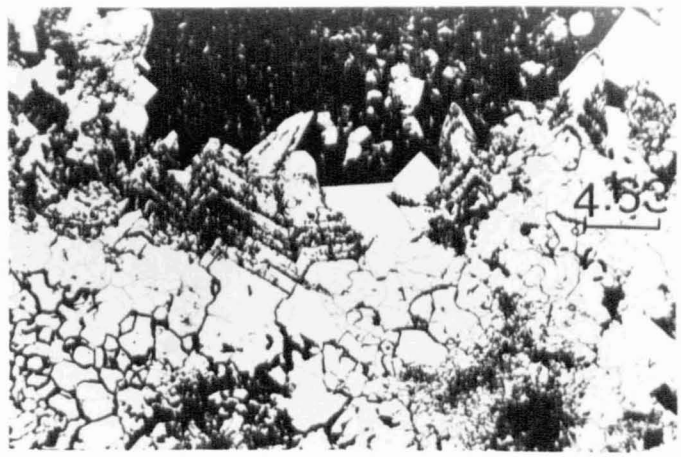
Plate 4-67. Sandy friable massive ore consisting of intensely corroded pyrite. Black area is pore space.

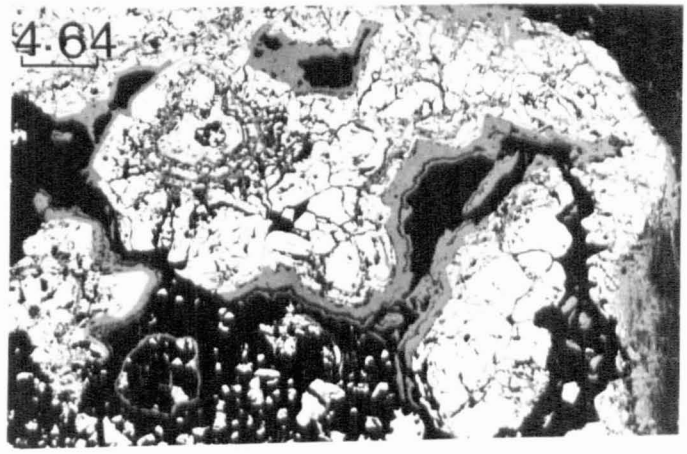
PPL scale bar = 400 microns

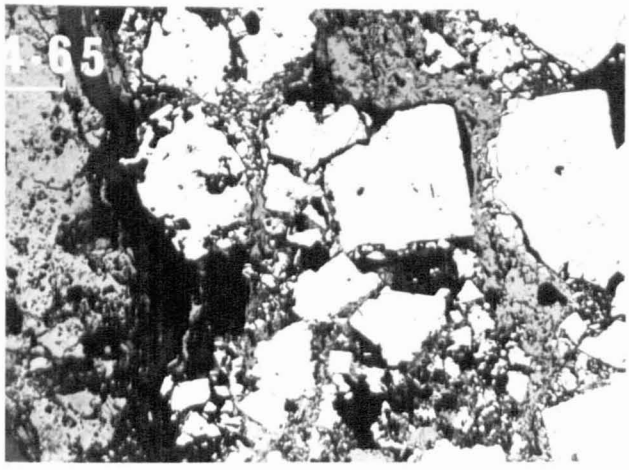
Plate 4-68. Polished section of a block of solid sulphide from the conglomeratic ore. It mostly consists of zoned and unzoned pyrite I partly replaced by pyrite II. At the lower left fine grained anhedral pyrite III replaces the pyrite I.

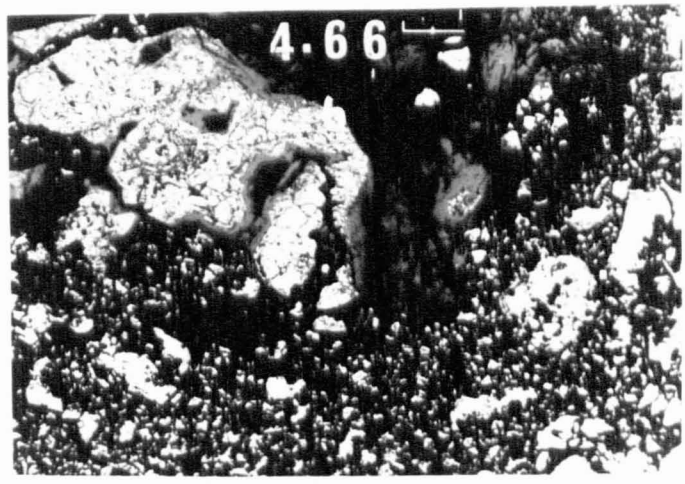
PPL scale bar = 400 microns

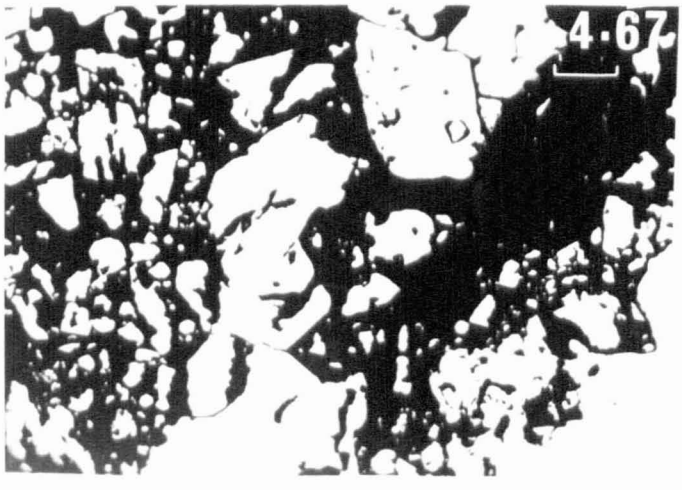

4.62

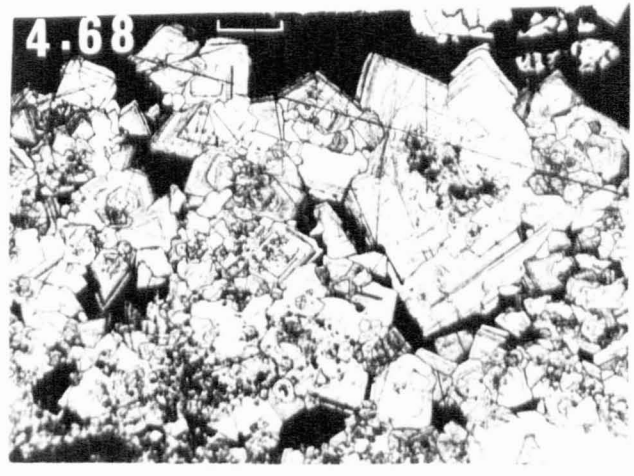

4.63


4.64


4.65


4.66


4.67


4.68

The zoned calcite is frequently truncated by quartz which commonly contains inclusions of iron oxide. Veins of iron oxide also intersect grain boundaries of quartz or are concentrated around the quartz grain boundaries (Plate 4.62). It appears that the iron oxide was originally mixed with the silica but was pushed outwards during the crystallization of the quartz.

One sample of silicious limestone was investigated by Dr. M. Muir of the Department of Micropalaeontology, Imperial College. This investigation revealed that the limestone contains abundant algal filaments and mucilage associated with liquid hydrocarbons. The algae appear to be indigenous in the rock suggesting that the limestone was deposited in rather shallow water i.e. not greater than the depth of penetration of light. The same investigation failed to find any evidence of terrigenous material in the silicious limestone.

(c) The silicious calcareous tuff

The silicious calcareous tuff in many parts of the 340 and 335 levels rests directly on massive sulphide ore (Plate 4.57) but more often is interbedded with the limestone and the brown yellow ochre. In the field it has a pale-grey colour and at its contact with the massive ore is stained with iron oxides (Plate 4.57); veins of later selenite gypsum are common in the tuff particularly at its contact with the sulphide ore. The tuff consists of clastic volcanic material which is cemented with quartz and calcite. Pyrite is common in the tuff and its amount decreases away from the sulphide-tuff contact. In thin sections the pyrite in the tuff is intensely corroded and replaced by quartz; frequently quartz or calcite fills zones of corrosion in pyrite.

4. Contacts and wallrock relationships

The present position and configuration of the Mathiatis orebody resulted mainly from two parallel 300° trending faults. These faults occupy the northeastern and southwestern contacts of the orebody (Fig. 4.9). These faults are traceable to the west of the pit for several kilometres until they disappear under the sedimentary rocks (Searle and Panayiotou 1968). Both faults are

normal and dip steeply away from the orebody and downthrow the Upper Pillow Lavas. In both faults the fault plane consists of a zone of brecciated and argillized lava 3 to 5 metres wide and the hanging wall consists of unmineralized Upper Pillow Lavas (Plate 4.56). The footwall of these faults is occupied by low grade, medium grade and massive ore (Fig. 4.9).

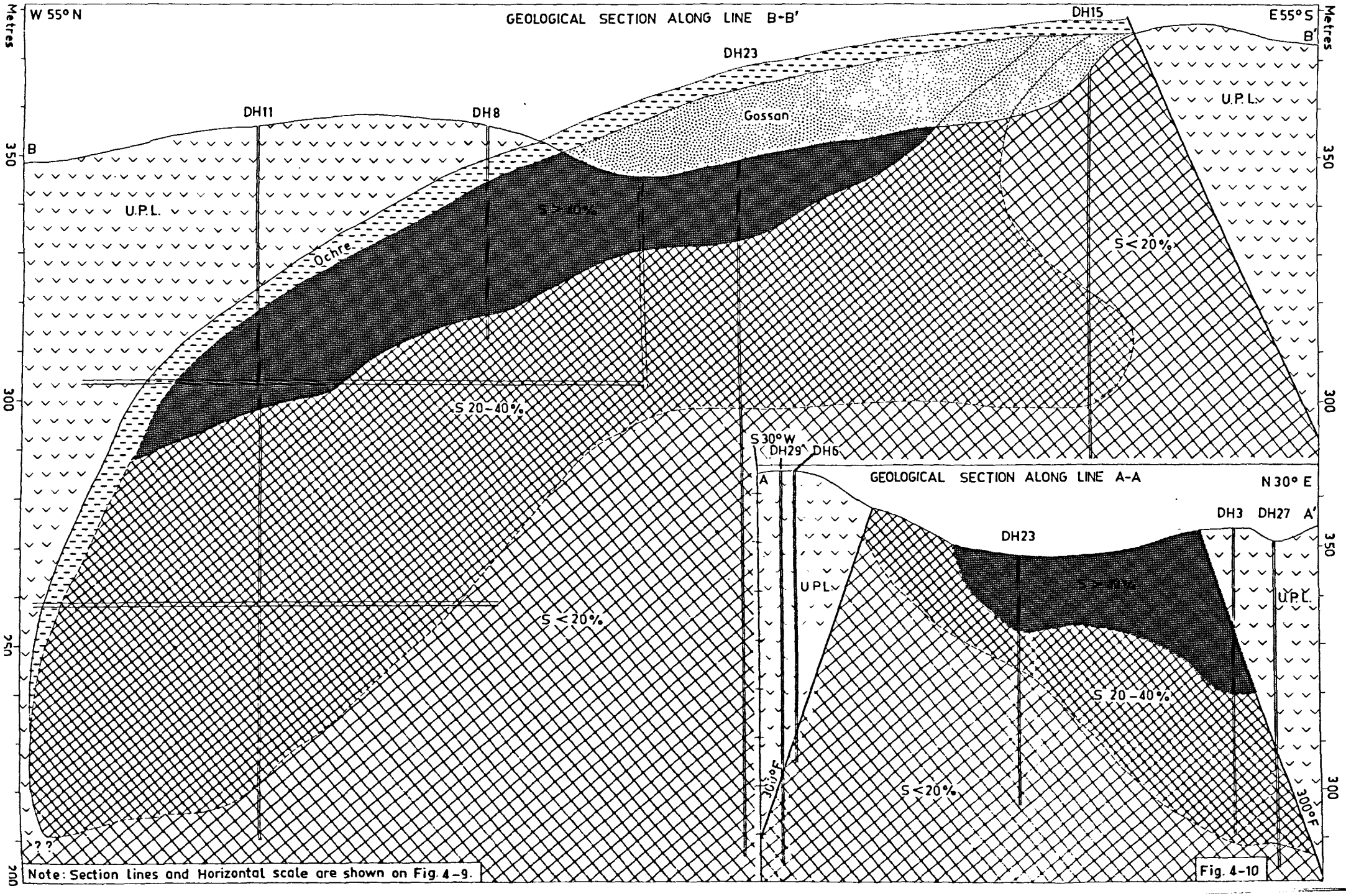
The eastern contact of the orebody is marked by a 350° trending fault. This is a normal fault. It deeps steeply to the east and downthrows the unmineralized Upper Pillow Lavas and upthrows the sulphide ore which was exposed to the surface and oxidized to massive gossan (Fig. 4.10). The 350° trending fault truncates the two 300° trending faults and in the triangle which is formed by the intersection of the 350° trending fault and the southern 300° trending fault, unmineralized Upper Pillow Lavas rest on mineralized and hydrothermally altered lavas. To the east several hundred metres away from the orebody the U.P.L. are overlain by Perapedhi umber which in turn is overlain by marls and chalks of the Lefkara Group.

The northwestern part of the orebody is overlain conformably by the sediments of the Ochre Group which in turn are overlain by unmineralized U.P.L. (Figs 4.9, 4.10). The contact of the ochre Group with the orebody dips to the northwest and the amount of dip varies from 30° to 60°. Not infrequently this contact contains shear zones and slips the presence of which suggests that some movement had occurred along the contact.

5. Shape, Structure and Trace Element Chemistry of the Mathiatis Oredbody.

The present form and attitude of the Mathiatis orebody is the result of postmineralization faulting. It appears that during the faulting the orebody was tilted about 35° to the northwest.

A characteristic feature of the Mathiatis orebody is the zoning of the ore. Because of the tilting the originally vertical zoning now occurs on a horizontal plane (Fig. 4.9). The upper part of the orebody consists of massive ore which contains more than 40per cent sulphur. After correction for the tilting the massive ore appears to have had a lenticular form and a flat lying surface.



Note: Section lines and Horizontal scale are shown on Fig. 4-9.

Fig. 4-10

As mentioned before the massive ore is overlain by the ochre Group which in turn is overlain by unmineralized Upper Pillow Lavas.

The massive ore is underlain by the zone B which consists of medium grade sulphide ore, intimately mixed with silica, and containing 30 to 40 per cent sulphur. Zone B is in turn underlain by the stockwork zone which consists of low grade ore in hydrothermally altered lavas. At the upper part of the stockwork the sulphur content is less than 30 per cent and decreases to less than 10 per cent at its lower parts.

Grap samples of ore were collected along 3 almost parallel lines, intersecting the massive ore, the zone B and the stockwork zone (Fig. 4.9). These samples had been analysed with Atomic Absorption Spectrophotometer for copper, zinc, nickel and cobalt by the Chemical Laboratory of the Cyprus Geological Survey. The distribution of these elements along two of the three lines is illustrated in figure 4.11, and it is obvious that:

(a) copper is generally low and erratically distributed in the Mathiatis orebody and in one line it decreases substantially near the top of the massive ore.

(b) zinc is also erratically distributed and is generally higher than copper.

(c) cobalt is generally low and is erratically distributed, and tends to increase considerably in the stockwork zone, and

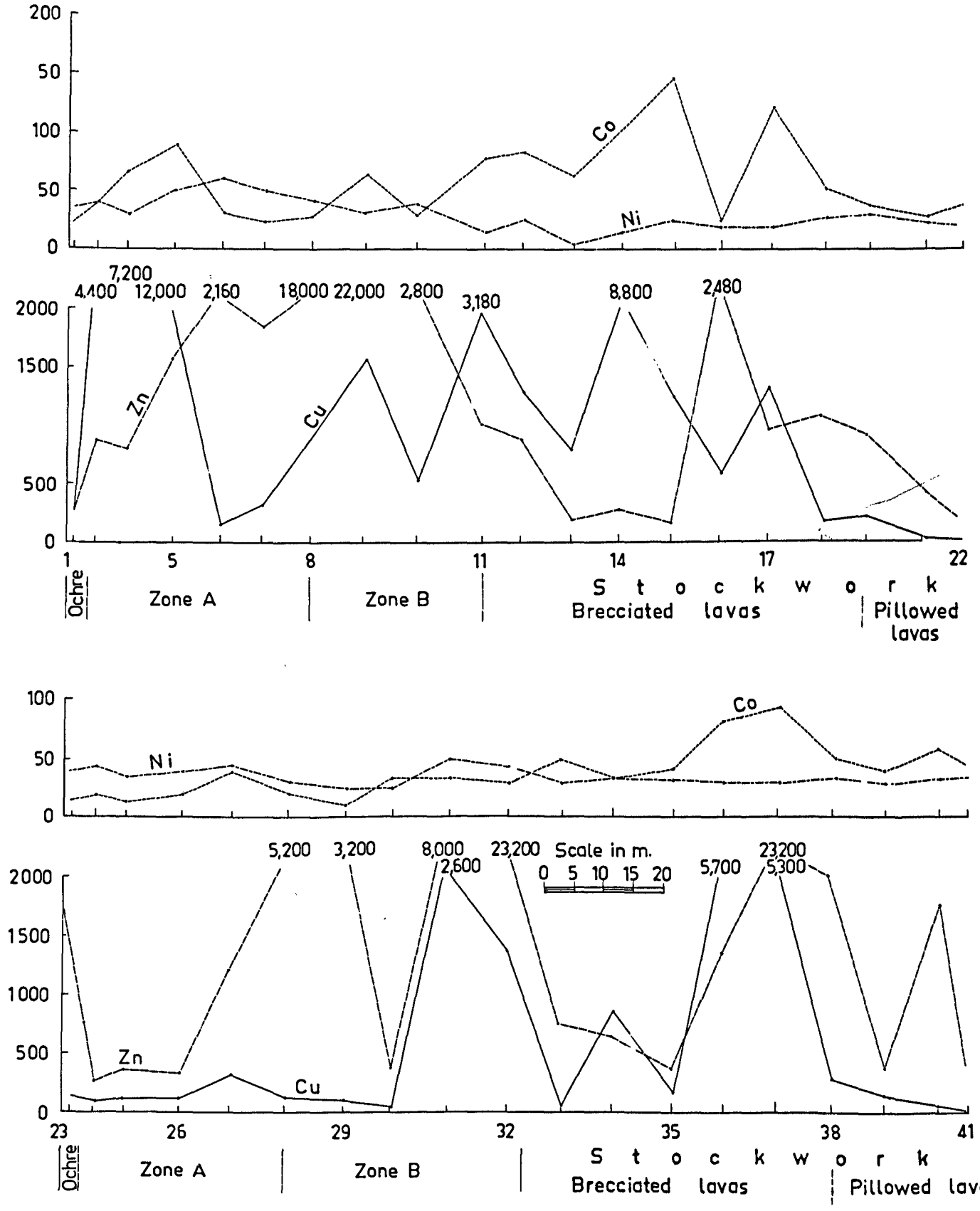
(d) nickel is generally low and is less erratically distributed than the other three elements. In the massive ore it generally tends to be higher than cobalt whereas in the stockwork zone it decreases considerably and is much lower than cobalt.

6. The Massive Ore (Zone A)

(a) General Characteristics of the Massive Ore.

The massive ore at its contact with the sediments of the Ochre Group consists mostly of sandy friable and highly porous ore in which are embedded rare blocks of solid sulphide (Plate 4.57). Away from this contact towards the massive ore the proportion of solid sulphide blocks increases regularly at the expense of the

Fig. 4-11. Trace element distribution in the zones A,B and stockwork at the 330 metre level of the north Mathiatis orebody.



sandy friable ore. About 5 metres away from the above contact the massive ore has a conglomeratic structure and consists mainly of solid sulphide blocks encased in a matrix of sandy friable ore.

The solid sulphide blocks are angular, subangular or rounded and have a variable size. They are characterized by high porosity but are much less porous than the surrounding sandy friable ore. In hand specimens the cavities have a random distribution and variable size; most of the cavities are empty but near the top of the massive ore the cavities are partly filled with silica and gypsum. Colloform banding is common in the solid sulphide blocks; optical studies suggest that the colloform banding is related to differences in reflectivity which is due to differences of the total porosity in the individual bands.

(b) Ore Mineralogy of the Massive Ore.

The mineral assemblage in the massive ore of the Mathiatis orebody is rather simple and includes pyrite, marcasite, and minor amounts of sphalerite, chalcopyrite and secondary copper sulphides. The sandy friable ore is highly porous and its porosity generally exceeds 50 per cent of the surface area as viewed in polished sections (Plate 4.63). It consists mostly of intensely corroded remnants of unzoned Pyrite I (Plate 4.67). Covellite is the only other mineral found in the sandy friable ore and it occurs only in trace amounts.

In the conglomeratic ore the solid sulphide blocks consist of either pyrite or a mixture of pyrite and marcasite. The solid blocks which contain no or very little marcasite, consist of zoned pyrite I with internal characteristics similar to those described in the Skouriotissa orebody. The zoned pyrite I is truncated by later anhedral pyrite II (Plate 4.68). Collomorphic pyrite is common and truncates both pyrite I and pyrite II (Plate 4.68).

In the sulphide blocks with abundant marcasite - the latter forms mainly elongated bladed crystals often with radiating arrangement. Anhedral marcasite crystals with smooth curved grain boundaries, as well as marcasite with euhedral zoned structure are common. In electrolytically etched polished sections the internal zoned structure of marcasite resembles the internal zoned structure

of pyrite I. In some rare cases where zoned marcasite is in contact with zoned pyrite similar growth zones are traceable from pyrite to marcasite (Plate 4.70). Collomorphic marcasite was observed along fractures which truncate euhedral or bladed marcasite (Plate 4.76).

In the sulphide blocks with abundant marcasite the age relationship between pyrite and marcasite is very complicated; their grain boundaries are very irregular and both minerals project into each other. Despite the fact that all the criteria indicative of replacement, e.g. mutual boundaries relationship, inclusions, residual and graphic intergrowths are present it is not possible in this case to distinguish between the host and the guest mineral (Plates 4.68, 469). However the tendency of marcasite to concentrate in fractures which intersect pyrite and its tendency to decrease abruptly away from these fractures (Plate 4.71) seem to suggest that marcasite is later than pyrite.

Many solid sulphide blocks contain framboidal and pseudoframboidal pyrite and less commonly marcasite. Isolated pyrite framboids are rare whereas clusters of framboids are common. In these clusters the individual framboids are inter connected with narrow bridges which consist of pyrite or marcasite. The clusters of framboids tend to be concentrated in cavities and are connected to the surrounding wreath-like marcasite with narrow bridges of marcasite (Plate 4.75). Clusters of framboids are also common in zones of high porosity (Plates 4.72, 4.73, 4.74, 4.75). The contact of the marcasite with the highly porous zones, and the associated framboids is very irregular and resembles a replacement boundary (Plates 4.72, 4.33). It appears that the whole surface area shown in Plates 4.72 and 4.73 was originally occupied by pyrite which was partly corroded and partly replaced by marcasite and framboidal pyrite and marcasite.

In the conglomeratic ore sphalerite is the second most common sulphide after pyrite and marcasite. Most of the sphalerite occurs as interstitial material to pyrite or marcasite and tends to be concentrated in fractures or zones of high porosity. The interstitial sphalerite is mostly anhedral but etching revealed that in some cases it has an internal euhedral zone.. structure

Plates 4-68a, 4-69. Grain boundary relationships between pyrite (high relief) and marcasite in a marcasite-rich solid sulphide block.

PPL scale bar = 1.2 mm

Plate 4-70. Zoned marcasite along a fracture in a solid sulphide block. At the centre zoned pyrite (white) is in contact with zoned marcasite and growth are traceable continuously through pyrite to marcasite.

PPL scale bar = 480 microns

Plate 4-71. Marcasite confined to the vicinity of the fracture (lower half) whereas it decreases abruptly away from it (upper half mostly pyrite.

PPL scale bar = 1.2 mm

Plate 4-72. Framboidal pyrite and/or marcasite restricted to zones of high porosity in marcasite. The zones of high porosity develop at the expense of marcasite.

PPL scale bar = 400 microns

Plate 4-73. Clusters of pyrite and/or marcasite framboids associated with zones of high porosity. The contact between zones of high porosity and marcasity is irregular.

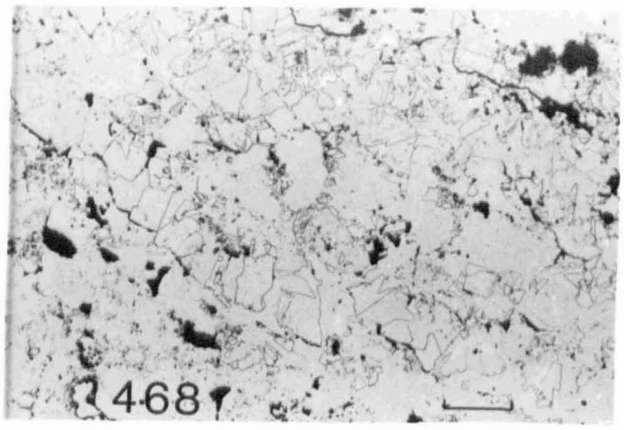
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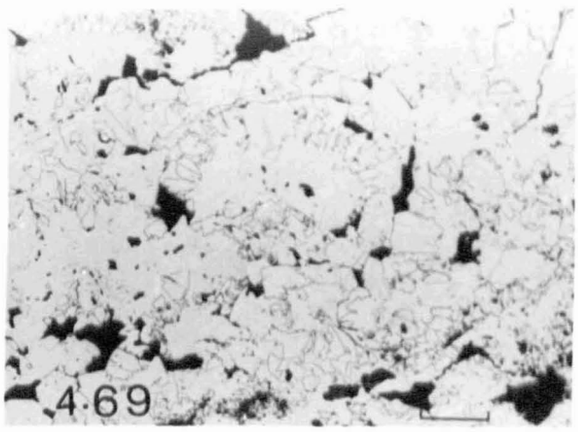
Plate 4-74. Clusters of pyrite framboids surrounded with bladed marcasite.

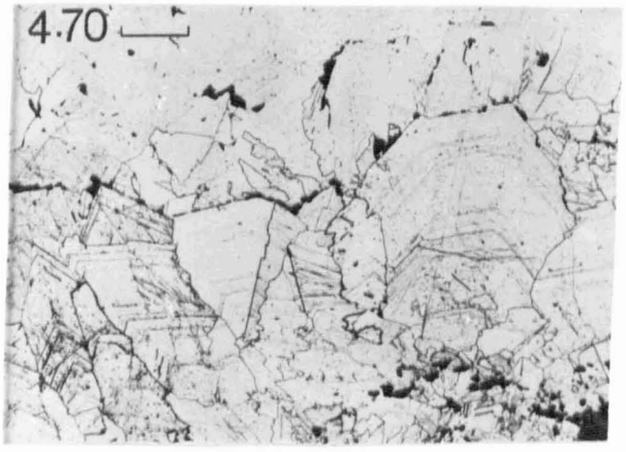
PPL scale bar = 480 microns

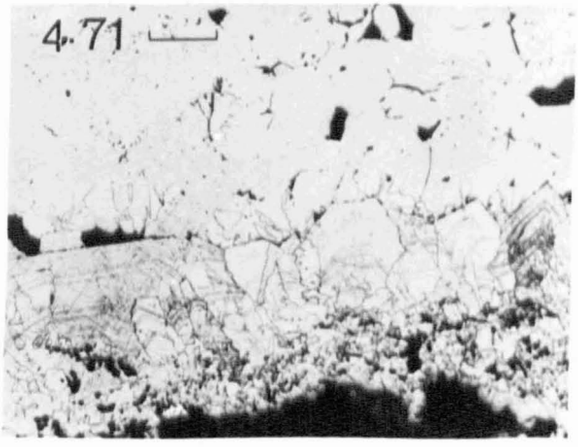
Plate 4-75. High magnification of the central part of the plate 4-74, showing that the clusters of pyrite framboids are connected with the surrounding marcasite with narrow bridges.

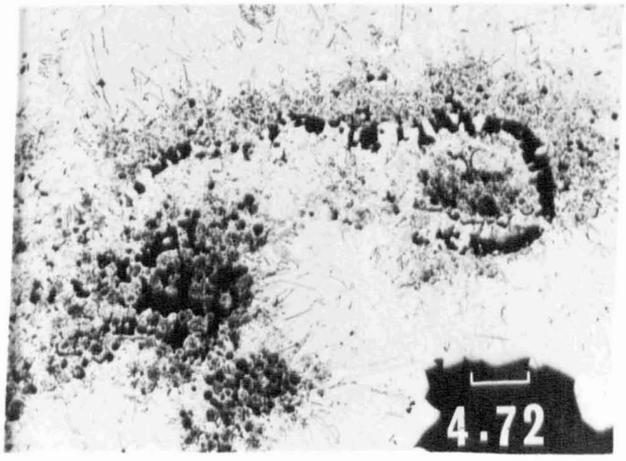
PPL scale bar = 187 microns

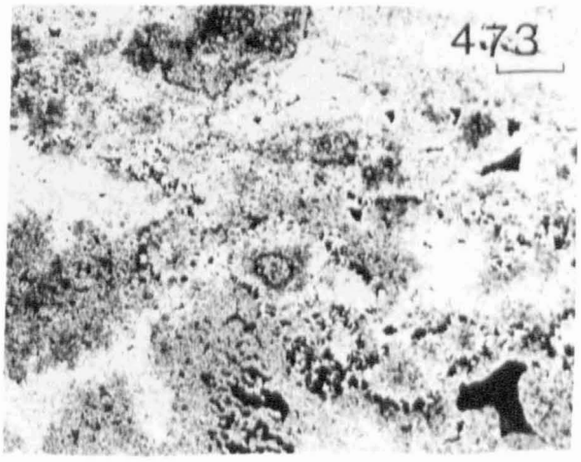

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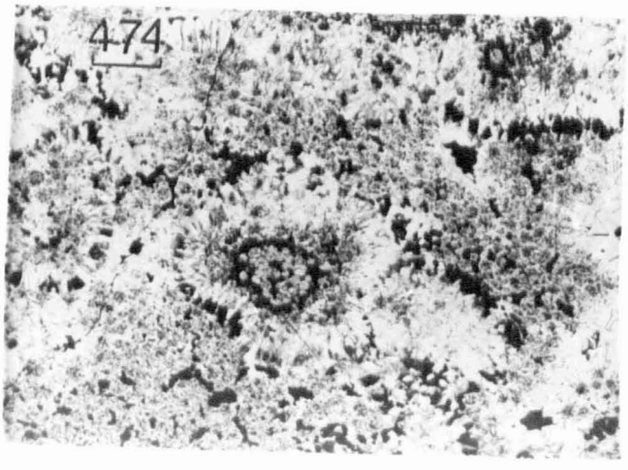

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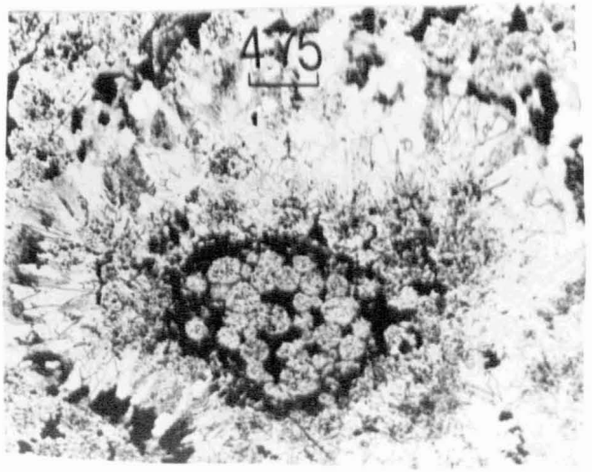

4.70


4.71


4.72


4.73


4.74


4.75

(Plate 4.78). In some cases the interstitial sphalerite has two markedly different colours and contains remnant pyrite (Plate 4.77). Sphalerite is also present in the form of small anhedral crystals included in pyrite.

Covellite is the most common copper sulphide in the massive ore of the Mathiatis orebody. It exists at the ochre-sulphide ore contact, in the domains of the sandy friable ore and in the conglomeratic ore and it fills cavities in pyrite or marcasite. Digenite is the next most common secondary copper sulphide; it exists only in the conglomeratic ore and it also fills cavities in pyrite and marcasite. Minor amounts of chalcopyrite were observed only in the conglomeratic ore in the form of small anhedral crystals included in the pyrite and less commonly as interstitial material to pyrite.

7. The Zone B

In the Mathiatis orebody the Zone B is 10 to 30 metres thick and consists of lumpy very hard medium grade ore with a sulphur content ranging between 30 and 40 per cent (Plate 4.57a). In this zone the sulphide ore is intimately mixed with white silica and red jasper. The red jasper is in the form of veins but more commonly in the form of nodules with a diameter up to 30 centimeters. Veins of late chalcedony commonly truncate the veins and nodules of the red jasper.

Pyrite, mostly unzoned and intensely corroded, is the predominant sulphide mineral in the zone B (Plates 4.80, 4.81). The morphology of the corroded pyrite in the zone B is generally similar with the morphology of the corroded pyrite of the sandy friable ore and the morphology of the remnant pyrite found in the ochre (compare Plate 4.81 with Plates 4.66, 4.67). In zone B the empty space in the sandy friable ore, is occupied by silica. The quartz-pyrite grain boundaries are very irregular, and careous textures are common (Plate 4.81). Remnants of zoned pyrite are rare in the zone B (Plate 4.80).

In thin sections the silica is represented by granular quartz and chalcedony. The latter is more common near the corroded pyrite and very often exhibits collomorphic textures with

Plate 4-76. Collomorphic marcasite filling fracture. The side of the fracture is occupied by euhedral and bladed marcasite whereas away from the fracture (upper part) only euhedral pyrite occurs.

PPL scale bar = 480 microns

Plate 4-77. Sphalerite filling cavities in pyrite and containing remnants of corroded pyrite. Note that sphalerite has two distinct colours of which the dark grey predominates.

PPL scale bar = 185 microns

Plate 4-78. Electrolytically etched specimen showing zoned sphalerite filling cavities in pyrite.

PPL scale bar = 185 microns

Plate 4-79. Thin section showing sphalerite filling cavities in pyrite (black). The randomly distributed black areas in sphalerite represent zones of dark brown colour grading outward, into pale brown colour.

PPL scale bar = 150 microns

Plate 4-80. Intensely corroded zoned and unzoned pyrite embedded in silica (black).

PPL scale bar = 1.0 mm

Plate 4-81. Intensely corroded pyrite embedded in silica. The total space occupied by silica in this plate is generally equal to the total empty space in Plate 4-67.

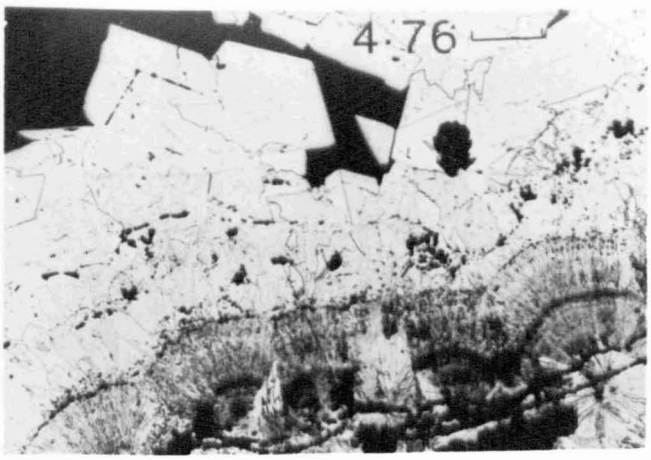
PPL scale bar = 1.2 mm

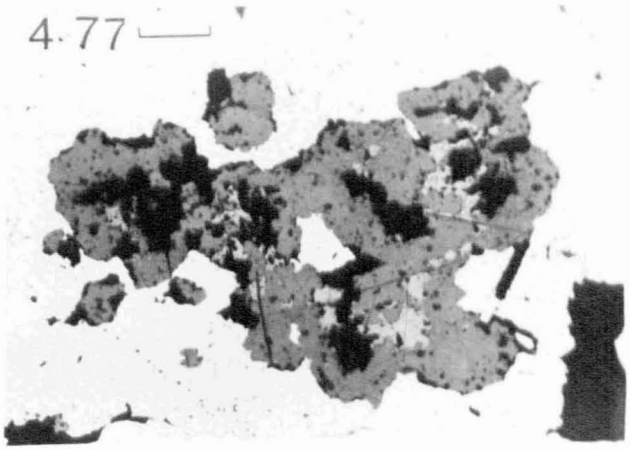
Plate 4-82. Highly corroded pyrite embedded in silica.

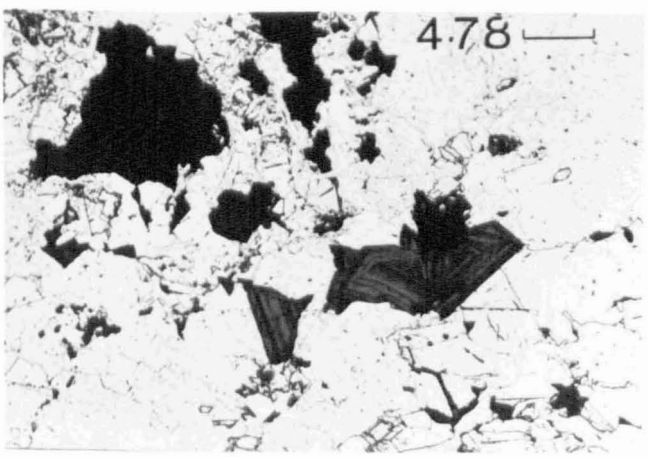
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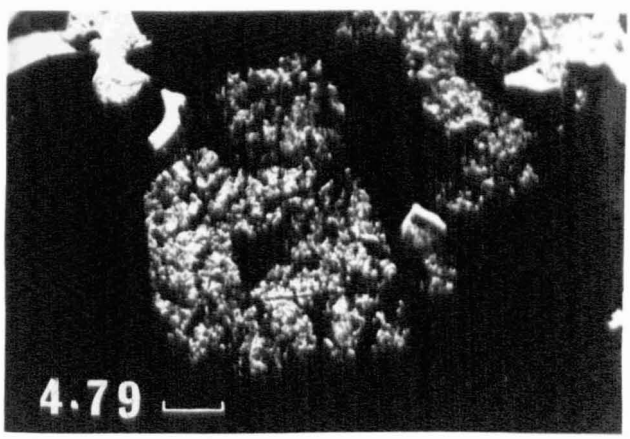
Plate 4-83. Collomorphic chalcedonic silica with synaeresis cracks. Euhedral pyrite as well as remnants of corroded pyrite are scattered in the silica.

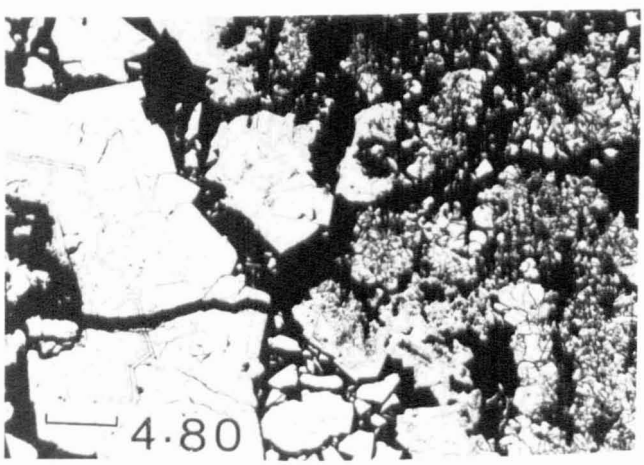
PPL scale bar = 516 microns

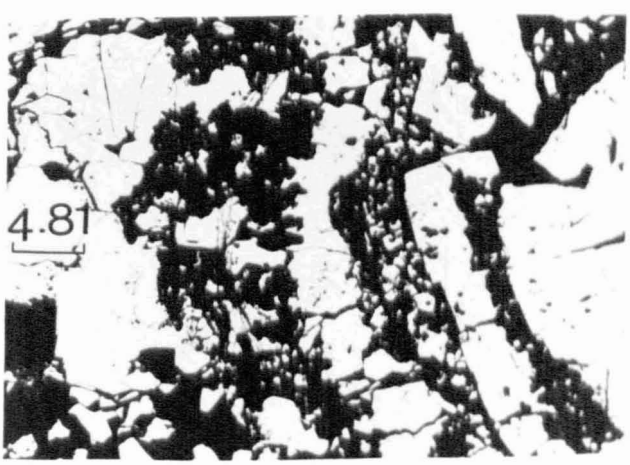

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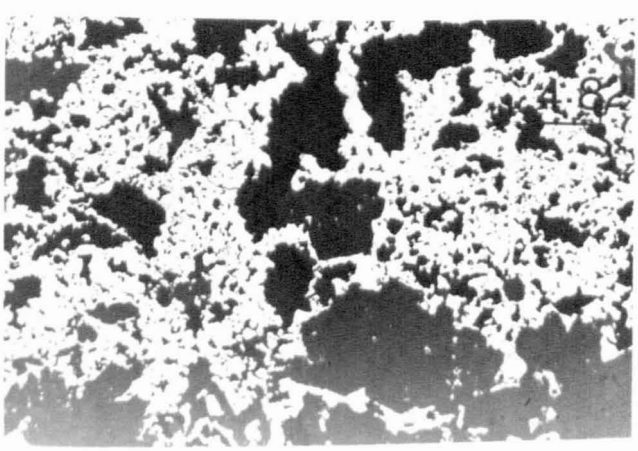

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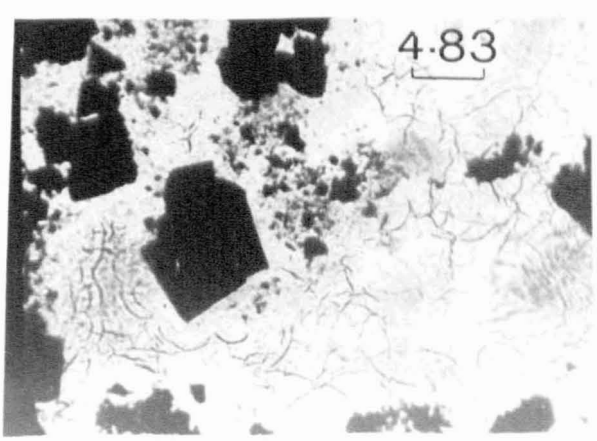

4·78


4.79


4·80


4.81


4·82


4·83

well defined syneresis cracks (Plate 4.83). Frequently the quartz which is in contact with corroded zoned pyrite has a characteristic internal zoned structure (Chapter 7, Plates 7.16, 7.17). It generally appears that originally the zone B was made up of massive ore which had disintegrated, and subsequently the pyrite fragments were healed with quartz.

Sphalerite tends to increase at the contact of the zone B with the massive ore. The sphalerite is either in the form of interstitial material to pyrite or is scattered in the silica matrix. The sphalerite which is scattered in the quartz is corroded and the zones of corrosion are filled with quartz. In thin sections this sphalerite exhibits characteristic colour variation which consists of randomly distributed zones with a dark brown core grading outward, into pale brown colour. Electron probe analyses of polished sections from the same samples show that the colour variation in this sphalerite is due to variation in iron content (Chapter 8, Plates 8g, 8j Table 8.1).

8. The Stockwork Zone

The Zone B is underlain by the stockwork zone and the contact of these two zones is sharp. The upper part of the stockwork zone consists of low grade ore in brecciated and hydrothermally altered lavas. The lower part of the stockwork consists of mineralized and hydrothermally altered Pillow Lavas (Fig. 4.9). At the upper part of the stockwork the mineralization is represented by sulphide veins which cement the brecciated lava or fill fractures in the lava fragments and by pyrite which is disseminated in the brecciated lava. Its sulphur content ranges from 15 to 30per cent and it decreases regularly with depth. In the lower parts of the stockwork the mineralization is represented by sulphide veins which fill fractures in the pillows and by pyrite which impregnates the pillow lava. Its sulphur content is generally less than 15per cent.

The sulphide veins consist of unzoned and less commonly zoned pyrite which is intensely corroded and replaced by quartz (Plate 4.82). Chalcopyrite and sphalerite are rare in the sulphide veins and they occur in the form of small anhedral crystals included in pyrite.

Polished section studies have shown that the brecciated and the pillowed lavas are impregnated with fine grained pyrite but no chalcopyrite or sphalerite was observed disseminated in the lava. Skeletal leucoxene is commonly scattered in the lava and it also exists as rare inclusions in the pyrite which is disseminated in the lava. Thin section studies have shown that in many cases the original texture of the mineralized lava is preserved. Thus ghost vitreous and microporphyritic textures are common and the plagioclase and pyroxene are replaced by quartz whereas the glassy matrix is altered to a mixture of chalcedony and chlorite.

The sulphide mineralization was associated with hydrothermal alteration of the lavas. X-ray diffraction analyses of hydrothermally altered lavas indicate that in addition to pyrite the products of alteration include quartz chlorite and traces of illite (Table 10.2). Chlorite-rich specimens were leached with boiled 15% H.Cl. and analysed again with the diffractometer to test if there was any contribution by kaolin group minerals to the 7A° reflection. This test has shown that no kaolin group minerals had been produced during the hydrothermal alteration of the lavas in the stockwork of the Mathiatis orebody.

9. Summary

The present configuration and position of the Mathiatis orebody resulted from postmineralization faulting and tilting. During the faulting the block which contains the orebody was uplifted and subsequent erosion exposed part of the ore which oxidized to gossan. The orebody is surrounded by unmineralized olivine basaltic Upper Pillow Lavas. Most of the contacts of these lavas with the orebody are faulted but at the southeastern part of the orebody the U.P.L. are resting on weakly mineralized and hydrothermally altered lavas.

At the northwestern part of the orebody the massive ore is overlain by the sediments of the Ochre Group which in turn are overlain conformably by unmineralized olivine basaltic Upper Pillow Lavas which are covered with umber. The Ochre Group consists of alternating beds of brown ochre, silicious limestone and siliceous tuff. The brown ochre-sulphide ore contact is

gradational and optical studies suggest that the goethite which is the main constituent of the ochre is replacing the pyrite. The occurrence of the Ochre Group suggests that after the emplacement of the orebody and before the extrusion of the U.P.L. there was a period of weathering and sedimentation. The fact that ochre or limestone overlie directly the massive ore suggests that during the deposition of the ochre and/or the limestone the massive ore was exposed at the seafloor.

In the Mathiatis orebody because of the tilting the original vertical zoning exists in a horizontal plane. The upper part of the orebody consists of massive pyritic ore containing more than 40 per cent sulphur and less than 0.3 per cent copper. The upper part of this massive ore consists of sandy friable and highly porous ore whereas the rest of the massive ore consists of conglomeratic ore. Pyrite is the predominant mineral in the massive ore. Zoned and unzoned pyrite I, Pyrite II, collomorphic and framboidal pyrite all are common in the massive ore. Marcasite is common in the solid sulphide blocks of the conglomeratic ore; it appears to replace the pyrite and is probably later than pyrite. Sphalerite covellite, digenite and chalcopyrite are the other minerals of the massive ore.

The massive ore is underlain by the zone B which consists of sulphide mixed with silica and contains 30 to 40 per cent sulphur. Pyrite is the predominant sulphide mineral followed by sphalerite and chalcopyrite in decreasing order of abundance. All the sulphides are corroded and replaced by silica which was probably introduced after the sulphides. The silica is in the form of granular quartz (often with internal growth zoning), chalcedony (often exhibiting collomorphic textures and syneresis cracks) and cryptocrystalline red jasper.

The zone B is underlain by the stockwork zone which consists of sulphide ore in brecciated or pillowed lavas and generally contains less than 30 per cent sulphur. The sulphide mineralization is represented by sulphide veins (filling fractures) and pyrite disseminated in the lava. The sulphide veins consist of intensely corroded pyrite in places replaced by quartz. Rare chalcopyrite and sphalerite occur in the sulphide veins in the form

of anhedral crystals included in the pyrite. The lavas are impregnated with pyrite and contain no sphalerite or chalcopyrite. Skeletal leucoxene is scattered in the lavas or is included in pyrite. The sulphide mineralization was associated with hydrothermal alteration of the lavas. The products of the hydrothermal alteration are quartz, variable proportions of chlorite and traces of illite.

CHAPTER V

THE KALAVASOS MINING AREA

(A) INTRODUCTION

1. Location and History

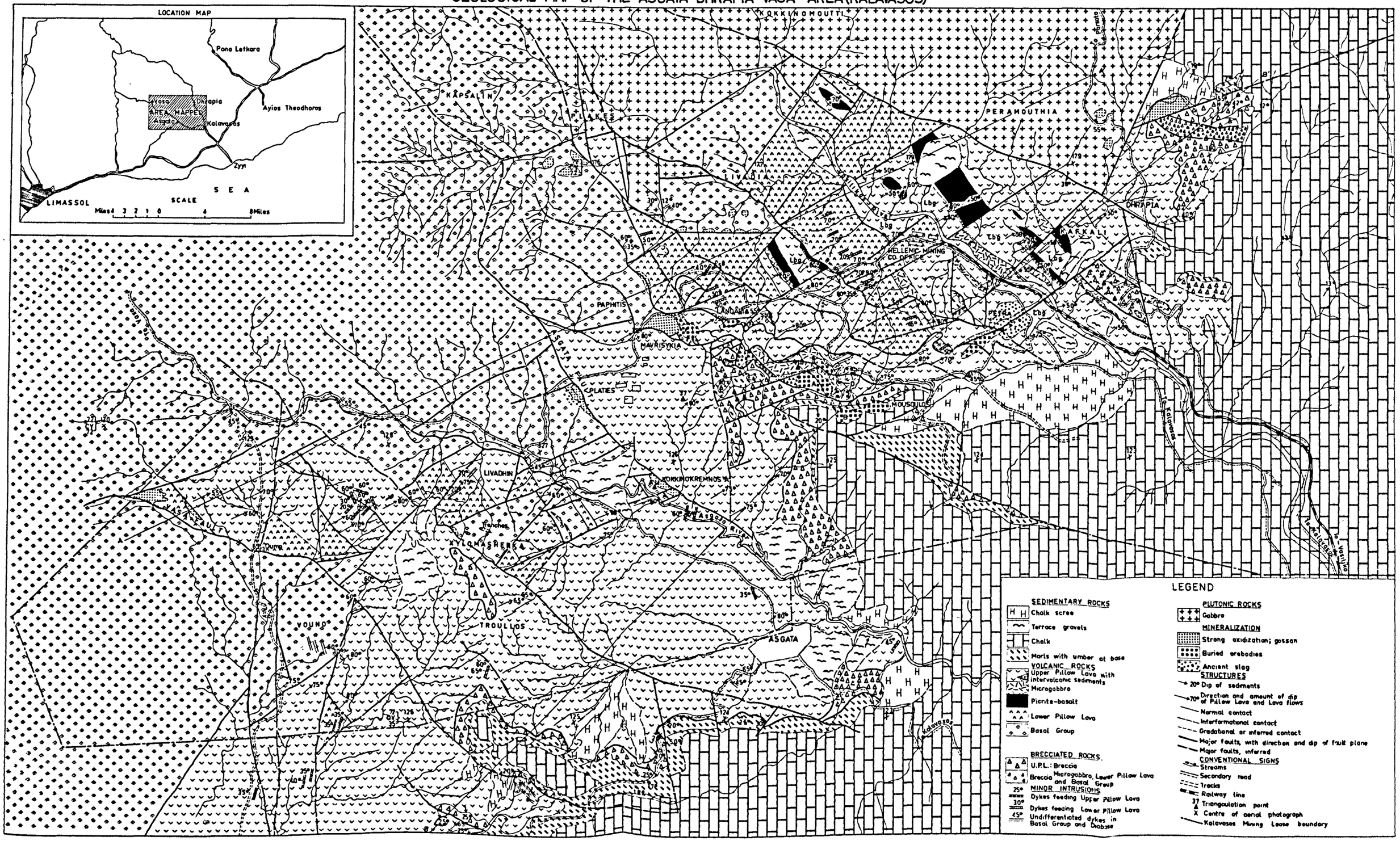
The Kalavasos mining area, measuring approximately 8.5 by 4.5 kilometres, is situated on the southern side of the Troodos range and about 10 kilometres from the southern coast. The area is 64 road kilometres due south of Nicosia and 4 kilometres west of the Kalavasos village (Fig. 5.1). The area covers part of the Mining Lease No.20 held by the Hellenic Mining Company.

The Kalavasos area has had a long history of exploitation dating back to the Early Bronze Age. In this area were located the most important mines of the Kingdom of Amathus (to the east of the present town of Limassol) which was founded prior to 800 B.C. Exploitation probably continued during the Roman times (58 B.C. - 395 A.D.). Evidence of ancient workings has been found in most of the orebodies in the area. The extensive nature of this ancient activity is indicated by the 750,000 tons of slag (Gordon-Smith 1963) existing around Petra, Mavridia, Platies and Mavri Sykia orebodies (Fig. 5-1). There is no record of mining activity after the Roman times until the first decades of this century, when the Pyrites Company started exploration in the area in 1927.

The Pyrites Company discovered some massive pyritic ores but, because of the depression in the 1930s the company allowed their permit to lapse. In 1935 the Hellenic Company of Chemical Products and Manures . Limited acquired the prospecting rights in the area and resumed extensive exploration. Substantial tonnages of massive ore were located and in 1937 a Mining Lease covering 28 square kilometres was issued to the above company. A plant was erected at Vasiliko, on the southern coast, for the treatment and shipment of the ore, and in 1937 commenced the mining of the Mavridhia orebodies. In 1948 the above mining company changed to Hellenic Mining Company Limited. Since 1937 ten separate orebodies ranging in size from 50,000 tons to 1,500,000 tons have been discovered and worked the area. The most recently

GEOLOGICAL MAP OF THE ASGATA-DHRAPIA-VASA AREA (KALAVASOS)

Fig. 5-1



After Searle and Constantinou (1967)

discovered Mousoulos orebody is now the only working mine.

2. Previous work and present investigation

The first detailed account of the geology of the area was written by Mousoulos (1957, in Greek). In the official records of the Hellenic Mining Company there is an unpublished interim report on the area by Gordon-Smith (1963) who also discussed the geology of the area in his Ph.D thesis (Gordon-Smith, 1968); Schmidt (1960) refers to some of the Kalavasos mines in a paper dealing with structural problems of the Cyprus sulphide deposits; Bear (1963) gives a summary of the previous geological work and compiled the production figures up to 1962. The Kalavasos Mining area covers part of the Pharmakas-Kalavasos area described by Pantazis (1967) in Memoir No. 8 of the Cyprus Geological Survey. In this memoir a general description of the orebodies was presented and the production figures were brought up to date. The same author in a recent publication (in Greek), gave a general description of the orebodies and discussed their genesis(Pantazis 1969).

At the beginning of 1966 Searle undertook the detailed surface mapping of the area containing all the economic orebodies, as part of the Mineral Exploration of the U.N.S.F.P. in Groundwater and Mineral Resources. The mapping was carried out intermittently up to 1967 on a scale of 1.2500 using as base map or topographical map of the area supplied by the Hellenic Mining Company.

At the end of 1966 the writer joined Searle as local counterpart in the above project and undertook the mapping of the area north of Vasilikos river and west of the mine offices. In collaboration with Searle the writer also mapped the Asgata Vasa area (Fig. 5-1). The mapping was done on a scale of 1:10000 using aerial photographs. Because most of the orebodies in the area were closed, for their detailed study the writer undertook the logging of many boreholes over and around these orebodies using the mounted on scale-board chippings, made available by the Hellenic Mining Company. Finally, for the better study of the geological setting of the orebodies the writer undertook the detailed underground mapping of the Mousoulos

orebody the only operation mine in the area on the scale of 1:250 using as base map the mine plans kindly supplied by the Hellenic Mining Company. The results of the field work were compiled in two U.N. reports(Searle and Constantinou 1967, 1967a).

B. GEOLOGY OF THE KALAVASOS AREA

1. General statement

The northern part of the area (Fig. 5-1) is occupied by Plutonic rocks which are mainly gabbros similar to the gabbros of the Troodos Plutonic Complex. The plutonic rocks are faulted against the Upper and Lower Pillow Lava and the Basal Group but their study is beyond the scope of the present investigation.

The first volcanic phase in the area is represented by the formation of the Basal Group. After the extrusion of the Basal Group and before the second volcanic phase which formed the Lower Pillow Lavas there was a pause in volcanicity and a period of tectonic movements. The last volcanic cycle resulted in the accumulation of the Upper Pillow Lavas. The thin layers of ochreous sediments lying on weathered Lower Pillow Lava and overlain conformably by Upper Pillow Lavas suggest that between the extrusion of the Lower and Upper Pillow Lavas there was a pause in volcanicity and a period of submarine weathering, followed by sedimentation.

The presence of sporadic intervolcanic sediments in the Upper Pillow Lavas is a fundamental feature of the Kalavasos area. The intervolcanic sediments facilitated the subdivision of the Upper Pillow Lavas into three lithostratigraphical units with destinct field and petrographic characteristics. The intervolcanic sediments also suggest that during the accumulation of the U.P.L. there were periodic pauses in v lcanicity. Between the Upper Pillow Lavas and the overlying sedimentary rocks a discontinuous zone of breccia is interposed. The breccia consists entirely of Upper Pillow Lava fragments and rests unconformably on the Pillow Lavas and is overlain conformably by the Perapedhi sediments.

A regional feature of this area is the steep northeasterly dip of the Lower and Upper Pillow Lavas and the Basal Group. This steep inclination of the lavas was the result of intense faulting and tilting which followed the extrusion of the U.P.L. and before the deposition of the Perapedhi sediments. The tilting of the lavas is responsible for the marked unconformity

between the pillow lavas and both the lava breccia and the sedimentary rocks. In this area faulting was more intense than in the Skouriotissa and Tamassos areas, and normal contacts in the volcanic rocks are rare. However the tectonic pattern in this area is generally similar to that in the other two areas and is represented by block faulting resulting in a mosaic of small horst and graben structures.

2. Basal Group

The distribution of the Basal Group outcrops is shown in figure 5-1 indicating that this volcanic rock is concentrated at the western part of the area. Although one kilometre to the west of Platies (Fig. 5-1) the Diabase is more common than the Basal Group, no distinction has been made between the two rock units. The Basal Group generally has a brown colour produced by the oxidation of sulphides to limonite. It contains a high proportion of dykes which generally trend at about 50°, and have variable amounts of dip. Pillow structure is relatively rare and the pillows dip about 50° to the northeast. Outcrops of brecciated Basal Group are common and not infrequently are intersected by undisturbed olivine basaltic dykes. Outcrops consisting of pale-grey, poorly mineralized, and steeply dipping pillows of Basal Group occur north of the Mavri Sykia mine; surface indications of mineralization in the Kalavasos area are mostly confined to the Basal Group rock such as the outcrops at Kokkinokremmos, part of Platies, Mavri Sykia and part of Landaria (Fig. 5-1). Strong gossans are found in the Basal Group at its faulted contact with the L.P.L. (South of Livadhia) and the U.P.L. (at Plates Fig. 5-1). A strong gossan, partly exploited by Phoenicians, was found at Paphitis Hill north of Platies. Drilling data indicate that mineralized Basal Group often epidotized is widespread in this area under a cover of unmineralized U.P.L. with a variable thickness.

The gossan outcrops in the Basal Group suggest that the primary mineralization consisted of disseminated and fracture filling sulphides. Where the oxidized sulphide veins were massive not infrequently boxwork textures are well developed. The sulphide mineralization was associated with

silicification and chloritization of the host rock.

3. Lower Pillow Lavas (L.P.L.)

The surface extent of the Lower Pillow Lava outcrop is smaller than that of the Upper Pillow Lavas and Basal Group. The Lower Pillow Lava outcrops are concentrated in the central part of the area. No unfaulted contact between L.P.L. and B.G. was found, whereas rare normal L.P.L. - U.P.L. contacts were seen. At an outcrop west of the Mine Offices weathered and broken L.P.L. is overlain unconformably by limburgite pillow lavas which constitute the base of the U.P.L. in the area. The contact of the two rock units is marked by a thin layer of dark brown ochreous sediment about 20 cm thick. The weathered surface of the L.P.L. and the occurrence of the ochreous sediment suggest that in this area there was a pause in volcanicity and a period of submarine weathering and sedimentation, after the extrusion of the L.P.L. and prior to the extrusion of the U.P.L.

In the field the L.P.L. have a dark grey colour, with green celadonite commonly filling vesicles and fractures in the pillows. The individual pillows are defined by black glassy selvages 3-6 cms thick, and have a steep northeasterly dip. The L.P.L. is characterized by high proportion of dykes and sill rocks but only a limited number is shown on the map. The dykes generally trend at 60° and dip steeply to the southeast. Many of the intrusive rocks are contemporaneous with the enclosing lavas and have similar composition with them and are commonly intersected by younger olivine basaltic feeder dykes to the overlying Upper Pillow Lava.

The petrography of the L.P.L. in the Kalavasos area is similar to that of the L.P.L. in the Skouriotissa (Chapter 3) area. The surface indications of mineralization in the L.P.L. are rather limited. The most interesting one is located on the road from Kalavasos to Drapia northeast of the Petra orebody (Fig. 5-1). The mineralization is in the form of a weak gossan in brecciated L.P.L. The primary mineralization appears to have had cemented lava fragments and was associated with silicification and argillization of the host rock. Other gossan outcrops occur to the west of the Mine Offices along the faulted contact between

Upper and Lower Pillow Lava (Fig. 5-1). Finally at Paphitis Hill north of the Mavri Sykia orebody there is a gossan outcrop in the L.P.L. along its faulted contact with the B.G. (Fig. 5-1).

4. Upper Pillow Lava (U.P.L.)

The outcrops of the Upper Pillow Lava cover most of the central part of the area. The U.P.L. is mostly faulted against the B.G., L.P.L. and the plutonic rocks (Fig 5). The presence of intervolcanic sediments in the U.P.L. assisted in their subdivision into three mappable lithostratigraphical units. Thus the base of the U.P.L. is occupied by the limburgites overlain conformably by picrite basalts, the latter grading upwards into basalts containing variable amounts of olivine. The contact of the limburgites with the picrite basalts is persistently marked by the intervolcanic sediments (Fig. 5-1).

Limburgites were found at the base of the U.P.L. in the Tamassos area (Chapter 4) but in the Kalavasos area this rock type is more widespread and its stratigraphic position more conclusively determinable. As already mentioned the limburgite pillow lavas overlie conformably the L.P.L. with ochreous sediment in some cases interposed between them. The limburgites have a dark-grey to black colour. In stream sections where pillow structure is well exposed the individual pillows are defined by glassy selvages (Plate 5-5) The thickness of the selvages varies from 1 to 15 cms, and they consist of black friable and shattered volcanic glass, Angular fragments are commonly entrapped in the glassy selvages. The individual pillows consist of rounded egg-like pebbles varying in diameter from 6 to 15 cms. These egg-like pebbles are encased in black glassy matrix.

In thin sections the limburgites consist of a matrix of augite microlites and pale brown glass in which small but variable amounts of olivine and magnetite are present. Most of the olivine is in the form of anhedral microphenocrysts, but small subhedral or euhedral grains are also present. The olivine microphenocrysts not infrequently are corroded. The olivines are mostly altered to a pale brown, to greenish highly anisotropic substance most

Plate 5-1. Tuffaceous conglomeratic grit consisting of limburgite fragments encased in a matrix of green glass and overlain by lithic tuff (top).

Plate 5-2, 5-4. Well developed ripple marks in lithic tuff.

Plate 5-3. Massive picrite basalt flow with well developed spheroidal weathering.

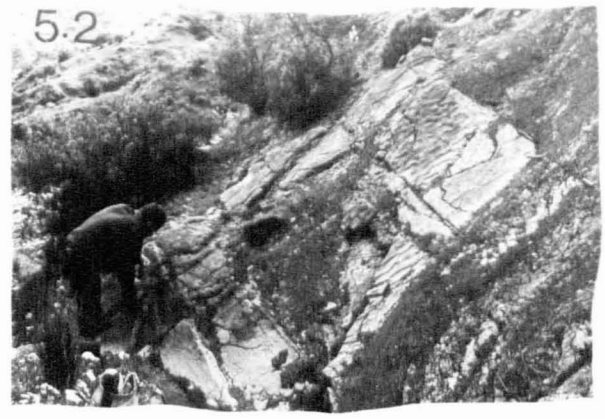
Plate 5-5. Typical limburgite pillow lavas. The pillows are surrounded by black glassy selvages.

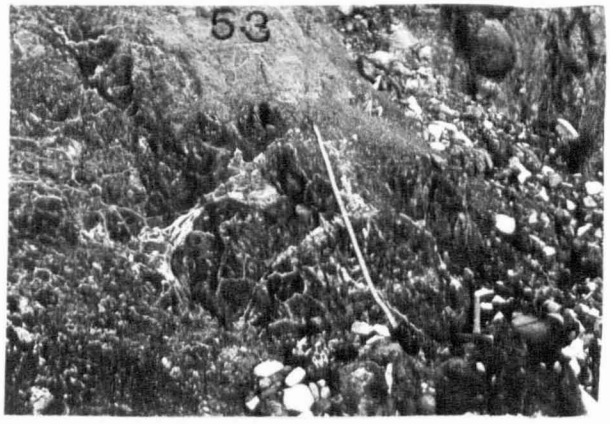
Plate 5-6. Hand specimen of lithic tuff (natural size).

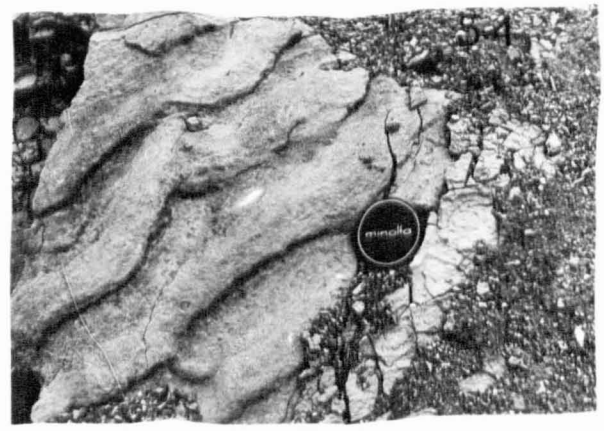
Plate 5-7. Hand specimen of lithic tuff with well developed mud-infilled sedimentary cracks (natural size).

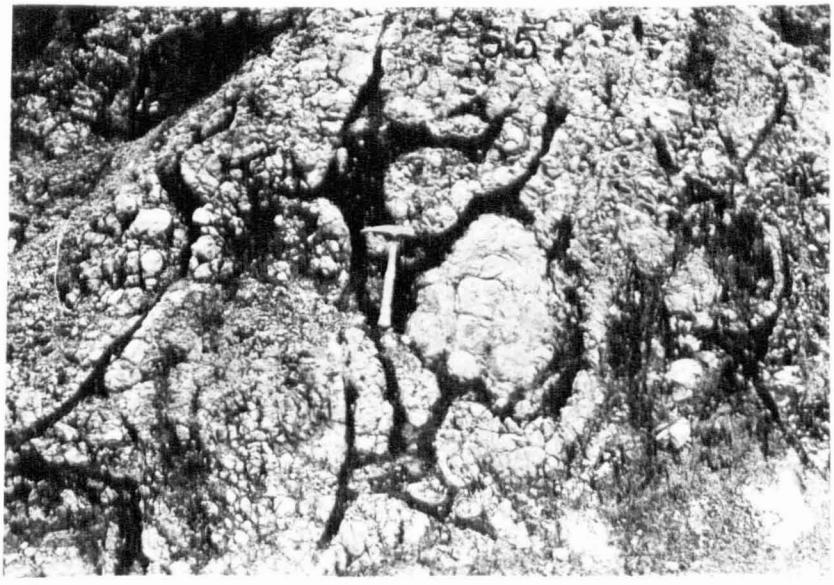
Plate 5-8. Hand specimen of finely banded lithic tuff (natural size).

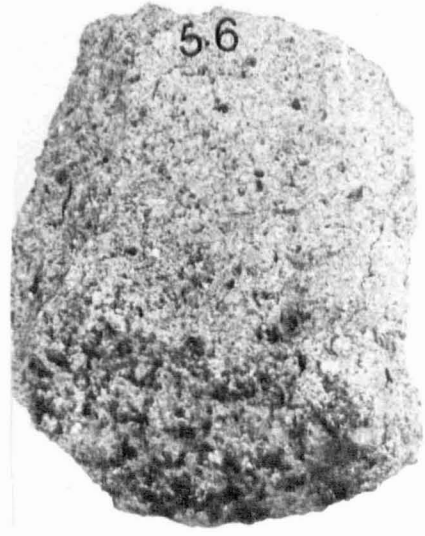

5.1

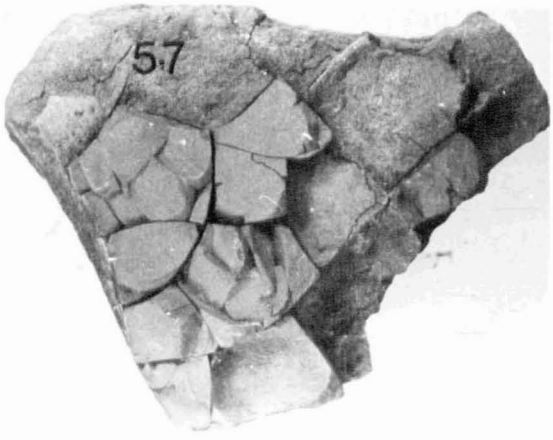

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probably baulingite. (G. Walker, Imperial College-Personal) communication). The augite microlites exhibit characteristic supercooling textures in a variety of forms; well developed radiating plumes is the more common form but skeletal dentritic and herring-bone forms are common too. Two generations of magnetite were recognized. The early generation consists of euhedral grains whereas the second generation consists of finer anhedral grains. The latter in polished sections exhibit characteristic supercooling textures. The great proportion of the glassy matrix in the limburgite pillows and the well developed supercooling textures suggest that probably there was a strong interaction between the hot limburgitic lava and the sea water during the extrusion of the limburgites.

Picrite basalts overlie conformably the limburgite with intervolcanic sediments persistently marking their contact.

The detailed distribution of the picrite basalt and the underlying intervolcanic sediments is shown in Fig. 5-1. In the Kalavasos area there are picrite basalt flows and picrite basalts with pillow structure. Picrite basalt flows vary in thickness from 30cms to over 10 metres. Differentiation is very common in both the picrite basalt flows and pillows (Searle and Vokes 1969). Individual flows 30cms thick have a basal picrite basalt layer 10 cms thick which grades to an olivine-free top layer, through an olivine rich layer 10cms thick. The same pattern of differentiation was also observed in thick flows and in pillows and appears that the differentiation was active after the extrusion of the basaltic magma. Another field characteristic of the thick picrite basalt flows in their common spheroidal weathering (Plate 5-3). The petrography of the picrite basalts of the Kalavassos area was described by Searle and Vokes (1969).

X-ray diffraction analyses of olivine from samples of picrite basalt collected by the writer from the Kalavasos and Tamassos areas were carried out by Maliotis. These analyses indicate that these olivines show very low Fa values generally below Fa12 (Maliotis 1969). Chemical analyses of olivines of picrite basalts from the Kalavasos area were also presented by Searle and Vokes (1969). These analyses indicate a high content of the fosterite-molecule. (Fo 90.8).

The picrite basalts are succeeded upwards by olivine rich pillows which in turn grade into olivine-poor pillows which constitute the upper part of the Upper Pillow Lavas. The olivine-basaltic pillow lavas vary in colour from pink pale-grey to grey and the individual pillows are defined by green glassy selvages. They are highly vesicular and the vesicles are infilled with calcite and zeolites. Petrographically these lavas are similar to the U.P.L. of the Skouriotissa Mining area (Chapter 3).

A common feature of the U.P.L. at the central part of the Kalavasos area is the occurrence of thick microgabbro flows and dykes. A thick microgabbro flow in the vicinity of the A-orebody (Fig. 5-1) was described by Searle (in Searle and Constantinou 1967).

5. Intervolcanic Sediments

The term intervolcanic sediments was used to describe the waterlain volcanic products occurring between the limburgite and the picrite basalt. A very small outcrop of similar sediments was found in the U.P.L. in the Tamassos area (Chapter 4). In the Kalavasos area these sediments are well developed, particularly north of the Vasilikos river (Fig. 5-1). The intervolcanic sediments in this area are so closely associated with the picrite basalt flows that the presence of the latter indicates the presence of the former. In some outcrops the intervolcanic sediments are traceable for several hundred metres pinching and swelling along their strike, and thinning gradually to the west. The thickness of these sediments varies from several tens of cms up to 12 metres. At an outcrop west of the road leading from the Mine Offices to the Platies mining camp, (Fig. 5-1), the sedimentation was interrupted three times by thin picrite basalt flows 30 cms thick. These flows exhibit the characteristic differentiation described before. No evidence of thermal metamorphic effect, i.e. baking or hardening of the sediments at their contact with the picrite basalt was found.

The intervolcanic sediments consist of alternating layers of ochreous material, lithic tuff and tuffaceous conglomeratic grit. The layers of ochreous material consist of alternating thin bands of dark brown to red and pink iron rich material. The thickness of these bands varies from several millimetres to

2 cms whilst the thickness of the ochreous layers as a whole range between 10 and 40 cms. Graded bedding and mud-infilled sedimentary cracks are very common in the ochrous layers. The colour variation in the individual bands is due to variation in grain size and probably in the iron and manganese content but chemical analyses are not available.

The layers of lithic tuff consist of alternating bands of compact, relatively fine grained, volcanic material. The thickness of these bands varies from 1 to 4 cms; their colour varies from grey through pale grey to pinkish grey (plate 5-8). The tuffaceous bands at irregular intervals are separated by thin bands of pink mud, 2 cms thick, with well developed mud-infilled sedimentary cracks (plate 5-7). Graded bedding and ripple marks are also well developed in the layers of lithic tuff (plates 5-2, 5-4).

The layers of tuffaceous conglomeratic grit consist of limburgite fragments encased in a matrix of green glass; the proportion of the volcanic glass is variable and in some layers it exceeds 80 per cent of the volume of the rock. The lava fragments are mostly angular or subangular and less commonly rounded andtheir size ranges from 1 up to 15 cms (plate 5-1).

The intervolcanic sediments have many features suggesting subaqueous deposition. Since these sediments are confined to the limburgite-picrite basalt flows contact, their deposition represents a pause in volcanicity between the extrusion of the two rock units. Their discontinu character and the pinching and swelling of their outcrops suggest that these sediments were probably deposited in local depressions on the limburgite lava surface. Most of the material was derived from the underlying limburgites. Micropalaeontological examination of samples from the intervolcanic sediments carried out by the Cyprus Geological Survey failed to identify any microfossils.

6. Lava Breccia

A common feature of the Kalavasos area, not found in the Skouriotissa and Tamassos areas, is the occurrence of a thick and discontinuous breccia zone, interposed between the U.P.L.

and the sedimentary rocks (Fig. 5-1). The breccia-zone consists exclusively of micrograbbo and olivine basalt fragments encased in a matrix of pinkish coloured rock flour. Volcanic glass is lacking in the matrix in which the lava fragments are encased. The lava fragments are generally disordered angular, sub-angular to rounded ranging in size from 5 to 25 cms (Plate 5-16). The breccia zone rests unconformably on the U.P.L. and is overlain conformably by the sedimentary rocks.

The mode of formation of the breccia zone has been the subject of much debate in the literature. The breccias were considered as volcanic agglomerates by Mousoulos (1957), Gordon-Smith (1963, 1968) and Pantazis (1967,1969). Searle (in Searle and Constantinou 1967). argued against this hypothesis and suggested that the breccias are tectonic in origin, and formed by thrusting of a block of U.P.L. over igneous rocks of different ages; the thrust movement was from south to north. The tectonic hypothesis was based on:

(a) The common slickensided and polished surfaces of the lava fragments,

(b) The common occurrence of hematitic clay gouge along the shear planes and surfaces, and

(c) The production of magnesite and earthy calcareous material in the matrix (Plate 5-16).

Lundberg (1969) after the mapping of a similar breccia zone 16 kilometres long, extending from Anglisidhes to Pano Lefkara (12 kilometres north-east of the Kalavasos area) argued against both the pyroclastic and tectonic origins. The pyroclastic origin was rejected because of:

(i) the lack of glassy material in the breccia,

(ii) the lack of field evidence indicating the presence of a large or several smaller volcanic vents,

(iii) the marked discordance between the breccia and the underlying pillow lava, and

(iv) the lack of evidence of renewal of volcanism after a long period of faulting and tilting of the pillow lavas.

The thrust hypothesis was also rejected because it implies the movement of a relatively thin slice of U.P.L. over considerable distances, but evidence of such large scale tectonic movements in this area is lacking.

Lundberg (1969) advocates a detrital accumulation of the breccia. He maintains that the erosion responsible for creating the breccia must have been violent and intense and it is associated with denudation of sharply elevated mountains that resulted from the emergence of the Troodos Igneous Complex.

However it is probable that the breccias represent olisthostroms brought in their present position by slumping of detrital products during the regional tilting of the pillow lavas. This tilting took place prior to the deposition of the sediments of the Perapedhi Formation. Evidence substantiating this hypothesis is provided by minor slump structures observed along road cuttings in the vicinity of the Mousoulos orebody and south of Asgata village. These slump structures are closely associated with the breccia - Perapedhi umber contact. Slumping of this nature is believed to be responsible for the slickensided and polished character of the lava fragments.

7. Sedimentary Rocks

The sedimentary rocks occupy the eastern and south-eastern parts of the Kalavasos area. Drilling data indicate that in the central part of the area the thickness of the sediments range from 10 to over 155 metres. The overall outcrop pattern of the sedimentary rocks was modified by faults which postdate their deposition. The base of the sedimentary rocks is occupied by the Perapedhi Formation of Maestrichtian age.

The base of the Perapedhi Formation consists of umber; the latter forms discontinuous outcrops ranging in thickness from a few to 35 metres. In some outcrops the relationship between the umber and the underlying breccia is obscured by slumping, but in general the umber overlies conformably the breccia zone. In the central part of tha area drilling over and around the orebodies indicates that the umber extends laterally underneath the sediments of the Lefkara Group. The umber generally is dark

brown, poorly bedded or massive, and grades upwards into the brown and pink argillites. On the Perapedhi Formation rest conformably the calcareous sediments of the Lefkara Group, of Upper Cretaceous to Lower Miocene age. The base of the Lefkara Group consists of pink marl containing bands or lenticles of chert, grading upwards into whitish to creamy marly chalks. (Table 5-1).

The regional dip of the sediments in the outcrops south of the Vasilikos river is towards the south or southeast and varying between 15° and 25°. In the outcrops north of the river the regional dip of the sediments is towards the northeast varying from 10° to 15°. The dip of the sediments is at variance with the steep dip of the U.P.L. in the area, and is believed to be due to regional tilting of the Pillow Lavas before the deposition of the sedimentary rocks.

8. Structure

The Kalavasos area tectonically is more disturbed than the Skouriotissa and Tamassos areas. The structure of the area was first discussed by Mousoulos (1957) and later in more detail by Searle (in Searle and Constantinou 1967) Tectonic movements brought in contact the Plutonic rocks with the Basal Group, the Lower and the Upper Pillow Lava. The general structural pattern in the area is one of block faulting resulting in a mosaic of small horst and graben tectonics.

The sequence of tectonic events is visualized as follows:-

(a) A set of faults resulted from the first phase of tectonic movements trends 320°.

(b) A set of faults resulted from the second phase of tectonic movements trends, 060° and less commonly 040° and 020° and truncates the 320° faults.

(c) A set of faults resulted from a later phase of tectonic movements trends 350° and truncates the set of faults of the second tectonic phase.

(d) The final tectonic phase produced a set of normal faults trending between 290° and 310° and dipping 35° to 55° to the south, and cutting across all the previous structures. The last three

tectonic phases affected both the volcanic and sedimentary rocks.

A fundamental feature of the area is the persistent steep dip of the volcanic rocks. The dip has a northeasterly direction between 040° and 070° its amount being invariably greater than 50°; in some cases the pillows are overturned. The steep northeasterly dip is a regional feature and affected all the lithostratigraphical units including the intervolcanic sediments. This suggests that the steep dip of the pillows is not due to primary deposition on inclined surfaces but it is due to tilting of the area after the extrusion of the Upper Pillow Lava. Searle (in Searle and Constantinou 1967) after correction for the tilting of the Pillow Lavas estimated that the B.G. was tilted approximately 24° to the NW before the extrusion of the Lower and the Upper Pillow Lavas The fact that brecciated B.G. is intersected by undisturbed basaltic dykes substantiates the hypothesis that in this area the B.G. was faulted and tilted before the extrusion of the L.P.L. and U.P.L.

9. Geological Features of the Worked Orebodies in the Kalavasos Area.

Prior to the recent discovery of the Mousoulos orebody in the central part of the Kalavasos area, nine other orebodies had been worked. The distribution of these orebodies is shown in Fig. 5-1. The ore in all these orebodies which ranged from 50000 to 1500,000 tons was mined out by underground methods, thus the orebodies were not accessible to direct study. However, detailed geological sections through these orebodies constructed by Searle (in Searle and Constantinou 1967) give information about their geological setting and structure. Also, Mousoulos (1957) described the macroscopic and microscopic characterestics, as well as the mineralogy of the ore, of some of the worked orebodies. Finally, information about the grade of the ores was compiled from the assay plans and drilling records provided by the Hellenic Mining Company. A critical examination of the available data gives the following facts.

(a) The worked orebodies are partly or entirely overlain by a volcanic cover of a variable thickness. The volcanic cover consists of unmineralized olivine basaltic lavas (either

pillowed, or brecciated or both). In some orebodies the volcanic cover is overlain by sediments of the Perapedhi Formation which in turn are overlain by sediments of the Lefkara Group (Fig. 5-2).

(b) The sulphide orebodies in the Kalavasos area constitute an integral part of the volcanic succession and had undergone similar tectonic movements, with the enclosing lavas. As a result of the tectonic movements the orebodies were tilted to the northeast and most of their contacts with the surrounding volcanic rocks are faulted. In some orebodies upthrown blocks of ore were exposed to the surface and oxidized to colourful massive gossans. The latter had been worked in the early 1940s for their gold and silver content.

(c) When account is taken of the faulting and tilting most of the orebodies appear to have the characteristic vertical zoning described in the Mathiatis and Kokkinoyia orebodies (Chapter 4). The upper part of the orebodies consists of massive ore containing over 40 per cent sulphur and variable amounts of copper. The contact of the massive ore with the overlying unmineralized olivine basaltic lavas is sharp. The massive ore commonly has a conglomeratic structure and is highly porous. Because of the high porosity the weight of a cubic metre of massive sulphide ore rarely exceeds 3,000 kilograms (Mousoulos 1957). In the massive ore pyrite, chalcopyrite and marcasite are the primary minerals whereas covellite and chalcocite are the most common secondary ones (Mousoulos 1957).

(e) The massive ore is underlain by a stockwork zone with similar chemical and mineralogical characteristics of the same zone in the Mathiatis orebody (Chapter 4). Drilling data indicate that low grade stockwork type mineralization is widespread beyond the limits of the worked orebodies under a cover of greatly varying-thickness of unmineralized U.P.L.

10. Summary

The Kalavasos area is mostly covered by the volcanic and sedimentary rocks and only in its extreme northern part do plutonic rocks occur. The oldest volcanic rock in the area is the Basal Group, which was affected by widespread sulphide mineralization and silicification; subsequent supergene oxidation of the sulphides to limonite produced the characteristic brown discolouration of the rock and many outcrops of gossan. After the extrusion of the B.G. and before the extrusion of the L.P.L. probably there was a pause in volcanicity associated with brecciation and tilting of the B.G. lavas.

After the extrusion of the L.P.L. and before the extrusion of the U.P.L., there was another pause in volcanicity during which there took place submarine weathering of the L.P.L. and sporadic deposition of ochreous sediments. The accumulation of the U.P.L. started with the extrusion of the limburgite, and followed by a pause in volcanicity and sporadic deposition of waterlain intervolcanic sediments. The deposition of the latter was followed by a renewal of the volcanic activity and the extrusion of the picrite basalts. The volcanic activity continued with the extrusion of the olivine basalts.

The extrusion of the U.P.L. was followed by a period of weathering faulting and tilting of the area. The tilting is a regional characteristic of the area and affected all the volcanic rocks including the intervolcanic sediments. A consequence of the tilting was the slumping and accumulation of detrital U.P.L. material to form the breccia zone. The tilting is also responsible for the steep homoclinal nature of the pillow lavas and the marked angular unconformity between the lavas and the sedimentary rocks in the area.

The sedimentation started with the deposition of the umber of the Perapedhi Formation. The umber grades upwards into brown and pink argillites of the same Formation. The Perapedhi Formation is overlain conformably by the marls and chalks of the Lefkara Group.

In addition to the regional tilting the Kalavasos area was affected by various phases of intense block faulting represented

by a mosaic of small horst and graben tectonics. Some of these phases of faulting antedate the deposition of the sediments whereas some other postdate the formation of the sediments.

In the Kalavasos area nine sulphide orebodies had been discovered and worked. These orebodies are overlain by unmineralized Pillowed and/or brecciated olivine basaltic lavas and are invariably intersected by unmineralized dykes, similar in composition and texture to the overlying lavas. The worked orebodies as an integral part of the volcanic succession, had undergone similar tectonic movements with the enclosing lavas. Information compiled from previous workers indicate that these orebodies generally have similar structure, chemical composition and mineralogy.

C. GEOLOGY OF THE MOUSOULOS OREBODY

1. General Statement

The Mousoulos orebody is hidden under a cover of volcanics and sedimentary rocks (Fig. 5-2). The volcanic and sedimentary cover protected the ore of this orebody from subaerial oxidation to limonitic gossan. The lack of any surface indications prevented the discovery and exploitation of the orebody by the Ancients. Thus, the Mousoulos orebody is devoid of two major sources of uncertainties commonly encountered in the study of the sulphide ores in Cyprus, i.e. (a) the oxidation of part of the ore by supergene processes and (b) the exploitation of the upper part of the orebodies by the Ancients.

The orebody has been affected by faulting and tilting (the latter has a steep northeastern direction) similar to the surrounding volcanics. Correction of this tilting shows that originally the orebody had the characteristic vertical zoning found in other orebodies in Cyprus. Its top consists of massive ore overlain conformably by a layer of ochreous sediments, which in turn is overlain conformably by unmineralized olivine basaltic Upper Pillow Lavas. The massive ore contains more than 40 per cent sulphur and variable amounts of copper. The ore has a conglomeratic structure and is highly porous. The most common mineral is pyrite, followed in abundance by marcasite (restricted to the top), chalcopyrite, sphalerite, covellite and pyrrhotite.

The massive ore is underlain by a thin zone (zone B) consisting of an intimate mixture of sulphide and silica. The sulphur content in this zone ranges from 30 to 40 per cent; copper is sporadically distributed in the zone B. The latter is underlain by the stockwork zone which consists of mineralized and hydrothermally altered, brecciated or pillowed lavas. The sulphides in this zone fill fractures and impregnate the lavas. The introduction of sulphides was associated with silicification, chloritization and argillization of the lavas. The ore of the zones A, B and stockwork is intersected by a number of unmineralized olivine basaltic dykes. Detailed investigation of these dykes indicates that they post-date the emplacement of the orebody and probably represent feeder dykes to the unmineralized basaltic lavas overlying the Mousoulos orebody.

Fig. 5-2

GEOLOGY OF THE MOUSOULOS AND "B" OREBODIES
(ISOMETRIC PROJECTION VIEWED FROM THE NORTHWEST)

LEGEND

- Surface
- Chalks with marls and argillites at the base
- Umber
- Upper pillow lava
- Sulphide orebodies
- Fault
- Inferred fault
- Normal contact
- Inferred contact
- 70° Strike and dip of sediments
- 75° Direction and amount of dip of pillows
- 5400 / 23700 Mine coordinates, in metres

Horizontal and Vertical scales

2. Previous Work and Present Investigation

The Mousoulos orebody was the only operating mine when the study of the Kalavasos area was undertaken. The orebody was discovered after 1960 and very little was written on it by previous investigators. Vokes (1966) referred briefly to the Mousoulos orebody and presented a schematic section through it. Pantazis (1967) gave a general description of the orebody and compiled figures on the ore mined up to 1966.

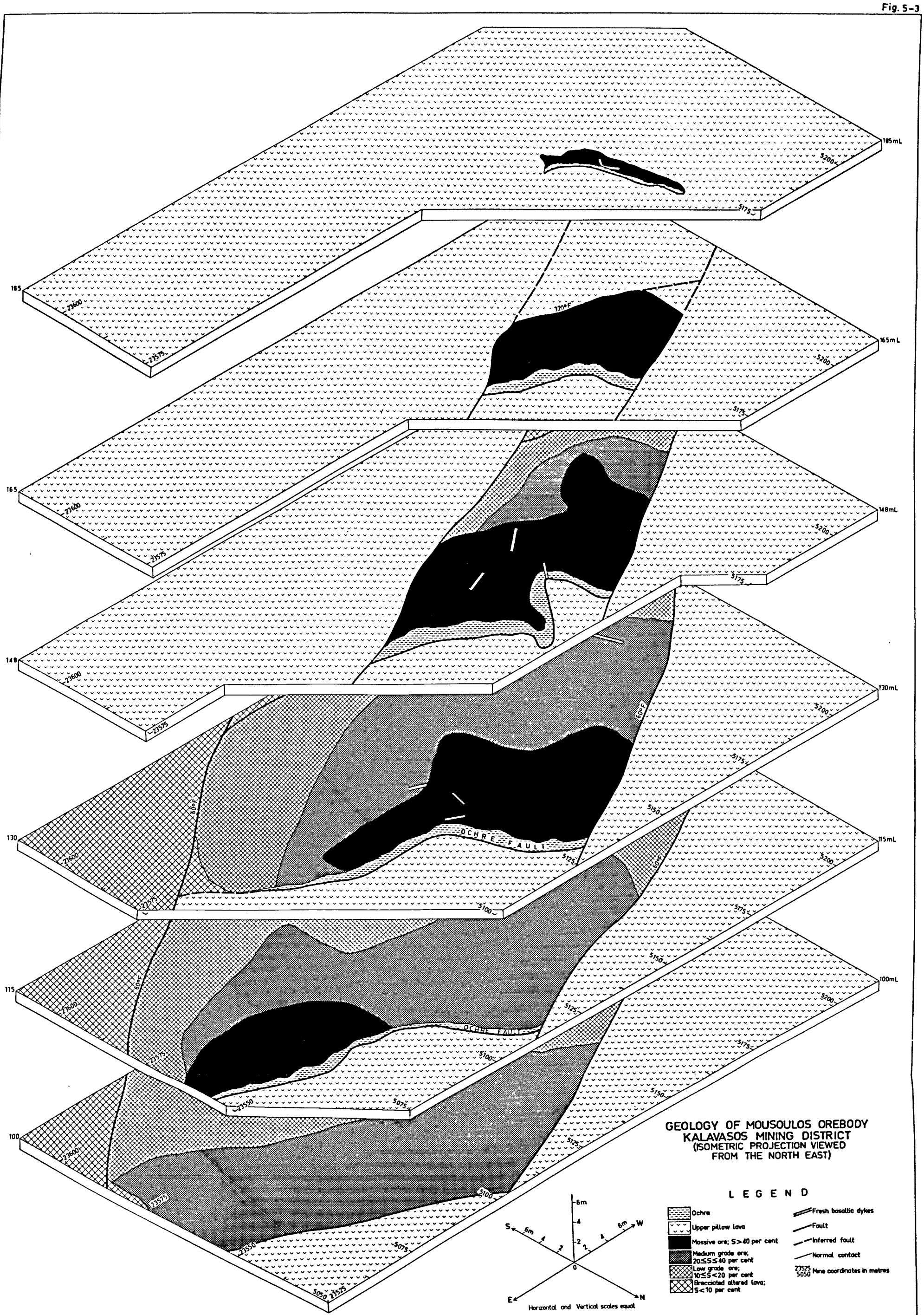
The underground mining of the Mousoulos orebody started in 1964. From the 185 metre level (which is the top of the orebody, Figs. 5-2, 5-3) down to the 130 metre level the ore is extracted in descending order by horizontal slices 3 metres thick. The mining methods employed are the top slicing for the high grade ore and sublevel caving for the low grade ore. Below the 130 metre level the only method employed is sublevel caving and the horizontal slices are 5 metres thick.

By the end of 1966 when the detailed underground mapping started, the ore was mined out down to the 157 metre level. The detailed mapping and sampling was carried out in all the nine levels from the 157 metre level down to the 115 metre level. The mapping was carried out on a scale of 1:250, using as a base map the mining plans of the Hellenic Mining Company. The intersection of the drives and crosscuts were taken as fixed surveying points; only tape and compass was used for mapping. In each level the contacts of the ore with the surrounding rocks as well as the various zones of the orebody were mapped. The Hellenic Mining Company kindly provided detailed assay plans for all the mine levels. Furthermore, all the samples of the drill-holes through and around the Mousoulos orebody were made available for logging. Samples from a selected number of drill-holes were taken for detailed laboratory investigation. All the above data were used to construct the two isometric projections illustrated in figures 5-2 and 5-3. In addition, a model of the orebody was constructed and is kept in the Cyprus Geological Survey.

3. The Surrounding Rocks

The Mousoulos orebody lies under a cover consisting of sedimentary and volcanic rocks (Fig. 5-2) and the minimum thickness

Fig. 5-3


185mL
185
165mL
165
148mL
148
130mL
130
115mL
115
100mL
100
OCHRE FAULT
OCHRE FAULT
60°F
320°F
GEOLOGY OF MOUSOULOS OREBODY
KALAVASOS MINING DISTRICT
(ISOMETRIC PROJECTION VIEWED
FROM THE NORTH EAST)
LEGEND
Ochre
Upper pillow lava
Massive ore; S>40 per cent
Medium grade ore; 20≤S≤40 per cent
Low grade ore; 10≤S<20 per cent
Brecciated altered lava; S<10 per cent
Fresh basaltic dykes
Fault
Inferred fault
Normal contact
23525 5050 Mine coordinates in metres
Horizontal and Vertical scales equal

of this cover is 88 metres. Drilling data indicate that the top of this cover is occupied by chalks, marly chalks and marls of the Lefkara Group which are succeeded downwards by pink to brown argillites and brown umber of the Perapedhi Formation (Table 5-1). The Perapedhi sediments are underlain by a breccia zone consisting of fragments of olivine basaltic lava. The breccia zone is succeeded in depth by olivine basaltic pillow lavas. Drilling data indicate that the pillow lavas in some cases are intersected by olivine basaltic dykes.

The lavas exposed in underground drives and inclines connecting the various mine levels have a dark grey green to pale-grey colour. Macroscopically these lavas are generally similar to the lavas exposed at the lower levels of the Mathiatis pit (Chapter 4). Pillow structure is well defined, the individual pillows being surrounded by dark grey green selvages 4 to 10cms thick. Not infrequently the central part of the pillows is brecciated and the fractures are filled with calcite and zeolites. Calcite and zeolite also fill the vesicles in the lavas which are more abundant at the margins of the pillows. At the 130 metre level near the orebody the fractures of brecciated pillow lavas are filled with ochreous material. The latter was also observed in the glassy selvages around the pillows, and are commonly intersected by veinlets of white and pink calcite.

Optical study of the olivine basaltic lavas surrounding and overlying the Mousoulos orebody indicate that these lavas generally have a vitreous texture and tend to be vesicular. The glassy matrix often exceeds 80 per cent of the volume of the rock but at the centre of large pillows the lava has a microporphyritic texture. The most common mineral is plagioclase in the form of microlites and microphenocrysts. Pyroxene is present in small and variable amounts. Fresh olivine is rare but brown pseudomorphs after olivine are present in variable amounts.

Much of the plagioclase is altered to cryptocrystalline montmorillonite. Not infrequently compositional zoning in the plagioclase is shown by differential alteration. The pyroxene is partly altered to cryptocrystalline chlorite. The glassy matrix is altered to an intimate mixture of cryptocrystalline

Table 5-1 The stratigraphic succession in the Kalavassos Mining area

	LITHOLOGY	FORMATION	AGE	MAXIMUM THICKNESS in metres
Sedimentary rocks	Whitish to creamy marly chalk, with bands of marl, pink marl and chert	LEFKARA GROUP	LOWER MIOCENE TO UPPER CRETACEOUS	155
	Umber, argillites	PERAPEDHI	MAESTRICHTIAN (UPPER CRETACEOUS)	32
Volcanic rocks with intercalated volcanic sediments and massive sulphide ores	Lava, breccia consisting of unsorted fragments of olivine basalt and microgabbro in a matrix of pinkish rock flour.	UPPER PILLOW LAVAS	PRE-MAESTRICHTIAN (UPPER CRETACEOUS)	>600
	Olivine basalts, basalts			
	Picrite basalts			
	Intervolcanic sediments consisting of alternating layers of ochreous material, lithic tuff and tuffaceous grit with common graded bedding and mud infilled sedimentary cracks			
	Limburgites			
	Thin layer of ochre overlying the Mousoulos orebody and occasionally intercalated between U.P.L. and L.P.L.	MINERALIZATION	CRETACEOUS?	60?
	PETRA, MOUSOULOS, MAVRIDIA "A" and "B" LANTARIA massive sulphide orebodies, all intersected by unmineralized olivine basaltic dykes			
	Grey-green basaltic and andesitic lavas with green celadonite	L.P.L.	?	?
	Brown iron stained silicified lavas in places with red jasper (Upper part of Basal Group)	BASAL GROUP		?
	Blue-grey altered lavas with common epidote (Lower part of Basal Group)			

Table 5-2 * Partial major element analyses of ochre and **Atomic absorpion spectrophotometer analyses for Cu, Zn, Mn, Ni and Co in ochre from the Mousoulos orebody

SAMPLE No.	LOCATION	DESCRIPTION	Al_2O_3 %	MnO_2 %	Fe_2O_3 %	Cu p.p.m.	Zn p.p.m.	Ni p.p.m.	Co p.p.m.
MS2/3b	Level:130m, Coords: -5145 m. -23548 m.	Brown banded ochre	2.04*	0.24*	75.5*	1980	1538	32	16
MS/139	Level:139m, Coords: -5112 m. -23556 m.	Brown yellow ochre	1.67*	0.31*	69.2*	3040	2000	48	34
L/136	Level:136m., Coords: -5110 m. -23555 m.	Brown yellow ochre	–	0.39	–	2700	1660	58	37
L/151	Level:151m., Coords: -5146 m. -23556 m.	Brown yellow ochre	–	0.22	–	3960	860	19	21
MS3/21	Level:125m, Coords: -5102 m. -23557 m.	Orange ochre with pyrite	–	0.16	–	6400	2020	39	98
MS/142	Level:142m, Coords: -5123 m. -23553 m.	Orange ochre with pyrite	–	0.08	–	6400	2400	25	107
MS/148	Level:148m, Coords: -5143 m. -23552 m.	Orange ochre with pyrite	–	0.04	–	1740	2020	32	27
					Means	3746	1785	36	49
Ratios : Cu : Zn = 2.1 , Ni : Co = 0.74, Cu : Co = 77.1									

* Analyst, Pure Geochemistry Department, Imperial College
** Analyst, Chemical Laboratory of the Cyprus Geological Survey

montmorillonite and an amorphous substance tentatively identified as chlorophaeite. The latter also fills vesicles and minute fractures in the altered lava X-ray diffraction analyses indicate that the products of alteration of the unmineralized lavas surrounding the Mousoulos orebody are distinctly different from the products of hydrothermal alteration of the lavas in the stockwork zone in the same orebody (see Chapter 10, Table 10-1). The X-ray diffraction analyses indicate that the unmineralized lavas contain considerable plagioclase and montmorillonite and traces of pyroxene. Chlorite was not detected in any of the unmineralized lavas which were analysed.

4. The Ochre Overlying the Mousoulos Orebody.

A fundamental feature of the Mousoulos orebody is the occurrence of an ochreous layer between the sulphide ore and the overlying unmineralized basaltic lava. The ochreous layer marks the eastern-northeastern contact of the orebody and it was found in all the mine levels above the 115 metre level, but it disappears in the levels below the 115 metre level (Fig. 5-3). The ochreous layer is continuous but varies in thickness from 20 cms to as much as 4 metres. The contact of the ochre with the overlying unmineralized lavas is sharp whereas the ochre-sulphide ore contact is gradational.

At the ochre-sulphide ore contact the proportion of ochre by far exceeds the proportion of sulphide blocks embedded in it. Away from the above contact towards the orebody the quantity of ochre diminishes gradually (Plates 5-9, 5-11) and at the distance of 6 metres from the contact, the ochre is only found occurring as rare small pockets and veins in the massive ore.

In the Mousoulos orebody the ochreous layer consists exclusively of ochre. The latter generally is massive but in some thick exposures it tends to be well bedded. Colour banding consisting of alternating bands of dark brown, brown, and brown-yellow colour is common in the ochre. In the field this colour banding was thought to be due to variation in the chemical composition of the individual bands; for example, high manganese content was considered to be responsible for the dark brown bands. However

Plate 5-9. Mousoulos underground. Ochre (brown) containing blocks of solid sulphide, overlain by brecciated unmineralized U.P.L. (dark grey) in turn overlain by U.P.L. with well developed pillow structure (top right).

Plate 5-10. Mousoulos underground. Blocks of solid sulphide surrounded and veined with ochre (brown).

Plate 5-11. Mousoulos underground. Blocks of solid sulphide encased in ochre (left) grading into sugary massive sulphide ore with rare pockets and veins of ochre.

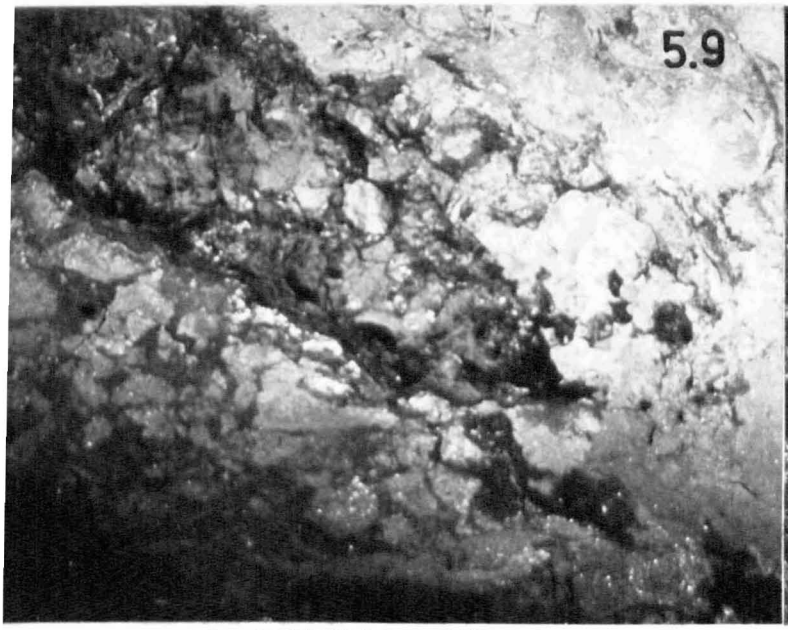
Plate 5-12. Mousoulos underground looking northeast. Faulted contact between massive conglomeratic ore (point indicated by arrow) and grey clayey gouge in which are encased fragments of lava.

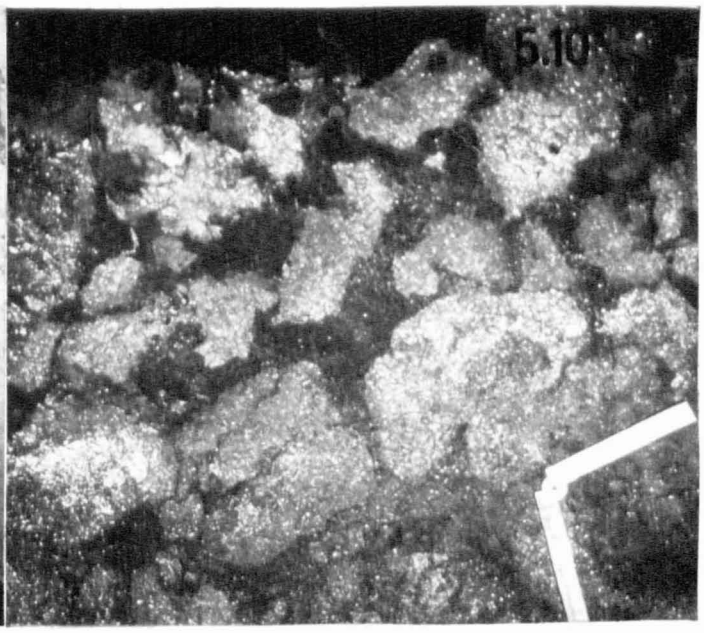
Plate 5-13. Mousoulos underground. Conglomeratic massive sulphide ore with solid sulphide blocks embedded in a matrix of sandy friable sulphide ore.

Plate 5-14. Mousoulos underground looking (south). Southern faulted contact between brecciated unmineralized U.P.L. (dark grey) and brecciated and mineralized lavas (grey) containing sulphide veins rich in chalcopyrite (point indicated by arrow).

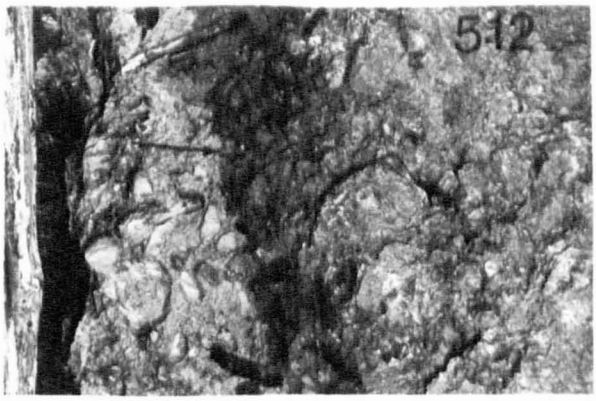
Plate 5-15. Mousoulos underground. Typical conglomeratic mass massive ore. Solid sulphide blocks varying greatly in size and shape are encased in a matrix of sandy friable massive ore.

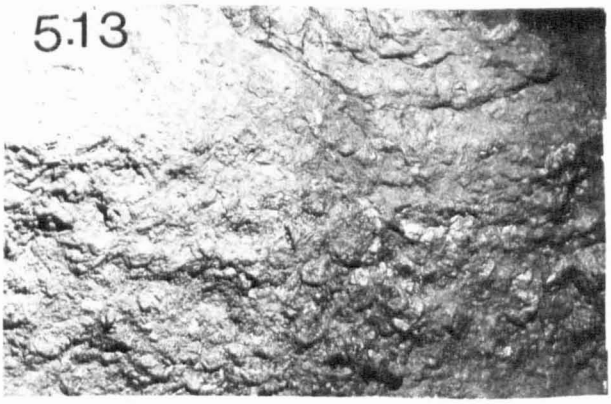
Plate 5-16. Typical lava breccia consisting of fragments of olivine basalt embedded in a matrix of rock flour.

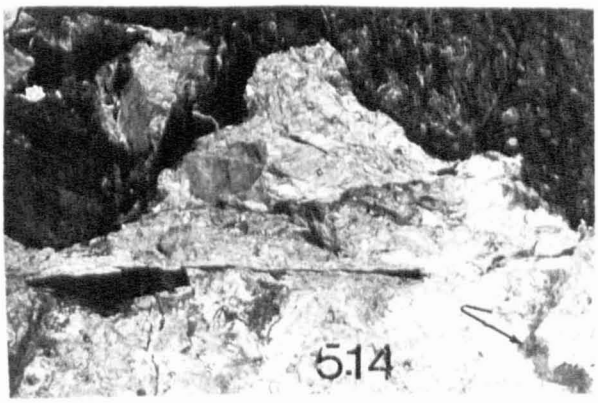

5.9


5.10

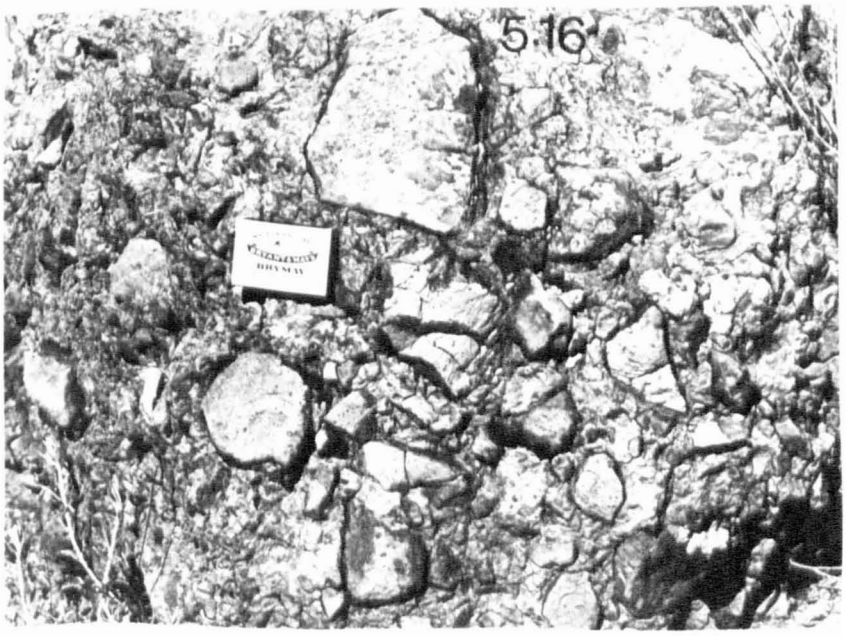

5.11


5.12


5.13


5.14


5.15


5.16

several A.A.S. analyses, carried out by the Chemical Laboratory of the Cyprus Geological Survey indicate that manganese is persistently low in the ochre of the Mousoulos orebody, even in the more dark brown bands (Table 5-2). The colour banding is probably d to variations in grain size and degree of crystallinity. Table 5-2 also indicates that the trace elements copper, zinc, nickel and cobalt are erratically distributed in the ochre of this orebody and the ratios Cu:Zn, and Co:Ni are higher than one.

X-ray diffraction analyses of samples of ochre from the Mousoulos orebody indicate that goethite is the most common mineral being mixed with variable amounts of pyrite (Table 6-1 Chapter 6). Quartz, which is commonly found in the ochre of the Skouriotissa and Mathiatis orebodies, was not detected in the ochre of the Mousoulos orebody. One sample of sheared ochre, taken from the contact of the ochre with the overlying basaltic lavas, contained rare montmorillonite, in addition to goethite.

In polished sections the ochre is seen to consist of matrix of poorly crystalline goethite in which zones of well crystalline goethite are found. The latter has a pale blue colour and has higher reflectivity than the matrix. Detailed study of a number of polished sections indicates that the goethite of the ochre is replacing the pyrite. This relationship is more clear in sections of specimens taken from the ochre-sulphide ore contact. The replacement of pyrite by goethite follows grain boundaries and fractures in the pyrite (Plates 5-27, 5.28). Not infrequently the goethite replaces only the central part of pyrite aggregates producing characteristic atole texture (Plate 5-29). Goethite more readily replaces the zoned pyrite, and the replacement follows the contacts of the individual growth zones (Plates 5-30). Zoned pyrite is extremely rare in the ochre whereas the unzoned euhedral pyrite, which is more resistant to replacement, is more abundant. Away from the ochre-solid sulphide block contact the amounts of remnant pyrite in the ochre gradually decrease (Plates 5-31, 5-32, 5-33, 5-34) and few centimetres away from the above contact the remnants of pyrite are very rare (Plate 5-35). The solid sulphide blocks, which are in the ochre, in polished sections are seen to be veined by goethite

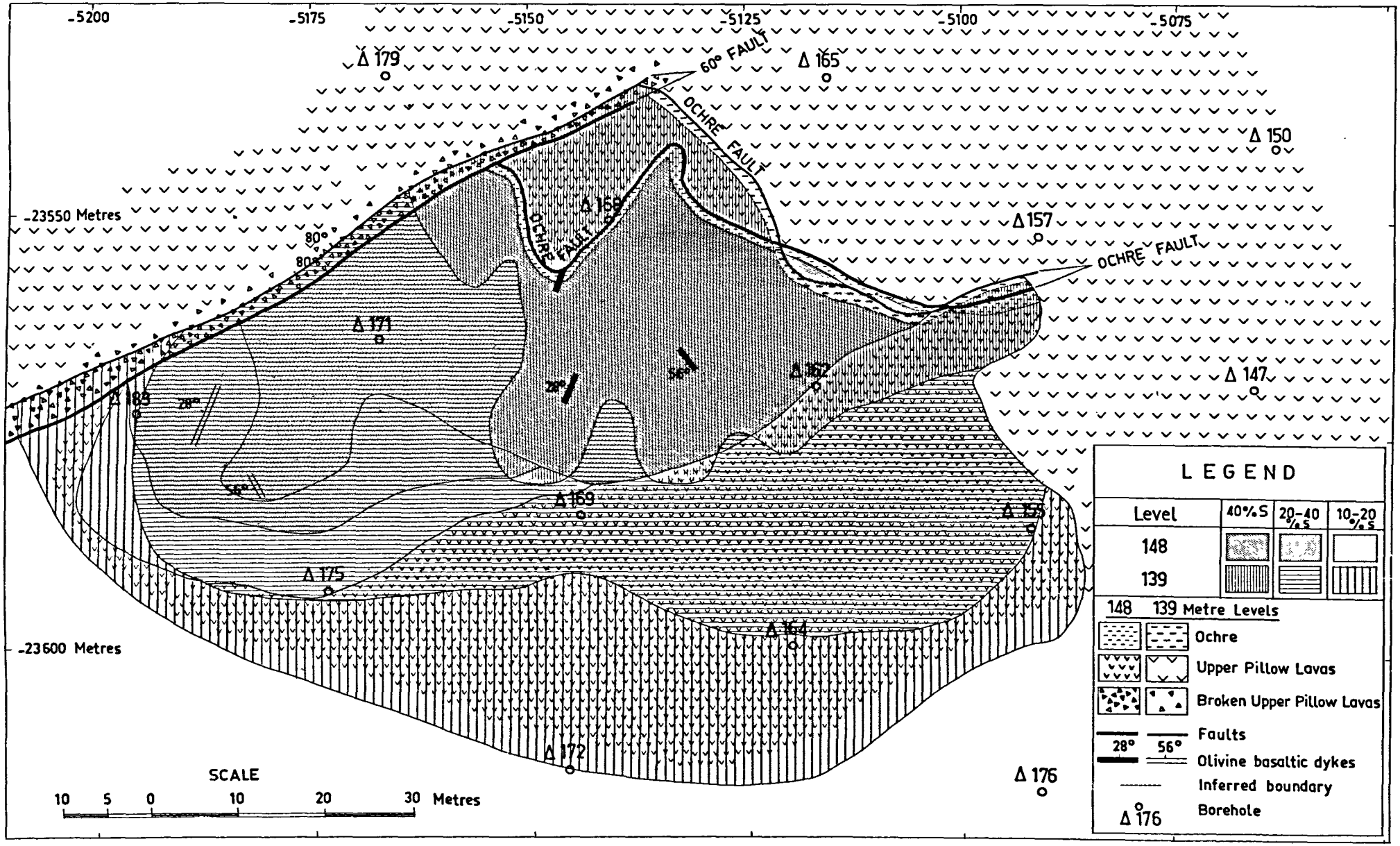


Fig.5-4. Geological sketch map of the 148 and the 139 metre levels of the Mousoulos orebody (Kalavasos Mines).

containing remnants of badly corroded euhedral unzoned pyrite (Plates 5-36, 5-37, 5-38, 5-39, 5-40).

Rare maghemite was observed in the ochre veining the solid sulphide blocks. The maghemite is mostly restricted to fractures or zones of corrosion in pyrite, and was not observed in the ochre away from pyrite grains. Covellite and sphalerite are relatively common in the ochre near its contact with the sulphide ore. Chalcopyrite is generally rare and found only as remnants partly replaced by covellite. A chalcopyrite grain found in a vein of ochre intersecting a sulphide block, is rimmed with orange bornite. The orange bornite is surrounded by digenite which, in turn, is rimmed with covellite.

5. Contacts and Wallrock Relationships

The Mousoulos orebody is an underground mine and development work exposed to direct observation only the northern, eastern and western contacts of the orebody with the surrounding rocks. The southern contact of the orebody with the surrounding volcanic rocks was not accessible to direct observation because in most mining levels the development work was terminated in very low grade ore.

The northwestern contact of the orebody is marked by a prominent fault seen in all the levels of the mine. The fault postdates the emplacement of the orebody, strikes 060° and dips steeply to the northwest (Figs. 5-2, 5-3, 5-4). The hanging wall of this fault consists of unmineralized olivine basaltic pillow lavas. At the upper levels the footwall is occupied exclusively by brecciated massive ore whereas at the lower levels it is occupied by massive, medium grade and low grade ore. (Figs. 5-3, 5-4). The fault plane consists of a zone of grey clayey gouge 20 to 40 cms wide containing disseminated pyrite, and having a sharp contact with sulphide ore (Plate 5-12). The zone of fault gouge is succeeded outwards by a zone of brecciated unmineralized basaltic lava one to three metres wide (Fig. 5-4).

The northeastern contact of the Mousoulos orebody is defined by the "ochre fault" (Figs. 5-3, 5-4); the "ochre fault" most probably represents a primary depositional contact with the ochre filling irregularities at the top of the orebody, being in turn overlain conformably by later basaltic pillow lavas. Due to the regional tilting the basaltic pillow lavas slided to the northeast with the ochre acting as lubricant. The "ochre fault" generally strikes at about 320° and dips to the northeast; the amount of dip is not constant but ranges from 35° to 65°. The hanging wall consists of unmineralized basaltic lavas mainly pillowed (Plate 5-9) but not infrequently along the fault plane are found brecciated and sheared lavas. Along the fault plane the brecciated lava is mixed with red hematitic ochre. The footwall is occupied by the ochreous layer described in the previous section.

The southern contact of the orebody with the surrounding rocks was not accessible to direct observation. However, drilling data indicate that at the higher levels the sulphide ore is in contact with unmineralized olivine basaltic lavas (Figs. 5-2, 5-3, 5-4). At the lower levels the ore is in contact with brecciated and hydrothermally altered lavas, containing minor amounts of sulphide. (Fig. 5-3). At the 142 metre level two drivers proceeded up to the contact which is defined by a normal fault striking 060° and dipping 45° to the southeast. The fault plane consists of a zone of red and grey clayey gouge about one metre wide. The hanging wall consists of brecciated and sheared unmineralized lava. The footwall consists of brecciated and argillized lava impregnated with pyrite. Pockets and veins of sulphide rich in chalcopyrite are common in the argillized lava (Plate 5-14). Away from the contact towards the orebody the argillized lava is gradually succeeded by brecciated and silicified lava impregnated with fine grained pyrite.

6. Shape, Size and Structure of the Mousoulos Orebody.

The Mousoulos orebody in general has a rhombohedral shape; its long axis strikes slightly south of east. The two previously described parallel 060° tending faults appear to be responsible for the present shape of the orebody. The orebody

is plunging 35° to the east-southeast. Drilling and underground investigations indicate that the total tonnage of the Mousoulos orebody hardly exceeds the 1.5 million tons. Massive ore constitutes about one third of the tonnage whereas medium and low grade ore make up the remaining two thirds.

The top level of the orebody is 185 metres above sea level and in plan is 20 metres long and 6 metres wide. In depth these dimensions increase: at the 115 metre level the orebody is 152 metres long and 90 metres wide. Economic low grade ore extends down to 50 metres above sea level but below that level the mineralization, although it extends to a considerable depth, is not of economic significance.

The Mousoulos orebody appears to have been tilted 60° to the northeast, the direction and amount of the tilting being conformable to that of the regional tilting of the surrounding volcanic rocks, At Mousoulos, because of the tilting, the vertical zoning of the ore commonly found in the Cyprus sulphide orebodies, is found in a horizontal plane. Thus every mine level between 148 and 100 metres above sea level is made up of massive ore (Zone A) medium grade ore (Zone B) and low grade ore (Stockwork zone). All the mine levels between 185 and 148 metres above sea level contain only massive ore, whereas the latter is lacking in the levels below 100 metres above sea level. The layer of ochre is found only in the mine levels that contain massive ore.

In the mine levels that contain ochre the sequence ochre-massive ore-Zone B- stockwork zone is invariably encountered from the northeastern contact towards the southwest (Figs. 5-3, 5-4). On the other hand, by rotating the isometric projection illustrated in figure 5-3 about 60° to the southwest, and when account is taken of the possible sliding, it appears that the horizontal sequence was originally vertical. Therefore, the massive ore represents the top of the Mousoulos orebody and is overlain by the layer of ochreous sediment. The massive ore is underlain by a narrow zone (Zone B) consisting of an intimate mixture of sulphide and silica. Zone B is underlain by the stockwork zone which in the upper part consists of brecciated and mineralized lava, followed by mineralized pillowed lavas.

7. The Massive Ore (Zone A)

(a) General Characteristics of the Massive Ore

The entire massive ore of the Mousoulos orebody has a conglomeratic structure similar to that described in the Skouriotissa (Chapter 3) and Mathiatis (Chapter 4) orebodies. Thus, the massive ore consists of solid sulphide blocks, embedded in a matrix of sandy, friable sulphide (Plates 5-12, 5-13, 5-15). The proportions of solid sulphide blocks and the sandy sulphide matrix varies considerably. Thus, at the ochre-sulphide ore contact the massive ore consists mostly of sugary matrix. The sugary matrix constitutes more than 80 per cent of the volume of the massive ore and only rare solid sulphide blocks are embedded in it. (Plate 5-17). Away from the ochre-sulphide ore contact the proportion of the sandy matrix gradually decreases whereas the proportion of the solid sulphide blocks increases (Plates 5-28, 5-20). Finally, at the base of the massive ore, near its contact with Zone B, the sandy matrix constitutes less than 20 per cent of the volume of the massive ore (Plate 5-19). The form of the solid sulphide blocks in all parts of the massive ore is variable (angular, subangular or rounded), and there is also a great variation in the size of the blocks.

In the massive ore of the Mousoulos orebody, the collomorphic banding is a common feature of the solid sulphide blocks, and is generally similar to that described in the conglomeratic ore of the Skouriotissa orebody. A striking characteristic of the massive ore is the high porosity; the weight of a cubic metre of massive ore hardly exceeds the 3000 kilograms (M. Papadopoulos Mine Manager personal communication). The porosity in the sandy matrix is much higher than the porosity in the solid blocks encased in it. In the solid blocks the cavities vary in size from less than one millimetre to several centimetres. In parallel sections of a single hand specimen of sulphide block the cavities are randomly distributed and their morphology exhibits a wide variation. (Plates 5-23, 5-24).

Plate 5-17. Mousoulos underground. Massive sulphide ore near the ochre - sulphide ore contact. It mainly consists of sandy friable ore in which are embedded rare blocks of solid sulphide.

Plate 5-18. Mousoulos underground. Massive sulphide ore in which the proportion of the solid sulphide blocks increases whereas the proportion of the sandy friable ore decreases.

Plate 5-19. Mousoulos underground. Typical conglomeratic massive ore; the proportion of solid sulphide blocks is much higher than the proportion of the sandy friable ore.



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Plate 5-20. Mousoulos underground. Contant of sugary massive ore (left) with conglomeratice massive ore (right).

Plate 5-21. Mousoulos underground. Mineralized brecciated lava. The lava fragments are angular or rounded and have a variable size.

Plate 5-22. Hand specimen of mineralized brecciated lava. Lava fragments ore cemented with opal and sulphide (natural size).

Plates 5-23, 5-24. Two parallel sections of a solid sulphide block containing cavities of a variable size and form (natural size).

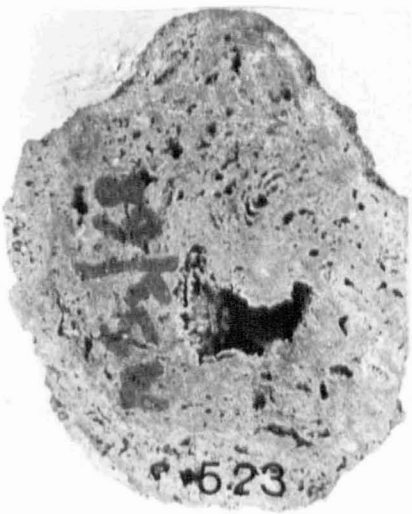
Plate 5-25. Hand specimen showing contact (point indicated by arrow), between a solid sulphide block and ochre (top), (natural size).

Plate 5-26. Hand specimen of mineralized brecciated lava. Lava fragments are cemented with opal exhibiting colloform banding (natural size).


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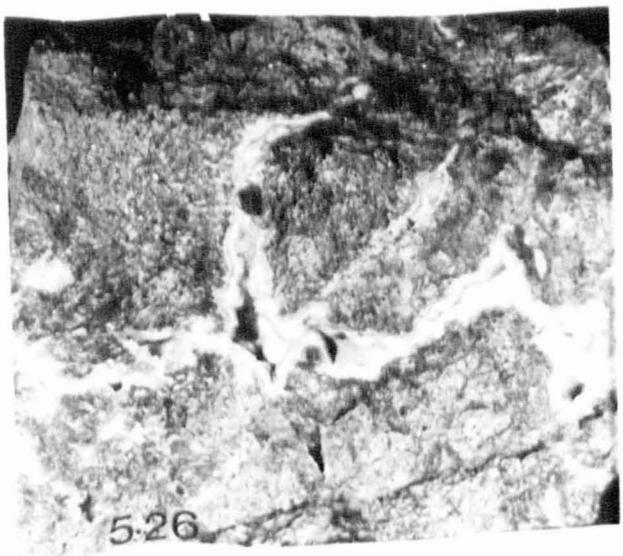

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Plates 5-27, 5-28. Replacement of pyrite by strongly and poorly crystalline goethite. Replacement follows grain boundaries and fractures in pyrite. Note that in the goethite matrix are scattered remnants of intensely corroded pyrite.

PPL, scale bar = 688 microns

Plate 5-29. Atoll textures produced by replacement of the central parts of pyrite aggregates by strongly and poorly crystalline goethite.

PPL, scale bar = 200 microns

Plate 5-30. Replacement of zoned pyrite by goethite. Replacement follows the contacts of the individual growth zones.

PPL, scale bar = 200 microns

Plate 5-31. Polished section of the area indicated by arrow in Plate 5-25. Note that the sulphide block-ochre contact is gradational.

PPL, scale bar = 634 microns

Plate 5-32. Intensely corroded pyrite embedded is strongly and poorly crystalline goethite at the solid sulphide-ochre contact.

PPL, scale bar = 1200 microns

Plate 5-33. Intensely fractured and corroded pyrite scattered in poorly and well crystalline goethite 2 cms away from the contact shown in Plate 5-31.

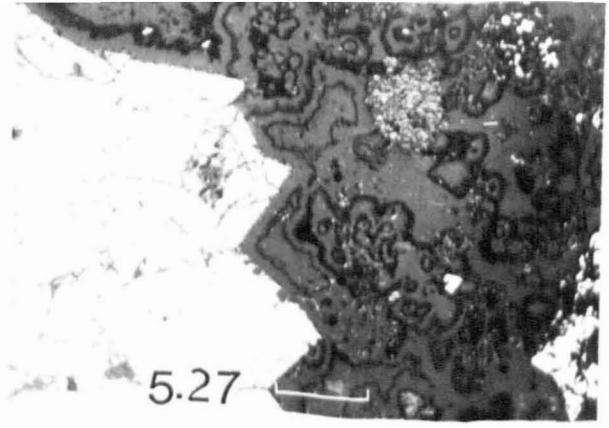
PPL, scale bar = 516 microns

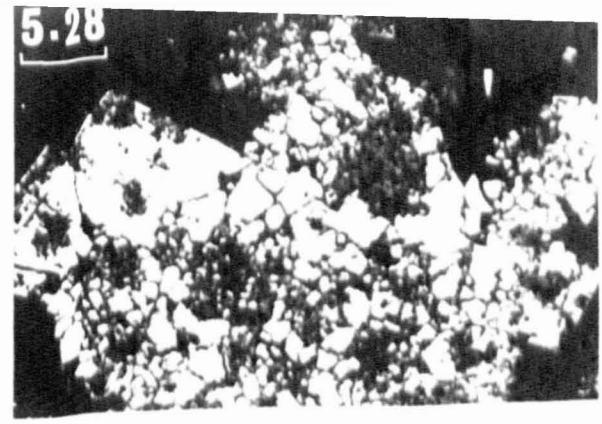
Plates 5-34, 5-36. Intensely corroded pyrite embedded in strongly and poorly crystalline goethite at the solid s sulphide-ochre contact.

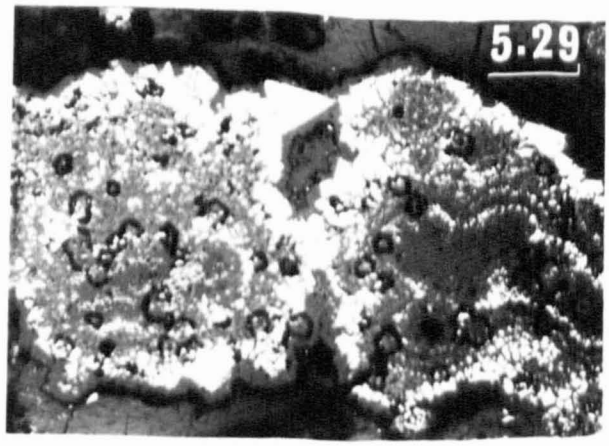
PPL, scale bars= 180, 516 microns respectively

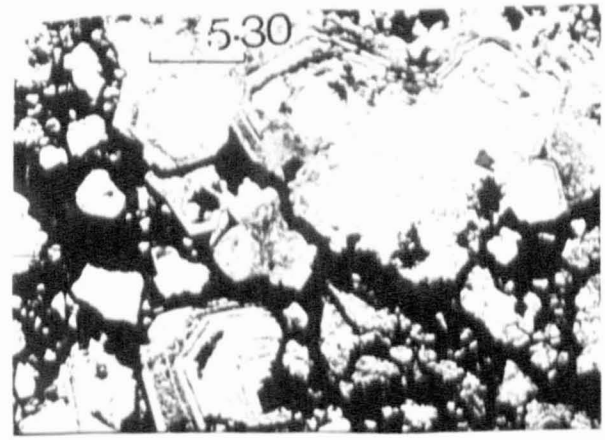
Plate 5-35. Rare fragments of intensely corroded pyrite embedded in a matrix of goethite several cms from the contact shown in plate 5-31.

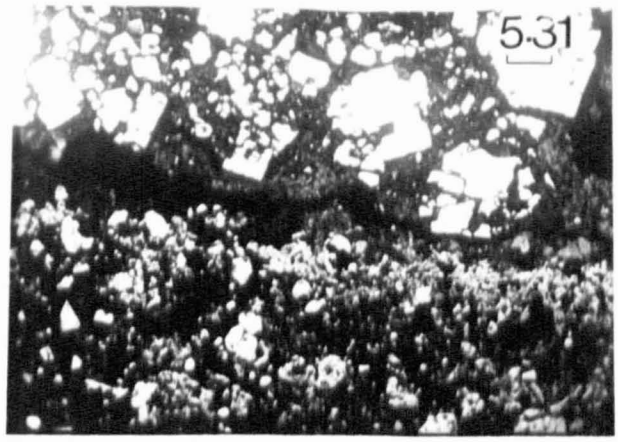
PPl, scale bar = 180 microns

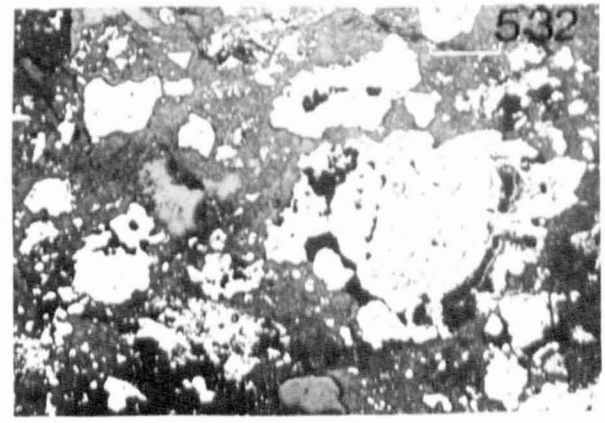

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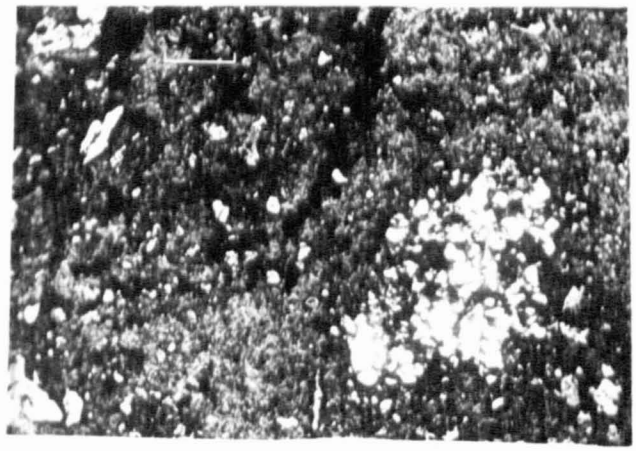

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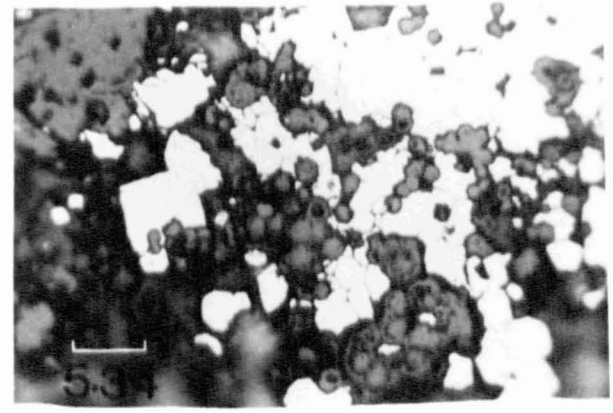

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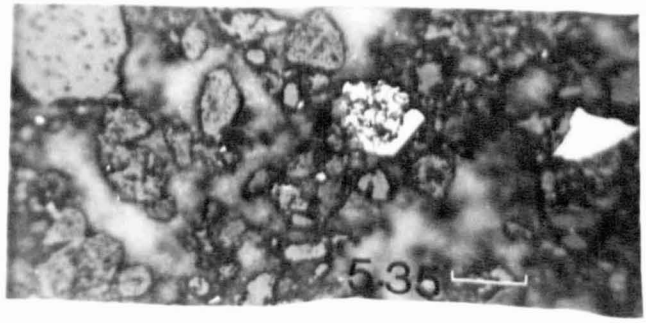

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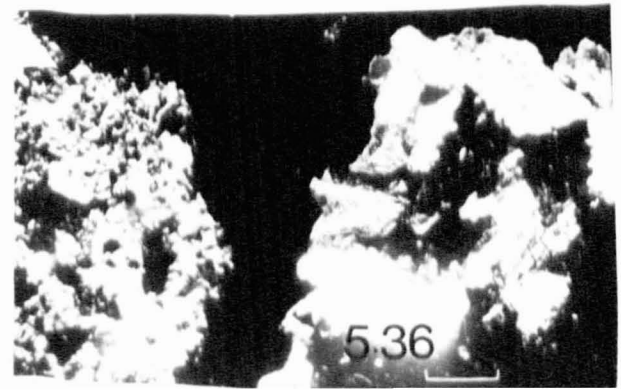

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(b) Major and Minor Element Chemistry of the Massive Ore

The major element chemistry of the massive ore of the Mousoulos orebody was studied from the detailed assay plans and the drilling data provided by the Hellenic Mining Company. The assay plans contain analyses of samples taken every $1\frac{1}{2}$ metre from drives and crosscuts at all the mine levels; all the samples were analysed for copper and sulphur. Furthermore, the samples of the drill holes which intersected the Mousoulos orebody were analysed for copper and sulphur. All these data indicate that in the Mousoulos orebody the massive ore consists mostly of sulphur, iron and small but variable amounts of copper. (Fig. 5-5)

In the massive ore the sulphur content ranges from 40 to 51 per cent (Fig. 5-6). Not infrequently in the assay plans the copper increases from 0.2 to 4.5 per cent over a distance of $1\frac{1}{2}$ metres. The copper is generally very low in the zones of sugary massive ore and increases substantially in the conglomeratic ore. In the latter, sulphide blocks rich in chalcopyrite are found in contact with sulphide blocks containing very little chalcopyrite. In polished sections the chalcopyrite is seen to be erratic too; in a single polished section, areas rich in chalcopyrite were observed in contact with areas very low in chalcopyrite.

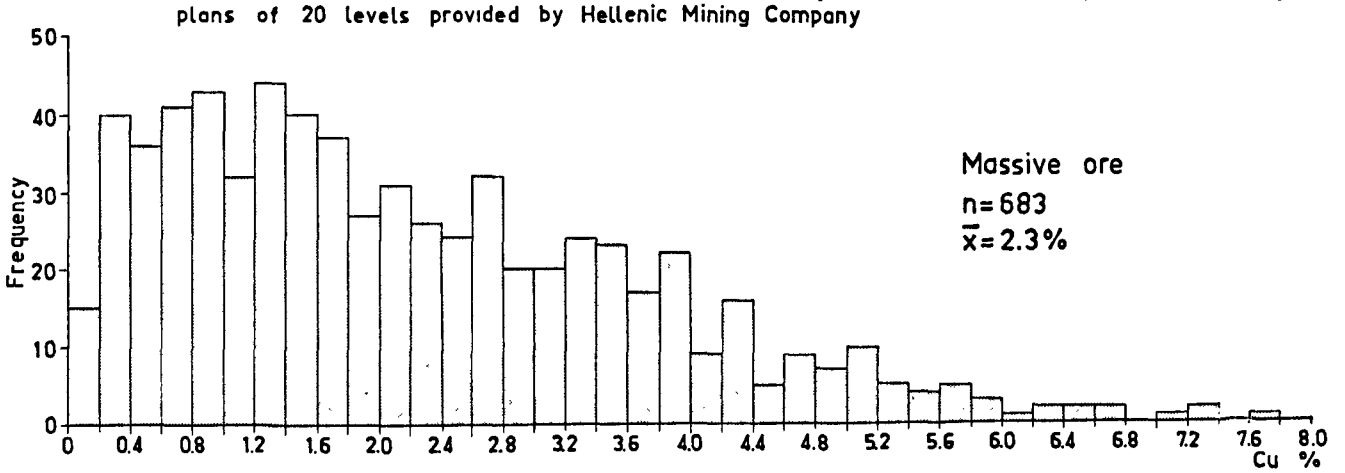
Samples of ore taken from three selected drill holes through the Mousoulos orebody were analysed with Atomic Absorption Spectrophotometer by the Chemical Laboratory of the Cyprus Geological Survey for copper, zinc, nickel and cobalt. The results of these analyses are illustrated in figures 5-6 and indicate that:-

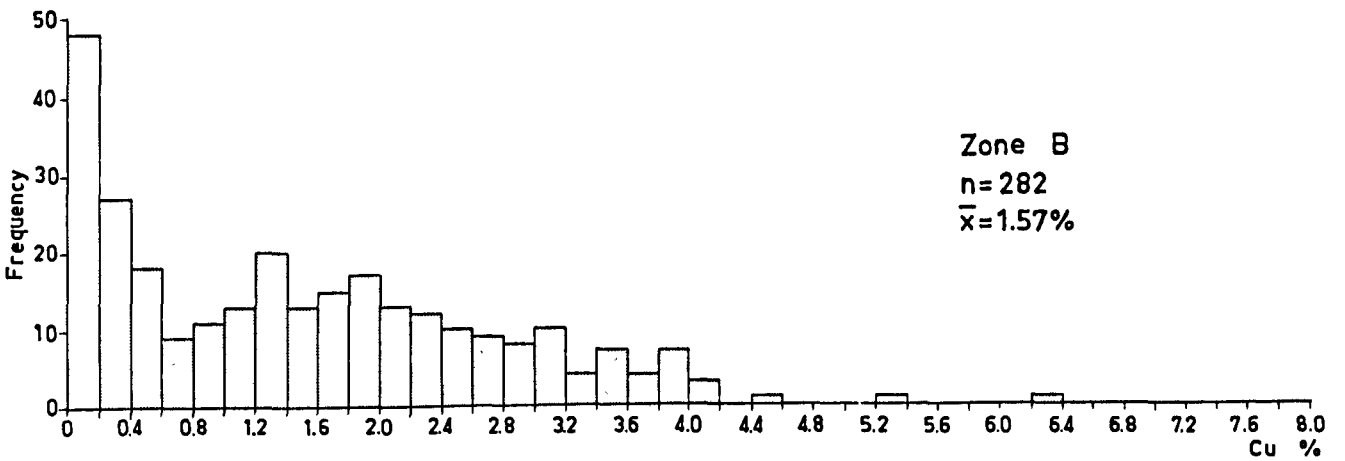
(a) The Zinc content in the massive ore is generally less than one per cent, and is erratically distributed. The ratio, Cu:Zn is generally higher than one.

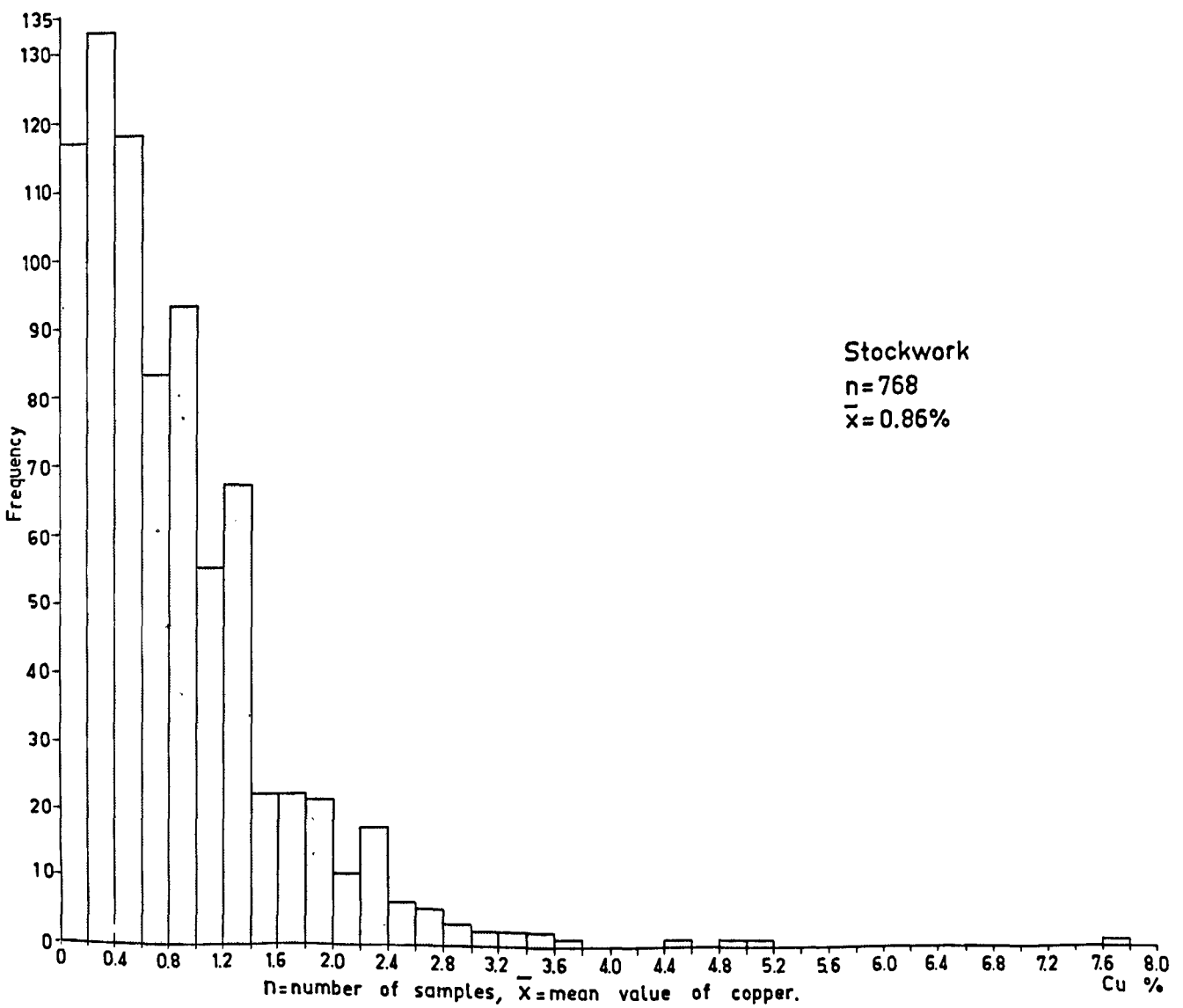
(b) Cobalt is erratically distributed in the massive ore, and tends to decrease at the top of the massive ore and to increase at depth.

(c) Nickel is less erratically distributed than cobalt; at the top of the massive ore the ratio Co:Ni tends to be less than one, whereas at depth it is higher than one.

Fig. 5-5. Distribution of Copper in the massive ore ($S > 40\%$), the zone B ($30 \leq S \leq 40\%$) and the stockwork zone ($S < 30\%$) of the Mousoulos orebody. Based on data compiled from assay plans of 20 levels provided by Hellenic Mining Company







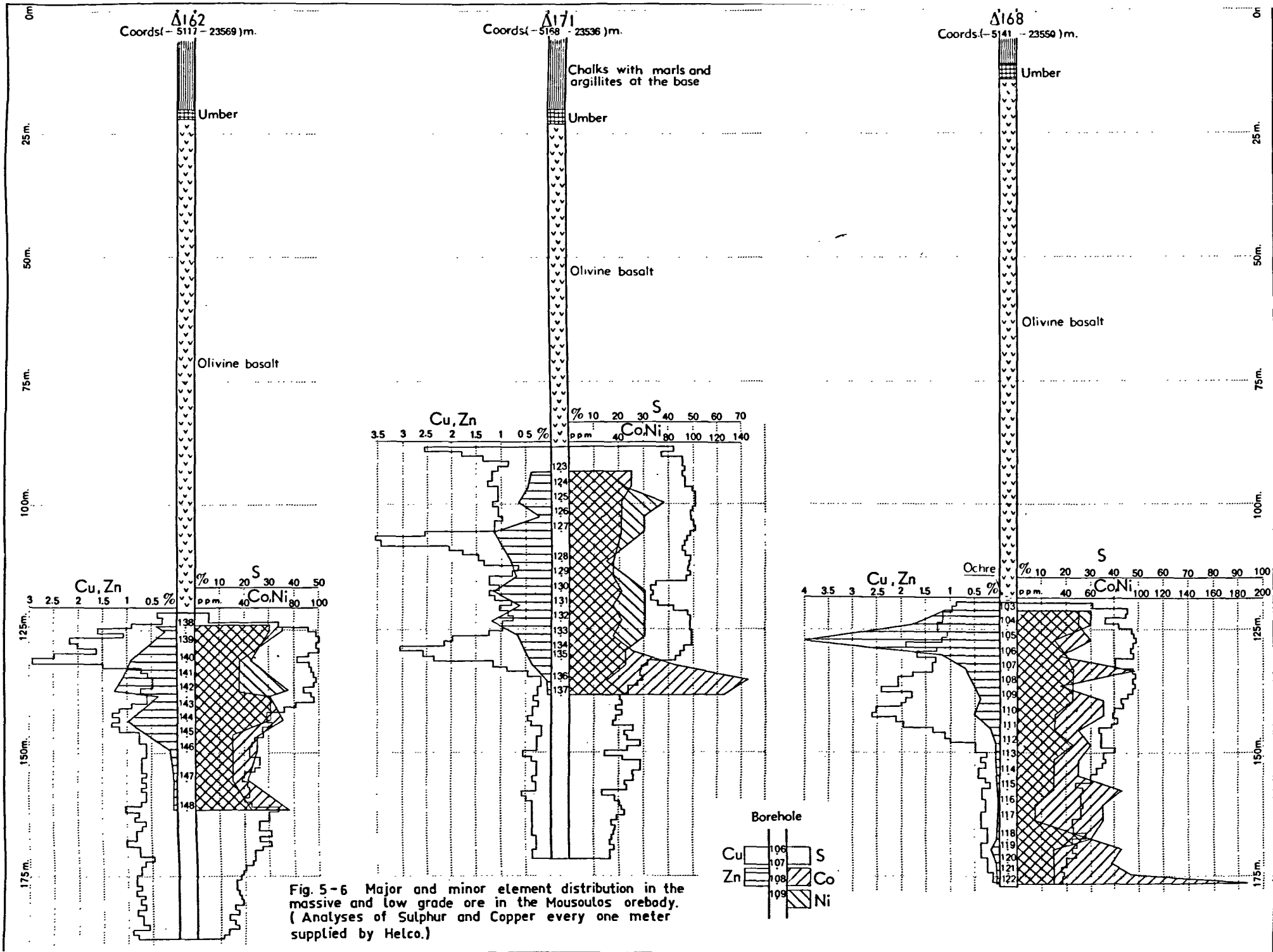


Fig. 5-6 Major and minor element distribution in the massive and low grade ore in the Mousoulos orebody. (Analyses of Sulphur and Copper every one meter supplied by Helco.)

c. Ore Mineralogy of the Massive Ore

i. Opening Statement

Detailed studies of polished sections indicate that both the sugary matrix and the solid blocks are highly porous. The cavities appear to be secondary and most of them are empty; however, some of them are filled with chalcopyrite or sphalerite. In the massive ore of the Mousoulos orebody the mineral assemblage is generally simple whereas the forms and textures of the ore minerals are complex. Pyrite is the predominant ore mineral followed by chalcopyrite, sphalerite, and pyrrhotite in decreasing order of abundance. Marcasite is restricted to the top of the massive ore near its contact with the ochreous layer. Covellite is the most common secondary copper sulphide, being restricted to the upper parts of the massive ore. Digenite, chalcocite and bornite are present in the massive ore but are generally rare.

ii. The Cavities

The sulphide blocks encased in the ochre (Plates 5-41, 5-42, 5-43, 5-44) and the sugary sulphide matrix of the massive ore, (Plates 5-45, 5-46, 5-47) are highly porous. Pore space generally occupies more than 50 per cent of the surface area as viewed in polished sections. In the sulphide blocks embedded in the ochre part of the disintegrated pyrite is healed with goethite (Plates 5-37, 5-38, 5-37, 5-40) but more commonly the cavities are empty.

In the solid sulphide blocks of the conglomeratic ore the porosity is much less than in the surrounding sugary matrix. The size and morphology of the cavities vary greatly even in a single polished section. The cavities may be isolated or interconnected and their contact with pyrite is invariably irregular (Plates 5-49, 5-50). The pyrite around the cavities is corroded with the cavities invariably projecting into it (Plates 5-47, 5-50, 5-51, 5-52). Remnants of corroded pyrite very commonly occur in the cavities (Plates 5-49, 5-50, 5-51, 5-52). Not infrequently the remnants of corroded pyrite are connected with the surrounding pyrite with narrow bridges

Plates 5-37, 5-38. Veins of disintegrated pyrite healed with goethite (black) intersecting a solid sulphide block embedded in the ochre. The sides of the veins consist of massive pyrite (top right of Plate 5-38).

PPL, scale bars = 800 microns

Plates 5-39, 5-40. Veins of euhedral and intensely corroded pyrite cemented with goethite, intersecting a solid sulphide block embedded in ochre. At left of Plate 5-39 side of the vein.

PPL, scale bars = 800 microns

Plates 5-41, 5-42. Veins of disintegrated pyrite intersecting solid sulphide blocks embedded in ochre. (Black areas represent empty space).

PPL, scale bar = 800, 125 microns respectively

Plate 5-43. Vein of euhedral and intensely corroded pyrite intersecting a solid sulphide block. (Top right and bottom left sides of the vein). Black areas represent empty space.

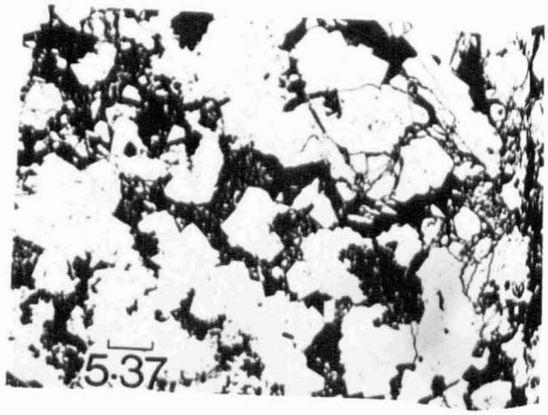
PPL, scale bar = 800 microns

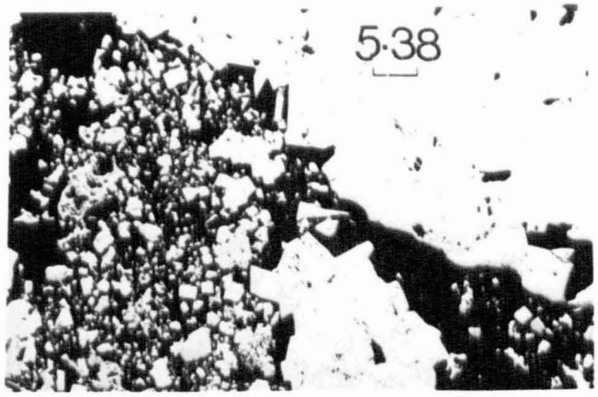
Plate 5-44. Intensely fractured and corroded idiomorphic euhedral pyrite in a vein of disintegrated pyrite intersecting a solid sulphide block. Black areas represent empty space.

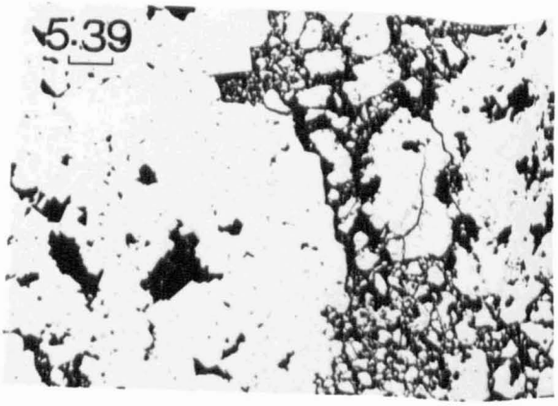
PPL, scale bar = 800 microns

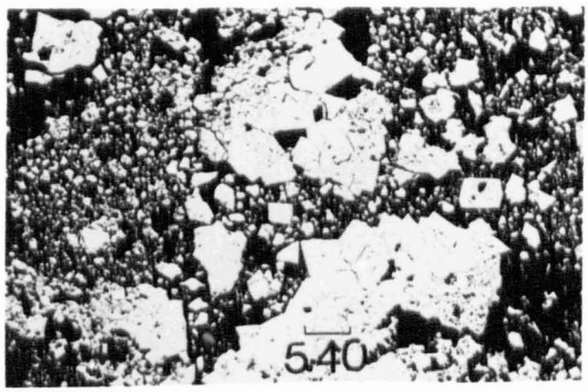
Plates 5-45, 5-46. Sandy friable matrix in which are encased the solid sulphide block of the conglomeratic ore. Black areas represent empty space.

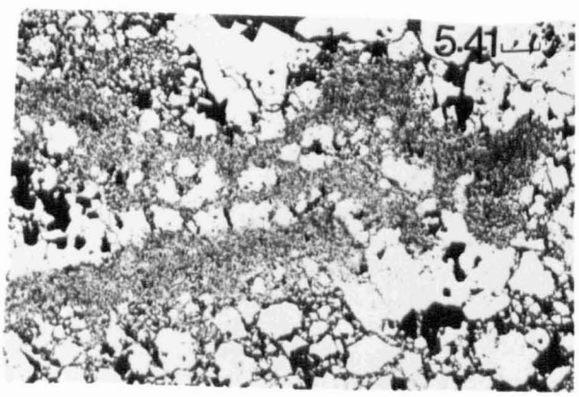
PPL, scale bar = 344, 125 microns respectively

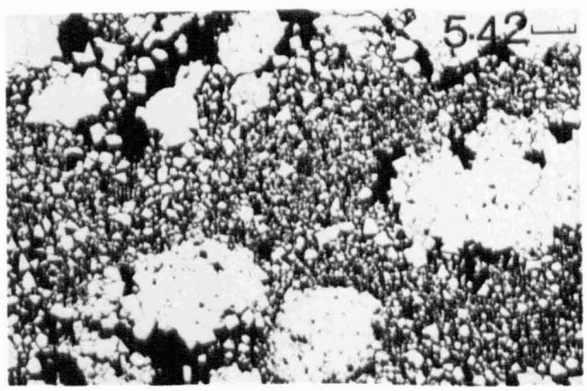

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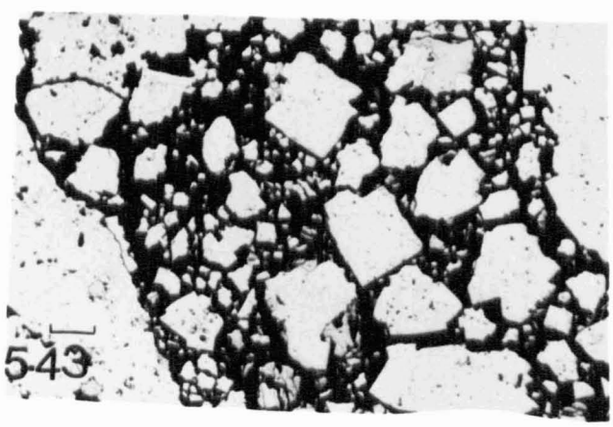

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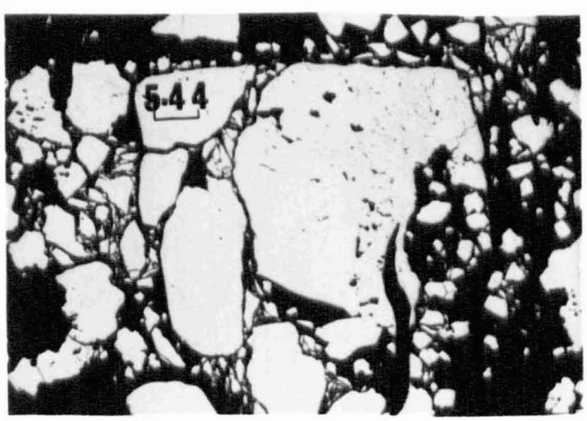

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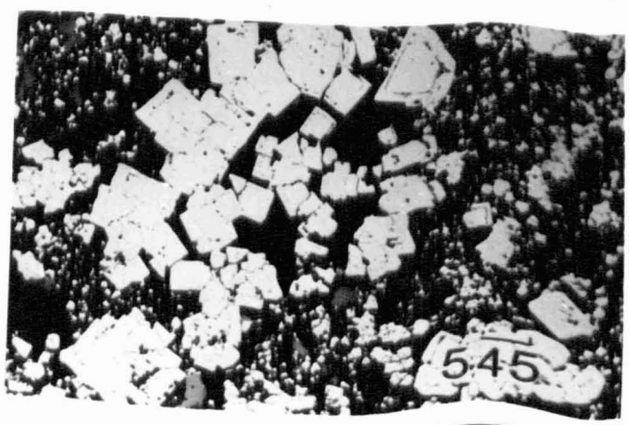

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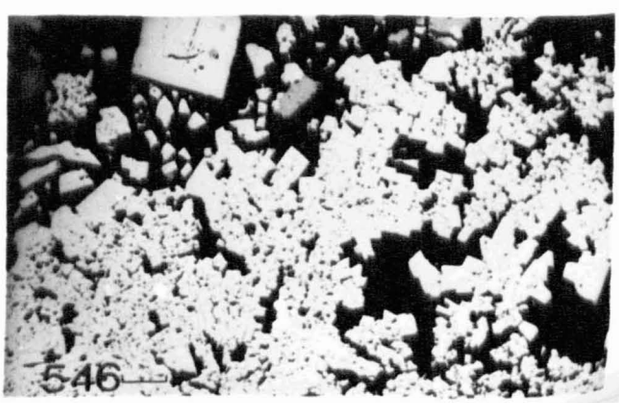

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(Plates 5-49, 5-50, 5-51, 5-52). All these observations suggest that probably the cavities are not primary but were produced by partial dissolution of pyrite. The possible processes involved will be discussed in Part II.

The cavities are generally empty but in the sulphide blocks rich in chalcopyrite or sphalerite, considerable proportion of these cavities are filled with these two minerals. (Plates 5-54, 5-55, 5-56). Remnants of corroded pyrite are commonly enclosed in the chalcopyrite and sphalerite filling the cavities. The morphology of the pyrite is similar to the remnant pyrite found in empty cavities in the zones of high porosity (compare the plate 5-51 with the plate 5-59 the plate 5-54 with the plate 5-64 and the plate5-48 with the plate 5-56). Even in a single polished section the morphology of the remnant pyrite found in empty cavities is similar to the pyrite enclosed in chalcopyrite (Plate 5-55) or sphalerite (Plate 5-61) Frequently pyrite with internal growth structure was partly dissolved along the contact of the individual growth zones (Plates 5-58, 5-60, 5-61, 5-65). Part of the space produced by the dissolution of pyrite is filled with sphalerite whereas part of it is empty.

iii. Pyrite

The predominant mineral in the massive ore of the Mousoulos orebody is the pyrite. Pyrite I with internal growth zoning is found only in the solid sulphide blocks, whereas it is very rare or absent in the sugary matrix. The latter consists mainly of remnants of corroded unzoned pyrite I (Plates 5-41, 5-42, 5-43, 5-44, 5-46, 5-47). In the solid blocks the amounts of zoned pyrite vary considerably. Electrolytic etching (Plates 5-63) and "natural etching" indicate that in the zoned pyrite, the zoning is restricted to the outer parts of the crystals. In many cases the morphology of the individual growth zones is similar to the morphology of the remnant pyrite observed in the zones of high porosity (compare plates 5-51, 5-52 with plate 5-63) and the remnant pyrite enclosed in sphalerite (compare plate 5-63 with plate 5-57).

A common feature of the solid sulphide blocks is the colloform banding. The latter was described by Mousoulos (1957)

Plate 5-47. Highly porous sugary massive ore from the ochre-sulphide ore contact. Black areas represent empty space.

PPL, scale bar = 125 microns

Plate 5-48. Highly porous sandy friable ore containing anhedral sphalerite (grey). Growth zoning in pyrite (left) marked by sphalerite (grey).

PPL, scale bar = 120 microns

Plates 5-49, 5-50. Cavities (black areas) varying greatly in size, associated with intensely corroded pyrite.

PPL, scale bars = 800, 2400 microns respectively

Plates 5-51, 5-52. Empty cavities (black areas) containing remnants of corroded pyrite which often are connected with the surrounding pyrite by narrow pyrite bridges.

PPL, scale bar = 2400, 1000 microns respectively

Plate 5-53. Cavities in pyrite partly filled with sphalerite (grey). The latter contains remnants of corroded pyrite.

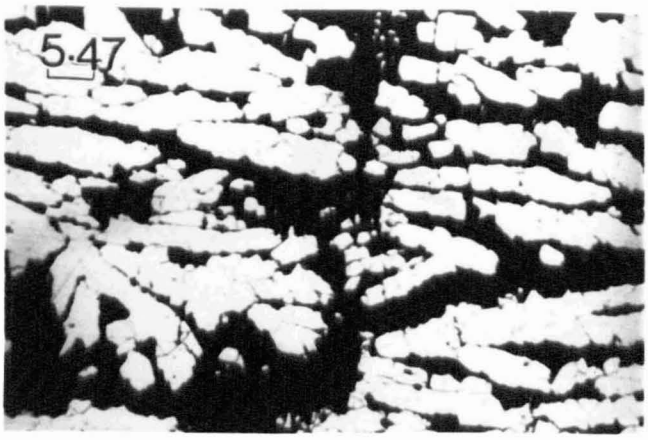
PPL, scale bar = 2400 microns

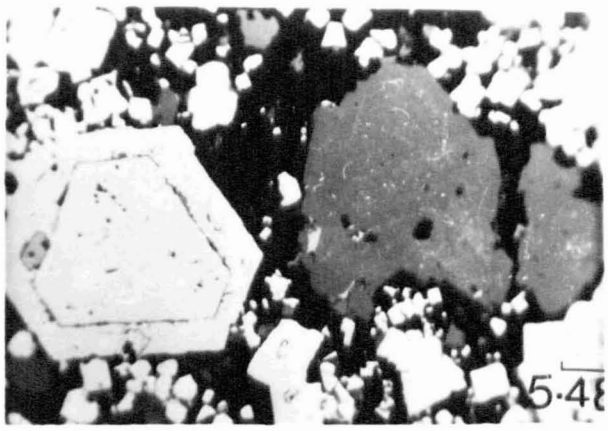
Plates 5-54, 5-56. Sphalerite (grey) filling part of the cavities in pyrite and containing intensely corroded pyrite.

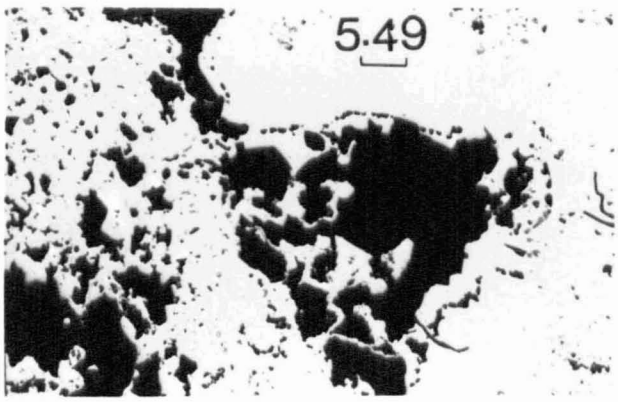
PPL, scale bar = 1000, 1200 microns respectively

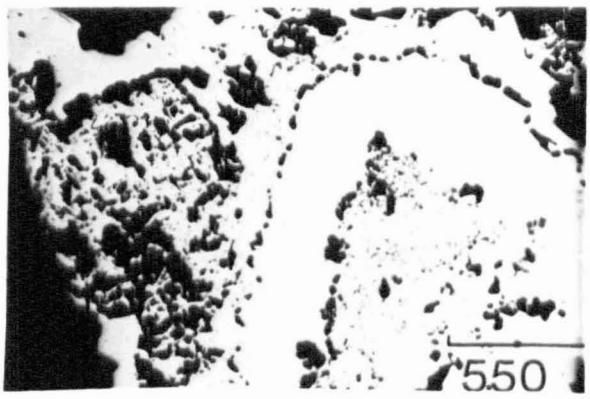
Plate 5-55. Chalcopyrite (grey white) filling part of the cavities in pyrite (white).

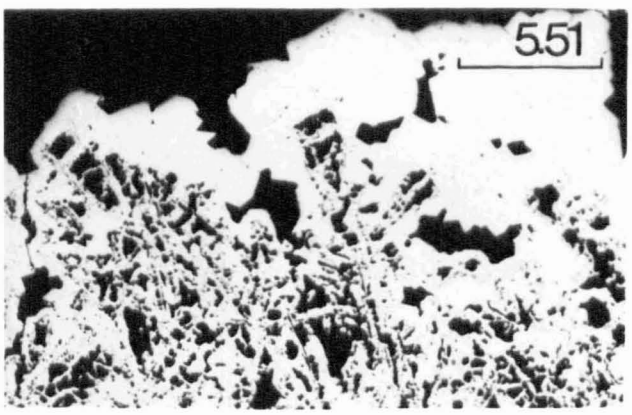
PPL, scale bar = 1000, 1200 microns

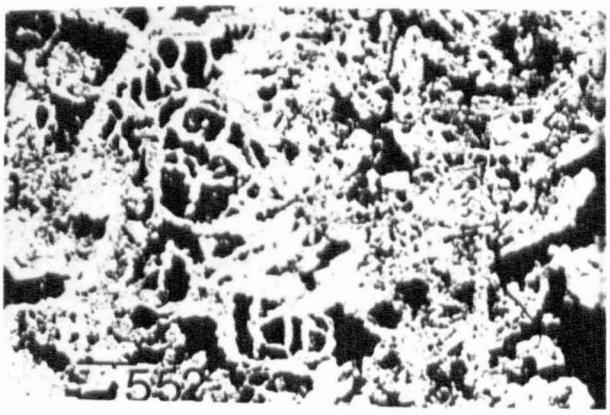

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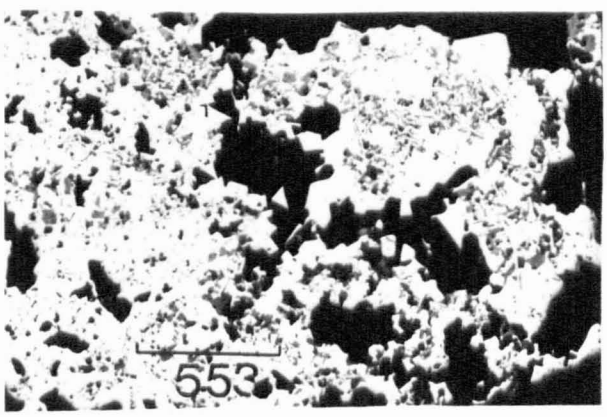

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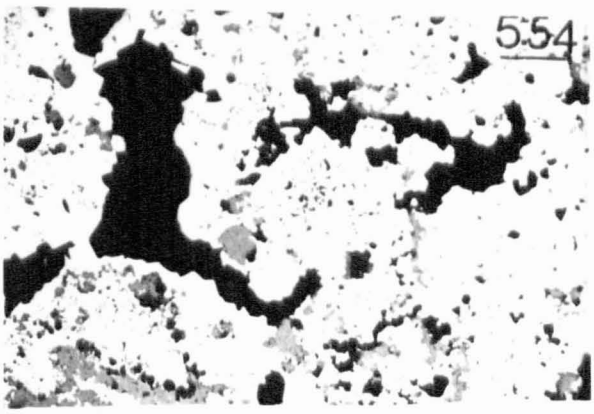

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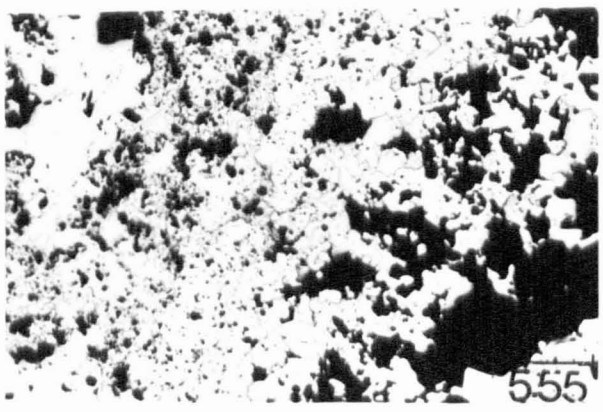

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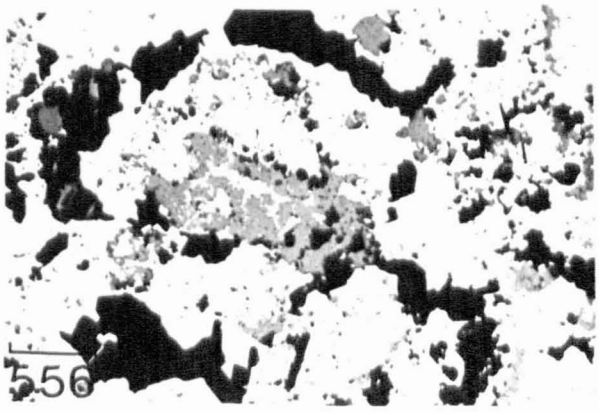

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Plate 5-57. Subhedral and anhedral chalcopyrite (top) as well as anhedral sphalerite (grey) filling part of the cavities in pyrite.

PPL, scale as in plate 5-59.

Plates 5-58, 5-60. Growth zoning in pyrite revealed by partial dissolution of pyrite along contacts of growth zones. Part of the resultant empty space is filled with sphalerite (grey).

PPL, scale bars = 1250 microns

Plate 5-59. Cavities in pyrite partly filled with sphalerite (grey).

PPL, scale bar = 1250 microns

Plate 5-61. Cavities in pyrite partly filled with sphalerite (grey). A large isolated cavity in the centre contains remnants of corroded pyrite.

PPL, scale bar = 1250 microns

Plate 5-62. Cavities in pyrite partly filled with sphalerite (grey).

PPL, scale bar = 640 microns

Plate 5-63. Euhedral zoned pyrite I. Specimen electrolytically etched.

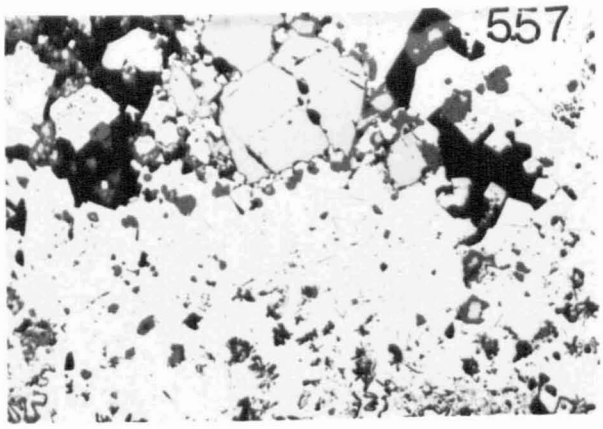
PPL, scale bar = 250 microns

Plates 5-64, 5-66. Disintegrated pyrite cemented with sphalerite (grey).

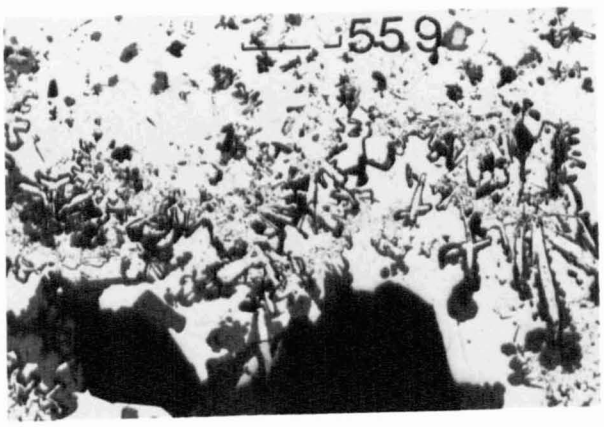
PPL, scale bar = 250, 1600 microns respectively

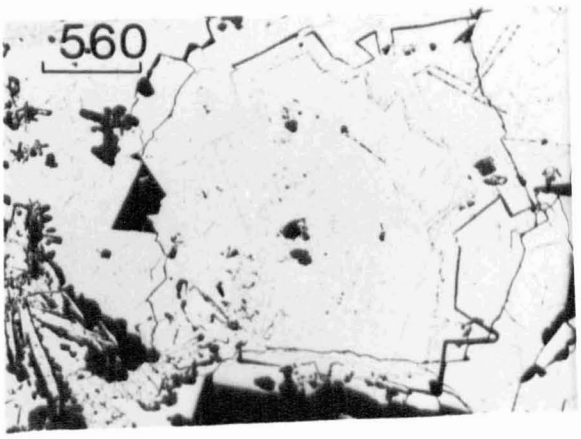
Plate 5-65. Growth zoning in pyrite revealed by dissolution along contacts of growth zones. The empty space produced is filled with sphalerite (grey).

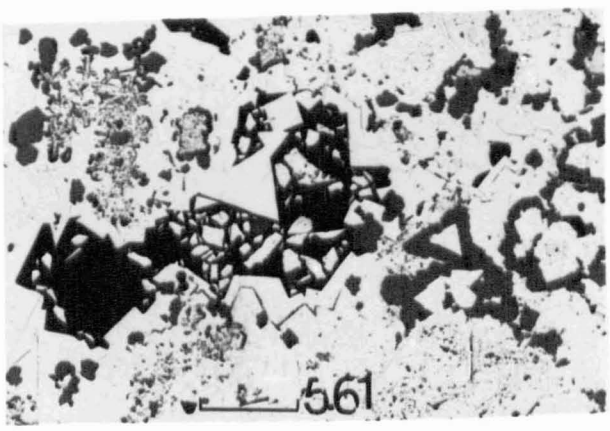
PPL, scale bar = 250 microns

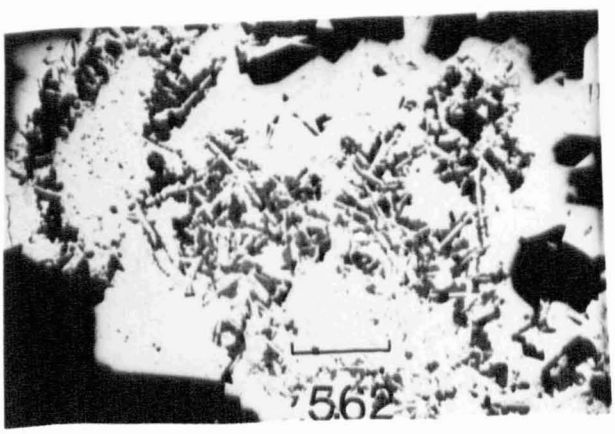

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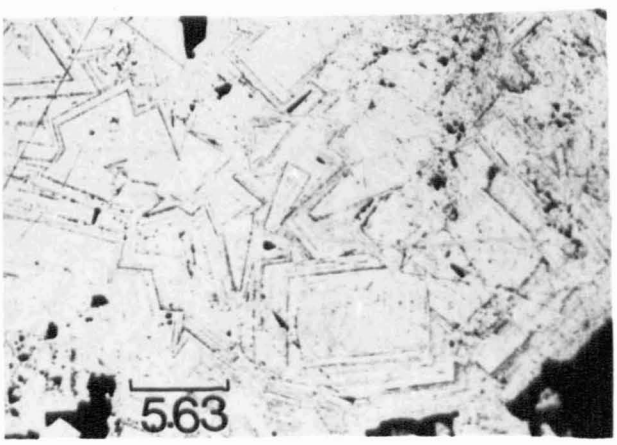

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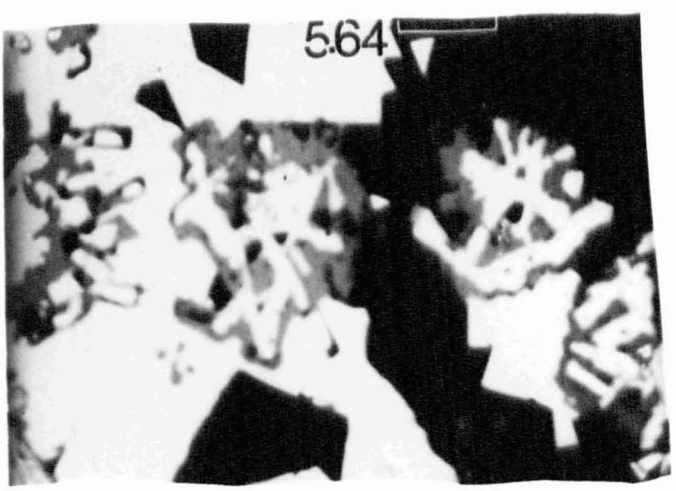

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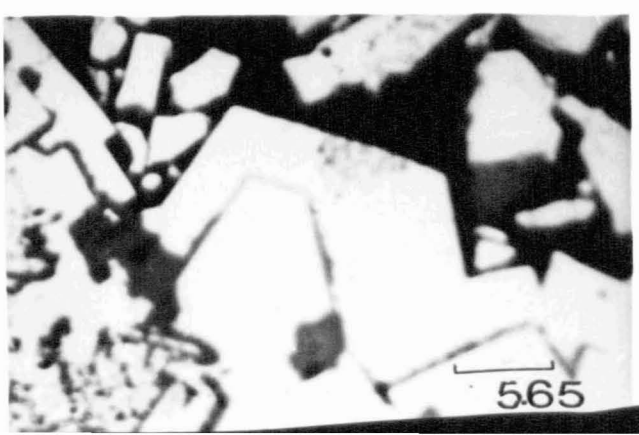

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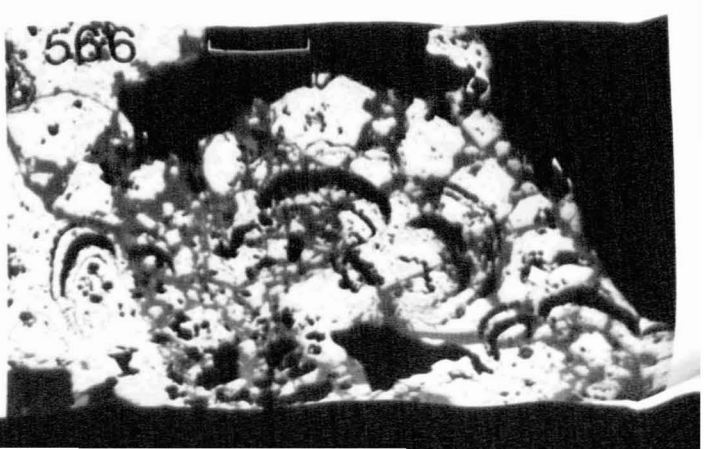

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5.66

in the massive ore of some of the worked orebodies in the Kalavasos area. He suggested that the colloform banding was due to alternating bands of pyrite, marcasite and less commonly chalcopyrite, but the present study revealed that the colloform banding is not due to variations in mineralogical composition but is due to differences in porosity. Colloform banding was observed in samples containing no marcasite and very little or no chalcopyrite.

Collomorphic pyrite is common in the solid sulphide blocks but it is absent in the sugary matrix. The collomorphic pyrite is characterized by low relief and low reflectivity (the latter results from high microporosity) (Plates 5-67, 5-69, 5-71). The most simple form of collomorphic pyrite in two-dimensional view is the sphere. Isolated spheres are common (Plates 5-67, 5-68, 5-69, 5-70) but more commonly single spheres join together to form composite spheres (Plates 5-67, 5-69, 5-71, 5-72). Not infrequently many spheres join together to produce the composite colloform structures illustrated in plates 5-67, 5-69 and 5-71). Colloform structures consisting of aggregates of fine anhedral pyrite are common too (Plates 5-73, 5-75). The boundaries of the euhedral pyrite I and the collomorphic pyrite are irregular and the latter invariably projects into the former. Even the pyrite I, which is enclosed in isolated spheres of collomorphic pyrite, is highly corroded, the zones of corrosion being occupied by zones of pyrite with lower relief and lower reflectivity (Plates 5-68, 5-70, 5-72). The cavities commonly found in the zones of collomorphic pyrite are generally empty (Plates 5-67, 5-69, 5-71, 5-72) but not infrequently the cavities are filled with chalcopyrite or sphalerite (Plates 5-70, 5-72, 5-74, 5-76). In electrolytically etched polished sections the collomorphic pyrite invariably truncates and replaces the euhedral zoned or unzoned pyrite I (Plates 5-73, 5-75). It appears that in the Mousoulos orebody the collomorphic pyrite is later than the pyrite I and that the former replaces the latter.

iv, <u>Chalcopyrite, Sphalerite and Pyrrhotite</u>

Chalcopyrite is the second most common mineral after pyrite. This mineral is erratically distributed in the massive

Plates 5-67, 5-69, 5-71. Isolated spheres as well as bands of collomorphic pyrite associated with high porosity. The contact between the pyrite I (high relief and high reflectivity) and the collomorphic pyrite is irregular with the latter prospecting into the former. Black areas represent empty space.

PPL, scale bars = 250, 560, 1600 microns respectively.

Plate 5-68. Isolated spheres of collomorphic pyrite associated with high porosity in a matrix of pyrite I. Note the occurrence of intensely corroded pyrite in a large cacity (bottom).

PPL, scale bar = 1600 microns

Plate 5-70. High magnification of the central part of Plate 5-68; remnants of intensely corroded pyrite I occur in the isolated spheres of collomorphic pyrite.

PPL, scale bar = 560 microns

Plate 5-72. Collomorphic pyrite associated with high porosity.

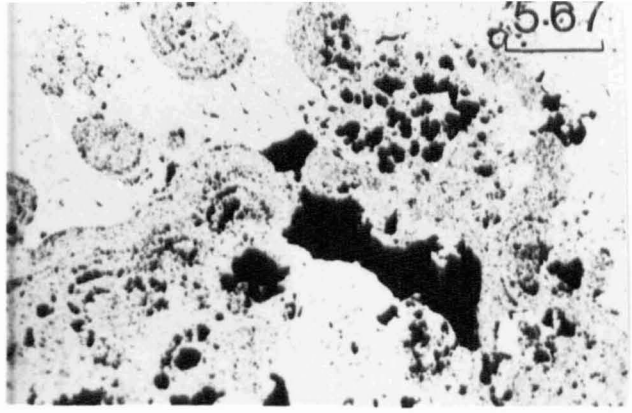
PPL, scale bar = 1600 microns

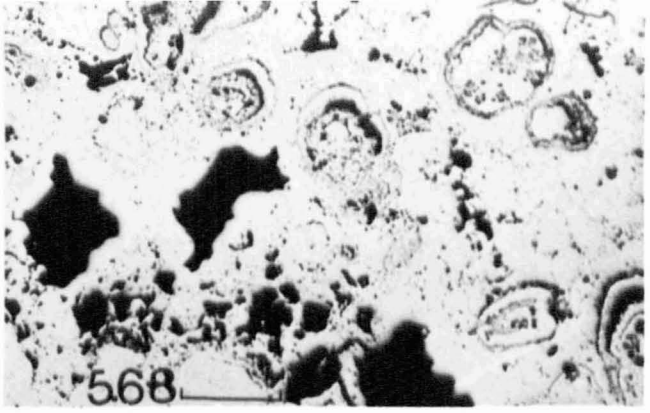
Plates 5-73, 5-75. Collomorphic pyrite truncating zoned and unzoned pyrite I (specimens electrolytically etched).

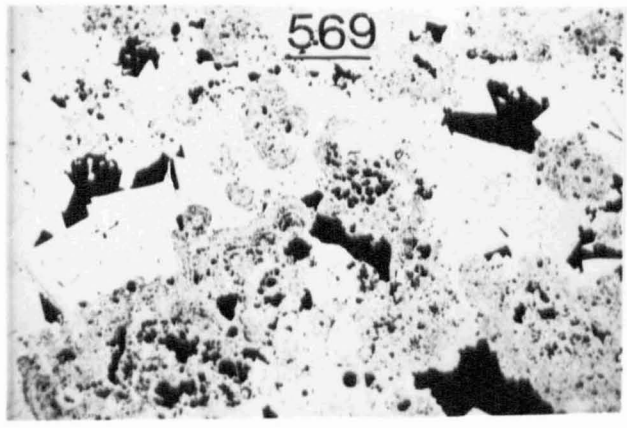
PPL, scale bars = 560, 1600 microns respectively.

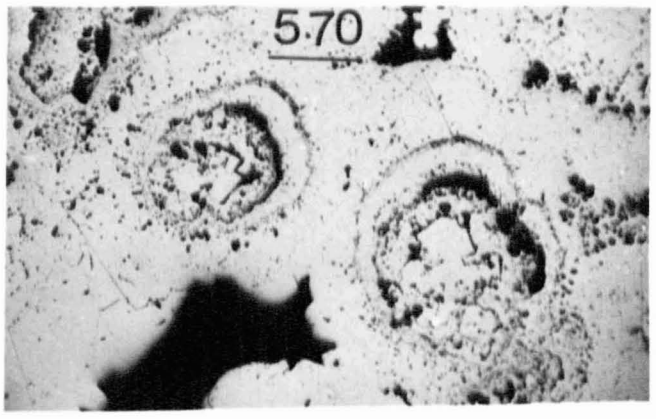
Plates 5-74, 5-76. Collomorphic pyrite associated with high porosity. Part of the cavities filled with sphalerite (grey).

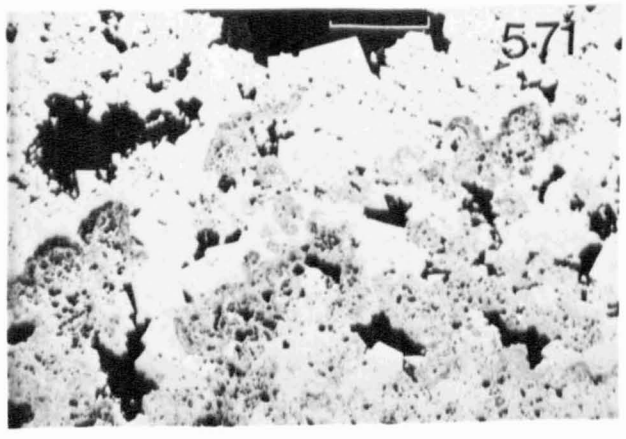
PPL, scale bars = 640, 250 microns respectively.

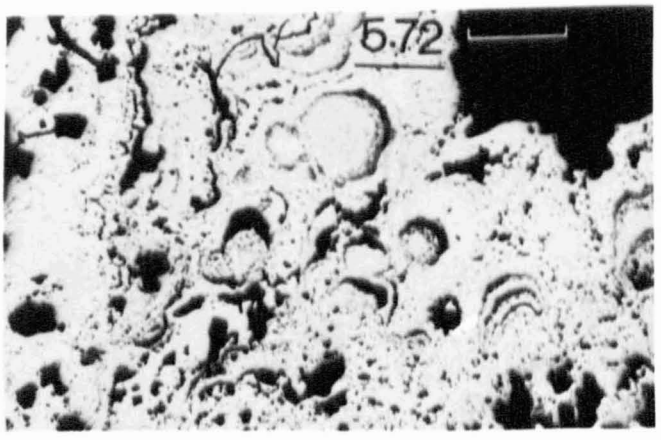

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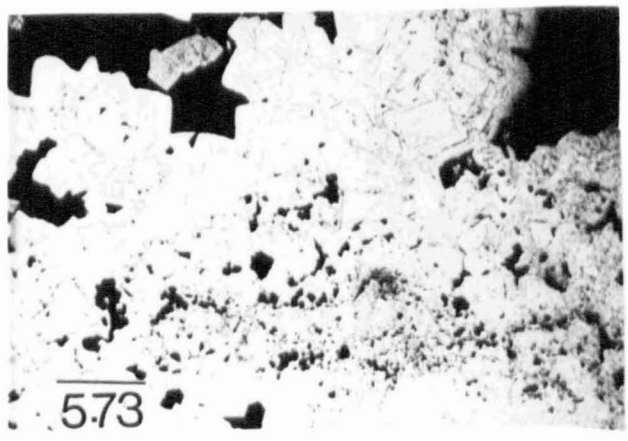

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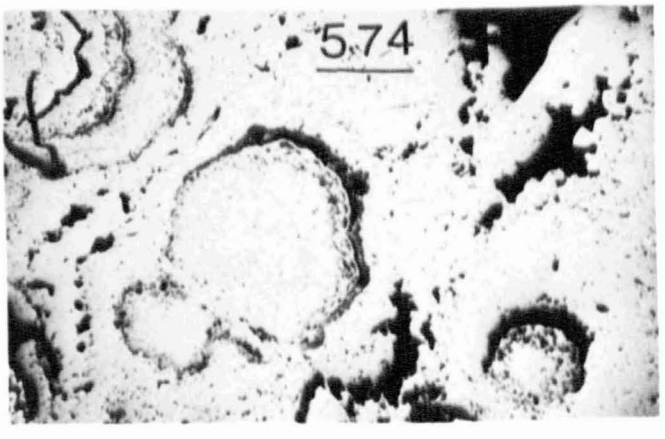

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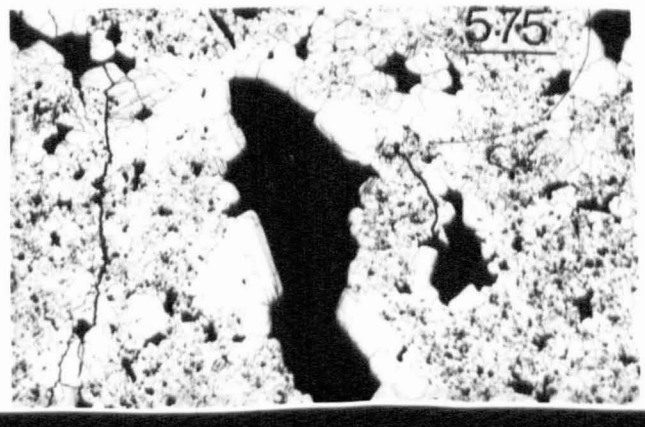

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ore and in general follows the distribution pattern of copper in the massive ore. Thus, chalcopyrite tends to be rare in the sulphide blocks encased in the ochre, and in the sugary ore near the ochre-sulphide ore contact; on the other hand, chalcopyrite increases considerably in the conglomeratic ore in contact with the sugary ore.

The most common mode of occurrence of chalcopyrite in the massive ore is as interstitial material to other minerals. The interstitial chalcopyrite fills part of the cavities in the pyrite; the grain boundaries of the interstitial chalcopyrite are irregular and in general follow the irregularities of the cavities it fills. This is obvious in polished sections where cavities filled with chalcopyrite coexist with empty cavities. (Plate 5-55). Euhedral or subhedral chalcopyrite is also present in the cavities (Plate 5-57). Simple and lamellar twining is a common feature of the interstitial chalcopyrite in the massive ore of the Mousoulos orebody.

Chalcopyrite is also commonly found as anhedral grains 10 to 20 microns in diameter enclosed in euhedral pyrite I. Not infrequently the inclusions of chalcopyrite in zoned pyrite I are sandwiched between the individual growth zones. Finally, a small proportion of the chalcopyrite in the massive ore is found as minute anhedral intergrowths in sphalerite (Plates 5-48, 5-81, 5-82).

The sphalerite like the chalcopyrite is erratically distributed in the massive ore, following the distribution pattern of zinc. The sphalerite tends to be rare in the massive ore near its contact with the ochre, increasing considerably in the conglomeratic ore several metres away from that contact.

Similar to chalcopyrite the most common form of spalerite in the Mousoulos orebody is as interstitial material to other minerals. The interstitial sphalerite fills part of the cavities in the pyrite (Plates 5-53, 5-54, 5-55). The morphology of the interstitial sphalerite is irregular and follows the morphology of the cavities and often contains remnants of corroded pyrite (Plates 5-59, 5-61, 5-62, 5-64, 5-66). Not infrequently the interstitial sphalerite was observed filling cavities along the

Plate 5-77. Chalcopyrite (cp) associated with bornite (bn) and digenite (nd) filling a cavity in pyrite.

PPL, scale bar = 136 microns

Plate 5-78. Sphalerite (grey) filling cavities in pyrite (white) often containing well oriented fragments of pyrite (bottom).

PPL, scale bar = 136 microns

Plate 5-79. Sphalerite (grey) associated with pyrrhotite (grey white) filling cavities in pyrite.

PPL, scale bar = 240 microns

Plate 5-80. Sphalerite (grey) associated with pyrrhotite (point indicated by arrow) developed along the grain boundaries of euhedral pyrite I.

PPL, scale bar = 136 microns

Plate 5-81. Sphalerite (grey) grown in a cavity, containing fine grained chalcopyrite.

PPL, scale bar = 136 microns

Plate 5-82. Sphalerite (grey) filling cavities in pyrite containing well oriented chalcopyrite.

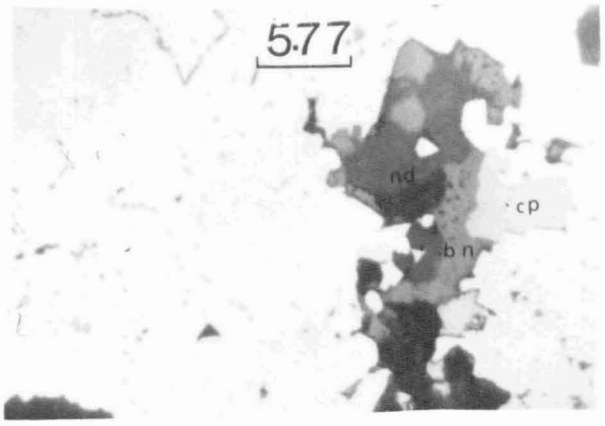
PPL, scale bar = 136 microns.

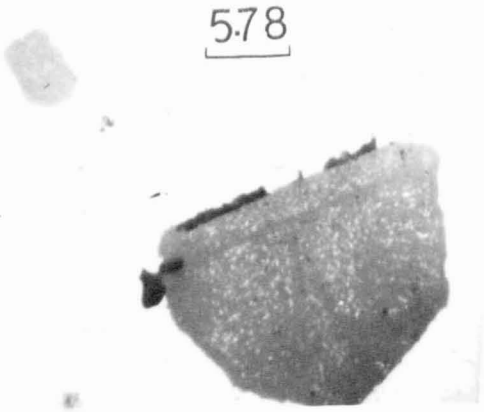
Plate 5-83. High magnification of part of the sphalerite grain shown in Plate 5-82. (top right). Showing oriented exsolution lenses of chalcopyrite in sphalerite. Photograph taken with Cambridge stereoscan Scanning Electron Microscope.

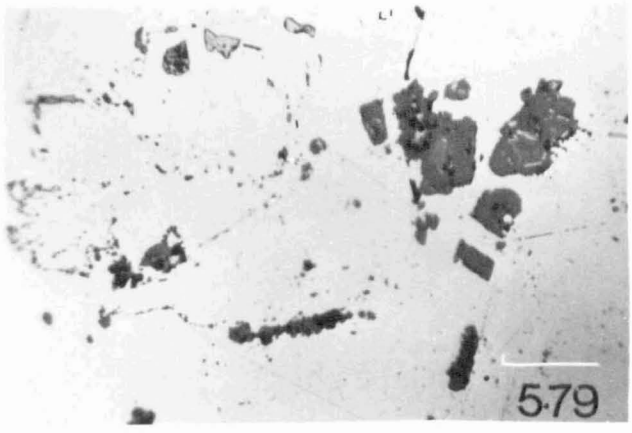
Magnification X 1400

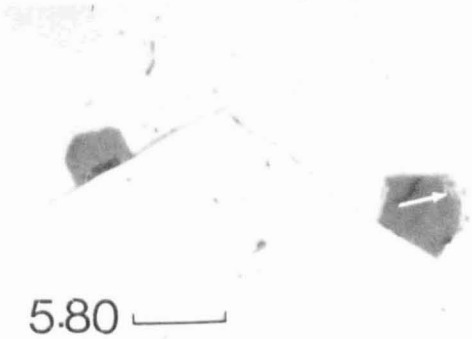
Plates 5-84, 5-85. High magnifications of two areas of the sphalerite shown in Plate 5-83, showing oriented exsolution lenses of chalcopyrite in sphalerite. Photographs taken with Cambridge Stereoscan Scanning Electron Microscope.

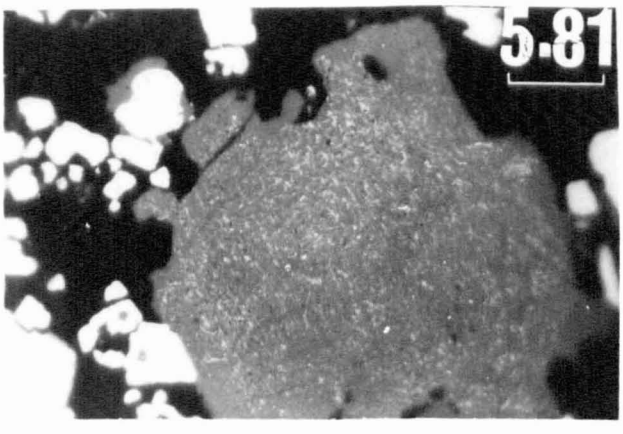
Magnifications X 8000.

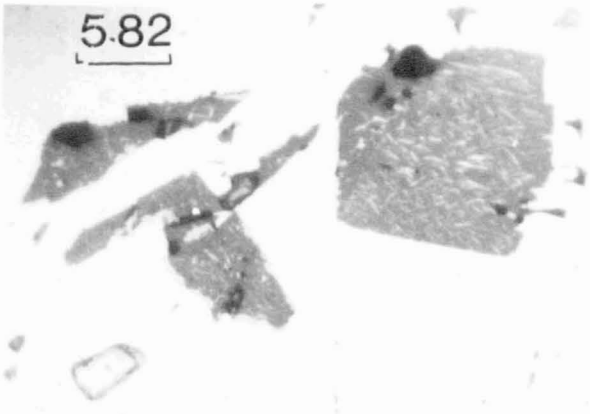

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nd
cp
bn

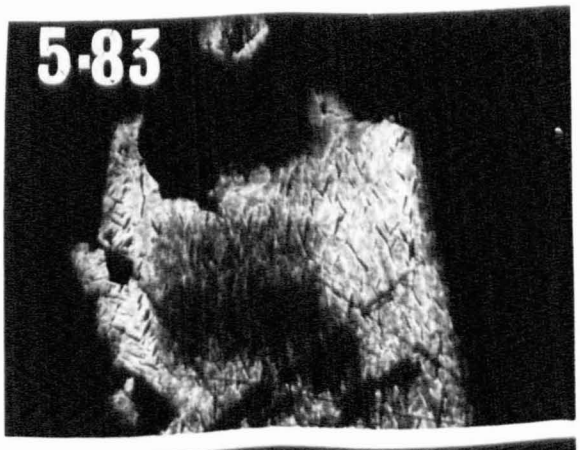

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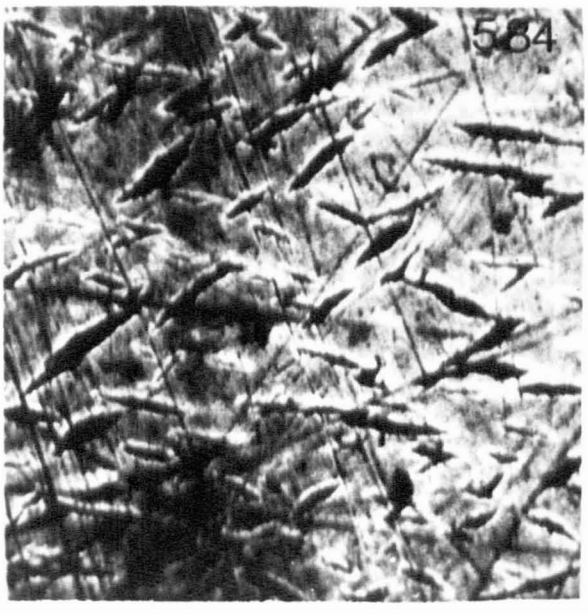

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contacts of growth zones in zoned pyrite I. (Plates 5-58, 5-60, 5-64, 6-65). Subhedral and euhedral interstitial sphalerite is also common (Plates 5-78, 5-79, 5-80, 5-81, 5-82). In some cases the grains of subhedral sphalerite are developed along the grain boundaries of euhedral pyrite I. (Plate 5-80). The euhedral and subhedral interstitial sphalerite contains inclusions of minute anhedral pyrite, which in some rare cases form euhedral outlines (Plate 5-78).

Intergrowths of chalcopyrite are also common in the sphalerite. Frequently the chalcopyrite intergrowths form well oriented "lenses and wedges" (Plates 5-82, 5-83, 5-84, 5-85) but fine grained non-coherent textures are also common (Plate 5-81). A small proportion of the sphalerite in the massive ore occurs in the form of small anhedral grains included in pyrite I. In the zoned pyrite the anhedral sphalerite grains are sandwiched between the growth zones of pyrite.

Rare pyrrhotite is persistently present in the solid sulphide blocks of the massive ore but it appears to be absent in the sugary matrix. The pyrrhotite mostly occurs as small anhedral grains, less than 15 microns across, filling cavities in the pyrite (Plates 5-68, 5-79). However, a small part of the pyrrhotite in the massive ore forms intergrowths in sphalerite (Plates 5-79, 5-80) and less commonly in chalcopyrite.

v. Marcasite and Copper Sulphides

Marcasite is restricted mainly to the top of the massive ore near its contact with the ochre and tends to be very rare or absent at the lower parts of the massive ore. The marcasite occurs either as isolated euhedral or anhedral grains in the pyrite or as bladed crystals with radiating arrangement around cavities in pyrite. In the cavities surrounded by marcasite, isolated pyrite framboids or clusters of pyrite framboids occur commonly. The occurrence of framboidal pyrite is similar to marcasite inasmuch as it is restricted to the sulphide blocks near the contact of the massive ore with the ochre.

Covellite is the most common copper sulphide after chalcopyrite in the Mousoulos orebody. It is the predominant

copper mineral in the sulphide blocks encased in the ochre as well as in the sugary ore at the upper parts of the massive ore. The covellite mostly replaces the chalcopyrite forming rims around it, or projecting into it along fractures. Digenite and bornite were rarely observed associated with chalcopyrite (Plate 5-77).

8. The Zone B

In the Mousoulos orebody the massive ore is underlain by the ore of the zone B; the latter in turn is underlain by the stockwork zone. The thickness of the zone B varies at the different parts of the various levels but generally ranges between 1 and 4 metres. In the field the structure of the ore of the zone B is similar to the structure of the massive ore differing only by the presence of silica in the zone B. The ore in the zone B consists of blocks of sulphide mixed with silica embedded in a sulphide-silica matrix. Red jasper constitutes appreciable proportion of the silica present in the zone B. The sulphur content in the zone B is lower than 40 per cent and higher than 30 per cent. The detailed assay plans and the drilling records indicate that in this Zone copper is erratically distributed and ranges from 0.08 to as high as 6.4 per cent with a mean content of 1.67 copper.

The predominant mineral in the zone B is euhedral unzoned pyrite I intensely corroded and replaced by silica (Plate 5-87). Remnants of intensely corroded pyrite scattered in a silica matrix are commonly found in zones of ore where the silica is more abundant than the pyrite (Plates 5-86, 5-87); chalcopyrite is the second most common sulphide in this zone. The chalcopyrite occurs in cavities in pyrite but is also scattered in the silica matrix (Plate 5-87). Sphalerite is rare and was found as inclusions in pyrite or scattered in the silica matrix. Zoned pyrite I, collomorphic pyrite, marcasite, pyrrhotite, and other copper sulphides were not observed in the zone B of the Mousoulos orebody.

Optical investigations indicate that in the zone B the quartz is later than the sulphides; the quartz invariably replaces the pyrite and when the replacement is incomplete the remnants of pyrite form euhedral outlines (Plate 5-87). Fractures

Plates 5-86. Intensely corroded pyrite (white) scattered in silica (dark grey).

PPL, scale bar = 1600 microns

Plate 5-87. Intensely corroded pyrite (white) embedded in silica (grey). Anhedral chalcopyrite (white-grey) fills part of the cavities in pyrite.

PPL, scale bar = 1600 microns

Plate 5-88. Intensely corroded pyrite (black) embedded in silica (white).

PPL, scale bar = 496 microns

Plate 5-89. Fractured and corroded idiomorphic euhedral pyrite (black), partly replaced by quartz (white).

PPL, scale bar = 1250 microns

Plate 5-90. Remnants of intensely corroded pyrite (black) scattered in zoned quartz.

PPL, scale bar = 1600 microns

Plate 5-91. Euhedral as well as corroded pyrite scattered in zoned quartz.

PPL, scale bar = 1600 microns

Plate 5-92. Zoned quartz with remnants of corroded pyrite scattered in it.

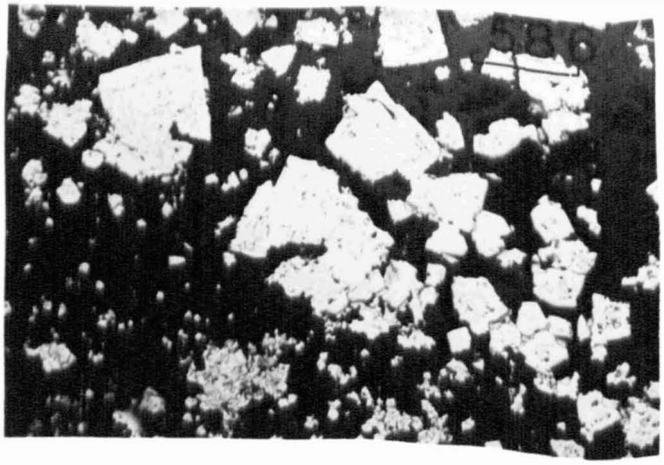
PPL, scale bar = 1600 microns

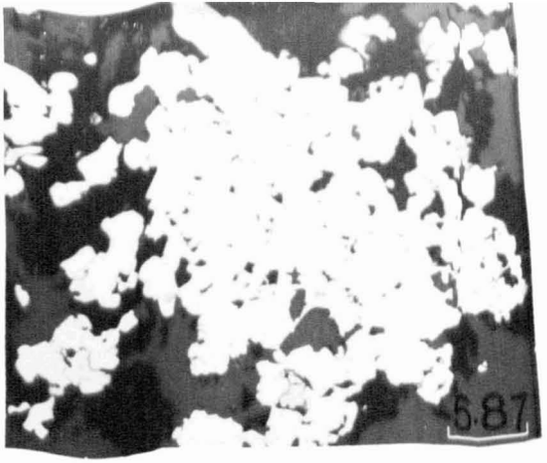
Plates 5-93, 5-94. Mineralized basaltic lava containing dissemin disseminated Pyrite (black). Laths and microlites of plagioclase in the lavas replaced by quartz (white).

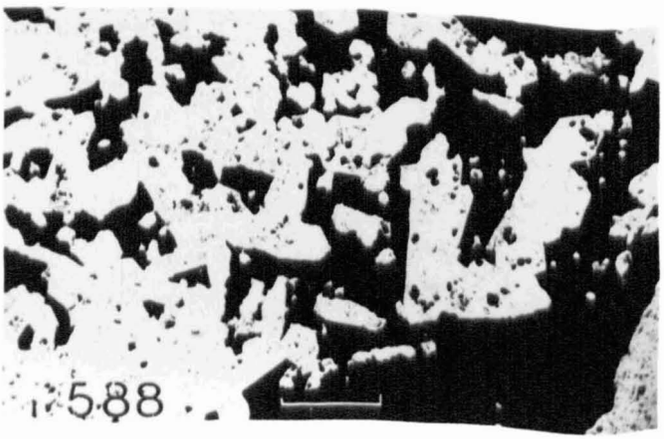
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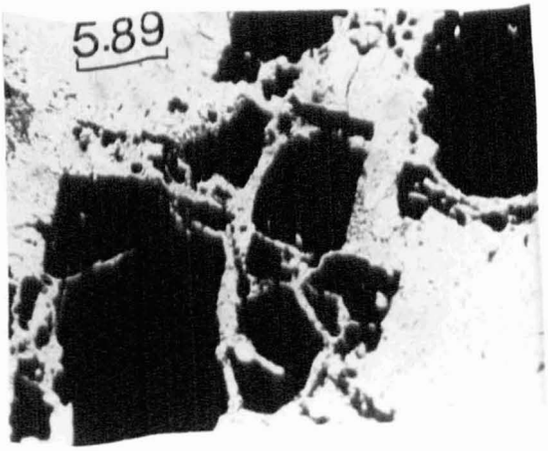
Plate 5-95. Subhedral and anhedral pyrite (white) in mineralized lava containing anhedral rutile (point indicated by arrow).

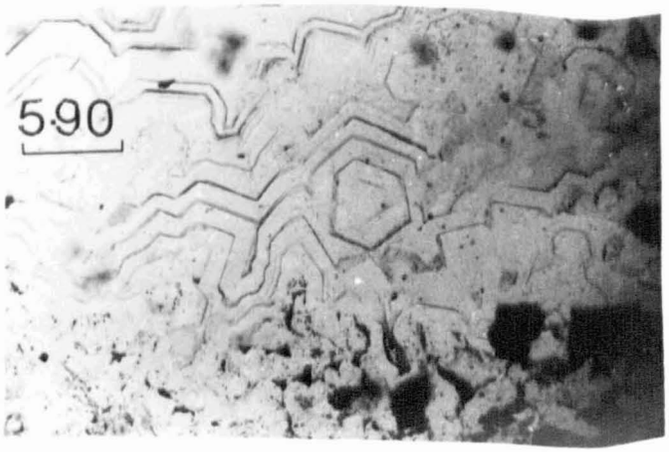
PPL, scale bar = 240 microns


5.86

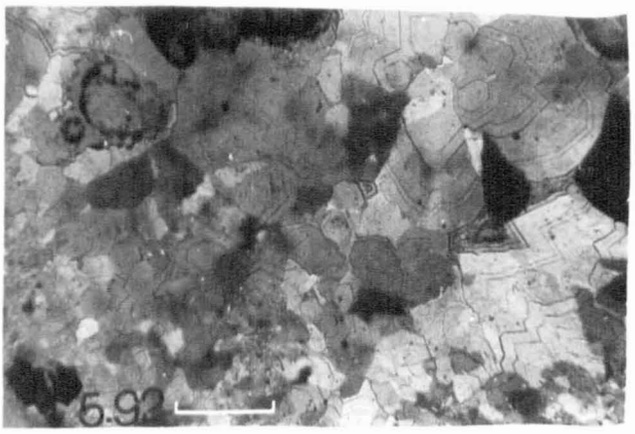

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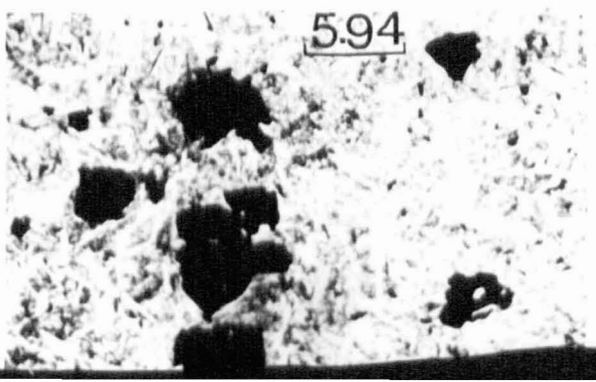

5.89

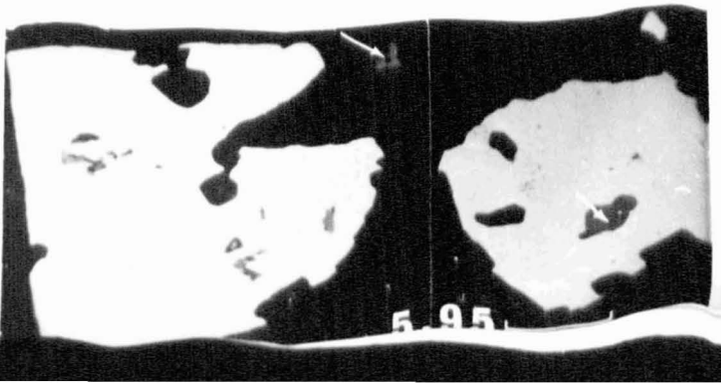

5.90


5.91


5.92


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5.94


5.95

and zones of corrosion in pyrite tend to be filled with chalcedony whereas away from the pyrite granular quartz is more common. The quartz of the Zone B is commonly zoned and in many cases the textures of the zoned quartz are very similar to the textures of the zoned pyrite I which occurs in the massive ore, (Plates 5-90, 5-91, 5-92).

9. The Stockwork Zone

The Zone B is underlain by the stockwork zone the upper part of which consists of brecciated and mineralized lavas whereas its lower part consists of mineralized pillowed lavas. The sulphur content in this zone in general is less than 30 per cent, and gradually decreases to less than 10 per cent at the deeper parts of the zone. In the stockwork the copper is erratically distributed ranging from zero to as much as 5.2 per cent with a mean value 0.86 per cent (Fig. 5-5). Copper tends to be more abundant in the upper part of the stockwork and decreases substantially in its deeper parts.

In the mineralized brecciated lava the lava fragments are rounded or angular and have a variable size (Plate 5-21). The lava fragments are cemented with sulphide but at the contact of the stockwork zone with the Zone B the lava fragments are commonly cemented with opal which frequently exhibits delicate colloform banding (Plates 5-22, 5-26). The sulphides cementing the lava fragments consist mostly of pyrite often corroded and replaced by quartz. Chalcopyrite and less commonly sphalerite fill cavities in pyrite or form minute anhedral inclusions in it. Chalcopyrite was also observed in the colloform opal cementing the lava fragments.

The lava fragments are impregnated with fine grained anhedral or subhedral pyrite commonly corroded and replaced by quartz (Plates 5-93, 5-94, 5-95); the pyrite decreases considerably away from the fractures. The disseminated pyrite often contains anhedral grains of leucoxene, the latter being also observed in the silicified lava (Plate 5-75). No chalcopyrite or sphalerite was observed impregnating the lava away from the fractures. In thin sections the original textures of the mineralized lava is preserved. Thus, hydrothermally altered lavas with ghost vitreous or microporphyritic textures are common (Plates 5-73, 5-74). The

plagioclase and pyroxene is replaced by quartz whereas the glassy matrix is altered to an intimate mixture of chalcedony and chlorite.

The mineralization at the lower parts of the stockwork zone consists of sulphide veins filling fractures in the pillows as well as pyrite disseminated in the lava. The microscopic characteristics of the mineralized pillow lavas are similar to those of the brecciated lava. X-ray diffraction analyses of samples of mineralized brecciated and pillowed lava (Table 10.2 chapter 10) indicate that (a) quartz is the predominant product of the hydrothermal alteration (b) pyrite is the second most common mineral followed in abundance by chlorite, and the two minerals exhibit an antipathetic distribution and (c) small amounts of illite are present in the hydrothermally altered lavas whereas montmorillonite was not detected.

10. Summary

The Mousoulos orebody is hidden under a sedimentary and volcanic cover which protected the ore from supergene oxidation to massive gossan and it remained undiscovered and unexploited by the Ancients. The orebody is surrounded by unmineralized lavas which petrologically are similar to the olivine basaltic Upper Pillow Lavas of the Kalavasos area. All the contacts of the orebody with the surrounding lavas are faulted. The faulting postdates the emplacement of the orebody and was associated with tilting which is comformable with the tilting of the volcanic rocks in the area.

Correction of this tilting indicates that the orebody is overlain by a layer of ochre which in turn is overlain by the Upper Pillow Lavas. Field relationships suggest that the ochre was deposited on the top of the orebody prior to the submarine extrusion of the overlying Upper Pillow Lavas. Chemical and mineralogical data suggest that the material of the ochreous layer was derived from the underlying massive ore.

The vertical zoning, which is common in other Cyprus orebodies (massive ore - Zone B - Stockwork Zone), is found in a horizontal plane in the Mousoulos orebody. The top

of the massive ore consists mainly of sugary, friable and highly porous ore in which rare blocks of solid-sulphide are embedded. Away from the ochre-ore contact the proportion of solid sulphide blocks gradually increases at the expense of the sugary ore and the structure of the massive ore becomes conglomeratic. The sulphur content generally is higher than 40 per cent. The copper is erratically distributed and in the sugary ore tends to be lower than in the conglomeratic ore. Zinc is also erratically distributed in the massive ore and the ratio Cu:Zn is generally more than one.

The sugary ore consists mainly of corroded unzoned Pyrite I; zoned pyrite I and collomorphic pyrite ore restricted only to the rare solid sulphide blocks. In the sugary ore covellite tends to be more common than chalcopyrite while sphalerite tends to be less common than in the conglomeratic ore.

In the conglomeratic ore the solid sulphide blocks consist mostly of variable proportions of zoned and unzoned pyrite I and collomorphic pyrite. Framboidal pyrite tends to be restricted to sulphide blocks in the vicinity of the ochre and it is mainly associated with marcasite. The second most common mineral after pyrite is the chalcopyrite which fills mainly cavities and interstices in pyrite and less commonly it occurs as minute inclusions in pyrite and sphalerites. Sphalerite follows the chalcopyrite in order of abundance filling cavities in pyrite or occurring as minute inclusions in pyrite. Marcasite tends to be more common in the solid sulphide blocks at the top of the orebody gradually decreasing in abundance with depth. Rare pyrrhotite, filling cavities in pyrite or present as intergrowthsin sphalerite, is found only in the solid sulphide blocks of the conglomeratic ore whereas it is absent in the sugary matrix. Covellite is the second most common copper sulphide and tends to be more abundant at the top of the massive ore. Rare digenite and bornite were observed; orange bornite was found only in one sample of solid sulphide block encased in the ochre.

In the Mousoulos orebody the Zone B is well defined but narrow. This zone consists of sulphide intimately mixed with silica and is characterized by the lack of lava fragments. In the zone B the sulphur content ranges from 30 to 40 per cent; the

copper is erratically distributed and is generally less than in the massive ore. The most common sulphide is unzoned and badly corroded pyrite I followed by chalcopyrite and sphalerite in decreasing order of abundance. Zoned pyrite I, collomorphic or framboidal pyrite, as well as marcasite and pyrrhotite were not observed in this zone. Quartz is the second most common mineral, after pyrite; it invariably replaces pyrite and fills cavities and zones of corrosion in chalcopyrite and sphalerite. Zoning is common in the quartz of this zone and frequently this zoning resembles, the zoning of the pyrite I in the conglomeratic ore.

The zone B is underlain by the stockwork zone the upper part of which consists of mineralized brecciated lava followed in depth by mineralized pillowed lavas. The sulphur content of this zone at its upper parts is less than 30 per cent, and gradually decreases to less than 10 per cent in the lower parts of the zone. The copper content is generally less than one per cent. The mineralization is represented either by veins of sulphide which cement lava fragments and fill fractures in the lavas, or by disseminated pyrite impregnating the mineralized lava. No chalcopyrite or sphalerite were observed impregnating the lava; the disseminated pyrite is frequently seen to contain very small grains of leucoxene. The mineralized lavas were also hydrothermally altered. The main products of this alteration were silicification and chloritization and to a lesser extent argillization.

D. UNMINERALIZED BASALTIC DYKES IN THE MOUSOULOS OREBODY

(1) General Statement

A striking feature of the Mousoulos orebody is the occurrence of unmineralized olivine basaltic dykes in the massive ore, the zone B, and the stockwork zone. The mine plans indicate the existence of these dykes at the top levels. (Fig. 5-3) whereas underground mapping establishes their presence in all the mine levels down to the 115 metre level. Similar occurrence of unmineralized basaltic dykes in all the worked orebodies in the Kalavasos area is indicated by drilling records and old mine plans. Dykes with similar composition and texture were found in the Kokkinopezoula, Kokkinoyia, Agrokipia A and B orebodies. (Chapter 4). Similar dykes were also reported to occur in the Sha orebody (Fig. 1) by Gass (1960) and Panayiotou (1969).

The dykes in the Mousoulos orebody have identical composition and texture with the typical feeder dykes to the Upper Pillow Lavas, suggesting that these dykes most probably served as feeders for the U.P.L. surrounding the orebody. Thus the determination of the relative ages of the dykes and the emplacement of the Mousoulos orebody is crucial for the establishment of the relative ages of the Mousoulos orebody and the surrounding olivine basaltic Upper Pillow Lavas; if the dykes antedate the emplacement of the Mousoulos orebody then the overlying U.P.L. were there before the emplacement of the orebody, whereas if the dykes postdate the formation of the Mousoulos orebody, then the U.P.L. were extracted after the formation of the orebody. Furthermore, the determination of the chronological sequence of the three episodes viz. emplacement of the Mousoulos orebody, dyke intrusion, and the extrusion of the olivine basaltic U.P.L. is also applicable to the Kokkinoyia, Agrokipia A, and B, orebodies all intersected by unmineralized dykes and overlain by unmineralized U.P.L. (Chapter 4), with similar compositions.

2. Previous Work and Present Investigation

It has been generally agreed by the geologists who have studied the dykes in the Cyprus sulphide ores that these dykes are petrologically and chemically similar to the olivine basaltic Upper Pillow Lavas. On the other hand the relative ages of the dykes and the orebodies and the relative ages of the orebodies and the olivine basaltic U.P.L. are the subject of controversy. The occurrence of the unmineralized basaltic dykes in sulphide ore was first reported by Mousoulos (1957) in the Mavridia orebodies at the Kalavasos area. He considered that the dykes postdate the emplacement of the orebodies. Searle and Constantinou (1967) from their detailed investigations of the orebodies in the same area also concluded that the dykes postdate the emplacement of the orebodies. On the other hand Pantazis (1969) concluded that the dykes in the orebodies of the Kalavasos area antedate the emplacement of the orebodies and were not replaced by the sulphides but acted as barriers for the mineralizing solutions.

Gass (1960) gave a sketch map of the Sha mine showing the location and trend of the unmineralized dykes in the sulphide ore. He considered that the dykes predated the emplacement of the sulphide ore but were not replaced by the sulphides, as were the adjacent pillow lavas, because of their higher density. Panayiotou (1968, 1969) after a detailed study of the Sha mine concluded that the basaltic dykes had been intruded into the orebody and he reported the lack of any contact metamorphic effects along the dyke-sulphide ore contacts.

Bear (1960) reported fresh basaltic dykes intersecting the Kokkinopezoula and Agrokipia orebodies. He considered the Kokkinopezoula dykes as predating the sulphide mineralization but he accepted that a thick dyke in the Agrokipia orebody postdated the emplacement of the orebody. In his discussion of the genesis of the Cyprus sulphide orebodies, Bear (1963) deduced that the dykes predate the mineralization and attributed their resistance to replacement "to some feature of their physical structure". Kattamis (1962) and Wolff (1964), working independently

considered the dykes of the Kokkinopezoula and Agrokipia orebodies as postdating the sulphide mineralization.

For the present work most of the laboratory investigations were carried out on specimens taken from dyke-ore contacts, and at 15 centimetres intervals up to two metres from either side of the contact. Such samples were collected from dykes at the 120, 125, 130, 142, 145 and 148 metre levels. At the first three levels the dykes were in contact with ore of the zone B and stockwork, whereas at the last three levels the dykes intersect massive ore. The Mousoulos orebody was considered to be the best orebody in which to study the basaltic dykes problem, for the following reasons:-

(a) The orebody is worked underground and most of the specimens were taken immediately after the dykes had been exposed and before they had suffered any surface alteration.

(b) The dykes in this orebody intersect low and medium grade as well as massive ore; thus a detailed study of the thermal effect of the dykes on the different ore types, and vice versa, was possible.

(c) The orebody is rich in copper, and detailed assay plans for copper are available and can be used to study the effects, if any, of the dykes on the redistribution of copper. The location of the dykes in each level is accurately known and the study of such effects is possible.

(d) The orebody is surrounded by olivine basaltic Pillow Lavas, this enables a detailed comparative study of the dykes and lavas.

Samples of similar dykes in contact with medium and low grade ore were also collected from the Kokkinopezoula and Sha orebodies. The samples from these two orebodies were compared with those from the Mousoulos orebody.

3. Field Characteristics of the Dykes

The dark grey-green, almost black, colour of the dykes contrasts strongly with the pale white-grey colour of the hydrothermally altered lavas and even more with the yellow-grey colour of the massive ore. This colour contrast is even greater

in nearly exposed faces because the colour of the dykes changes rapidly when it is exposed to the atmosphere.

The contact of the dykes with the adjacent ore is straight or sinuous the two types often occurring in a single dyke. Not infrequently a single intrusion occurs as dyke or sill; branching of the dykes along-strike is common. The dykes contained in the orebodies of the Kalavasos area have the same general trend as similar dykes occurring in the L.P.L. and U.P.L. outside the orebodies.

The thickness of the dykes ranges from one to two metres the average thickness being about 1.5 metre. Along-strike pinching and swelling of the dykes is common. Most of the dykes have clearly defined chilled margins varying in thickness from 2 to 15 centimetres. Columnar jointing perpendicular to the strike is very well developed in dykes more than one metre thick, poorly developed in dykes less than 1 metre thick and absent in very thin dykes. Some of these dykes are traceable for more than 25 metres. At the 142 metre level a dyke was traced continuously through low grade, medium grade and massive ore and terminated against the postmineralization 060° fault which defines the northwestern contact of the orebody with the surrounding olivine basaltic Upper Pillow Lavas. At the 148 metre level a dyke was traced continuously through massive ore into the overlying ochreous layer and terminated against the ochre fault. (Figs. 5-3, 5-4).

4. Petrography of the Dykes

The dykes at their margins have a vitreous texture (Plates 5-100) whereas at their centre they have a microporphyritic texture (Plate 5-96). Specific gravity varies at different parts of the dykes the average value being about 2.71 at the margins and 2.47 at the centre. Vesicularity increases considerably at the margins of the dykes. Optical studies indicate that plagioclase is by far the most abundant pyrogenic mineral followed by pyroxene, olivine and opaque minerals in decreasing order. Glassy mesostasis is invariably present and occurs in variable amounts at different parts of the dykes.

Plate 5-96. Centre of a thick unmineralized basaltic dyke consisting mainly of plagioclase and pyroxene and rare magnetite. Differential alteration revealed compositional zoning in plagioclase (bottom right)

PPL, scale bar = 300 microns

Plates 5-97, 5-99. Growth textures of magnetite (grey) in unmineralized basaltic dyke intersecting sulphide ore. Initial stages of growth of cubic magnetite crystals. In plate 5-99 (top left) chalcopyrite (white) intersects magnetite.

PPL, scale bars = 102, 180 microns respectively.

Plate 5-98. Unmineralized basaltic dyke intersecting sulphide ore consisting mainly of plagioclase (bottom) pyroxene (top) and rare olivine (centre) scattered in abundant glassy matrix.

PPL, scale bar = 300 microns

Plate 5-100. Outer part of unmineralized basaltic dyke intersecting sulphide ore. Laths and microlites of plagioclase are embedded in glassy matrix.

PPL, scale bar = 1200 microns

Plates 5-101, 5-103. Growth textures of magnetite in unmineralized basaltic dyke intersecting sulphide ore. Initial stages of growth of tabular magnetite crystals. In Plate 5-101 (top left) chalcopyrite(white) rims magnetite. At bottom right of the same plate occurs a grain of fractured and corroded early idiomorphic chalcopyrite.

PPL, scale bar = 102, 102 microns respectively.

Plate 5-102. Zeolite (laumontite ?) filling a vesicle and a fracture in unmineralized basaltic dyke intersecting sulphide ore.

PPL, scale bar = 1200 microns.

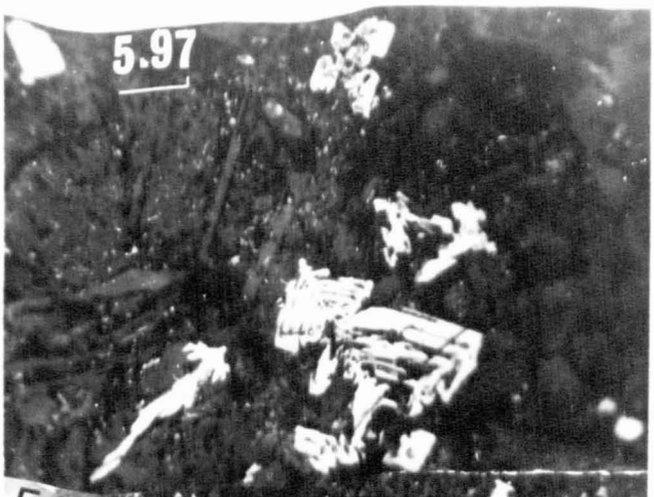
Plate 5-104. Vesicle in unmineralized basaltic dyke intersecting sulphide ore filled with chlorophaeite and lined with chalcedony.

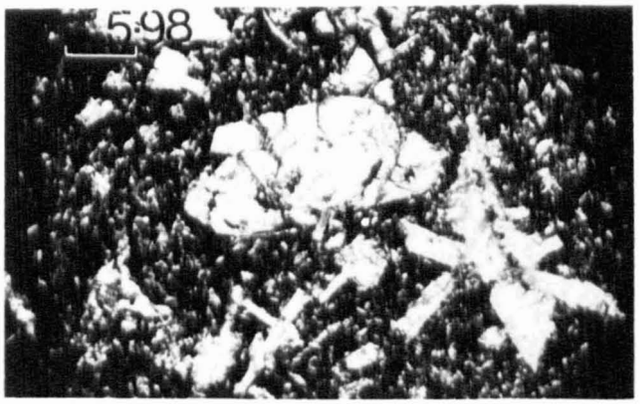
PPL, scale bar = 480 microns.

Plate 5-105. Four stages of growth of cubic magnetite crystals; chalcopyrite (white) intersects magnetite.

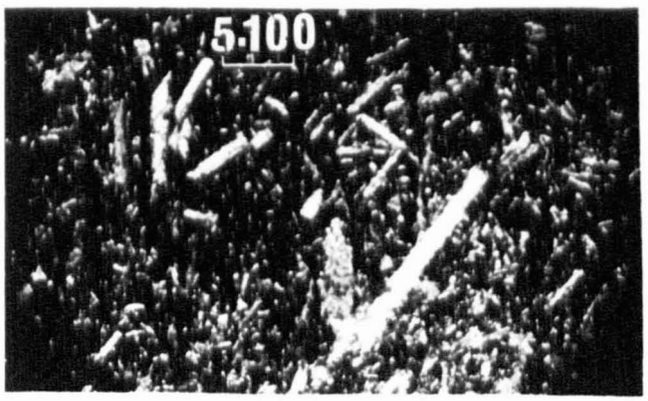
PPL, scale bar = 102 microns.


5.96


5.97


5.98

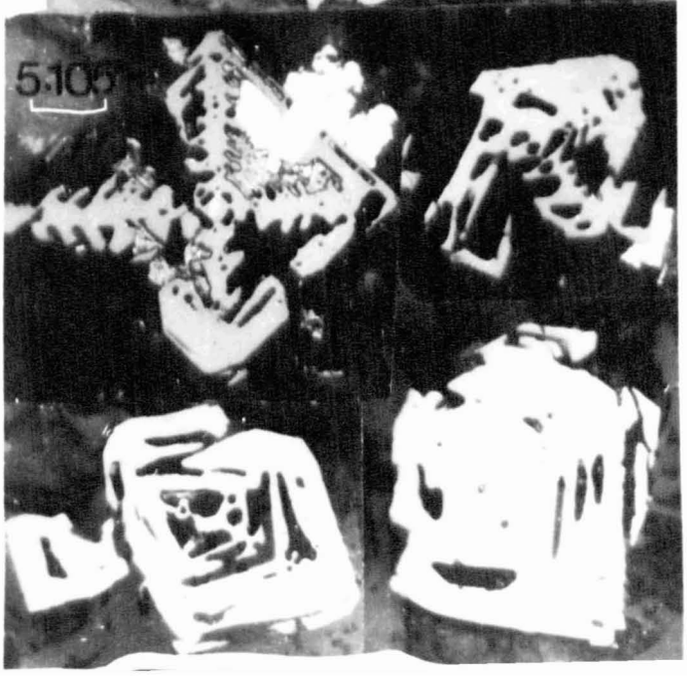

5.99

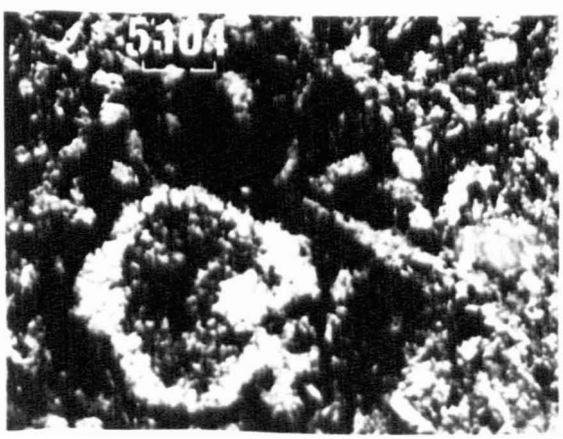

5.100

5.101


5.103


5.102


5.105


5.104

In the centre of some dykes the volume of plagioclase exceeds the volume of the other constituents (Plate 5-96). The plagioclase occurs as laths of varying size and as microlites scattered in the glassy mesostasis (Plates 5-96, 5-98, 5-100). Differential alteration revealed structural zoning in the plagioclase at the centre of the dykes (Plate 5-96). Augite is the second most common mineral and is largelly altered to chlorite particularly the early microphenocrysts. Olivine is invariably present in the dykes (Plate 5-98) and is usually altered; the most common product of alteration is a dark chocolate-brown amorphous iron hydroxide.

Glassy mesostasis with plagioclase is the most common constituent of the dykes although the actual proportions vary considerably from the chilled margins to the centre of the dykes. This variation is more noticeable in the thick dykes in which the chilled margins consist almost entirely of glass and the centre contains only small amounts of glass which fills angular interstitial spaces between the pyrogenic minerals (Plate 5-96). In dykes of average thickness (1.5 metre) the glassy mesostasis occurs in appreciable amounts in the centre and constitutes more than 75 per cent (by volume) at the margins. The amount of glassy mesostasis and the field characteristics of the dykes (common sinuous contacts, very thin dykes, branching, and pinching and swelling of dykes), suggest that the intruded magma was probably of low viscosity.

5. Alteration of the Dykes

Considering the types of alteration encountered in the basaltic dykes of Kokkinopezoula - see chapter 4 - it is important to specify that no hydrothermally altered dykes are recorded in the vicinity of Mousoulos orebody. The alteration of dykes described below is therefore generally considered to be of the "non hydrothermal alteration" type. (See Chapter 10).

In the unmineralized basaltic dykes contained in the Mousoulos orebody the pyrogenic minerals and the glassy matrix have been extensively altered. The degree of alteration increases towards the margins of the dykes although even the central regions of the thicker dykes have been intensely altered. Two main products

of alteration are distinguishable in thin sections, but the alteration products are intermixed thus rendering quantitative estimation of each phase difficult.

The first product of alteration is an amorphous phase varying in colour from pale green through olivine-green light brown to dark chocolate brown and which often occurs as black fibres. In the past it has been considered to be a chlorite mineral and has been held to be responsible for the dark green colour of the hand specimens. X-ray diffraction analyses of representative samples (Table 10.2 chapter 10) failed to detect chlorite in the dyke rocks and this product of alteration most probably is chlorophaeite (Cambell and Lynn, 1925). The chlorophaeite was also observed filling vesicles in the dyke rock (Plate 5.104).

Montmorillonite is the second product of alteration. It is produced by the alteration of plagioclase, and the glassy matrix. X-ray diffraction analyses indicate that montmorillonite is invariably present in considerable amounts in all dyke specimens (Table 10.2 Chapter 10). In thin sections it is light green to light brown and is probably an iron-rich variety. In thin sections minor amounts of crypto-crystalline chlorite were observed in the form of rims around the pyroxene.

Zeolites were observed in two specimens of dyke taken from the 130 metre level. The zeolites occur as colourless to brown aggregates of interlocking grains filling fractures and vesicles (Plate 5.102). The zeolite most probably is laumontite (Dr. G.P. L. Walker personal communication) and appears to be the latest mineral phase in the dykes and truncates both the chlorophaeite and the montmorillonite.

The above described products of alteration are distinctly different from the products of hydrothermal alteration found in the mineralized lavas in the stockwork of the Mousoulos orebody (Table 10.2) They are also different from those found in the mineralized dykes in the Kokkinopezoula orebody (Table 10.2) and in the mineralized dykes of the Basal Group in general. On the other hand the same alteration products were found in the unmineralized U.P.L. overlying the Mousoulos orebody. This alteration probably

is due to diagenesis and/or burial metamorphism of the unmineralized lavas and the dykes they contain and to a lesser exten to interraction of hot lava with sea water. This alteration bares no relation with the usual hydrothermal alteration processes associated with the emplacement of the Cyprus sulphide ores.

6. The Opaque Minerals in the Dykes

A detailed study of the opaque minerals in the basaltic dykes was undertaken on specimens collected from the chilled margins in contact with sulphides and from the centre of the dykes. The most common opaque minerals in the dykes are magnetite, chalcopyrite and traces of pyrite. There is no significant variation in the amount of magnetite from the chilled margin to the centre of the dyke, or with depth within a single dyke. However a significant variation of the grain size and the degree of development of the magnetite crystal growth is observed.

The growth textures of the magnetite, present in the dykes, are very characteristic. Completed euhedral crystals are extremely rare and most of the crystals exhibit various stages of magnetite crystal growth. There are two distinct forms of magnetite: These are a cubic form and a tabular form. The intial stage of growth of the cubic form is cruciform with the arms exhibiting a herring-bone texture (Plates 5-97, 5-99). Bridging of the ends of the arms by addition of magnetite results in crystals with square outline with the central part of the crystal being empty (Plate 5-105). The empty central part is filled by the successive addition of magnetite the filling process moving from the outer parts towards the centre, as illustrated in the plate 5-105.

In the tabular magnetite crystals, the growth is initiated from a central long axis from which crystallites grow in a dendritic form (Plate 5-101). Further addition of magnetite interconnects the crystallites ends thus forming an almost rectangular crystal with an empty core. Subsequent filling of the empty space takes place from outside towards the centre. A similar process was noted to take place from two or three parallel axes rather than from a single central axis (Plate 5-103). The empty spaces of the incomplete crystals contain glassy mesostasis, plagioclase microlites and less commonly chalcopyrite.

Similar magnetite textures from quenched fine grained lavas and the chilled margins of dykes and flows from Iceland have been described in detail by Haggerty (1968). The same author suggested that the development of skeletal crystals was favoured by the sudden quenching of the basalts. Schwartz (1926) from his experimental work and his work on sinters described magnetite textures similar to those described in the dykes of the Mousoulos orebody. The above author suggested that such textures are the result of spontaneous crystalization of super-saturated solutions.

Electron-probe analyses of 15 magnetite crystals indicated that the magnetite occurs as titanomagnetite with Ti content ranging from 3.6 to 7.1 per cent with a mean content of 5.1 per cent Ti. The titanium is homogeneously distributed within the titanomagnetite. Detailed optical studies of the titanomagnetite of the dykes of the Mousoulos orebody failed to find any titanomaghemite or hematite-ilmenite assemblages which are commonly the products of oxidation of the titanomagnetite in basaltic dykes and flows (Haggerty 1968).

Chalcopyrite is the second most common opaque mineral in the dykes and its amount increases towards the margins of the dykes. It shows no significant variation with depth. Most of the chalcopyrite is associated with magnetite, and fills empty spaces in the incomplete magnetite structures; in many cases it replaces part of the magnetite (Plates 5-99, 5-105). Rare chalcopyrite has been found surrounding central remnants of unreplaced magnetite (Plate 5-101). Rare early idiomorphic crystals of chalcopyrite are found scattered in the glassy mesostasis (Plate 5-101) and these crystals are invariably fractured and corroded; under high magnification within the corrosion zones, minute crystals of covellite were observed. Pyrite is very rare and occurs in the mesostasis in the form of minute skeletal crystals. At the chilled margins of dykes in contact with massive ore there was not observed any increase in pyrite content.

7. Contact Effects

Contact metamorphism of sulphide ores under the thermal

effects of later intrusive bodies have been reported from many parts of the world. Such contact metamorphism causes conspicuous changes in mineralogy, texture and composition of sulphide bodies on a localised scale. Sales and Meyer (1951) reported mineralogical changes in ores adjacent to rhyolite dykesat Butte. These changes include dissociation of pyrite to iron-oxide and transformation of pyrite-chalcocite assemblage to chalcopyrite-bornite with concomitant release of silver from chalcocite. Mookherjee (1964) reported dissociation and recrystallization of pyrite, increase in iron content of sphalerite and several other textural and mineralogical changes in a sulphide ore in contact with a dolerite dyke at the Zahar mine India. Mookherjee and Suffel (1968) and Mookherjee (1970) reported unequivocal evidence of local but intense mineralogical textural reconstitutions of the sulphide wall against the N.S. Late Diabase dyke at the Horne mine, and also noted the reciprocal effects in the intrusive. The effects observed are the dissociation of primary pyrite to pyrrotite and/or magnetite, development of a chalcopyrite rich zone at the contact, development of second generation of pyrite from pyrrhotite and ferromagnesian silicate minerals. A review of well-documented instances of contact metamorphism of sulphide ores under the thermal effects of later intrusive bodies was given by Vokes (1969).

Kattamis (1962) reported slight increase in copper concentration in the ore adjacent to the basaltic dykes in the Kokkinopezoula orebody, due to remobilization of copper under the thermal effects of the dykes. Gordon-Smith (1963) reported copper concentration in the ore adjacent to dykes in the Agrokipia orebody. He suggested that this concentration is primary because, he believes, the dykes were there before the emplacement of the ore and acted as barriers to the mineralizing solutions. Pantazis (1969) also reported an increase in copper content in the ore in the vicinity of the dykes in the orebodies of the Kalavasos area and concurs with the idea that this increase is primary. However, the detailed study of the assay plans of the Mousoulos orebody failed to detect any noticeable increase in copper concentration in the ore adjacent to the basaltic dykes. Copper is erratically distributed in the ore of the Mousoulos

orebody both adjacent to the dykes and away from them. Any mobilization of copper due to the thermal effects of the basaltic dykes would tend at least to modify the erratic pattern of distribution of copper in the ore adjacent to the dykes but no such modification was detected.

Polished and thin sections of the ore adjacent to the dykes, were examined to study the thermal effects of the dykes, if any, on the sulphides. The specimens were taken from the dyke-ore contacts and at 15 cms intervals up to two metres from the contact. Electrolytic etching was used for the detailed study of the pyrite textures of the massive ore against the basaltic dykes. No difference was observed in the mineralogy and textures of the massive ore in contact with the basaltic dykes and the massive ore away from the dykes. Also there were no mineralogical and textural changes in the ore of the stockwork zone adjacent to the dykes.

Field relationships suggest that the dykes intruded the orebody after its emplacement. The argument that the dykes predate the mineralization but were not affected by the mineralizing solutions because of their structure Gass (1960) Bear (1963) is difficult to sustain because:

(a) In the stockwork zone of some orebodies, particularly at the Kokkinopezoula orebody, many pre-mineralization dykes of widely varying thickness had been hydrothermally altered and mineralized and are intersected by post-mineralization thin basaltic dykes. Furthermore, in the Skouriotissa, Tamasos and Kalavasos areas many dykes in the Basal Group had undergone the same hydrothermal alteration and mineralization with the adjacent lavas.

(b) The common joints and fractures in the dykes intersecting massive and low grade ore contain no sulphides. If the dykes antedated the emplacement of the orebody at least these open spaces in the dykes should be filled with sulphides.

The layer of ochre which is intercalated between the massive ore and the overlying Pillow lavas is generally considered to be a marine sediment and to represent a time interval between the emplacement of the orebody and the extrusion of the overlying pillow lavas. At the 148 metre level an unmineralized basaltic dyke was traced continuously through the massive ore and the layer of ochre, up to the ochre fault (Fig. 5.5). This dyke and the other dykes contained in the Mousoulos orebody are considered to represent the feeder dykes to the overlying olivine basaltic Upper Pillow Lavas, which are generally considered to represent submarine lava flows. It is therefore possible to assume that these feeder dykes intruded the Mousoulos orebody when the latter was still under the seawater.

A source of uncertainties for the conclusive demostration of the younger age of the dykes was the lack of recognizable thermal effects. The explanation for the negligible thermal effect of the dykes upon the intruded sulphides seems to lie in the following facts:

i. The dykes in the orebody probably did not occupy the channelways along which great volumes of hot magma moved for a long time to feed lava flows at higher levels: therefore their heat capacity was rather limited (Frankel, 1967).

ii. When emplaced as dykes or sills the basaltic magma lost its heat quite rapidly as indicated by the observed quenched textures of magnetite.

iii. The glass produced by chilling at the margins of the dykes probably acted as an insulator preventing heat transfer from the interior of the dykes. It has been observed that the volcanic glass acts as a good insulator in recent lava flows in Iceland (Dr. G.P.L. Walker, personal communication).

iv. The dykes intruded the orebody when the latter was under seawater; the hydrostatic pressure of the latter probably exceeded the pressure of the volatiles in the emplaced basaltic magma and therefore prevented the escape of gases and vapours which are mostly responsible for the heat transfer into the country rocks.

v. The demand for water imposed by the formation of the montmorillonite and chlorophaeite in the dykes could cause flow of water into the cooling magma and therefore an abnormally low thermal effect at the contacts. It is worth noting however that the montmorillonite and chlorophaeite were mainly produced from the later burrial metamorphism of the dykes.

As mentioned in a previous section of this chapter, picrite basalt flows resting directly upon iron-rich intervolcanic sediments produced no recognizable thermal effects, although there can be no greater heat source than that contained in these very basic lavas. Searle and Vokes (1969) suggested that "the lack of thermal effect, on the above sediments was due to the fact that the picrite basalt flows were extruded into wet sediments, and the steam generated acted as a blanket against any metamorphic effect." Dykes and sills contained in the L.P.L. and the U.P.L. of the Skoutiotissa, Tamassos and Kalavasos areas generally produced negligible metamorphic effects at their contact with the enclosing pillow lavas.

8. Summary and Conclusions

In the Mousoulos orebody the three zones of ore are intersected by unmineralized dykes. These dykes have generally a black colour and their thickness varies greatly. The common occurrence of very thin dykes, their sinuous contacts, the common branching observed along their strike as well as the high proportion of glass even in the thick dykes suggest that the original basaltic magma was probably of low viscosity. The presence of well defined chilled margins and the predominance of magnetite with well developed quenched textures suggest that the magma of the dykes had solidified rather rapidly. The composition and texture of these dykes is similar to those of the feeder dykes to the U.P.L. The composition and petrography of these dykes are also similar to the composition and petrography of the unmineralized basaltic dykes intersecting the Kokkinopezoula, Agrokipia A and B, Kokkinoyia, and Sha orebodies in the Tamasos area and the worked orebodies of the Kalavasos area.

Optical studies of samples taken from the dykes-sulphide ore contacts indicate that pyrite is extremely rare or absent in all parts of the dykes, including dyke margins chilled against massive ore. Pyrite is also lacking in fractures and joints in dykes intersecting massive ore. X-ray diffraction analyses indicate that the products of alteration in the dykes are identical with the products of alteration in the unmineralized olivine basaltic Pillow Lavas overlying the orebody, and are distinctly different from the alteration products in the mineralized and hydrothermally altered lavas and dykes in the stockwork zone.

The field relationships and the laboratory data strongly suggest that the unmineralized basaltic dykes had intruded into the Mousoulos orebody after its formation. Thus, the olivine basaltic upper pillow lavas overlying the orebody and to which these dykes acted as feeders had been extruded after the formation of the orebody.

The commonly observed similar hydrothermal alteration and mineralization of adjacent dykes and pillow lavas, combined with field relationships and laboratory data strongly suggest that the common unmineralized basaltic dykes in the Kokkinoyia, Kokkinopezoula, Agrokipia A and B orebodies of the Tamassos area and in the worked orebodies of the Kalavasos area also had been intruded into the ores after their emplacement. The similarity in composition between the unmineralized dykes contained in the orebodies and the overlying olivine basaltic Upper Pillow Lavas suggest that these lavas are younger than the above orebodies.

Detailed macroscopic and microscopic studies indicate that the intrusion of dykes produced no recognizable mineralogical and textural changes of the ore against the dykes. Chemical data also suggest that the intrusion of dykes produced no detectable chemical changes of the ore in the vicinity of the dykes. The lack of recognizable thermal effects probably is due to the fact that the dykes were intruded into the orebodies when they were still under seawater. However, irrespective of any possible explanation, the detailed investigation of the Kalavasos, Tamassos mining areas indicates that dykes or sills produced no recognizable thermal effects upon intruded pillow lavas, sediments and sulphide ores.

CHAPTER VI

A DISCUSSION ON THE GENESIS OF UMBERS AND OCHRES

1. General Statement

Umber is a manganiferous iron-rich sediment, and ochre a manganese poor, iron-rich sediment. The restriction of umber to the contact of the volcanic rocks with the post volcanic sedimentary succession was noticed very early by geologists working in Cyprus. In early references, the umber was consideredto be product of contact metamorphism of marls during the intrusion of the lavas. The occurrence of umber above the Skouriotissa orebody was accounted for by a number of geologists as the result of hydrothermal alteration of the marls during the emplacement of the orebody.

Later detailed investigations of the lava-sediments contact proved that the umbers rest unconformably on the lavas, the latter being in places weathered. This indicated that the umber constituents were originated by the weathering of the lavas and that the umber was formed by processes of chemical sedimentation in lagoonal and/or open sea environments. Detailed mapping on the scale of 1:5,000 by the Cyprus Geological Survey, as well as recent by drilling, have shown occasional occurrences of thin bands of umber at the L.P.L. - U.P.L. contact, and it was suggested that the formation of umber was controlled by environmental conditions that occurred more than once.

Detailed mapping of the sulphide orebodies has shown that some of them are overlain by a layer of ochre which, in turn, is overlain by basaltic U.P.L. covered with umber. The ochres were considered to be primary sediments, deposited under prevailing oxidizing conditions after or during the formation of the underlying sulphides, and the metals they contain to have been introduced by submarine exhalative processes. Although it was recognized in the field that the ochres are of different age (younger) to the umber of the Perapedhi Formation, the presence of dark brown bands and the general acceptance that this colour is due to increase in manganese content have given rise to the term umberous and ochreous mudstones, or Perapedhi-type sediments, for the ochres overlying the sulphide bodies. However, the present investigation has shown that the ochreous sediments overlying some of the orebodies are

consistently low in manganese and that the dark brown and yellow brown banding is mainly due to grain size variation and a degree of crystallinity. The ochres appear to be closely related to the underlying sulphides whereas there is enough evidence to suggest that the umbers are related to the volcanic rocks and not to the sulphides.

2. General Characteristics of the umbers

The umber is the first sediment deposited after the extrusion of the lavas and is not found in any other formation of the sedimentary sequence. The unconformable relationship of the umber-lava contact was reported from both the north side of Troodos, (Jarrel, (1947), Bear, (1963); Searle and Constantinou, (1968) as well as the south side, (Wilson, (1959) Pantazis, (1967) Searle and Constantinou, (1967)). The umber overlies lavas which are in some places fresh, in others weathered and, at the southern side of Troodos they are frequently highly brecciated.

The Cyprus Geological Survey maps show that the umbers form isolated outcrops, sporadically distributed around the periphery of the Troodos Complex and fill irregularities on the top of the volcanics. They chiefly occur in the form of lenticular bodies rarely exceeding 170 metres in lateral extent and varying in thickness from one to 25 metres. In the type locality of the Perapedhi Formation, the umber is associated with red jasper, silts, grits, conglomerates, and radiolarian cherts Wilson, (1959)); In the Skouriotissa mining area the Perapedhi Formation includes only umber and brown and pink argillites whereas in the Tamassos and Kalavassos mining areas the umber also contains brown cherts.

In the field the umber is mainly massive, usually poorly bedded and commonly exhibits post-depositional slumping. In hand specimens it is typically structureless, extremely fine grained, homogeneous and chocolate brown in colour. Very high microporosity renders the umber lighter than would be expected from its chemical composition.

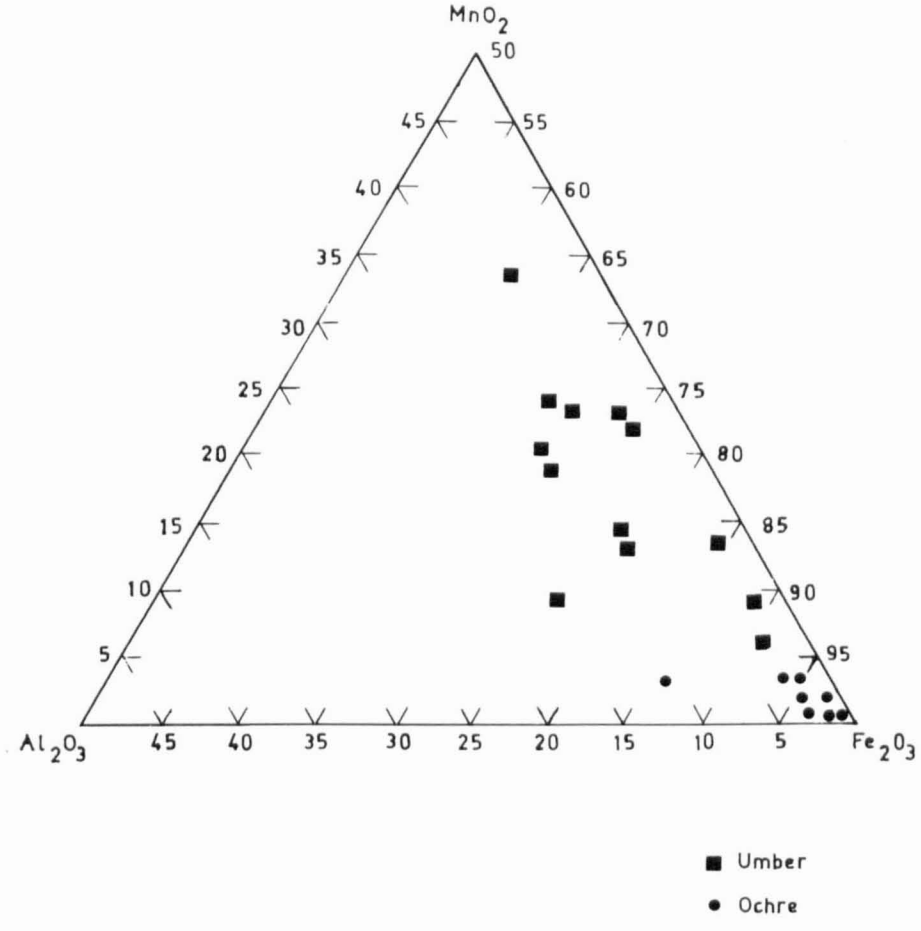
Chemically the umber consists mostly of iron and manganese oxides, silica, alumina and minor amounts of MgO, CaO K_2O and Na_2O.

Umbers from different localities differ widely in their iron and manganese contents and to a lesser extent in their silica content (Fig. 6.1.). The aluminium content of this rock type is consistently low.

X-ray diffraction analyses (Table 6.1) and polished section studies (Chapter 3) have shown that the umber contains little crystalline material; that which is present is mostly goethite. The Skouriotissa umber contains traces of what is probably detrital pyrite, partly replaced by maghemite and/or goethite. A sample containing as much as 21 percent MnO_2 contains no manganese minerals. Electron probe investigation has shown that in this sample the manganese is generally uniformly distributed and that high concentrations of manganese occur only in patches measuring several microns across (Plate 6.4). Qualifactive electron probe analyses also indicate that the Mn content in the zones of concentration is about three times higher than the background value (Plate 6.5). In the umber nickel tends to increase in sympathy with manganese. Electron probe microanalyses have shown that nickel is evenly distributed in the matrix of iron and manganese oxides.

3. Umber - Sulphide Mineralization relationships

Field relationships strongly suggest that the umber formed after the emplacement of the sulphide ores. In the Tamassos mining area the umber unconformably overlies the olivine basaltic lavas that cover the Kokkinoyia, Agrokipia B and part of Agrokipia A orebodies. The same relationship exists in the Kalavassos mining area (Chapter 5). The ochre overlying the Mathiatis orebody is succeeded by basaltic lavas which, in turn, are overlain by umber. In the Skouriotissa orebody the umber - sulphide ore relationship was uncertain mainly because (a) the orebody is resting on the U.P.L. and (b) it was very difficult to differentiate between ochre and umber. Detailed investigation has shown that at Skouriotissa the ore is overlain by ochre which in turn is overlain by umber; in some parts of the pit there is a marked angular unconformity between the ochre and the umber, (Plate 3.2), suggesting that here, as elsewhere, the umber was deposited after the emplacement of the ore.



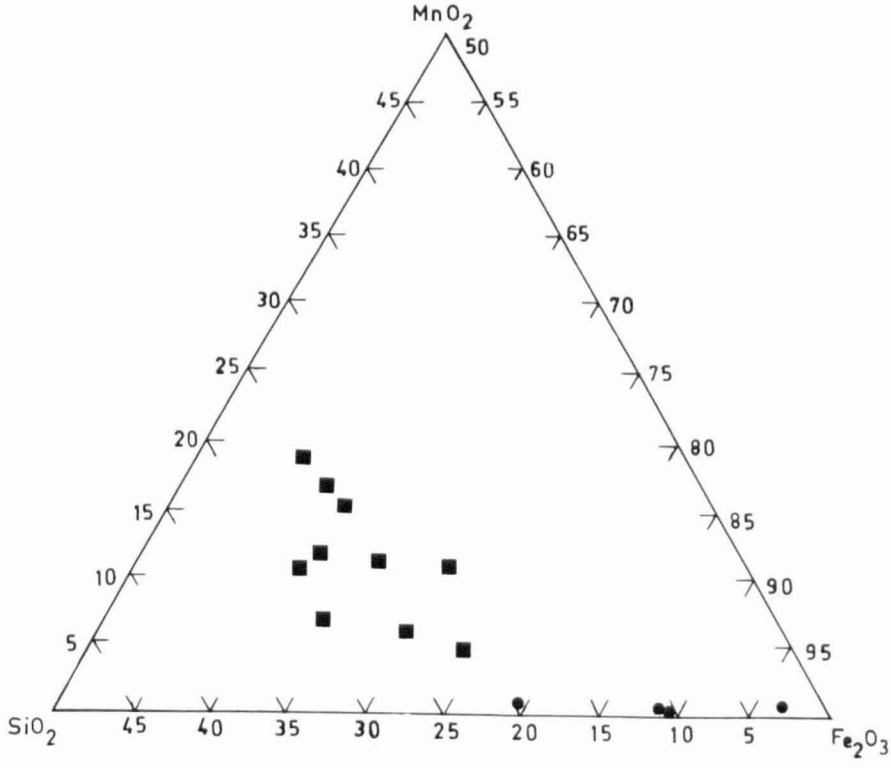


Fig. 6-1. Variation in $MnO_2 : Al_2O_3 : Fe_2O_3$ and $MnO_2 : SiO_2 : Fe_2O_3$ in umber and ochre. (Based on analyses compiled from Cyprus Geological Survey publications, and data given in chapters 3, 4 and 5)

Table 6-1. X-Ray diffraction analyses of samples of the Ochre Group and Perapedhi Umber from the Skouriotissa, Mathiatis and Mousoulos orebodies

Sample Nº	Location	Description of Specimen	Goe-thite	Quartz	Pyrite	Calcite	Gyp-sum	Illite	Mont/-/nite	Side-rite
SKOURIOTISSA OREBODY										
SK7/2	Cds: -126400 ft. 33950 "	Perapedhi argillite	X	XX	–	–	–	X	XX	–
SK9/11	Cds: -127475 ft. 34155 "	Perapedhi umber (Plate 3.3)	XX	–	–	–	–	–	–	–
SK / 3	Cds: -126535 ft. 33950 "	Ochre in contact with fresh lava	XXXX	–	–	–	–	–	–	–
SK / 4	Samples located between SK/3 and SK/30 (See Plate 3.2)	Ochre	XXX	XXX	–	–	–	X	–	–
SK / 5		Ochre mixed with clayey tuff	X	X	–	–	–	–	XXX	–
SK / 7		Fine grained clayey tuff (top of band)	–	XXX	–	–	–	–	XXX	–
SK / 7a		Coarse grained clayey tuff (bottom of band)	–	XXX	–	–	–	–	XXX	–
SK/14		Fine grained clayey tuff (top of band)	–	–	–	–	–	–	XXXX	–
SK/14a		Coarse grained clayey tuff (bottom of band)	–	–	–	–	–	–	XXXX	–
SK/16		Brown ochre	XXX	XX	–	–	–	–	–	–
SK/20		Band of red clay	X	X	–	–	–	–	XXX	–
SK/22a		Yellow ochre (Plate 3.4)	XXX	XX	–	–	–	–	–	–
SK/22b		" " "	XX	XXX	–	–	–	X	–	–
SK/22c		" " "	XX	XXX	–	–	–	X?	–	–
SK/24		" " "	XX	XXX	–	–	–	–	–	–
SK/25		Brown ochre "	XXX	XX	–	–	–	X?	–	–
SK/27a CC 4		Yellow ochre (Plates 3.4,3.6)	XX	XXX	–	–	–	X?	–	–
SK/27b CC 5		Brown ochre "	XX(X?)	XXX	–	–	–	–	–	–
SK/27c CC 6		Orange ochre "	XXX	XX	–	–	–	X?	–	–
SK/27d CC 7		Brown ochre "	XX	XXX	–	–	–	X	–	–
SK/30	Cds: -126445 ft. 33910 "	Perapedhi umber (Plate 3.2)	XX	–	–	–	–	–	–	–
MATHIATIS OREBODY										
MA/4a	Cds: 2708 m. -3082 "	Limestone in contact with massive ore (Plate 4.61)	X	X	–	XXX	XX	–	–	X?
MA/859a CC 32	Cds: 2689 m. -3109 "	Ochre (See arrow in Plate 4.58)	XXX	X	X	–	X	–	–	–
MA/859b	Cds: 2689 m. -3109 "	Brown ochre (top of Plate 4.58)	XXX	–	X	–	–	–	–	–
CC 28	Cds: 2689 m. -3083 "	Limestone	X	XX	–	XXX	XX	–	–	–
MA/879	Cds: 2690 m. -3114 "	"	X	–	X	XXX	X	–	–	–
MA/3	Cds: 2703 m. -3082 "	Ochre mixed with pyrite and gypsum	XXX	–	XX	–	XXX	–	–	–
MOUSOULOS OREBODY										
MS2/3b	Level: 130 m. Cds: -5115 " -23548 "	Brown ochre	XXX	–	–	–	–	–	–	–
MS 3/21	Level: 125 m. Cds: -5102 " -23557 "	Yellow ochre in contact with pyrite	XXX	–	XX	–	–	–	–	–
L/151	Cds: -5146 m. -23556 "	As above	XXX	–	X	–	–	–	–	–
MS/142	Cds: -5123 m. -23553 "	" "	XX	–	XX	–	–	–	–	–
MS/133	Cds: -5112 m. -23556 "	" "	XX	–	XXX	–	–	–	–	–
MS/148	Cds: -5143 m. -23552 "	" "	XXX	–	X	–	–	–	–	–
MS/148a	Cds:	Sheared ochre in contact with lava	XX	–	–	–	–	–	XX	–

XXXX = Abundant, XXX = Considerable, XX = Rare, X = Trace, – = Not detected

(Coordinates based on Cyprus Grid)

Plate 6-1. Electron image of an area 500x500 microns in which manganese mineral(s) were observed in the ochre.

Plate 6-2. X-ray Scanning (MnKa) micrograph of the area shown in plate 6-1.

Plate 6-3. X-ray Scanning (FeKa) micrograph of the area shown in Plate 6-1.

Plate 6-4. X-ray Scanning (MnKa) micrograph of an area of umber 400x400 microns showing patches of high concentration of manganese.

Plate 6-5. Micrograph of a traverse through the area shown in Plate 6-4 showing variation in manganese content (MnKa).

Plates 6-6, 6-7. Lath-shaped maghemite (grey) associated with pyrite (white) and quartz (dark grey). Skouriotissa orebody.

PPL, scale bars = 160 microns

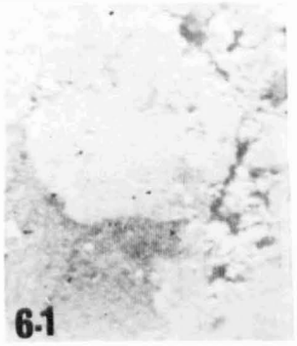
Plate 6-8. Well crystalline goethite and/or maghemite (grey) replacing fractured and corroded pyrite (Mathiatis orebody see Plate 4-64).

Plate 6-9. Zoned pyrite partly replaced by goethite and/or maghemite. Replacement follows contacts of growth zones (Mousoulos orebody).

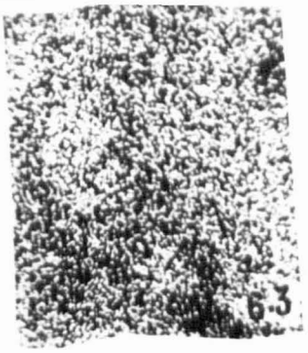
PPL, scale bar = 215 microns

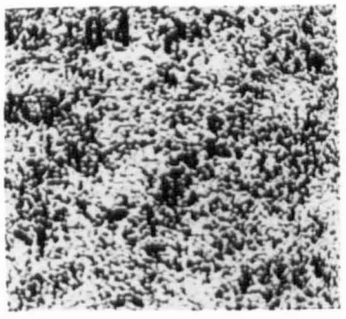
Plate 6-10. Fractured and corroded pyrite in red hematitic ochre. Fractures and zones of corrosion filled with goethite and/or maghmite (grey). (Skouriotissa orebody see plate 3-14).

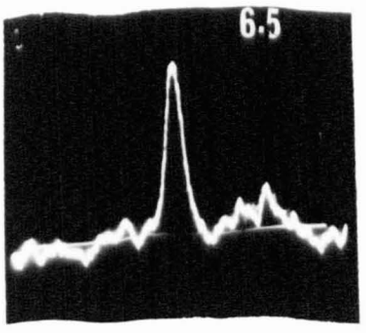
Plate 6-11. Rare fragments of corroded pyrite in ochre several cms away from the ochre-ore contact. (Mousoulos orebody see plate 5-35).

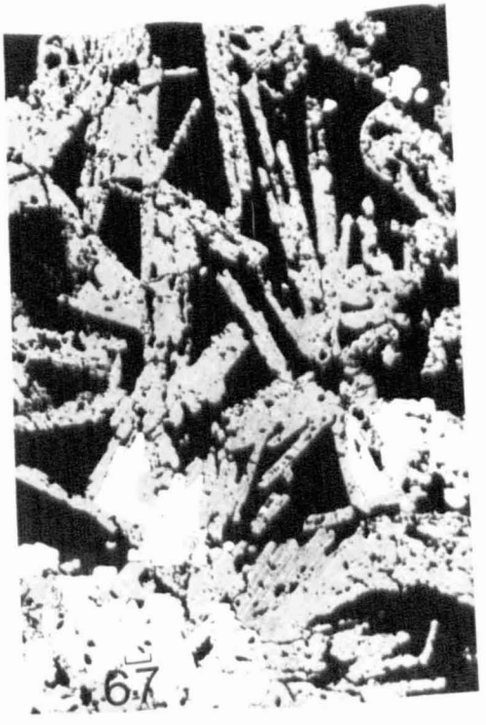

6·1

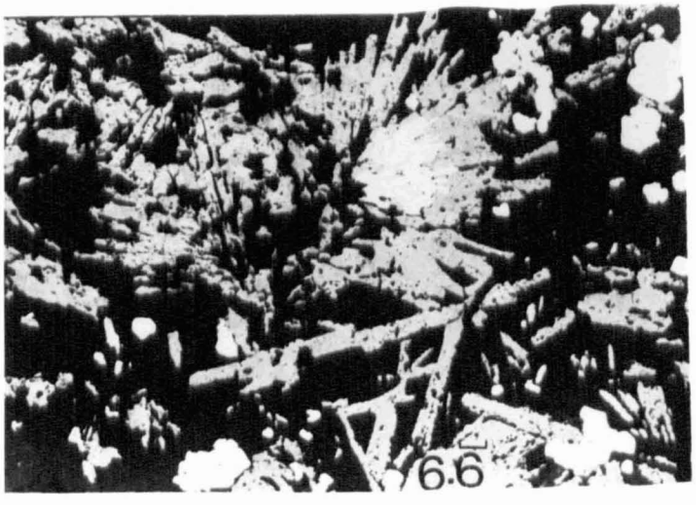

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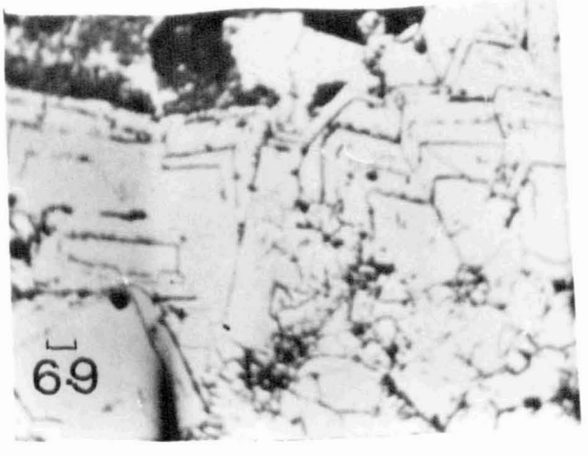

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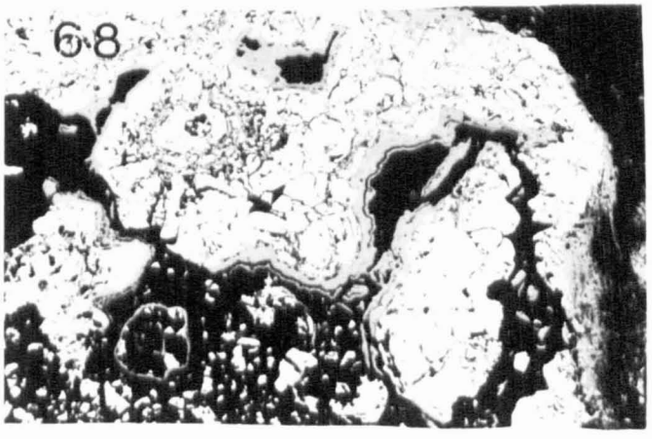

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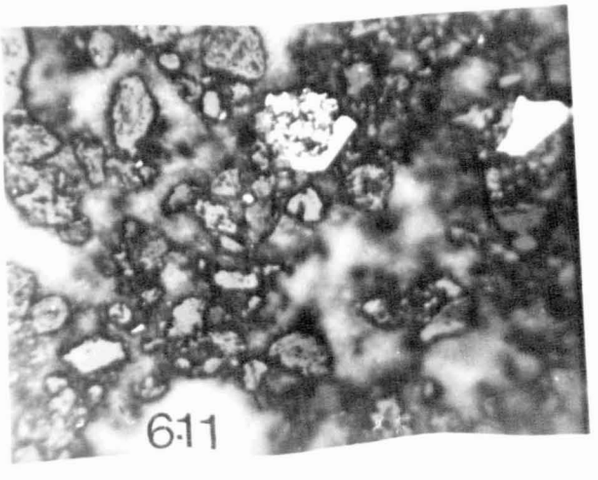

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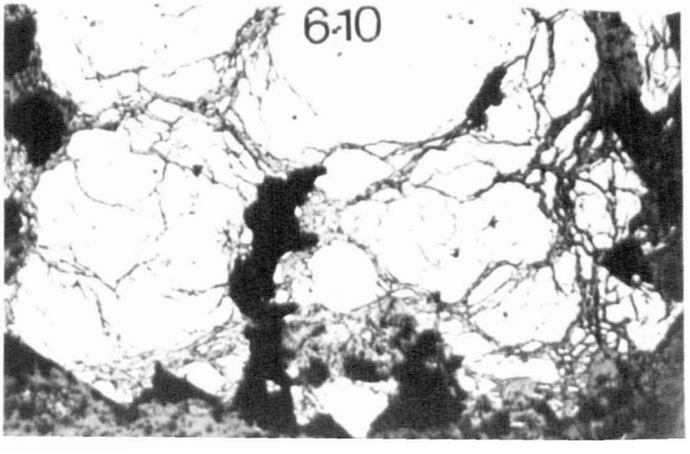

6·7


6·6


6·9


6·8


6·11


6·10

Searle (1965) investigated the trace element composition of umber from various outcrops around the Troodos complex, as well as the trace element distribution in umber and the overlying brown and pink argillites in a few isolated outcrops in the Limni mining area. His investigation has shown that:

(a) The argillites are substantially lower than the umber in copper and zinc.

(b) The copper and zinc contents of the umber away from mineralization are generally consistent throughout Cyprus, and

(c) There is a substantial increase of copper and zinc in the umber around orebodies.

On the basis of the last two features Searle concluded that weathering of the orebodies has contributed to the formation of some outcrops of umber.

A comparison of the trace element contents of sulphide ore and umber in the Skouriotissa and Mathiatis orebodies as well as the background lavas is summarized in Table 6.2 and graphically presented in which indicate that:-

(i) The variation of copper, zinc, nickel and cobalt in the umber above the Mathiatis and Skouriotissa orebodies is distinctly narrower than in the sulphides of these two orebodies.

(ii) There is a marked difference in the copper, zinc and cobalt contents of the sulphides of the Mathiatis and Skouriotissa orebodies but the contents of the same elements in the umber above these orebodies show a small difference.

(iii) Nickel is very low in the ore of both orebodies (but distinctly higher in the Mathiatis ore) whereas in the umber above both orebodies nickel is substantially high (distinctly higher in the Skouriotissa umber).

(iv) The ratios of Cu:Zn, Ni:Co and Cu:Co in the sulphides at Skouriotissa and Mathiatis differ by factors of about 58, 9.0 and 2.0 respectively between the two areas. The same ratios in the umbers are almost identical at the two orebodies and are very similar to the ratios in background lavas.

The umber was deposited in a marine environment and for copper, zinc, nickel and cobalt very little is known about the processes of their supply and removal in this environment. However the trace element composition of the umber seems to suggest that oxidation of sulphide ores contributed little to the formation of umber. This is further substantiated by the fact that the Cyprus sulphide ores contain no or very little manganese whereas the umber invariably contain high manganese.

Table 6.2. Mean values of Cu, Zn, Ni and Co and ratios of Cu:Zn Ni:Co and Cu:Co in ores and umbers at Skouriotissa and Mathiatis in umber from various outcrops around Cyprus (Searle 1965) and in background lavas (Govett 1969).

Rock	Orebody	Number of Samples	Mean ppm				Ratios		
			Cu	Zn	Ni	Co	Cu:Zn	Ni:Co	Cu:Co
Ore	Skouriotissa	10	21026	742	24	330	28.1	0.07	63.7
Ore	Mathiatis	56	11470	2850	33	51	0.5	0.6	28.8
Umber	Skouriotissa	13	1186	528	312	210	2.2	1.5	5.6
	Mathiatis	7	808	417	226	122	1.9	1.8	6.6
Umber	Around Cyprus	17	626	440	-	-	1.4	-	-
Background lavas		111	89	64	63	30	1.4	2.1	3.0

4. Source of the umber constituents

Field evidence leaves little doubt that the umbers are post-mineralization in age. The trace element assemblage in the umbers is clearly related to the volcanic rocks and not to the sulphides, suggesting that the umber material probably derived from the pillow lavas.

The most widely accepted process of supply of the umber constituents is that postulated by Jarrel (1947). He proposed that the pillow lavas were exposed and subaerially weathered under humid tropical climatic conditions, producing a residual blanket of lateritic affinities, rich in manganese, iron, SiO_2 and clay. The lateritic blanket was reworked mechanically and chemically when the Troodos Complex submerged again, to form the umber.

This hypothesis conforms with the recently recognized widespread unconformable lava-umber relationships on both sides of the Troodos Complex. On the southern side of the latter there are widespread outcrops of lava breccia (Kalavassos Mining area). If the origin of the lava breccias is attributed to erosion processes, then the erosion that took place prior to the deposition of the umber was more extensive than originally thought. The hiatus in sedimentation extending from Upper Cretaceous to Lower Middle Miocene in the Skouriotissa area, and the presence of leaf cuticles and some spores of land plants in the Skouriotissa umber suggest that parts of the Troodos Complex area probably emerged while others were still submerged. Weathering of the lavas however was probably operating while the Troodos Igneous Complex was under sea water.

Another plausible mechanism of supply of the umber material is through water-lava interaction during the extrusion of the latter. This mechanism was proposed by Bonatti and Nayudu (1965) to explain the formation of several iron and manganese oxide deposits closely associated with hyaloclastites in the Pacific. Bonnatti (1967) found that in the East Pacific Rise, glassy hyaloclastic grains associated with manganese oxides contain an order of magnitude less manganese than the fresh basalt which erupted at the same locality without directly reacting with sea water. He suggested that manganese and iron were leached out of submarine lavas during their interaction with seawater. A similar explanation was offered by Moore (1965) for the marked manganese depletion in some hydrated basalts spatially associated with manganese oxides around the MacCall Sea Mount. Bostrom (1967) presented calculations based on the manganese content of basalts and the excess of manganese in the pelagic sediments from which he concluded that the above-mentioned process could not account for the excess of manganese because of the large amount of basalt that would have to have been depleted in manganese.

In Cyprus there is clear evidence that there was strong and extensive hot lava-seawater interaction. Most of the volcanic pile consists of pillow lavas. The size of the pillows in the U.P.L. is generally uniform and less than one metre in diameter. The individual pillows are mostly surrounded by glassy selvages up to 10 cms thick consisting mainly of montmorillonite and hydrated glass.

The chilled margins of the pillows and the quenched textures of their magnetite strongly suggest a hot lava-seawater interaction. Taking into account the almost spherical shape of the pillows and the total volume of the lavas, then the total surface area of basalt that interacted with sea water in Cyprus is vast.

Extensive outcrops of limburgites occur in the U.P.L. at the southern side and, to a lesser extent, at the northern side of the Troodos Igneous Complex. The glassy structure and the well developed supercooling textures in these limburgites clearly suggest a strong water-lava interaction during the extrusion of the latter. In the Kalavassos area the limburgites are overlain by inter-volcanic sediments which probably were deposited during short pauses in volcanicity. These intervolcanic sediments included layers rich in iron and probably manganese. Although no analyses of hydrated glass of limburgite are available, it is probable that the iron and manganese of these sediments was leached out of the limburgite during its interaction with seawater.

Submarine volcanic activity by direct addition of metal bearing hydrothermal solutions was suggested by Wedepohl (1960) as being the source for enrichment of Zn, Ni, Pb, Cu, Co, Mn and Mo in the red pelagic clays in both the Atlantic and Pacific Oceans. Shutz and Turekian (1965) considered this mechanism as important for the enrichment of Co and Ni in the deep water and the underlying sediments of the South Pacific. In Cyprus, however, it is considered most unlikely that metal-bearing hydrothermal solutions have contributed to the formation of umber because:

(a) the lavas underlying the umber show no sign of hydrothermal alteration,

(b) the contact between the lava and umber is generally unconformable, and

(c) there was a period of erosion before the deposition of umber.

The last two features indicate a considerable time break between the end of volcanicity and commencement of sedimentation.

5. Formative Environment

In the Cyprus Geological Survey memoirs there is unanimous agreement that the umber is a marine sediment, whereas

Table 6.3. Chronological Summary of various opinions upon the origin of umber

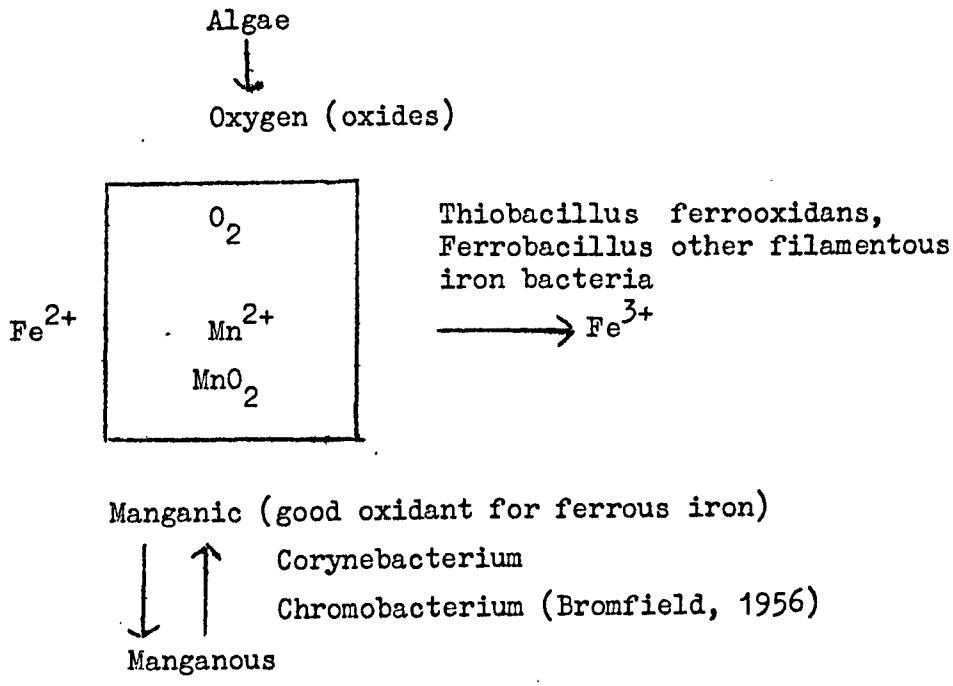
Gaudry (1862)	Umber is a product of contact metamorphism of marls during the "intrusion" of Troodos lavas.
Russel (1882)	- ditto -
Bellamy & Jukes-Brown (1905)	- ditto -
Cullis & Edge (1922)	Umbers are either early post-eruptive sediments charged with fine volcanic matter or more probably, were formed by the chemical action of iron - and manganese - bearing emanations given off from the lava and reacting with marl.
Lespineux-De Magnee (1935)	Umber is later than the Skouriotissa ore.
Jarrel (1947)	Subaerial weathering of lavas under humid tropical conditions produced a residual blanket of lateritic affiliations. Upon submersion, the residual deposits were reworked mechanically and chemically to form the umber.
Wilson (1959)	Umber was formed on the ocean bed either as a primary deposit, by reducing bacterial action, or as a replacement of volcanic ash.
Gass (1960)	The Source of umber was the igneous rocks. Precipitation was brought about through the agency of bacteria under reducing conditions.
Bear (1960)	The Source of umber was the weathering of lavas. Precipitation resulted through the agency of bacteria in lagoonal environment and reducing conditions.
Bagnall (1960)	The Source of umber was the pillow lavas, the Mn being concentrated by biological action in an open sea environment.
Pantazis (1967)	The Source of umber was the Troodos Pillow lavas and probably deposited in a fairly deep open sea.

there is disagreement about the specific conditions of deposition e.g. depth of water. The tendency of the umber to form discontinuous outcrops, confined to irregularies at the top of the volcanics, led most geologists to suggest a lagoonal environment and reducing conditions of deposition (Table 6.3). Bagnall (1960) and Pantazis (1967) suggested an open sea environment. Pantazis emphasised the presence of radiolaria in the umber and in the associated sediments to support his conclusion.

However, radiolarian cherts were not found in the umber of the Skouriotissa, Tamassos and Kalavassos mining areas. The manganese rich specimen investigated by electron probe micro-analysis was also examined for microfossils (Chapter 3). It was found to contain several leaf cuticles and some spores, both from land plants, which had been attacked by bacteria. It also contained small pieces of mucilagenous tissue, most probably algal in origin, suggesting rather shallow waters, at least sufficiently so as to permit penetration of light. Thus it appears that the depth of deposition of the umber varies in different parts of Cyprus.

Although umber contains high iron and manganese it is structureless or poorly crystalline, and consists of an intimate mixture of oxides of the two elements which was probably the result of accelerated precipitation. The accelerated oxidation of iron and manganese requires high availability of oxygen. Bostrom (1967) estimated that about 4.000 litres of seawater were required to oxidize one mole of Mn^{2+} to Mn^{4+} (assuming that seawater contains 10^{-4} moles/litre of dissolved oxygen).

A common property of iron and manganese is the speeding up of their oxidation by bacteria. Some of the same bacteria that help to precipitate iron can also derive energy from the oxidation of manganese, (Krauskopf 1967). Algae, also through photosynthesis, are very active in generating oxygen in seawater and are also known to synthesize potent organic oxides which should aid in iron oxidation, as shown diagrammatically below.



An algae-bacteria-Manganese triad in the oxidation of iron (After Zajic (1969)).

6. General Characteristics of the ochres

The ochres stratigraphically occur immediately above the sulphide ores and geographically are essentially restricted to the boundaries of the orebodies. As mentioned in Chapters 3,4 and 5, the ochres conformably overlie the Skouriotissa, Mathiatis N, and Mousoulos orebodies. In addition to these three orebodies, the C.M.C. official files and a published report (Kinkel 1966) indicate that ochre conformably overlies the massive ore at the Mavrovouni orebody (Fig.3-1) where it is in turn overlain by a thick cover of fresh Upper Pillow Lavas. A similar sulphide ore - ochre - U.P.L. relationship has been observed at the eastern part of the Apliki orebody (Fig. 2.1).

Ochre is a manganese-poor iron-rich fine-grained deposit with well defined bedding and graded banding. The ochre contains varying proportions of tuffaceous material, chert, limestone (Mathiatis and Apliki); it also contains sulphides in the form of massive layers, bands, fragments, and disseminations.

The major element composition of the ochre and umber is shown in Figs. 61a and 6.1b which indicate that:

(a) iron oxide in ochre is consistently higher than in umber,

(b) aluminium in ochre exhibits smaller variation than in umber, and

(c) manganese oxide in ochre is conspicuously lower than in umber. However, the manganese content in ochre tends to increase with increasing distance from the ochre - sulphide ore contact.

The trace element assemblage in ochre is very clearly related to the sulphides underlying the ochre. Thus, as shown in figure 6.2, the characteristic variable concentration of copper, zinc, nickel and cobalt in the ore at Skouriotissa is faithfully reflected in the overlying ochre. This similarity in trace element assemblage between the ore and ochre is less distinct at the Mathiatis orebody (Fig. 6.2) mainly because only a limited number of analyses are available. In Table 6.4 the values of the ratios of Cu:Zn, Ni:Co and Cu:Co in the ore at Skouriotissa are distrintly different from those at Mathiatis; the values of these ratios in ochre at Skouriotissa and Mathiatis are also distintly different. At each of the above orebodies, however, each ratio is essentially the same in the sulphide ore and in the respective overlying ochre.

Table 6.4. Mean values of Cu, Zn, Ni and Co and ratios Cu:Zn, Ni:Co and Cu:Co in ores and ochres at the Skouriotissa and Mathiatis orebodies.

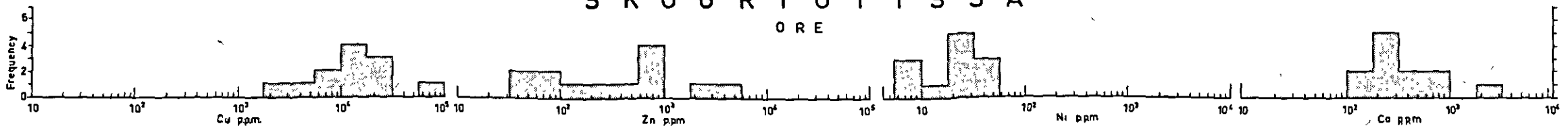
Rock	Orebody	No. of samples	Mean ppm				Ratios		
			Cu	Zn	Ni	Co	Cu:Zn	Ni:Co	Cu:Co
Ore	Skouriotissa	10	21026	747	24	330	28.1	0.07	63.7
Ore	Mathiatis	56	1470	2850	33	51	0.5	0.6	28.8
Ochre	Skouriotissa	17	11636	338	42	209	34.4	0.2	55.7
Ochre	Mathiatis	5	397	1084	32	17	0.3	1.9	23.4

The predominant mineral in the ochre is the ferric oxyhydroxide goethite, which is mixed in widely varying proportions with

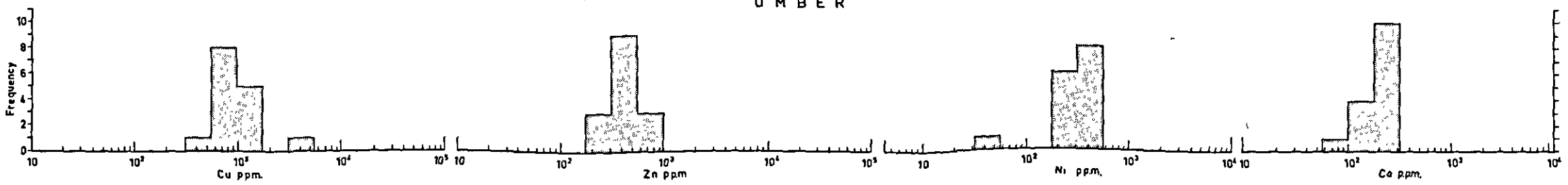
Fig.6-2 Graphical presentotion of Cu, Zn, Ni and Co content in the ore, umber and ochre of the Skouriotissa and Mathiatis orebodies

S K O U R I O T I S S A

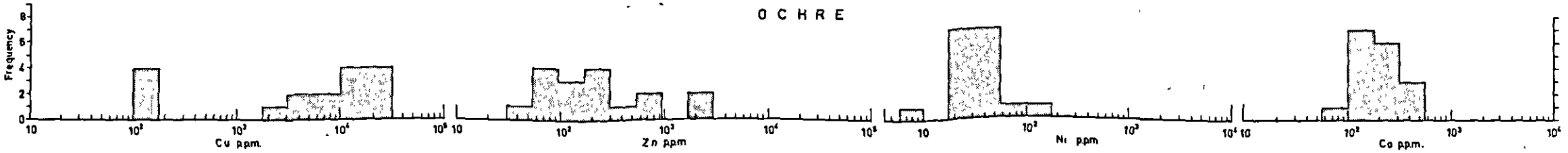
O R E



U M B E R

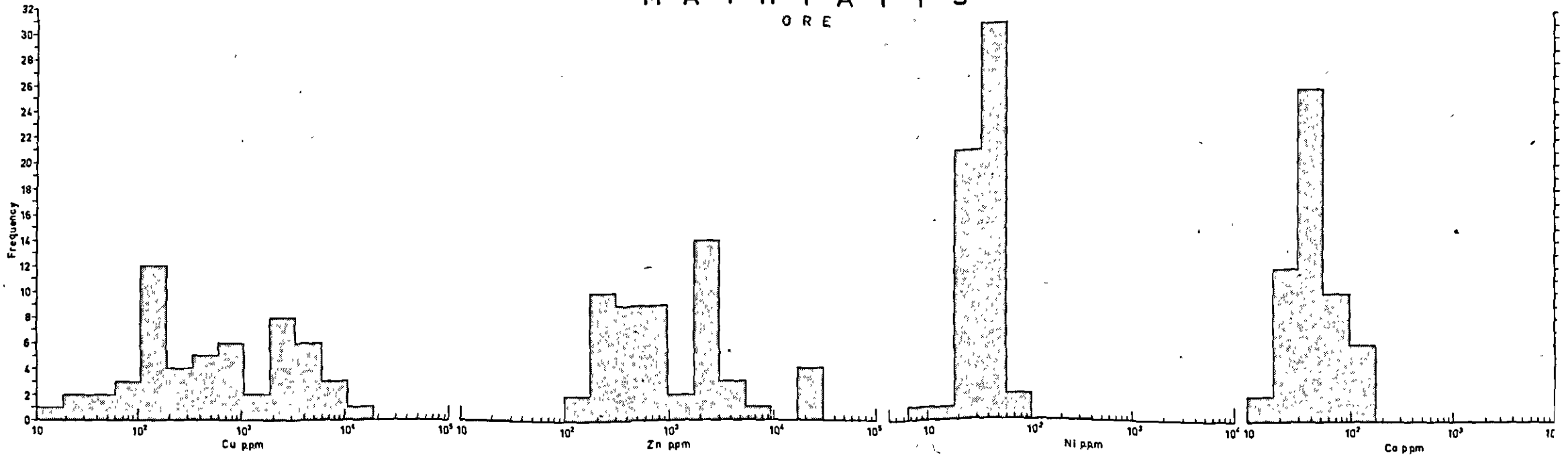


O C H R E

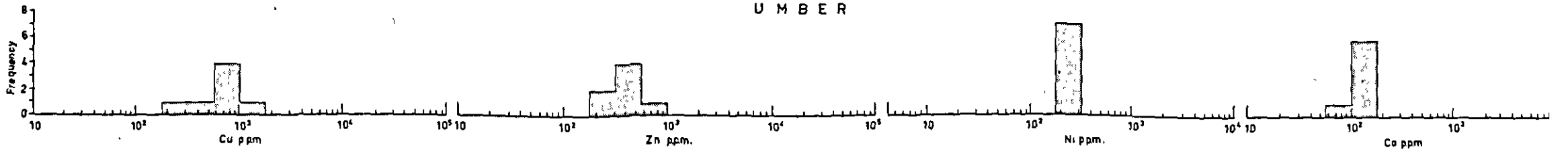


M A T H I A T I S

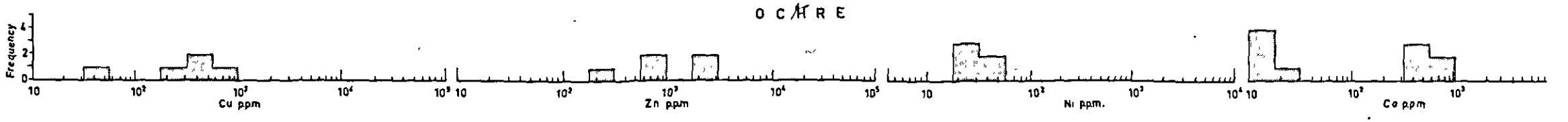
O R E



U M B E R



O C H R E



poorly crystalline ferric oxyhydroxides (chapters 3, 4, 5). Rare maghemite was found to be a persistent constituent of ochre at the ochre-sulphide ore contact but was not observed a few centimetres away from the sulphide ore. Maghemite was seen to replace pyrite either along fractures and grain boundaries (Plates 3.14, 3.15, 3.16, 3.17, 3.28, 4.65, 5.27, 5.28, 5.29, 6.8, 6.10) or along contacts of growth zones (Plates 6.9).

At the vicinity of the 300° trending fault, at the western Skouriotissa orebody, there are blocks which consist of a mixture of corroded pyrite, quartz, and maghemite. The latter forms aggregates of lath-shaped crystals which often exhibit a radiating arrangement (Plates 6.6, 6.7). Several electron probe analyses have shown that the average iron content of the maghemite illustrated in the plates 6.6 and 6.7 is 70.5 per cent. The pyrite-maghemite relationship and the common occurrence of remnant pyrite in strikingly similar lath-shaped crystals in the same speciment, seem to suggest that the maghemite replaced the pyrite.

Pyrite is a very common constituent of the ochre. At the Skouriotissa orebody it forms massive layers and fine bands interbedded with ochre and is also disseminated within it. In the Mousoulos and Mathiatis orebodies, pyrite diminishes rapidly away from the ochre-sulphide ore contact. About half a metre away from this contact the ochre contains only rare fragments of pyrite (Plate 6.11). In the ochre pyrite is invariably intensely corroded, and devoid of internal growth zoning whereas in the underlying massive ores the zoned pyrite is very common.

Chalcopyrite is present at the ochre-ore contact at the Mousoulos orebody, and in the red hematitic ochre and cherts in the Skouriotissa orebody; it is invariably rimmed by covellite and less commonly by digenite. In the same zone sphalerite, idaite and orange bornite were observed. About 10 cms from the ore-ochre contact the only copper sulphide present in the ochre is covellite, whereas at about 50 cms from that contact the covellite disappears and only rare fragments of unzoned pyrite are present.

Quartz is present in the ochre in greatly varying amounts. Cherts are common at the base of the ochre at the

Skouriotissa East orebody. They consist mostly of cryptocrystalline silica and exhibit fine colour banding due to dispersion of variable amounts of iron oxides in the silica. Siderite was found only in the siliceous limestone at the Mathiatis orebody whereas montmorillonite is restricted to the clayey tuffs in the Skouriotissa orebody. Rare illite was detected in the ochre at Skouriotissa.

Although the manganese content of the ochre is low, manganese mineral(s) were observed in some brown-yellow bands of ochre taken from the upper part of the ochre at the Skouriotissa East orebody (Plate 3.6). These mineral(s) occur as irregular crystals intimately mixed with goethite (Plates 6.1, 6.2, 6.3). Optical and X-ray powder investigations failed to identify the species.

7. Source of the ochre constituents

Bruce (1948) noted that at Skouriotissa "low in manganese content limonitic bands" are found intercalated between the sulphide ore and the manganese-rich umber. He suggested that these limonitic bands resulted from subaerial oxidation of sulphide ore. Hutchinson (1965) considered the ochre to be part of the Perapedhi sediments and reports that "Episodes of sulphide-sediment generation were probably accompanied by explosive gaseous volcanism (as the sediments are partly pyroclastic) but their fine pyritic and siliceous character suggests colloidal or chemical deposition probably under reducing sea-bottom conditions". Vokes (1966) rightly pointed out that reducing conditions could not produce sediments consisting of oxides. Kinkel (1966) referred to the ochre as umber and reports that in the Mavrovouni orebody rounded boulders of massive pyrite several inches across occur in well-stratified umbers and suggested that this umber was formed from the erosion of a massive sulphide gossan.

Recent detailed mapping has shown that at the Mousoulos orebody the ochre is stratigraphically different from the umber and that the ochre was genetically closely related to the underlying sulphide ore. Thus Searle and Constantinou (1967) suggested that the ochre constituents were exhaled into the sea penecontemporaneously with the sulphides and were deposited after

the sulphides when oxidizing conditions prevailed. A similar formative process has been suggested for the ochre overlying the Mathiatis orebody by Searle and Panayiotou (1968). Searle (1968) distinguished the ochre from the umber at Skouriotissa; he referred to the ochre as iron-rich sea bottom muds, and postulated an exhalative sedimentary origin for the ochre. He noted however, the common graded bedding in the ochre, and he suggested that part of the pyrite in it was washed out from the underlying massive sulphide ore.

The mineralogical textural and geochemical studies of the present writer have produced convincing evidence that the ochres overlying the Skouriotissa, Mathiatis and Mousoulos orebodies originated through oxidation of sulphides and that this took place under submarine conditions. The main oxidation process involved the replacement of pyrite by goethite and, to a lesser extent, by maghemite. That the oxidation took place under submarine conditions is strongly suggested by the following:

(a) Interstratification of ochre and clayey tuff at Skouriotissa (Chapter 3).

(b) The lack of terrestrial microfossils in the Skouriotissa ochres (Chapter 3).

(c) Interstratification of marine limestone and ochre at Mathiatis (Chapter 4).

(d) Common bedding and graded banding in the ochre at Skouriotissa, Mathiatis and Mousoulos.

(e) Superincumbence of pillow lavas on ochre at Mousoulos and Mathiatis.

(f) Physical dissimilarity between the ochres and the gossans that have been produced by subaerial oxidation of the sulphide orebodies at Skouriotissa and Mathiatis.

(g) The nickel content of ochres overlying the Skouriotissa and Mathiatis orebodies is essentially similar to that of the underlying sulphide ore and tends to increase away from the ochre-sulphide contact, whereas recent trace element studies (Govett personal communication) indicate that gossans formed by subaerial oxidation of these orebodies have a hardly detectable nickel content.

8. The Marine environment in Terms of Eh and pH

Seawater generally contains dissolved oxygen averaging at 35‰ salinity, 6 milligrams per litre. (Turekian 1968). The amount of dissolved oxygen varies with depth. It is more abundant in surface layers, being enriched by diffusion from the atmosphere and by the phytoplankton which produces it as a by-product of photosynthesis. On the other hand, below the zone of light penetration and with the help of dissolved oxygen living organisms burn organic compounds for food thus decreasing the dissolved oxygen content of the water. The depleted oxygen is replenished by advection, convection and eddy diffusion. (Turekian 1968). In isolated local depressions on the sea floor and in restricted basins, where the rate of aeration is slower than the rate of oxygen consumption, anaerobic conditions prevail e.g. in the Dead Sea, Black Sea, Central Gulf of California (Roberts et al 1968) and Atlantis III Deep, Red Sea (Emery et al 1969).

As well as the anoxic basins, cases of extremely low dissolved oxygen content have been recorded from the east tropical Pacific (Richards 1965). In this area dissolved oxygen as low as 0.1 ml./l was recorded at a depth of 400 metres and at another station in the same area the dissolved oxygen at a depth of 700 metres was 0.2 ml/l.

From the general pattern of sea life it seems that there are no drastic variations in the chemistry of sea water. Sea water normally has a pH of between 7.5 and 8.4. The partial pressure of 0.1 ml/l dissolved oxygen (the lowest published figure found) is 10^{-4} atmosphere. The oxidation potential of sea water at a pH of about 8 and an oxygen partial pressure of 10^{-4} atmosphere is higher than +0.6 volts. (Fig. 6.3b). For much lower partial pressure of oxygen (i.e. 10^{-20} atmosphere) at a pH of about 8 the oxidation potential of seawater is above +0.5 volts (Fig. 6.3). Therefore seawater in general is a highly oxidizing solution. This is borne out by the fact that in seawater most elements exist in solution in their higher oxidation states (Turekian 1968): Manganese nodules consisting of hydrous manganese and iron oxides are very common on the deep sea floor in the Pacific, Atlantic, and Indian oceans (Menard (1964); Turekian (1968); Bonatti (1967);

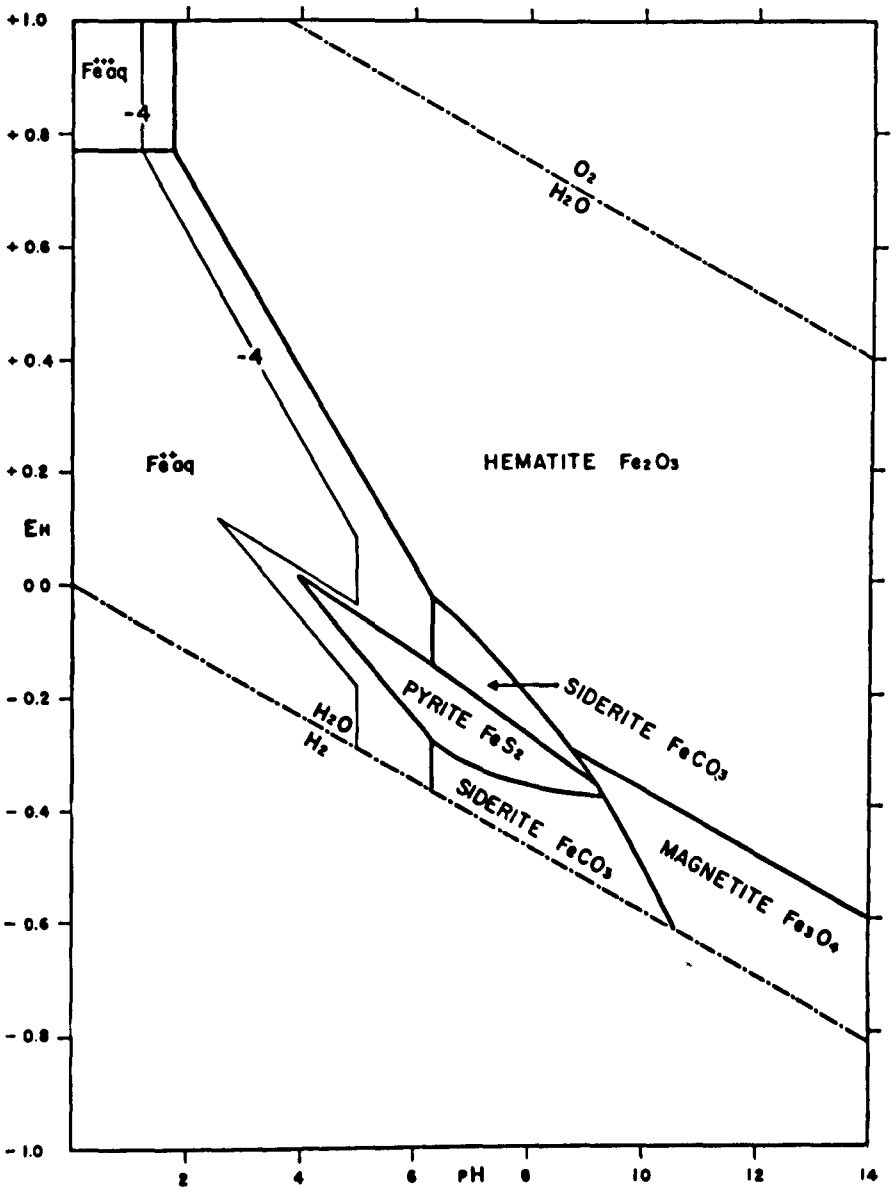


FIG. 6—3a Stability relations of iron oxides, sulfides, and carbonate in water at 25 °C and 1 atmosphere total pressure. Total dissolved sulfur = 10^{-6}. Total dissolved carbonate = 10^{0}. Note elimination of FeS field by $FeCO_3$ under strongly reducing conditions, and remarkable stability of pyrite in presence of small amount dissolved sulfur.

After Garrels and Christ (1965)

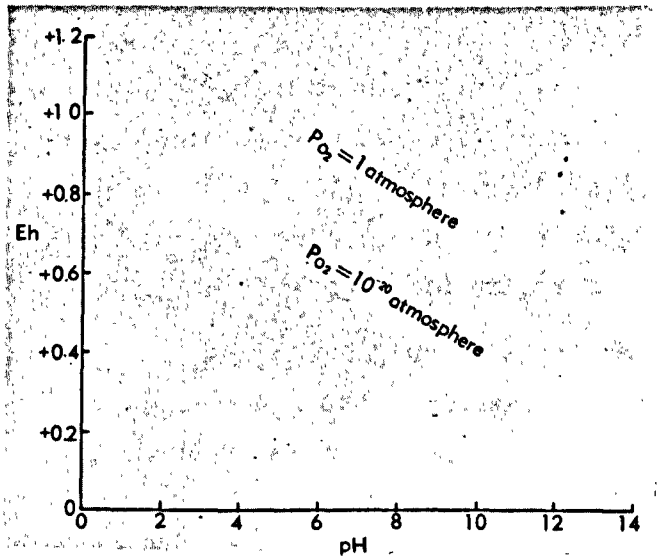


FIGURE 6-3b *The relationship of pH, Eh and the partial pressure of oxygen in the atmosphere. Although P_{O_2} is actually equal to 0.2 atmospheres instead of one atmosphere, the difference between the two lines is almost imperceptible. The relationship for P_{O_2} equal to 10^{-20} atmospheres is drawn for reference. The lines represent the half-cell: $2H_2O = 4$ electrons + $O_2 + 4H^+$. At a pH = 8 and 0.2 atmosphere P_{O_2} the Eh is about 0.75 volts.*

After Turekian (1968)

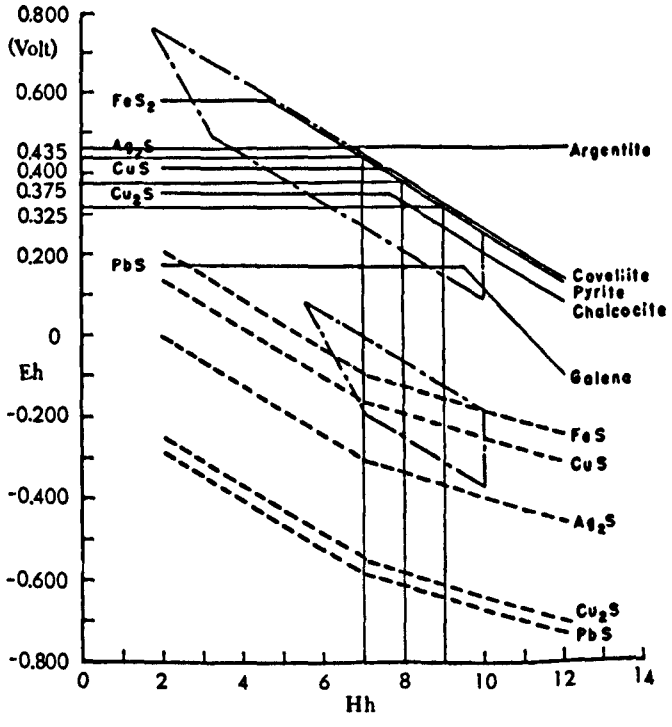


FIG. 6-3c. Experimental upper (solid lines) and lower (dashed lines) boundaries of immunity domains for various sulfide minerals.

After Sato and Mooney (1960)

Bostrom and Peterson (1966); Bostrom (1967)). Rickard (1968), on the basis of laboratory investigations and a review of the literature concluded that in the natural aqueous environment most iron is in the form of ferric oxyhydroxide.

9. Possible Chemistry of Submarine oxidation of Sulphides

As stated before, the ochres probably originated from the oxidation of the underlying sulphide ores, this process taking place under submarine conditions. The precise mechanism of chemical oxidation and sedimentation in marine environments is uncertain, since many dissolved solids are nearly in equilibrium with seawater, metastability is common among them and the kinetics of their precipitation are poorly understood. These difficulties were stressed by Garrels and Christ (1965) who concluded that ..... "It will be some time before it is possible to illustrate what should exist at equilibrium on the sea floor ...."

It was shown in the previous section that seawater in general is an oxidizing solution and its oxidation potential is above +0.5 volts even for extremely low values of dissolved oxygen. A review of the literature reveals some controversy about the upper Eh limit of the stability field of pyrite. Thus in the Eh-pH diagrams of Garrels and Christ (1965) the upper Eh limit of pyrite at a pH around 8 is -0.2 volts (Fig. 6.3a). Sato and Mooney (1960) calculated that for a pH about 8 the upper Eh of immunity domain of pyrite is about +0.4 volts (Fig. 6.3c). In the above two calculations the value of 10^{-6} moles/litre was chosen for the total activity of sulphur. Bostrom (1967), using a value of 10^{-4} moles/litre for the total activity of sulphur suggested that the upper Eh of the stability field of pyrite for pH 8 is -0.4 volts.

Considering the highest published oxidation potential (i.e +0.4 volts) under which pyrite is stable at a pH of 8, it is obvious that pyrite is unstable in sea water even if the latter's dissolved oxygen content is extremely low. Hence, when at one stage of their geological history the Skouriotissa, Mathiatis and Mousoulos orebodies were exposed on the sea-floor and the total activity of sulphur in the seawater in contact with the sulphide ores reached 10^{-6} moles/litre and when anoxic conditions were absent the pyrite at the surface of the orebody would start to oxidize.

The oxidation process can be represented as follows:

$$FeS_2+H_2O+3\tfrac{1}{2}O_2 \text{ ____ } FeSO_4+H_2SO_4 \text{ (Eq-1) Zajic (1969)}$$

Ferrous sulphate in the presence of sulphuric acid oxidizes to ferric sulphate:

$$2FeSO_4+H_2SO_4+\tfrac{1}{2}O_2 \text{ ____ } Fe_2(SO_4)_3+H_2O \text{ (Eq-2) Zajic (1969)}$$

The ferric sulphate produced in reaction (2) is stable in the presence of sulphuric acid and can be carried in solution to deeper parts of the orebody (for mechanism see Chapter 7). Its capacity to oxidize pyrite, chalcopyrite and sphalerite is very well known and is extensively used by hydrometallurgists. The reactions involved are:

$$FeS_2+Fe_2(SO_4)_3 \text{ ____ } 3\ FeSO_4+2S \text{ (Eq-3) Zajic (1969)}$$

$$CuFeS_2+2Fe_2(SO_4)_3 + 2H_2O+3O_2 \text{ ____ } CuSO_4+5FeSO_4+2H_2SO_4 \text{ (Eq-4) Zajic (1969)}$$

$$ZnS+2Fe_2(SO4)_3 + 2H_2O+O_2 \text{ ____ } ZnSO_4+4FeSO4+2H_2SO_4 \text{ (Eq-5) Zajic (1969)}$$

If sulphuric acid in the environment is depleted, either during reaction (2) or due to dilution, the ferric sulphate results, through hydrolysis, in sulphuric acid and a precipitate of ferric hydroxide.

$$Fe_2(SO_4)_3+6H_2O \text{ ____ } 2Fe(OH)_3 + 3H_2SO_4 \text{ (Eq-6) Zazic (1969)}$$

The ferric hydroxide produced in reaction (6) dehydrates, producing ferric oxyhydroxide:

$$Fe(OH)_3 \text{ ____ } a\text{-}FeO.OH + H_2O \text{ (Eq in 7) Rickard (1968).}$$

Edwards (1959), Burkin and Edwards (1966) and Burkin (1969) reported that"on treating pyrite crystals with 0.5m sodium hydroxide at 90°C and 1 atmosphere air pressure for one hour, a thin coating of maghemite was produced on the pyrite." Edwards, (1959) suggested that the formation of maghemite from pyrite under mild conditions of leaching is the result of a series of topotactic reactions. Thus if the S_2^{-2} groups in pyrite are replaced by O^{2-} ions and the latter occupy the S_2^{-2} positions in the pyrite lattice, the product would be wustite (FeO). The latter is unstable at low temperatures, and under oxidizing conditions alters to $FeOFe_2O_3$ and then to γ-Fe_2O_3.

The conclusions of the present investigation agree with the experimental results of Edwards (1959) and Burkin (1969). The topotactic replacement of pyrite by maghemite although the two intermediate stages were not observed, appears to be one of the processes involved during the oxidation of pyrite under submarine conditions. However lepidocrocite (γ-FeOOH), which is a common hydration product of maghemite (Rickard 1968) was not detected in the ochres.

Field relationships as well as petrological and mineralogical data suggest that the ochre at Mousoulos was probably produced entirely by oxidation of sulphides whereas at Skouriotissa and to a lesser extent at Mathiatis, there was a substantial contribution of material from the surrounding lavas. Thus the montmorillonite tuffs interbedded with ochre at Skouriotissa probably resulted from submarine weathering of the olivine basaltic Upper Pillow Lava penecontemporaneously with the submarine weathering of the sulphide ore. Montmorillonite is a common product of reaction of basaltic glass with seawater, (Mathews (1961); Peterson and Griffin (1964); Bonatti (1967) It is invariably present in the unmineralized basaltic lavas in Cyprus and is a major constituent of the glassy salvages around pillows. The contribution of the weathering of lavas to ochre is exemplified by the substantial increase of nickel and manganese, in the ochre away from the ochre-ore contact.

At Skouriotissa the ochres contain cherts which are restricted to the ochre-ore contact. This is probably a function of pH both directly on its effect upon the precipitation of colloidal silica (optimum pH 4.5 Okamoto et al 1957) and also indirectly, as it affects the precipitation of iron and aluminium hydroxides which themselves are a major factor in the precipitation of silica (Govett 1966). It appears that only at the ochre-ore contact the pH passed through the critical range, as the sulphuric acid from the oxidation of pyrite became diluted by seawater.

The silicious limestone at Mathiatis, although it was formed in an iron-rich environment, contains no ferrous iron implying that during its deposition oxidizing conditions prevailed.

The formation of rare siderite in the limestone/in competition with ferric oxyhydroxide suggests high dissolved carbonate ion activity in the formative environment of limestone and that the source of carbon dioxide was not only the atmosphere. (Rickard 1968). The abundant organic matter in the limestone (Chapter 4) suggests a contribution of carbon dioxide to the formative environment of the limestone by living organisms.

At Skouriotissa pyrite is a common constituent of the ochre and occurs as massive layers, fine bands and disseminations. This pyrite is believed to be detrital because:

(a) The pyrite is invariably corroded, even in the massive layers (Plates 3.28, 3.29, 3.30, 3.31, 3.32) suggesting that it is not in equilibrium with the enclosing rocks.

(b) The pyrite in the ochre is invariably unzoned whereas zoned pyrite predominates in the underlying massive ore (Chapter 3). It has been noted (see Chapter 7) that under oxidizing conditions unzoned pyrite is much more stable than zoned pyrite and is able to withstand transportation away from the ore zone.

(c) The sulphide layers intercalated with ochre, away from the ore-ochre contact, contain no copper sulphides whereas the ore below the ochre is enriched in copper sulphides. It appears that copper sulphides were less stable than unzoned pyrite under oxidizing conditions; they dissolved and were carried downwards in solution to be redeposited in the underlying massive ore.

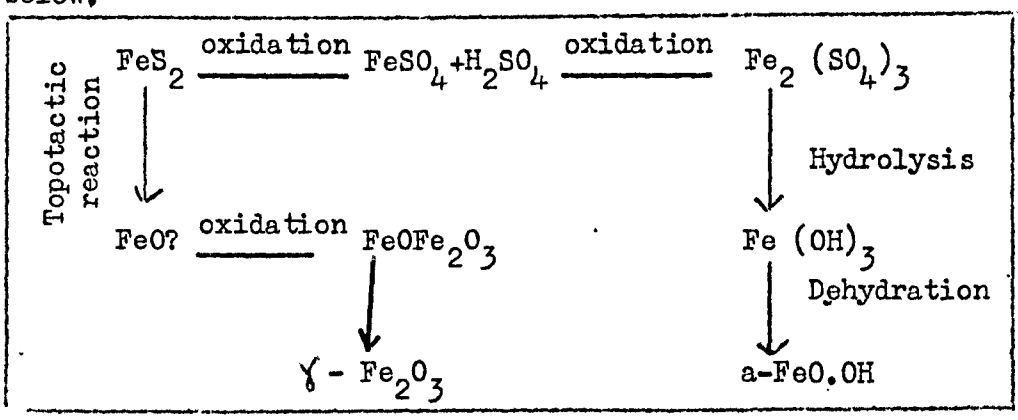
(d) The graded bedding and washouts are of an obviously detrital character.

10. Conclusions

Field relationships, petrological and minerological studies as well as major and trace element data strongly suggest that the Perapedhi umbers and the ochres are different marine sediments and that their constituents were derived from different sources. The umber is not genetically related to the massive sulphide ores. The most probable source of the umber constituents are

the Troodos Pillow Lavas, but the exact process of extraction and concentration of their iron and manganese is not definitely known. The umber was deposited in hollows and irregularities on the lava surface under oxidizing conditions. In the three mining areas considered the umber appears to have been deposited in rather shallow water, whereas in other parts of Cyprus it was deposited in a deep marine environment. Palaeontological evidence suggests that the formativeenvironment of the Skouriotissa umber contained algae. The oxygen and organic oxides which were produced by the algae had accelerated the precipitation of the iron and manganese oxides and resulted in the poor crystallinity of the umber.

The ochres at the Skouriotissa, Mathiatis and Mousoulos orebodies were essentially derived from submarine oxidation of the underlying sulphide ores. At one stage of their geological history these three orebodies were exposed on the seafloor. Seawater, even with very low partial pressure of oxygen, is an oxidizing solution and its oxidation potential is higher than the upper immunity domain of pyrite. Thus the pyrite of the sulphide ore in contact with seawater would be liable to oxidation. Two distinct mechanisms of oxidation are postulated; these are illustrated diagrammatically below.



The first mechanism involves dissolution of pyrite, followed by precipitation of h droxide and oxyhydroxide from solution. In the second mechanism the pyrite is altered to oxide via a solid-state, probably topotactic, reaction.

Submarine sulphide oxidation at Skouriotissa appears to have been more extensive than in the other two orebodies and was accompanied by submarine weathering of the surrounding basaltic lavas. The pyrite found in the Skouriotissa ochre is considered to be detrital and washed out from the underlying massive ore.

CHAPTER VII

A DISCUSSION ON THE GENESIS OF THE CONGLOMERATIC STRUCTURE, POROSITY AND COLLOMORPHIC TEXTURES OF THE MASSIVE ORE

1. General Statement

The ochre in the Skouriotissa, Mathiatis and Mousoulos orebodies is underlain by massive ore which is characterised by a conglomeratic structure, high porosity, and collomorphic textures (Chapter 3, 4 & 5). In addition to the above three orebodies a conglomeratic structure was observed in the ores of the Mavrovouni (Jarrel 1947), Kinousa (Harris 1956), Mavridhia A (Mousoulos 1957) and Apliki orebodies.

The genesis of the conglomeratic structure of the massive ore is highly controversial. Most geologists consider this structure to be a primary feature, related to the processes of ore deposition. Owing to the striking similarity between the conglomeratic ore and the volcanic agglomerates and pillow lavas, it was widely accepted that the conglomeratic structure of the ore was inherited from the lavas which were replaced by sulphides. Some geologists postulated that the ore has been brecciated by later tectonic movements and that such brecciation was probably accentuated by the deeply penetrating supergene processes. The latter would have been facilitated by the heterogeneous mineralogical composition of the ore (i.e. mixture of pyrite and marcasite) and the differential resistance of the two iron sulphides to the supergene processes.

The extensive underground ancient workings encountered in most of the orebodies in the Kalavassos area and the confinement of these workings to the domains of fragmented ore had led some geologists to suggest that collapse of ancient openings was partly responsible for the fragmentation of the ore. More recently some Canadian geologists who visited the Cyprus orebodies on their way back from Japan suggested that, similar to the Japanese ores, the circular structures exhibiting colloidal and gel textures are the result of colloidal precipitation. Some of them suggested that the fragmentation of the Cyprus ores was the result either of subaqueous extrusion of a partly crystallized sulphide fluid, or of the breaking up of banded sulphides by the final explosive escape of

pent-up gasses in the fumarole in which these ores had precipitated. The present investigation, however, indicates that conglomeratic ore structures are not primary, and, therefore, not indicative of the formative conditions of the massive ores. They are considered to be secondary and were imposed after these ores had formed. The characteristically high porosity of the Cyprus ore is suggested to be secondary and to have formed by partial dissolution of the ore. Part of the common colloform textures in the conglomeratic ore are also considered to be secondary and to have formed during the submarine leaching of the ores.

2. Conglomeratic structure

The field relationships, the macroscopic and microscopic characteristics of the conglomeratic ore were described in the Skouriotissa, Mathiatis and Mousoulos orebodies. Generally the conglomeratic ore consists of solid sulphide blocks varying widely both in size and shape being embedded in a sandy, friable sulphide matrix. (Plates 5.13, 5.15). The sandy matrix - solid blocks proportion varies widely even at the same level of a single orebody. In the Mousoulos and Mathiatis orebodies the sandy matrix is very abundant at the top and decreases gradually with depth.

The striking resemblance of the fragmented sulphide ores to the volcanic agglomerates and breccia (Plates 5.15, 5.16, 5.19) suggested to many geologists (Cullis and Edge (1922); Jarrel (1947); Bear (1963); Mousoulos (1957); Pantazis (1967); Harris (1956)) that the conglomeratic structure of the ore was inherited from the lava (brecciated or pillowed) which was replaced by sulphides. A later chapter summarises evidence suggesting that a replacement process is highly unlikely to have been responsible for the formation of massive ores in Cyprus.

Hutchinson (1965) postulated that "the brecciated sulphide masses and the ellipsoid textures were due to subaquous extrusion of a partly crystallized fluid." Searle (1969) suggested that the break-up of banded sulphides by the final explosive escape of pent-up gasses in the fumarole produced autobrecciation. Both hypotheses are based entirely on the general aspect of the ore and no supporting evidence was produced.

It seems most unlikely that collapse of ancient underground working made a significant contribution to the fragmentation of the Cyprus ores as Mousoulos (1957) advocates, because:

(a) Conglomeratic structure is best developed in the Mousoulos orebody which was not discovered by the ancients.

(b) At Skouriotissa it is precisely the hard compact ore which occurs in the areas of most extensive ancient workings.

(c) The conglomeratic structure of the ore in most of the deposits extends to depths where there is no evidence of ancient workings.

Thomaè (1923) suggested that the Skouriotissa ore originally consisted of a mixture of pyrite and marcasite. The latter, being more susceptible to supergene processes, oxidized more readily leaving behind the more resistant pyritic ore with high porosity and conglomeratic structure. This hypothesis is invalidated by the fact that the hard compact ore at Skouriotissa contains no marcasite, whereas the conglomeratic ore at Mathiatis, Mousoulos and Kokkinoyia contain marcasite which is more abundant in their upper parts where fragmentation is most intense. Vokes (1966) also suggested that deep going supergene processes probably accentuated the brecciation of the massive ore which was brought about by tectonic movements. At Skouriotissa, conglomeratic ore occurs not only in the vicinity of the gossan but also in zones of ore not affected by supergene leaching. At Mousoulos and Kokkinoyia the ore has a well defined conglomeratic structure although they have not been affected by supergene leaching. At Mathiatis the fragmentation of the massive ore predates the tilting and had therefore occurred before the subaerial oxidation of part of the ore. Thus it appears that supergene processes had no or very little effect on the fragmentation of the massive ore.

It was suggested that the conglomeratic structure of the massive ores was brought about by tectonic brecciation (Cullis and Edge (1922); Mousoulos (1957); Vokes (1966)); Field relationships indicate that in some orebodies the most intensely fragmented ore occurs in zones of less intense faulting whereas less fragmented ore occurs in zones of intense faulting. At Mousoulos and Mathiatis the zones of sandy friable ore (most intensely fragmented ore) occur

in the vicinity of ochre where faulting is less intense. At Skouriotissa the hard compact ore (not fragmented ore) tends to be concentrated at the intersection of the 350° and 300° trending faults whereas the ochre at the Eastern orebody is underlain by conglomeratic ore. Thus it appears that faulting was of minor importance to the fragmentation of the massive ore.

Detailed mineralogical studies have shown that microscopic fragmentation of pyrite is not due to cataclasis but was brought about by leaching of the ore, because:

(a) The fragmentation is associated with high porosity, in many cases exceeding 60 per cent of the total surface area (see following section).

(b) In many cases the crystal outline of idiomorphic pyrite is preserved though the crystal itself is highly fragmented (Plate 5.44).

(c) Remnants of corroded pyrite are frequently found in cavities surrounded either by euhedral pyrite (Plate 7.11) or intensely corroded pyrite (Plates 7.6, 7.9, 7.11, 7.15.).

(d) In the zones of fragmentation intensely corroded pyrite coexists with euhedral pyrite (plate 7.13); in many cases mild dissolution has revealed the grain boundaries and internal growth zoning (Plate 7.12).

(e) Narrow zones of highly fragmented pyrite intersect massive aggregates of pyrite (plate 5.43).

More detailed criteria for recognizing fragmentation of massive pyrite by leaching activity were reported by Read (1968). All these criteria are applicable to the Cyprus ores and it is concluded that tectonic macro and microbrecciation is of minor importance in the orebodies investigated.

3. Porosity

In the Skouriotissa, Mathiatis and Mousoulos orebodies the conglomeratic structure of the ore is invariably associated with high porosity. The porosity of the sandy matrix is substantially higher than that of the solid blocks which are encased in it. Quantitative measurements of total surface area

Plate 7-1. Large isolated cavity (black) containing fragments of corroded pyrite. Skouriotissa orebody.

PPL, scale bar = 1200 microns

Plate 7-2. Well oriented pits probably in euhedral pyrite. Kokkinoyia orebody.

PPL, scale bar = 300 microns

Plates 7-3, 7-4. Differential resistance of hard compact ore consisting mostly of zoned pyrite I to mild electrolytic etching. Skouriotissa orebody.

PPL, scale bar = 1200 microns

Plate 7-5. High magnification of the central part of Plate 7-3, showing differential resistance of the central and outer parts of two contiguous zoned pyrite crystals to mild electrolytic etching.

PPL, scale bar = 250 microns

Plate 7-6. Well oriented pits probably produced by leaching along contacts of growth zones of contiguous zoned pyrite crystals (Kokkinoyia orebody see plate 4-48).

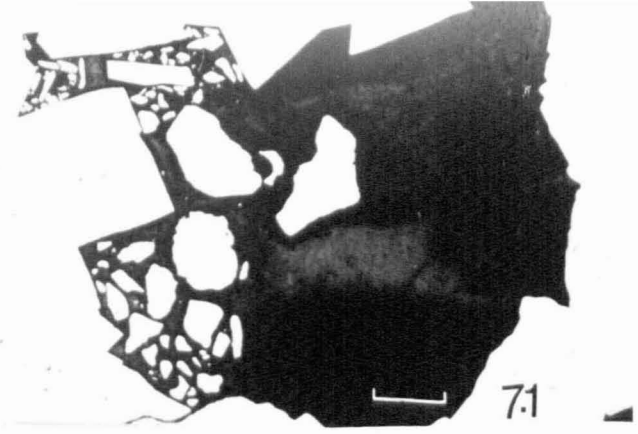
Plate 7-7. Two continguous grains of zoned pyrite (centre) with identical growth zones traceable in both grains. Skouriotissa orebody.

PPL, scale bar = 250 microns

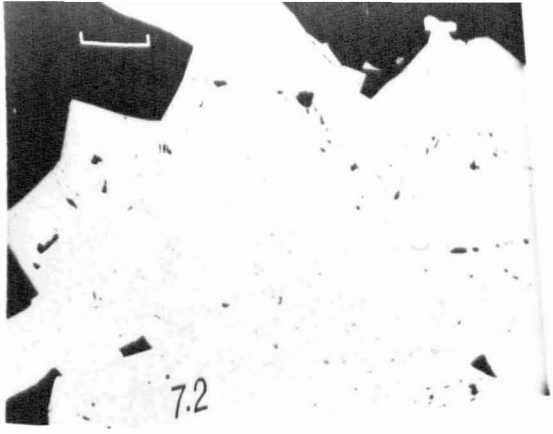
Plate 7-8. Boundary relations between porous and non porous areas (Kokkinoyia orebody see plate 4-50).

Plate 7-9. Spheroidal textures probably produced by intense leaching of euhedral pyrite I. Cavities are surrounded by euhedral (top) as well as by intensely corroded Pyrite (bottom) Skouriotissa orebody.

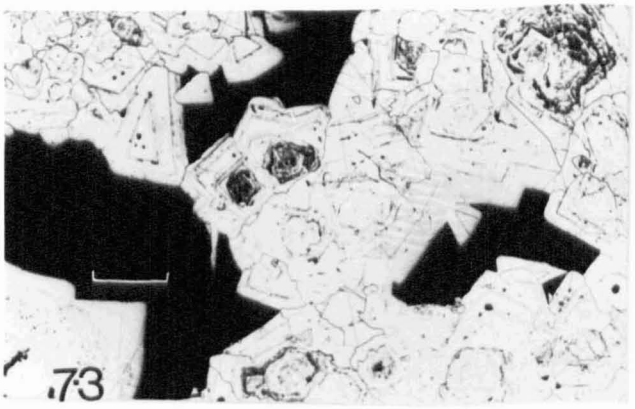
PPL, scale bar = 400 microns



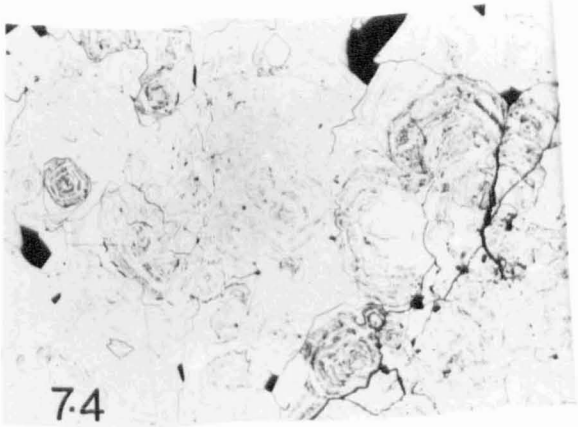
7·1



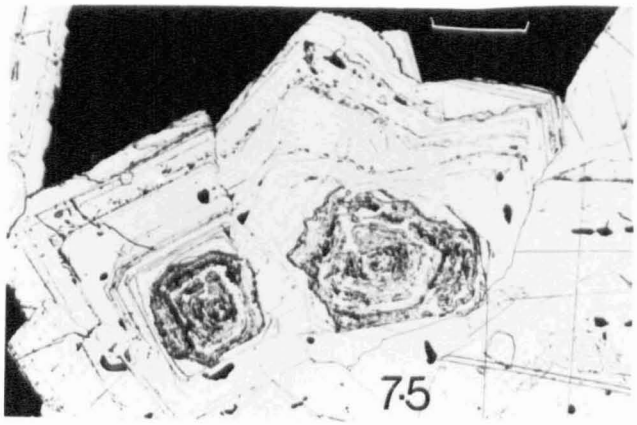
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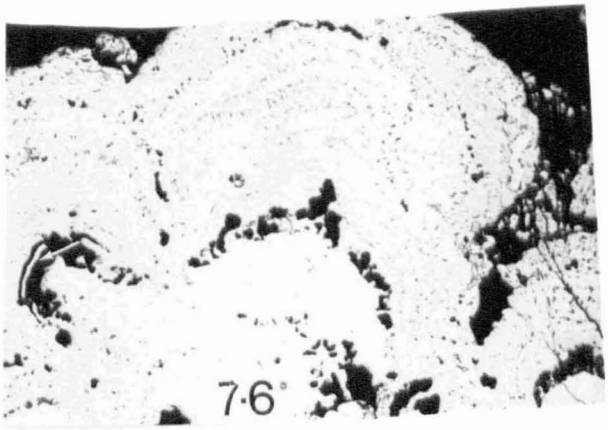
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7·4



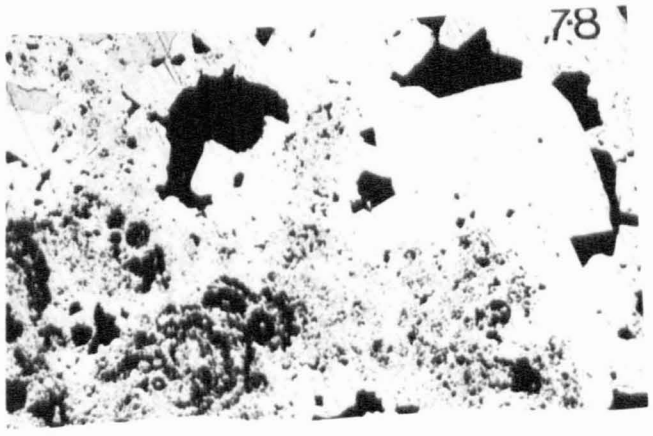
7·5



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7·8



7·9

covered by pores was carried out on polished sections from the Skouriotissa, Mathiatis and Mousoulos orebodies. The measurements were taken at equally spaced points along a series of parallel traverses. Results are shown in Table 7-1 and indicate that:

(a) The porosity of the sandy matrix is remarkably high, ranging from 44 to 90 per cent.

(b) The porosity of the sandy matrix is substantially higher than that of the solid sulphide blocks.

(c) The porosity of hard compact ore is distinctly low compared with that of the conglomeratic ore.

Depending on the degree of micro or macro porosity present in the ore it was established that various properties such as specific gravity, colour, thermal conductivity, reflectivity and polishing hardness are affected. Thus at Skouriotissa it was found that the hard compact ore is bright yellow in colour whereas the conglomeratic ore is dark yellow and that this is due to differences in porosity. In the same orebody it was found that colloform banding is a result of colour variations which, in turn, are due to differences in total porosity (Chapter 3). Colloform banding outlined by differences in grain size and porosity was also reported from San Dionisio orebody, Rio Tinto (Read 1968) and Mt Lyel, Tasmania, (Markham 1968). The high porosity decreases the specific gravity of the ore as a whole. Cullis and Edge (1922) report that in the Skouriotissa orebody 9-10 cubic feet of massive ore weigh one ton; theoretically this mass is contained in only 6.4-7 cubic feet of pure pyrite, or 7.84 cubic feet of pure chalcopyrite. In the Kalavassos orebodies the specific gravity of the massive ore was generally taken as 3 gr/cm^3 whereas theoretically, the density of pure pyrite is 5.02-5.08 gr/cm^3 and that of pure chalcopyrite 4.1-4.3 gr/cm^3. Because of high porosity the specific gravity of some of the Japanese massive sulphide ores is 3.5-4 gr/cm^3 (Kinkel 1966). Density determinations for hard, compact ore and solid sulphide blocks from the Skouriotissa orebody (Table 7-1) indicate that the specific gravity of the first type of ore is substantially higher than that of the second.

Another physical property of the massive ore which is considerably affected by high porosity is its thermal conductivity.

Measurements of this property were conducted on cores of three sulphide blocks from Skouriotissa, Mathiatis and Mousoulos by J. Wheildon (personal communication). The approximate porosity of the cores was calculated from their volume, weight and the theoretical density of pyrite. The comparison of thermal conductivity with porosity (Table 7.1) indicates that:

(a) The thermal conductivity of the conglomeratic ore is much lower than that of a pyrite single crystal. (Euken and Kuhn 1928), and

(b) The decrease in thermal conductivity is not proportional to the increase of porosity; this is probably due to variations in the proportion of effective porosity to total porosity. Measurements of

(i) the total volume of the pore space,

(ii) the volume of effective air porosity (interconnected pores), and

(iii) the volume of non-connected pores, on cores from the above three orebodies were conducted by Comber (personal communication).

The results are shown in Table 7-1 and indicate that all three types of porosity exhibit notable variation. The results also show that the effective porosity of the Cyprus ores is much higher than that of the highly porous Kuroko ores (Smirnov et al 1969).

With regards to the origin of porosity of Cyprus ores Cullis and Edge (1922) suggested that it is due to volume reduction resultant from the replacement of igneous rock by pyrite. Hutchinson (1965) postulated that the porosity is due to the escape of high sulphur or sulphur-gas content during the subaqueous extrusion of a partly crystallized sulphide melt. It is worth mentioning that the high porosity which characterises the kuroko ores of Japan was considered to represent shrinkage due to dehydration of a sol (Park and McDiarmid 1964).

During the present investigation it was found that pore spaces, varying in size from less than a millimetre to several centimetres, are randomly distributed and exhibit a wide morphological

Table 7-1 Determination of some physical properties of the hard compact and conglomeratic massive ore.

A) Percentage of area covered with pore space in polished sections of hard compact sulphide blocks and sulphide matrix in the various areas (Determination with Quantimeter).

Orebody	Specimen Nº	Polished Section Nº	Location	Description of Specimen	Measured Points	Pore Space Area %
Skouriotissa	SK 14/28	G.C. 162	Level 810 ft. Coords :- 127398, 33840 ft.	Sandy sulphide matrix	58	90±5
,,	SK 9/1	G.C. 156	Level 891 ft. Coords :- 127500, 34120 ft.	As above	37	48.5±5
,,	SK 9/14	G.C. 157	Level 891 ft. Coords :- 127470, 34120 ft.	As above	49	44 ±5
,,	SK 6/12	G.C. 161	Level 1016 ft. Coords :- 126290, 33760 ft.	As above	43	62 ±5
,,	SK14/3	G.C. 85	Level 810 ft. Coords :- 127160, 33600 ft.	Hard compact ore	53	11 ±5
,,	SK14/15	G.C. 63	Level 810 ft. Coords :- 127320, 33630 ft.	Hard compact ore unetched As above but rigorously etched	23 23	8±5 66±5
,,	SK16/1	G.C. 30	Level 825 ft. Coords :- 127180, 33315 ft.	Hard compact ore	50	13.5±5
,,	SK 639	G.C. 25	Level 981 ft. Coords :- 126980, 33300 ft.	As above	25	8 ±5
,,	SK 23	G.C.102	Level 1017 ft. Coords :- 126480, 34015 ft.	Sulphide band in ochre	46	72 ±5
Mousoulos	MS 3/59	G.C. 7	Level 125 m. Coords : - 5128,-23540 m.	Solid sulphide block	134	31 ±5
,,	MS 3/51	G.C. 65	Level 125 m. Coords : - 5131,-23532 m.	Sandy sulphide matrix	53	76 ±5
,,	MS 3/67a	G.C.135	Level 125 m. Coords : - 5123,-23541 m.	Sulphide block in ochre	51	37 ±5
,,	MS 3/67b	G.C.137	Level 125 m. Coords : - 5123,-23541 m.	Solid sulphide block	54	20 ±5
Mathiatis	MC 2-29	G.C. 14	Level 330 m. Coords : 2738, - 3124 m.	Sandy sulphide matrix	43	70 ±5
,,	MA 14	G.C.58	Level 330 m. Coords : 2750, - 3182 m.	Pyrite mixed with quartz	38	72 ±5
,,	MC1-3	G.C.147	Level 330 m. Coords : 2667, - 3096 m.	Outer part of sulphide block	43	40 ±5

B) Determination of thermal conductivity and porosity of solid sulphide blocks (conglomeratic ore).

Orebody	Specimen Nº	Polished Section Nº	Location	Description of Specimen	Thermal Conductivity	Calculated Porosity
Skouriotissa	SK14/27	G.C. 43	Level 810 ft. Coords :- 127400, 33840 ft.	Solid sulphide block	32.12×10^{-3}	26.65
Mousoulos	MS 3/38	G.C. 9	Level 125 m. Coords : - 5140,-23535 m.	As above	32.12×10^{-3}	32.5
Mathiatis	MG 2-25	——	Level 330 m. Coords : 2722, - 3090 m.	As above	28.24×10^{-3} Cal/cm sec°C	33.3

C) Determination of the total volume of pore space (total porosity) and the volume of interconnected pores (effective porosity) of solid sulphide blocks (conglomeratic ore).

Orebody	Specimen Nº	Polished Section Nº	Location	Description of Specimen	Total Porosity	Interconnected Porosity
Skouriotissa	SK 14/26	——	Level 810 ft. Coords :- 127410, 33760 ft.	Solid sulphide block	11%	11%
Mousoulos	MS 2/10	——	Level 130 m. Coords :- 5132, -23565 m.	As above	22.86%	27.47%
Mathiatis	MC 6-81	——	Level 330 m. Coords : 2749, - 3099 m.	As above	17.54%	14.82%

D) Determination of the specific gravity and calculation of the porosity of the hard, compact and conglomeratic ores.

Orebody	Specimen Nº	Polished Section Nº	Location	Description of Specimen	Measured Spec. Grav.	Calculated Porosity
Skouriotissa	SK 15/5	——	Level 818 ft. Coords :- 127240, 33410 ft.	Hard compact ore	4.48 gr/cm^3	10.8%
,,	SK 16/1	G.C.30	Table 7.1A	Table 7.1A	4.39 ,,	12.495%
,,	SK 14/32	——	Level 810 ft. Coords :- 127395,-33840 ft.	Solid sulphide block	3.85 ,,	23.18%
Mousoulos	MS 2/5	——	Level 130 ft.	As above	3.9 ,,	22.28%

(Coordinates based on Cyprus Grid)

variation. In the conglomeratic ore large cavities are frequently lined with corroded euhedral pyrite, which exhibits a honeycomb texture. In the hard compact ore at Skouriotissa the cavities are commonly lined with well preserved cubic and pyritohedral pyrite crystals. Microscopically, the pyrite around the cavities is mostly corroded (Plates 7.9, 5.49, 5.5, 4.52) and fragments of remnant pyrite are frequently found within the large cavities (Plates 7.1, 7.6, 7.11, 7.15). Corrosion of pyrite is most intense in the friable sulphide matrix (Plates 7.12, 7.13, 5.45, 5.46, 4.67). In a single polished section, areas of high micro-porosity surround areas of low micro-porosity and vice versa (Plates 7.10, 3.53, 3.60, 5.68, 5.69, 5.71). Microporosity is recognizable in pyrite because it decreases its reflectivity and polishing hardness. The boundary relationships between the porous and non-porous areas strongly suggest that the former has replaced the latter (Plates 7.8, 5.69, 5.71).

Both macroscopic and microscopic observations strongly suggest that macro- and microporosity are secondary and were brought about by dissolution of sulphides and removal of the products of dissolution. Read (1968) suggested that the high porosity characterizing the zones of soft, friable ore in the San Dionisio orebody was due to hydrothermal leaching of the pyrite. However, in the Cyprus sulphide ores it is concluded that the dissolution of sulphides was brought about during their submarine oxidation. The mechanism of this process is discussed in a later section of this chapter.

4. Colloform textures.

Colloform textures are widely distributed in the conglomeratic ore of all the orebodies, but are absent from the hard compact ore of the Skouriotissa orebody. Previous reports that the colloform banding in the Skouriotissa orebody is due to alternating bands consisting of pyrite, marcasite and chalcocite (Bear (1963); Hutchinson (1965)) have been discredited by detailed mineralogical investigations (Chapter 3). Replacement of lavas was the most widely accepted mode of origin of these textures, (Cullis and Edge (1922); Jarrel (1947); Mousoulos (1957)). Hutchinson (1965) suggested that the crustified banding of the Cyprus ores resulted

Plate 7-10. Pyrite with high relief and high reflectivity (no microporosity) surrounded by pyrite with lower relief and lower feflectivity (high microporosity). Skouriotissa orebody.

PPL, scale bar = 400 microns

Plate 7-11. Band of collomorphic pyrite intersecting euhedral zoned Pyrite. A large cavity (black) is surrounded by euhedral as well as corroded pyrite and contains remnants of corroded pyrite. Skouriotissa orebody.

PPL, scale bar = 480 microns

Plates 7-12, 7-13. Euhedral pyrite coexisting with intensely corroded pyrite. At the centre of Plate 7-12 mild dissolution has revealed the grain boundaries and internal growth zoning in pyrite. Mousoulos orebody.

PPL, scale bars = 430 and 516 microns respectively.

Plate 7-14. Intensely fragmented pyrite (white) healed with chalcopyrite (white grey) Skouriotissa orebody.

PPL, scale bar = 400 microns

Plate 7-15. Large cavity in pyrite surrounded by corroded pyrite and containing irregular fragments of pyrite. Mousoulos orebody.

PPL, scale bar = 187 microns

Plate 7-16. Zoned quartz (white) replacing pyrite (black). Mathiatis orebody.

PPL, scale bar = 372 microns

Plate 7-17. Polished section of the area shown in Plate 7-16. Note the striking similarity in form and texture of adjacent zoned pyrite and zoned quartz. (Points indicated by arrow).

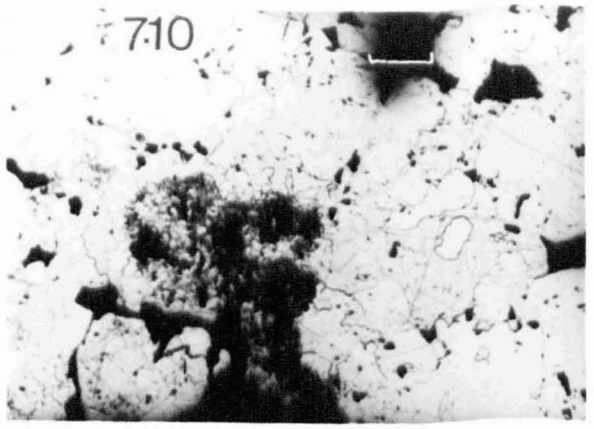
PPL, scale bar = 300 microns

Plate 7-18. Coarse grained pyrite (black) associated with quartz (white and grey) filling a large vesicle in mineralized lava. The latter is impregnated with fine grained pyrite (black). Agrokipia B orebody.

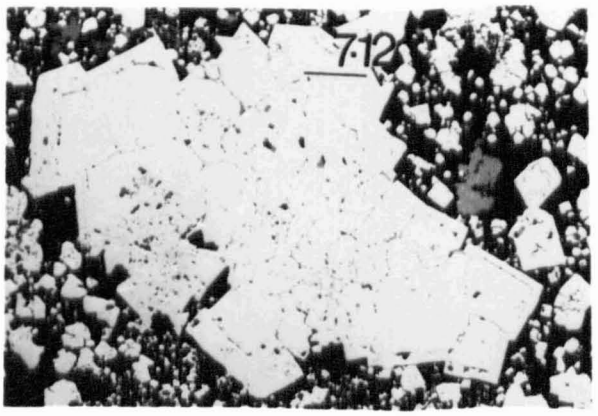
Nickols crossed, Scale bar = 372 microns

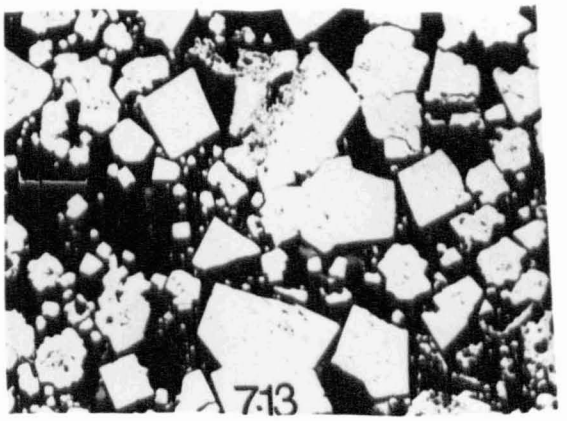
Plate 7-19. Mineralized lava impregnated with fine grained pyrite (black). Agrokipia B orebody.

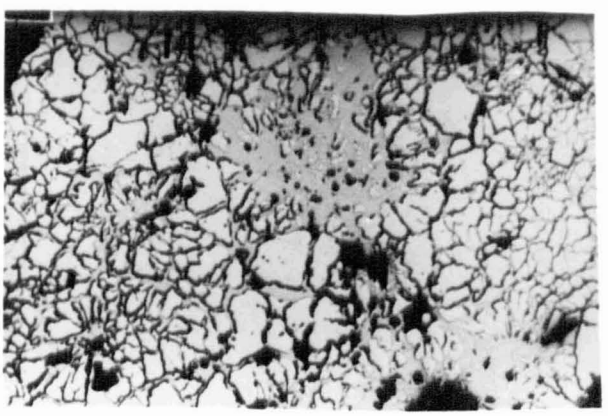
PPL, scale bar = 310 microns

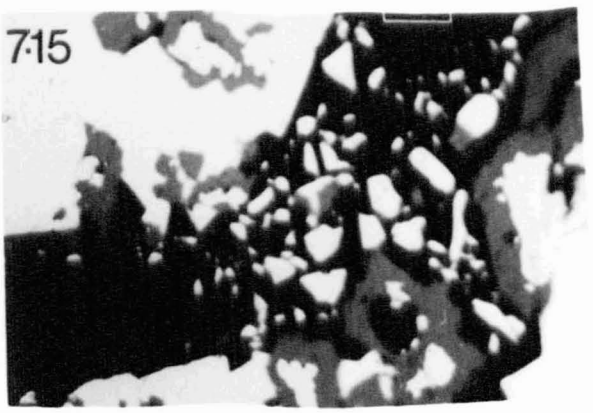

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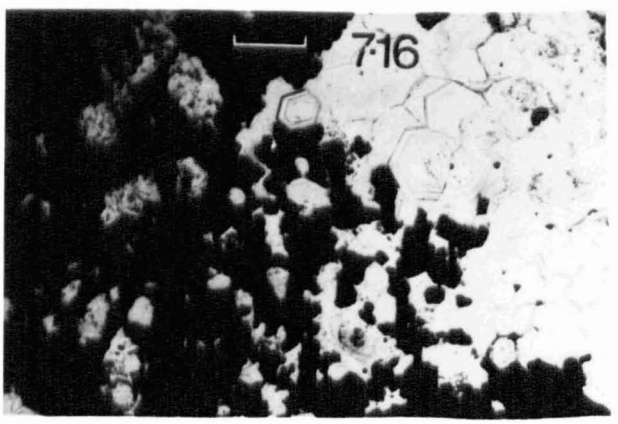

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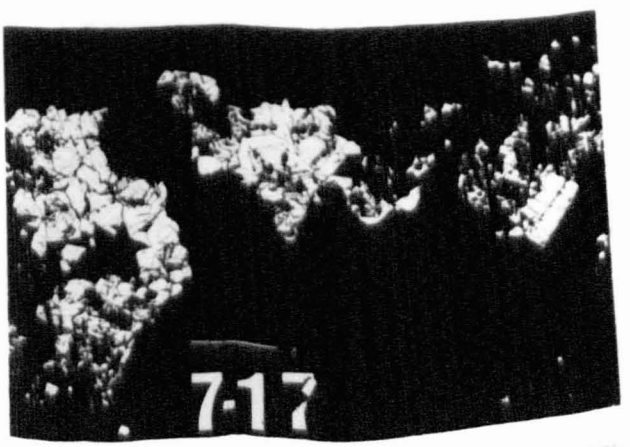

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from "local cooling conditions and compositions" of the subaqueously extruded sulphide melt. Callaghan (quoted by Kinkel 1966) prefers a colloidal origin which is the most widely accepted explanation for the genesis of colloform pyrite. (Lindgren (1934); Edwards (1954); Park and McDiarmid (1964); Ramdohr (1969)).

In the Skouriotissa orebody (Chapter 3) it was mentioned that collomorphic pyrite invariably truncates pyrite I and pyrite II (Plates 7.9, 3.44, 3.45, 3.56, 3.57, 3.58). A similar relationship was observed in the Mousoulos (Plates 5.67, 5.69, 5.71, 5.73 and 5.75) Mathiatis (Plate 4.76) and Kokkinoyia (Plate 4.50) orebodies. The margins of collomorphic pyrite aggregates are irregular and show projections into the surrounding pyrite grains. Etched specimens show that pyrite III frequently replaces zoned pyrite I (Plates 7.11, 3.45, 5.75). Careful examination of boundary relationships indicate that isolated spheroidal pyrite projects into pyrite I surrounding it (Plates 7.9, 3.52, 3.53, 5.67) or it is enclosed within it (Plates 4.46, 5.68, 5.70) This suggests that the pyrite spheroids grew at the expense of pyrite I. All these observations point to the conclusion that the colloform textures are secondary and were formed penecomtemporaneously with the development of porosity and fragmentation of the ore.

5. Possible original structure of the massive ore.

If the conglomeratic structure, porosity and colloform textures are indeed secondary, it follows that the present structure of the ore is not original and cannot be used to deduce its formative conditions. This section attempts to reconstruct the original structure of the massive ore.

In the conglomeratic ore there is a notable decrease in the amount of the sandy matrix from top to bottom. In the sandy matrix no collomorphic textures were observed; it consists entirely of remnants of highly corroded pyrite, mostly devoid of growth zoning. The porosity of the sandy matrix is conspicuously higher than that of the solid blocks and as a consequence the porosity of the ore decreases with depth. Moreover, the compact sulphideblocks increase in both amount and size with depth. These blocks are porous and generally tend to have a rounded form. They

consist mainly of euhedral zoned pyrite and collomorphic pyrite, with small amounts of euhedral pyrite.

In all orebodies it was observed that where the collomorphic pyrite increases the euhedral pyrite I decreases and that collomorphic pyrite replaces euhedral pyrite. At the lower levels of Skouriotissa orebody, the ore has a hard compact structure. It consists of large blocks of ore, separated by fractures filled with friable pyrite. Wherever it is porous, and the cavities were formed by dissolution of pyrite, its porosity is distinctly lower than that of the conglomeratic ore. The hard compact ore consists mainly of euhedral zoned pyrite and small amounts of pyrite II. Collomorphic pyrite is absent. Finally, it was observed that in prolonged electrolytic etching of polished sections from hard compact ore, differential etching of the originally homogeneous surfaces produced a colloform banding.

All these observations strongly suggest that the original structure of the conglomeratic ore probably was similar to that of the hard compact ore in the Skouriotissa orebody. Intense leaching of the ore is represented by the sandy matrix material and intermediate leaching by the conglomerate blocks. The original massive compact ore consisted mainly of euhedral zoned pyrite which was partly replaced by collomorphic pyrite in the intermediate stage of dissolution. The collomorphic pyrite itself was leached in the final stages of dissolution.

6. Probable mechanisms of leaching of massive ores.

The processes involved in the partial dissolution of the Cyprus massive ores, as well as the mechanism of removal of the products of this dissolution, are extremely complicated and not entirely clear. Furthermore, as it is suggested, these processes operate under submarine conditions, and no published data are available on the oxidation of sulphides under these conditions. The major difference between submarine and subaerial oxidation is the availability of oxygen which being conspicuously less in the former case renders the rate of oxidation slower. In the submarine environment the oxygen dissolved in the seawater immediately surrounding a sulphide orebody could be easily depleted by

oxidation of small amounts of sulphides, therefore, a mechanism for replenishing the oxygen content is essential. On the other hand oxygen by itself cannot oxidize sulphides and water is needed to promote the reactions. In subaerial oxidation there is only a seasonal supply of water, whereas in the submarine environment the supply of water is infinite.

The leaching of the massive sulphide ore under submarine conditions probably involved chemical or electrochemical processes, or a combination of both. It must be emphasized that only a mechanistic description of these processes is attempted below. This is based mainly on interpretation of detailed observations of the ore textures. Details of the chemistry, physics and thermodynamics of the processes are not entered into.

(a) Chemical leaching

In Chapter 6 it was suggested that when the orebodies were eventually exposed on the sea floor they were attacked by oxygenated seawater and oxidized to ferrous sulphate and sulphuric acid (Equation 6-1). Sulphuric acid is also produced from the reaction of oxygenated seawater with sulphur which is produced from the reaction 6-3 (Chapter 6) and the oxidation of the disulphide ions produced during the solid-state transformation of pyrite to maghemite (Chapter 6).

$$2H_2O+2S+3O_2 \longrightarrow 2H_2SO_4 \quad \text{(Eq 7-1)}$$

The ferrous sulphate in the presence of sulphuric acid oxidizes to ferric sulphate (E_1 6.2). Inorganically, this oxidation proceeds slowly but is catalysed in the presence of bacteria (Perel'man 1967) such as Thiobacillus ferrooxidants (Zajic (1969)). Ferric sulphate is a strong leaching agent and dissolves pyrite, chalcopyrite and sphalerite (Equations 6.3, 6.4, 6.5), (Sullivan (1933); Taylor and Whelan (1943); Thomas and Ingragham (1967); Downes and Bruce (1959); Zajic (1969); Burkin (personal communication). Sato (1960) suggested that peroxide, produced in trace amounts by the oxidation of water, is the active agent in oxidizing the sulphide.

Chemical etching of pyrite aggregates for mineralogical studies (chemical reagents $KMnO_4+H_2SO_4$) is based on the principle

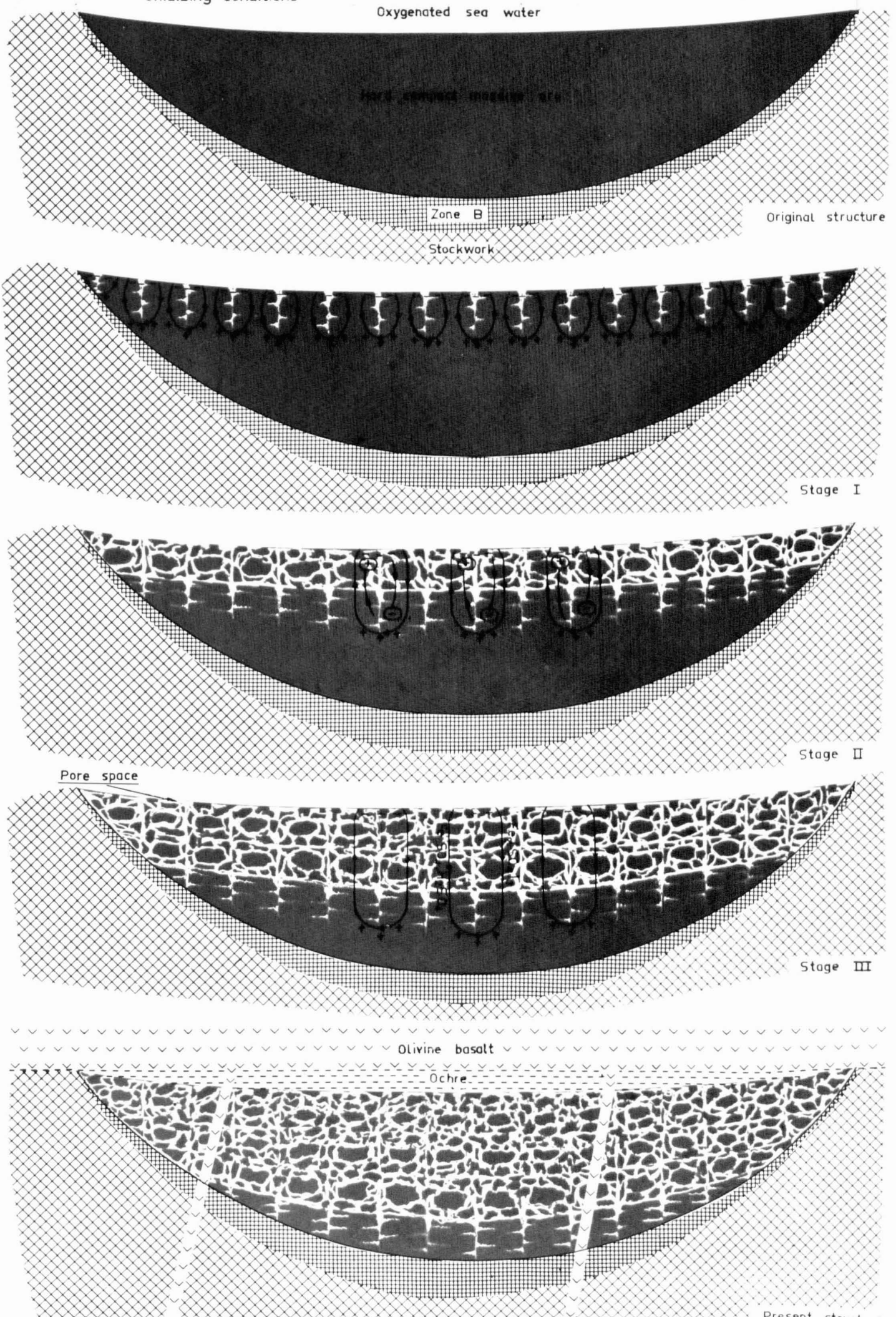
that the etching effects develop preferentially along grain boundaries. As etching is prolonged dissolution widens the outlines of the grain boundaries. At the same time preferential dissolution occurs along the boundaries of internal growth zones. This suggests that zoned pyrite would dissolve more readily than unzoned pyrite, because the boundaries of the individual zones increase considerably the total surface area reacting with the chemical reagents. In "natural chemical etching" the reagents, ferric sulphate and sulphuric acid, attack the sulphides in the same way as laboratory etching agents. It was observed that the unzoned pyrite particularly if not fractured, is very resistant to chemical dissolution whereas zoned pyrite dissolves readily. Therefore, because the massive ore of the Cyprus orebodies consists mainly of zoned pyrite, their dissolution under submarine oxidizing conditions proceeds rapidly.

By continuous leaching ramifying fractures are developed similar to those observed in the hard compact ore in the Skouriotissa orebody. These fractures gradually extend both vertically and laterally. Eventually they join and large blocks of sulphide separate from the main orebody, thus increasing the total surface area of chemical dissolution. The network of fractures is filled with seawater which penetrates under hydrostatic pressure. Each one block is attacked simultaneously from all sides and, since the effects of dissolution are more pronounced at corners and edges, the final products tend to exhibit rounded shapes.

The mechanism of leaching in the pyrite orebodies is illustrated in figure 7.1. The degree of dissolution is shown as decreasing with depth, because the upper parts were exposed to chemical attack for a longer time.

This mechanism resembles chemical sphaeroidal weathering of basalts, gabbros and dolerites (Holmes, 1965) and in this connection it is worth mentioning that the pillow structure of the lavas around Skouriotissa were interpreted by Thomae (1923) as representing the effects of sphaeroidal weathering of originally massive basalt. The products of oxidation and weathering in

Fig. 7-1. Idealized diagram illustrating the successive stages of fragmentation of the massive sulphide ore by chemical and electrochemical processes under submarine oxidizing conditions



the supergene environment are washed away by the groundwater or precipitate as stable compounds. In the submarine environment the mode of removal of the products of dissolution is problematic. However, a plausible mechanism is by diffusion. It is probable that a concentration gradient existed in the domains of dissolution of pyrite, because of the high concentrations of ferrous sulphate and sulphuric acid produced in reaction (6.3 Chapter 6). As these domains are connected with the seawater through fractures, ferrous sulphate and sulphuric acid diffuse upwards, to areas of lower concentration, i.e. the seawater - sulphide ore interface. At the same time, seawater at this interface charged with ferric sulphate and oxygen moves downwards. The ferric sulphate dissolves more pyrite (Eq. 6.3 Chapter 6) while the oxygenated water reacts with the sulphur produced (Eq. 7.1) to produce sulphuric acid. Thus water circulates constantly through the fracture system, carrying ferrous sulphate and sulphuric acid in its upward movement and ferric sulphate and dissolved oxygen in its downward movement (Fig. 7.1). On reaching the seawater - sulphide interface the ferrous sulphate follows the reactions described in Chapter 6, precipitating goethite as an end product.

(b) Electrochemical leaching

It has been known for a long time that when orebodies, particularly those containing pyrite, chalcopyrite and pyrrhotite, undergo differential oxidation they form a natural source of electric current. Maximum voltages ranging from a few to several hundred millivolts and showing a systematic pattern have been reported by many authors e.g. Jakosky (1961), Heiland (1940), Parasnis (1966)) and were used extensively by geophysicists in exploration for sulphide orebodies. In some exceptional cases voltages as high as 1800 millivolts have been reported over oxidizing sulphide deposits (Gay 1967). The origin of self potentials has been a heated controversy in the literature for a long time. A review of the various theories was given by Sato and Mooney (1960) who concluded that self potentials are due to differences in the oxidation capacity of the waters near the upper and lower surfaces of an orebody. The orebody itself does not participate in the process, acting only as a conductor of electrons.

Sveshnikov and Kedrinskyi (1965) demonstrated experimentally that every sulphide ore deposit creates a wet cell. The metal sulphides serve as electrodes in this cell and dissolve. Electric currents arise as a consequence of differences between the potentials generated by different ore minerals and water. This current passes through the sulphide minerals and brings about their electrochemical dissolution. Such a process can operate at depths below the zone of weathering. On the basis of kinetic considerations Habashi (1966) suggested that the oxidation of sulphide ores is an electrochemical process similar to the corrosion of metals.

During electrolytic etching tests it was observed that pyrite is attacked, the same way as in chemical etching. In prolonged tests pyrite dissolves preferentially along grain boundaries and internal growth zones. (Plate 7.7). A few polished sections of hard compact ore from the Skouriotissa orebody were etched in successive stages lasting 1, 2, 3 and 10 minutes respectively. (For electrolytic etching 10% chromic acid solution was used at a pH of about +0.3 units; current was D.C. at 4.5 volts) The etching effects at each stage were studied under the microscope. Most of the textures observed in the conglomeratic ore, including the collomorphic banding, were reproduced as a result of differential etching. At the end of the fourth stage the zoned pyrite was entirely dissolved, only deeply corroded unzoned pyrite and relics of individual zones being preserved. At the end of the last stage the measured porosity was about 66 per cent, whereas in the unetched half of the same specimen porosity was about 8 per cent. Polished sections from the Mousoulos and Skouriotissa orebodies show "natural etching effects" identical to those observed during electrolytic etching (Plates 5.58, 5.60).

It seems most likely that electrochemical processes were involved in the partial dissolution of the massive pyrite. The sulphide ore is an electronic conductor which is in contact with an electrolyte, the seawater. Electric current could arise as a consequence of the difference in the electric potentials created at the upper end of the conductor when it contacts an electrolyte with high oxidation potential, and its lower end, contacting an

electrolyte with lower oxidation potential (the seawater in the fractures contains less dissolved oxygen than the seawater in contact with the top of the orebody).

A second mechanism for generation of an electric current could be due to the fact that the Cyprus ores, in addition to pyrite, contain small amounts of chalcopyrite and minor amounts of sphalerite. When these minerals come intocontact with seawater they create potentials of different magnitutes, these differences generating currents (Sveshnikov and Kedrinskii 1965).

Finally electric currents might be generated because of different concentration of dissolved salts in the weawater contacting the ends of the orebodies (as mentioned before the seawater in the fractures contains more ferrous sulphate and sulphuric acid). These currents circulate in such a way that the open sea end of the galvanic couple is the cathode whereas the fractured sulphide is the anode. Thus the sulphides dissolve from top to bottom in the same succession as for chemical dissolution.

In accepting the above described mechanisms one has to explain why the entire massive ores were not dissolved, chemically and electrochemically. It is probable that eventually the oxidation was blocked by precipitation of enough iron oxyhydroxides, thus isolating the orebodies from the sea environment and producing reducing conditions. Something similar is known in marine sediments; at their contact with sea-water oxidizing conditions prevail whereas at shallow depths reducing conditions predominate. As was mentioned in Chapters 4 and 5 most of the orebodies are covered with olivine basaltic Upper Pillow Lavas which were extruded after the deposition and partial oxidation of the orebodies. It is highly probable that the accumulation of olivine basalts on top of these orebodies, brought about their isolation from the marine environment.

7. A probable mechanism of formation of collomorphic and framboidal textures in pyrite.

Primary collomorphic textures are very common in pyrite and were reported from many parts of the world (Section 7.4). It

was suggested that the collomorphic textures in the conglomeratic ores in Cyprus are secondary. Some of these textures possibly were formed in fractures created by dissolution of pyrite, by reprecipitation of the products of dissolution under suitable physicochemical conditions (Plates 3.44, 3.45, 4.76). However, detailed observations strongly suggest that many of the collomorphic textures are an outcome of differential leaching controlled by the geometry of the zoned pyrite.

The internal structure of the individual crystals, or a number of contiguous and structurally related crystals, controls the way in which these crystals respond to the processes of leaching. In a zoned crystal, leaching proceeds more rapidly in areas of structural inhomogeneities e.g. inclusions of small anhedral chalcopyrite and sphalerite grains; trace elements such as cobalt adsorbed at the surface or trapped within growth zones may increase the leaching rate of pyrite. Finally, the boundary atoms in two randomly orientated grains, or two successive growth zones, cannot have a perfect complement of surrounding atoms. This results in a region of transition where the atomic packing is not perfect and the rate of leaching is greatly enhanced. The differential resistance of single pyrite crystals or aggregates to electrolytic solution is illustrated in plates 7.3, 7.4 and 7.5.

The zoned pyrite in the original sulphide ore occurred as discrete crystals or clusters consisting of two, three or even more contiguous grains in which identical growth zones are traceable in all crystals (Plates 7.5, 7.7, 3.44 and 3.46). In such clusters mild leaching forms pits with definite orientations which are probably controlled by structural defects along growth zones (Plate 7.2). With further leaching these pits grow and coalesce, forming lines which delineate the growth zones. (Plate 7.5). As leaching becomes vigorous the lines of etch pits defining the individual zones are further widened and eventually form continuous separations between thin remnants of the alternating zones. The effects of leaching are more pronounced at the corners of the growth zones which gradually become rounded (Plate 7.6). The unzoned part of the aggregate becomes highly porous (Plate 4.49).

During leaching, structural inhomogeneities in single grains or aggregates may also produce the rounded textures illustrated in plates 7.4 and 7.5. Products of more advanced leaching are the spheroidal textures illustrated in plates 7.8, 7.9, 3.53, 4.47, 5.67 and 5.70.

Framboidal pyrite textures such as those found in the conglomeratic ore of the Skouriotissa, Mathiatis, Kokkinoyia and Mousoulos orebodies have been described by many investigators in many parts of the world. A review of the suggested origins of the framboidal pyrite was given by Love and Amstutz (1969). More recently they have been described by Read (1968) and Morrissey (1970). In the Cyprus ores the framboidal pyrite occurs only in the conglomeratic ore. It is particularly abundant in zones of high porosity (Plate F.1) suggesting that these textures were formed during leaching of the ore, either by reprecipitation of the products of dissolution or as a geometrical consequence of the leaching effects in an originally homogeneous pyrite matrix.

Detailed investigations of a cluster of framboids with a scanning electron microscope indicate that:

(a) The contact of the cluster of the framboids with the surrounding matrix is irregular (Plate F.2).

(b) The outlines of the individual framboids are irregular and interconnected by bridges of varying width (Plate F.3).

(c) The grains constituting the framboids exhibit a wide variation in their external outlines and size and are randomly oriented. (Plates F.4, F.5, F.6).

(d) In the matrix, successive stages of development of framboids are observable (Plates F.2, F.7), and this is better developed in the vicinity of clusters of fully developed framboids.

(e) Cavities in both the matrix and clusters of framboids contain remnants of pyrite (Plate F.2), and

(f) The matrix surrounding clusters of framboids, and the individual framboids are highly porous (Plates F.1, F.3, F.6).

Plate F-1. Framboidal pyrite and marcasite, associated with high porosity. (Mathiatis orebody - see Plate 4-73).

Plate F-2. High magnification of the cluster of pyrite framboids which occur at the centre of Plate F-1. The cluster is connected with the surrounding matrix and their contact is irregular. Photograph taken with Cambridge Stereoscan Scanning Electron Microscope.

Magnification X 240

Plate F-3. High magnification of part of the cluster shown in Plate F-2. The individual framboids are interconnected and their outlines are irregular. Cavities between the individual framboids contain fragments of pyrite. Photograph taken with Cambridge Stereoscan Scanning Electron Microscope.

Magnification X 600

Plates F-4, F-5, F-6. Very high magnifications of the cluster shown in Plate F-2, showing details of the internal structure of the individual framboids. Photographs taken with Cambridge Stereoscan Scanning Electron Microscope.

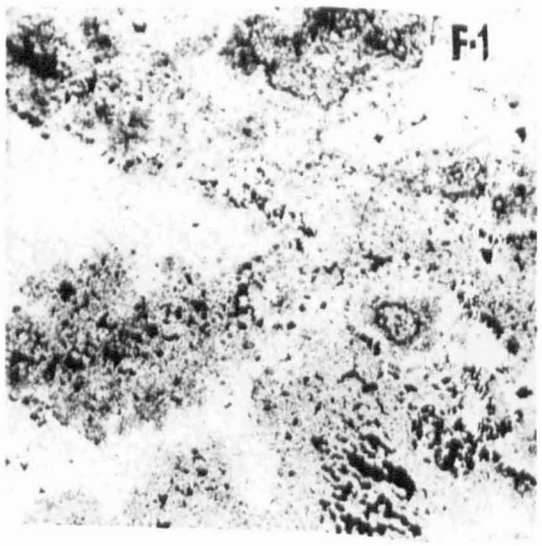
Magnification X 2200 X 6000 X 2600 respectively.

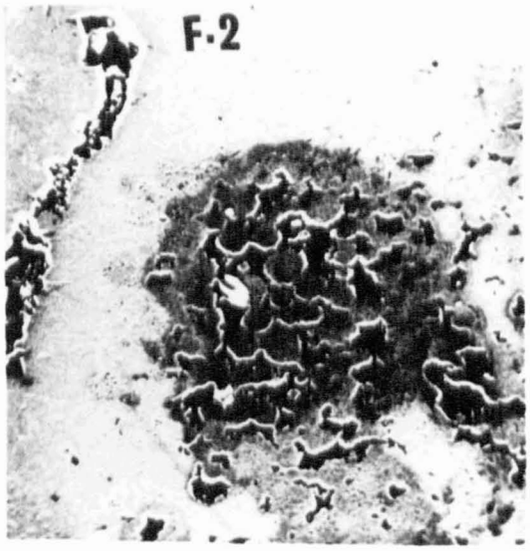
Plate F-7. Part of the contact between the cluster shown in Plate F-2 and the surrounding matrix. Note in the matrix the initial stages of development of new framboids and that the latter are more well developed near the cluster-matrix contact. Photograph taken with Cambridge Stereoscan Scanning Electron Microscope.

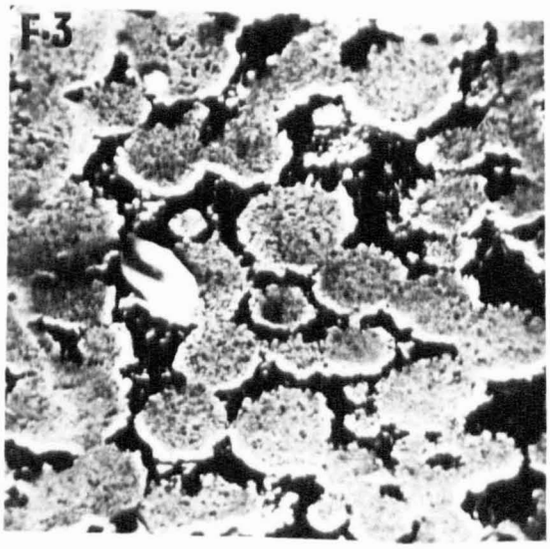
Magnification X 1300

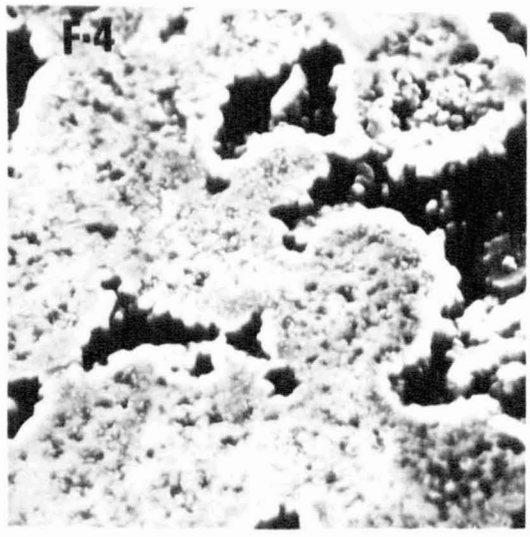
Plate F-8. High magnification showing the relationship of a new framboid (centre of Plate F-7) with the surrounding matrix. Photograph taken with Cambridge Stereoscan Scanning Electron Microscope.

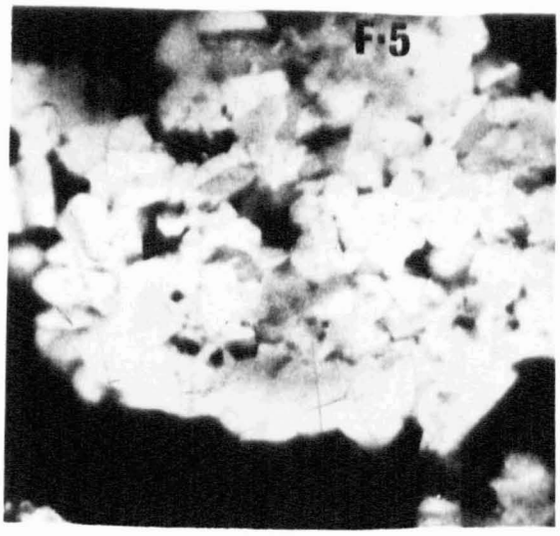
Magnification X 2600

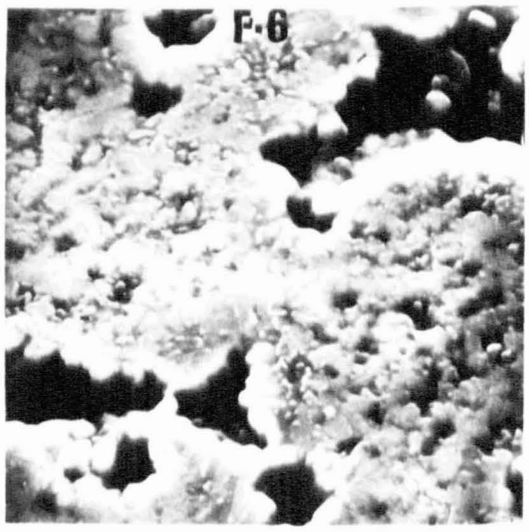

F·1

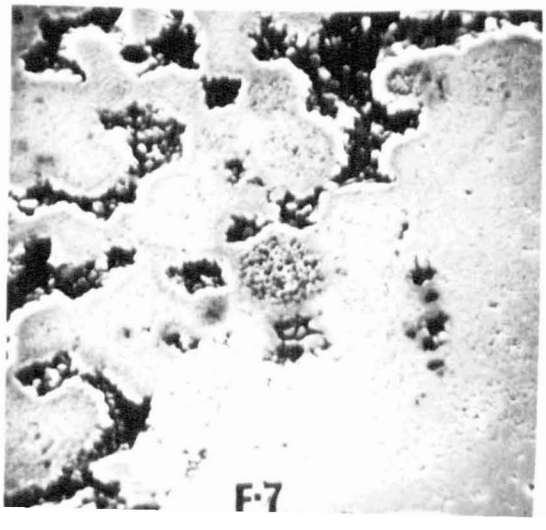

F·2

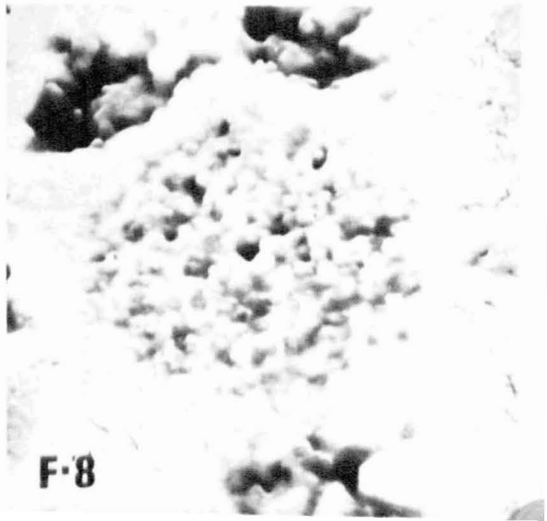

F·3


F·4


F·5


F·6


F·7


F·8

All these observations strongly suggest that many clusters of framboids in the Cyprus ores represent on a microscopic scale the end product of fragmentation through leaching of an originally euhedral pyrite matrix. The mechanism of this fragmentation resembles on a microscopic scale the mechanism of macroscopic fragmentation of the ore.

8. Conclusions

It is concluded that the original structure of the massive ore in the investigated orebodies was probably similar to the structure of the hard compact ore in the Skouriotissa orebody. This compact ore consisted mainly of zoned pyrite I. Its porosity was very low and it was devoid of colloform textures. The orebodies were eventually exposed on the sea floor and oxidized, their oxidation being facilitated by the high proportion of zoned pyrite. Acid solutions produced by the initial oxidation penetrated to the lower levels of the orebodies by continuous dissolution of sulphide.

The contact of the mineralogically inhomogeneous sulphide ore (an electronic conductor) with seawater (an electrolyte with different oxidation potentials and different dissolved salt concentrations at the upper and lower levels of an orebody) created differences in electrical potentials, a consequence of which was the generation of electric currents. The sulphide deposits, in this galvanic couple, formed the anode and therefore dissolved. Both chemical and electrochemical leaching, combined with processes of removal of the products of dissolution (probably by diffusion) resulted in fragmentation of the ore and an accompanying increase in porosity.

Collomorphic and framboidal pyrite textures are genetically related to the fragmentation of the ore and originated either through precipitation of the products of dissolution of pyrite I and/possibly pyrite II or as a consequence of differential leaching controlled by the geometry of the zoned pyrite. The differential leaching is probably due to inhomogeneities either in the internal structure of individual grains, or in aggregates of pyrite constituting the

hard, compact ore. Subsequent covering of the orebodies by their own decomposition products and by later olivine basalts probably isolated the orebodies from the seawater, thus protecting them from complete oxidation.

CHAPTER VIII

A DISCUSSION ON THE PARAGENETIC POSITION OF THE VARIOUS SULPHIDE MINERALS OF THE MASSIVE ORE

1. Opening Statement

In some of the investigated orebodies marcasite is the second most common sulphide mineral after pyrite. Other ore deposits contain none or very little marcasite. Marcasite is consistently restricted to the massive ore and invariably occurs in the upper levels; it diminishes in the lower levels and disappears in the stockwork zone. Textural and mineralogical relationships suggest that marcasite postdates pyrite I and is contemporaneous with, or later than, collomorphic pyrite. Thus it is considered to be secondary.

Chalcopyrite is the most common copper sulphide and its overall distribution generally reflects the distribution of copper in the ore deposits. The chalcopyrite content exhibits a wide variation in the massive ore but shows little change in the stockwork zone. In some orebodies there are zones which are definitely enriched in chalcopyrite. Similarly, in some orebodies there are zones enriched in sphalerite. The latter, though less abundant than chalcopyrite, is invariably present in all the investigated orebodies. Field, chemical, mineralogical and textural relationships strongly suggest that the chalcopyrite and sphalerite enrichment is secondary. Thus part of the chalcopyrite and sphalerite of the massive ore is secondary. Pyrrhotite is reported here for the first time as a mineral species in the Cyprus orebodies. It is generally rare and occurs only in the upper parts of the massive ores, particularly in the zones of the chalcopyrite and sphalerite enrichment. The distribution of pyrrhotite, as well as its chemical composition and mineralogical and textural relationships, strongly suggest that it is secondary and was therefore formed at low temperatures.

2. Marcasite

Of the investigated orebodies those of Kokkinopezoula, Agrokipia A, and Agrokipia B contain no marcasite. In the

Skouriotissa orebody this mineral is extremely rare (Chapter 3) but it is abundant in the Mathiatis, Mousoulos and Kokkinoyia ores. The distribution of marcasite in the last three orebodies was discussed in Chapters 4 and 5. Detailed mineralogical studies in the Mathiatis deposit indicate that:

(a) Marcasite tends to be more abundant at the top of the orebody, below the ochre-ore contact.

(b) Marcasite tends to concentrate along fractures and zones of high porosity in the solid sulphide blocks.

(c) Marcasite invariably truncates and replaces pyrite I; in many cases in the Skouriotissa and Mousoulos orebodies marcasite fills fractures, which intersect bands of collomorphic pyrite.

The features described here strongly suggest that the paragenetic position of marcasite is very late and that it was formed after the collomorphic pyrite and is, therefore, secondary.

Whether the marcasite is genetically related to late supergene processes or to the submarine oxidation of the ores is difficult to determine conclusively. However, a plausible answer could be obtained indirectly from the following observations:

(i) The Mousoulos and Kokkinoyia orebodies, although containing marcasite, have not been affected by supergene processes.

(ii) The Kokkinopezoula and part of Agrokipia A orebodies, although overlain by massive gossan, contained no marcasite.

(iii) The southwestern part of the Skouriotissa orebody, adjacent to the gossan, although affected by supergene solutions, is devoid of marcasite.

(iv) In the Mathiatis orebody the marcasite is more abundant near the ochre-ore contact and uncommon below the gossan overlying part of the orebody.

From these observations it appears that the formation of marcasite is probably not related to the subaerial oxidation of the orebodies. It is most likely that marcasite was formed

partly by direct replacement of pyrite, and partly by reprecipitation of the products of dissolution of pyrite during submarine oxidation of the sulphide ores.

The physico-chemical conditions of the formation of marcasite from pyrite are not easily determinable. The pyrite-marcasite relation has been a puzzle for many years. Until recently very little was known about the stability field of marcasite, except that it inverts to pyrite above 300°C (Barton and Skinner 1967) and that this inversion is monotropic (Edwards 1954) Kullerud (1967) has suggested that marcasite may be stabilized by the presence of bisulphide groups in its structure. From experiments he found that the inversion of marcasite to pyrite is complete at 400°C.

Rickard (1969) found experimentally that marcasite may be formed from the reaction of mackinawite and elemental sulphur. Water is essential for both the formation of mackinawite and the reaction of the latter to produce marcasite. The same experiments indicate that marcasite can be formed from the reaction of ferrous sulphate and sodium polysulphide solutions under acid conditions. In Cyprus ferrous sulphate and sodium polysulphide solutions were probably formed during the submarine oxidation of the ores. As acid environmental conditions prevailed when the above process was in operation it seems plausible to suggest that the marcasite in these ores was precipitated by the reaction of ferrous sulphate and sodium polysulphide.

3. Chalcopyrite

Chalcopyrite is the second most common mineral after pyrite in some of the investigated orebodies. The general distribution of chalcopyrite in these orebodies was discussed in Chapters 3,4 and 5. Field evidence suggests that the conspicuous chalcopyrite enrichment at the Kokkinoyia and Agrokipia B orebodies (Chapter 4) antedates the extrusion of the olivine basalts, and most probably took place under submarine conditions. In Chapter 6 it was suggested that during the submarine oxidation of the ores the copper contained in them moved away, probably downwards, and concentrated in the ore underlying the ochre (Plate 7.14).

Dissolution and redisstribution of the chalcopyrite during submarine oxidation of the sulphide ores could be an electrochemical or a chemical process (Chapter VI Eq. 6-4) or a combination of both. As mentioned in Chapter VII electric currents arise as a consequence of differences between potentials generated by different ore minerals and seawater. In the wet cell sulphides act as anodes and dissolve e.g. $CuFeS_2 - 4e \_\_\_ Cu^{2+} + 2S^{o}$ (Eq 8.1) (Sveshnikov 1965). The cupric ions formed move to the cathode, the seawater-sulphide ore interface. Owing to the extensive Eh-pH field area of aqueous cupric ion stability (Garrels and Christ (1965)), this interface would tend to be enriched in cupric ions. These aqueous cupric ions would move downwards and precipitate under favourable physico-chemical conditions.

The contribution of supergene processes to chalcopyrite or other copper sulphide enrichment is not easy to determine but appears to be limited. Orebodies with substantial chalcopyrite enrichment (Kokkinoyia, Agrokipia B, Mousoulos) have not been affected by supergene processes. On the other hand orebodies that have been affected by subaerial oxidation, such as Mathiatis and Kokkinopezoula do not exhibit notable chalcopyrite enrichment. Supergene chalcopyrite and covellite are abundant at the intersection of the 350° and the 300° trending faults in the Skouriotissa orebody (Chapter III). The chalcopyrite here occurs not as interstitial material to pyrite but forms thin coatings on pyrite along fractures and cavities.

Interstitial chalcopyrite is found to fill some of the pore spaces in pyrite aggregates and in many cases to cement remnant pyrite (Plates 3.62, 3.63, 3.65, 4.31, 4.32, 4.33, 4.41, 4.42, 4.43, 5.55). It is believed to represent chalcopyrite remobilized during leaching. Optical studies suggest that the interstitial chalcopyrite precipitated in preexisting cavities. Hutchinson and Searle (1970) report that the chalcopyrite filling interstices in the deeper parts of the copper-rich bodies sometimes show spectacular inversion twinning. The inversion twinning in chalcopyrite is produced when this mineral is inverted from a cubic to tetragonal structure during cooling at about 450° (Kullerud, 1967). It seems highly improbable that such high

temperatures prevailed at the top of these orebodies particularly close to the ochre-ore contact at Skouriotissa and Mousoulos.

The present investigation has shown that simple and lamellar twinning are very common in the interstitial chalcopyrite throughout the massive ore at the Skouriotissa, Agrokipia B, Kokkinoyia and Mousoulos orebodies. It appears that the lamellar and single twinning in the interstitial chalcopyrite of these orebodies represents a growth twinning. The latter is reported to be common in minerals which line vughs (Edwards, 1954) and in secondary chalcopyrite precipitated in cavities (Lindquist, 1969).

The hard compact ore at the Skouriotissa orebody contains none or very little interstitial chalcopyrite. Anhedral chalcopyrite grains are included in pyrite I or between grains of pyrite II. No quantitative measurements are available but the anhedral chalcopyrite probably represents 0.2 to 0.6 per cent of the total copper present in the ore. By accepting that the original Skouriotissa orebody was made up of hard compact ore (Chapter 7) it follows that the primary copper content of the Skouriotissa ore ranged between 0.2 and 0.6 per cent. Such amounts of chalcopyrite included in pyrites I and II were seen in all the orebodies under consideration. If the anhedral chalcopyrite represents the primary chalcopyrite in these orebodies, then it seems probable that their massive ores originally contained more or less the same amount of copper. This hypothesis offers a rational explanation for the small variation of the copper content in the stockwork of the orebodies studied whereas the copper content of their massive ores exhibits a very wide variation. This relationship is particularly clear in the orebodies of the Tamasos area (Chapter 4).

It was thought that differences in the physico-chemical conditions prevailing during the deposition of the primary and secondary chalcopyrite could possibly be detected through differences in the trace element composition of the two generations of chalcopyrite. Twelve pure samples of suspected primary and secondary chalcopyrite from different orebodies were prepared and analysed spectrochemically. The results are shown in Table 9-2 which indicate that only silver is present in detectable amounts

in both types of chalcopyrite.

4. Covellite and the other copper minerals

In the massive ore at Skouriotissa, Mousoulos, Kokkinoyia and Mathiatis covellite is the most common copper sulphide after chalcopyrite whereas chalcocite is characteristically rare. Covellite is the predominant copper mineral in the zones of sugary ore at Mousoulos and Mathiatis (Chapters 4 and 5); it is also the last copper sulphide observed in the ochre at short distances from the ochre-ore contact. Thus it appears that covellite is the most stable copper sulphide under submarine conditions of oxidation and associated leaching.

In the copper-rich ores, covellite occurs in the form of rims and ramifying veinlets in chalcopyrite (Plates 3.62, 3.65, 3.66)which were probably produced by solid-state transformation of chalcopyrite through leaching. Covellite probably represents the end product of a series of solid-state reactions with chalcocite and digenite as intermediate products. In the leaching environment covellite is thermodynamically the most stable copper sulphide and is invariably formed during the hydrometallurgical processing of copper ores (Sullivan (1933); Burkin (1969)). The leaching was restricted to the outer parts of the chalcopyrite crystals or along fractures in it probably because the initial rate of leaching was slow and the products of leaching were more stable than chalcopyrite and formed a layer which protected the rest of the chalcopyrite from further attack. Thus it seems probable that only the outer parts of the chalcopyrite were initially altered to chalcocite which subsequently was altered to digenite which in turn was altered to covellite. This sequence of events offers a rational explanation for the general scarsity of chalcocite in the investigated orebodies.

The idaite at Skouriotissa was probably formed by a solid-state transformation of chalcopyrite through leaching; this probably also explains the presence of well defined boundaries between chalcopyrite and idaite. (Plates 3.73, 3.74, 3.76, 3.77). The transformation of chalcopyrite to idaite is accompanied by a considerable reduction of volume so that the resulting idaite is

invariably fractured (Plates 3.73, 3.74, 3.75). The fractures facilitate further leaching of the idaite and its final transformation to covellite (Plates 3.73, 3.74, 3.75).

Bornite is found to be the most common copper mineral after chalcopyrite in the Agrokipia B orebody but is also found in minor amounts in the other orebodies. In the Agrokipia B it was formed by alteration of chalcopyrite (Plates 4.35, 4.36) but was also precipitated from solution because it was found riming pyrite or sphalerite. The copper oxides, tenorite delafossite and paramelaconite, are restricted to the zone of the 350° tending fault at Skouriotissa (Chapter 3) and appear to have been formed by supergene processes.

5. Sphalerite

Sphalerite is generally rare in the Cyprus deposits, but some of them have undergone substantial sphalerite enrichment (Agrokipia B, Mousoulos, Kokkinoyia). The zones of sphalerite enrichment coincide more or less with the zones of chalcopyrite enrichment; the general distribution of sphalerite in some of the orebodies studied was discussed in Chapters 4 and 5. Most of the sphalerite in the zones of enrichment fills cavities which were probably produced by partial dissolution of pyrite; (Plates 7.15, 3.70, 4.33, 4.71, 5.56, 5.59, 5.64, 5.66); remnants of dissolved pyrite are frequently cemented with sphalerite (Plates 7.15, 4.33, 4.77, 5.59, 5.61, 5.64, 5.66). In some cases fine remnants of pyrite in sphalerite are strongly oriented and form ill-defined euhedral outlines (Plates 3.70, 5.78). Sphalerite frequently fills pore spaces in collomorphic pyrite (Plates 5.68, 5.70, 5.72), or interstices along boundaries of growth zones in pyrite I (Plates 4.39, 5.48, 5.58, 5.65). As in the case of chalcopyrite, the amount of sphalerite is much more variable in the massive ore than in the stockwork. It appears that a considerable proportion of the sphalerite present in the massive ore was remobilized during submarine oxidation of the orebodies.

The mobilization of sinc occurred either through leaching by ferric sulphate (Eq 6.5), or electrochemical dissolution of primary sphalerite e.g.

$ZnS - 2e \rightarrow Zn^{2+} + S$ (8.2) (Sato (1960); Sveshnikov and Kedrinskiy (1965); Habashi (1966)). The acid conditions prevailing at the seawater-ore interface prevented precipitation of zinc and insoluble zinc hydroxides. Thus zinc ions would tend to concentrate along the interface and would eventually precipitate under favourable physico-chemical conditions. By assuming that the hard compact ore at Skouriotissa represents the original sulphide it follows that the sphalerite present in this type of ore represents the primary sphalerite of the orebodies. Quantitative estimation of the amount of this sphalerite is difficult. However, there is definitely much less sphalerite than chalcopyrite and it exhibits little variation from one deposit to another.

Kullerud (1953) found experimentally that iron substitutes for zinc in sphalerite and, because this substitution occurs more readily at higher temperatures, he suggested the use of iron content in sphalerite as a possible indicator of the temperature under which the sphalerite was formed. Edwards (1954) suggested that iron-rich sphalerite (10% Fe or more) characterises high temperature deposits, whereas iron poor sphalerites are common in low temperature deposits. Kattamis (1963), using this approach estimated that the sphalerite at the Agrokipia orebody was formed at about 280°C. However, recent investigators of the Fe-Zn-S system have concluded that the temperatures estimated with the "sphalerite geothermometer" were without quantitative foundation (Barton and Toumlin (1966); Barton and Skinner (1967); Boorman (1967); Einaudi (1968)).

It is worth noting that most of the above investigations and conclusions are based on bulk composition of natural and synthetic sphalerites. During the present investigation the iron content of a considerable number of sphalerite grains was analysed quantitatively using an electron probe microanalyser. The size of the grains analysed varied from a few tens of microns to 1 mm; these grains occurred in polished sections taken from different parts of several orebodies. The results of these analyses are shown in Table 8-1 and clearly indicate that the iron content varies considerably in individual sphalerite grains. These analyses also indicate that in a single polished section there are iron-rich

Table 8-1. Electron Probe analyses of iron content in sphalerite

MOUSOULOS OREBODY

Specimen: Nº MS_3 / 38												Specimen: Nº MS_1						MS_2 / 11	
Polished section: Nº G.C. 9												Polished section: Nº MS_1						G.C. 4	
Location: Level 125 m., Coords: - 5140, -23535 meters												Location: Level 148 m., Coords: -5175, -23557 m.						Level 130 m. Co. -6150 meters -23550 *	
Description of specimen: Solid sulphide block close to the ochre - ore contact												Solid sulphide block in ochre						ZnS in solid sulphide block	
Grains analysed *												Grains analysed *						Grains analysed *	
1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	1	2
2.5	1.8	2.3	1.9	6.2	9.8	4.9	1.6	14.2	4.0	2.4	3.2	8.8	11.5	15.2	9.7	9.5	10.4	14.6	14.6
7.0	2.2	1.	2.1	2.2	2.0	9.7	1.7	13.1	3.5	2.7	2.7	11.3	12.6	13.7	9.7	7.7	10.9	7.8	6.0
6.5	2.0	1.9	2.7	2.2	13.8	3.0	2.4		4.1	2.5	2.8	11.3	12.1	14.1		11.1	9.4	6.4	6.3
3.7	2.4	2.2	8.3	12.3	3.5	10.9	3.8		2.7	2.6	5.5	10.3	12.3			11.8	7.1	5.7	5.7
5.3	3.0			5.3	2.1	2.9	12.1		5.1	4.3	12.7	15.9	11.6			10.8	10.4		
4.1	1.7				11.4		10.2		2.6	5.3	3.3	11.4				8.4	6.8		
13.4	3.8						4.1		2.0			10.1				12.8	10.6		
4.0	2.0						8.5		8.6			13.5				12.7	8.3		
11.9	2.9						4.0		6.8			12.1				7.9	9.9		
3.2							12.1		5.5			11.5				11.7	12.4		
4.4																			
2.3																			

MATHIATIS OREBODY

Specimen: Nº MA/8							Specimen: Nº MC1-7				Specimen: Nº MA / 14						
Polished section: Nº G.C. 20							Polished section: Nº G.C.17				Polished section: Nº G.C. 59						
Location: Level 330 m, Coords: 2665, -3100 meters							Level 330 m, Coords: 2650, -3184 m.				Level 330 m. Coords: 2750, -3182 meters						
Description of specimen: ZnS in solid sulphide block near the ochre-ore contact							Description of specimen: ZnS in sulphide block				Description of specimen: ZnS in Pyrite and quartz (Zone B)						
Grains analysed *							Grains analysed *				Grains analysed *						
1	2	3	4	5	6	7	1	2	3	4	1	2	3	4	5	6	7
11.9	11.2	10.6	2.5	10.7	8.3	4.0	9.1	7.8	7.2	7.9	7.2	2.8	7.3	5.3	8.0	2.7	4.7
12.0	11.7	11.5	3.6	11.1	6.1		8.3	8.3			6.8		7.5	4.4	4.6	5.6	3.4
14.5	16.2	11.7	3.6	10.9			6.8	8.3			7.1		5.0	2.5	5.5	9.3	2.3
19.4	13.3	10.4	2.0	11.2									2.9	3.0	7.6	7.9	7.6
17.0	11.6	11.7	2.3	11.9									3.0	6.6	3.1	6.1	1.7
10.1	11.7	10.5	5.1											4.7	3.1	3.2	4.3
9.7	9.9	11.3												5.3	3.0	2.6	4.9
11.2	13.6															2.6	5.8
11.4	17.2															2.6	2.6
12.0																	7.1
16.8																	4.6
13.7																	
11.6																	

AGROKIPIA OREBODY

Specimen: Nº B.H. AΓ 103 / 34										Nº SK 14/27				Nº SK 14/31			KOKKINOYIA OREBODY	Nº B.H. M.72 / 64	
Polished section: Nº G.C. 57										Nº G.C. 43				Nº G.C. 45				Nº G.C. 55	
Location: (Fig. 4-5c) 149 meters below surface										Level 810 ft., Coords. -127400 ft. 33840 ft.				Level 810 ft., Co -127395 ft. 33840 ft.			Fig. 4, 201 meters below surface		
Description of specimen: ZnS filling cavities and as anhedral grains in Pyrite I										ZnS in solid sulphide block				ZnS in solid sulphide block			Anhedral ZnS grains in Pyrite I		
Grains analysed *										Grains analysed *				Grains analysed *			Grains analysed *		
1	2	3	4	5	6	7	8	9	10	1	2	3	4	1	2	3		1	
1.5	5.4	10.6	7.9	7.7	4.9	7.2	10.1	15.1	11.3	4.2	5.9	3.8	4.5	13.4	13.9	20.0		8.9	
3.7					2.7			12.5	11.5	4.0	4.0	4.1	4.5	13.8	13.5	19.0		22.1	
3.5									14.1	4.3	3.8	4.0		13.3	14.4	15.4		14.4	
									7.0	5.7	4.4	4.7		14.4	15.4	12.5		18.3	
									9.1	4.2	4.0				14.5				
										6.4	4.0				15.5				
											6.9								

* Analyses in weight per cent iron

Coordinates based on Cyprus Grid

and iron-poor sphalerite grains. Some grains show a small variation in their iron content but in others the iron content varies from 1-6 to as much as 12 per cent (Table 8-1) X-ray scanning micrographs show that the variation of the iron content in some sphalerite grains of the Mathiatis ore exhibits a well defined zoning (Plates 8.g 8.j). Quantitative analyses of the sphalerite grains, shown in the above two plates, indicate that the iron-rich zones contain up to 9.3 per cent iron whereas the iron-poor zones contain as low as 1.7 per cent iron (Table 8-1 specimens MA/14 grains 6 and 7).

It appears that the sphalerite geothermometer is not applicable in the investigated Cyprus ores because the obtained electron probe analyses of iron in sphalerite imply a wide range of temperatures of formation for different sphalerite grains in single specimens but also for different zones of individual sphalerite grains. The respective temperatures in the sphalerite geothermometer for some of the analyses shown in Table 8-1 are up to 500°C which are most unlikely to have had prevailed during the formation of the massive ores.

The frequency distribution of the iron content of the sphalerite grains analysed (Fig. 8.1) suggests two distinct populations but it is difficult to determine conclusively which population represents the primary and which the seconary sphalerite on the basis of the iron content alone. X-ray scanning micrographs show euhedral zones in pyrite, in which zinc is conspicuously enriched (Plate 8.i). Because pyrite is known to take up insignificant amounts of zinc (Barton and Tounlin, 1966) the zinc enrichment of pyrite is probably secondary. Complete replacement of the euhedral zones shown in plate 8.i could produce the euhedral or subhedral sphalerite shown in plates 8.o, 8.p 5.78, 5.80.

6. Pyrrhotite

The apparent absence of pyrrhotite has been considered as one of the important characteristics of the massive ores in Cyprus. (Bear (1963); Hutchinson (1965)). Pyrrhotite was recently identified in the Memi orebody by Johnson (quoted by Searle 1968). In the present investigation it was found that minor amounts of pyrrhotite are invariably present in the massive ores.

Plates 8-a, 8-b. X-ray scanning (FeKa and CoKa) micrographs of an area 500x500 microns in pyrite. Skouriotissa orebody.

Plate 8-c. Concentration profile (CoKa) along the line shown in Plates 8-a and 8-b.

Plate 8-d. Electron image of an area 500x500 microns in pyrite. Skouriotissa orebody.

Plate 8-e. X-ray scanning (CoKa) micrograph of the area shown in Plate 8-d.

Plates 8-f, 8-i. X-ray scanning (FeKa and ZnKa) micrographs of an area 500x500 microns in pyrite. Skouriotissa orebody.

Plates 8-g, 8-h. X-ray scanning(FeKa and CuKa) micrographs of sphalerite in quartz. Mathiatis orebody. Area 300x300 microns.

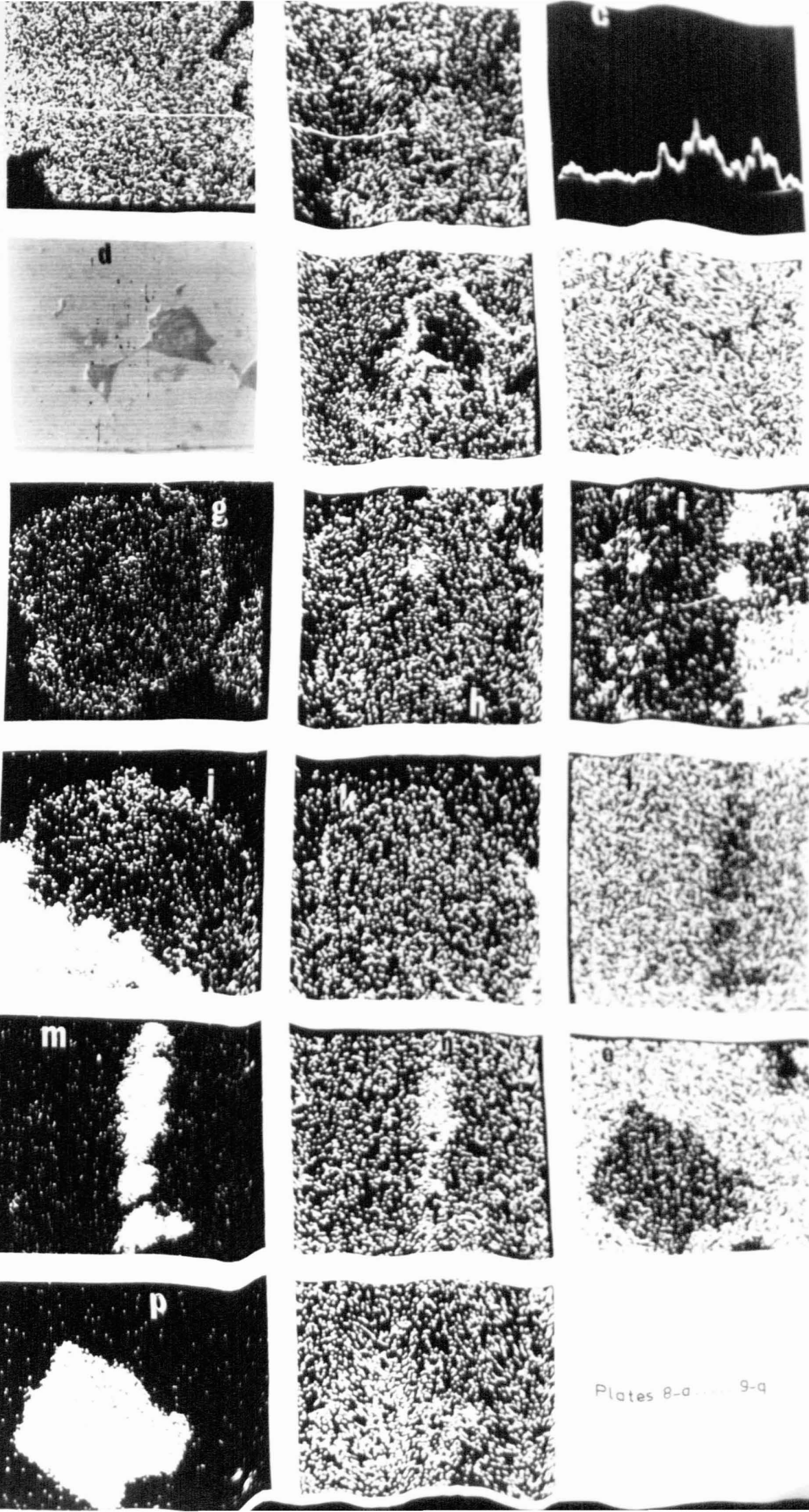
Plates 8-j, 8-k. X-ray scanning (FeKa and CuKa) micrographs of sphalerite in contact with quartz (top) and pyrite (bottom). Mathiatis orebody. Area 300x300 microns.

Plates 8-l, 8-m, 8-n. X-ray scanning (FeKa, ZnKa and CuKa) micrographs of pyrite associated with sphalerite. Skouriotissa orebody.

Areas 150x150 microns.

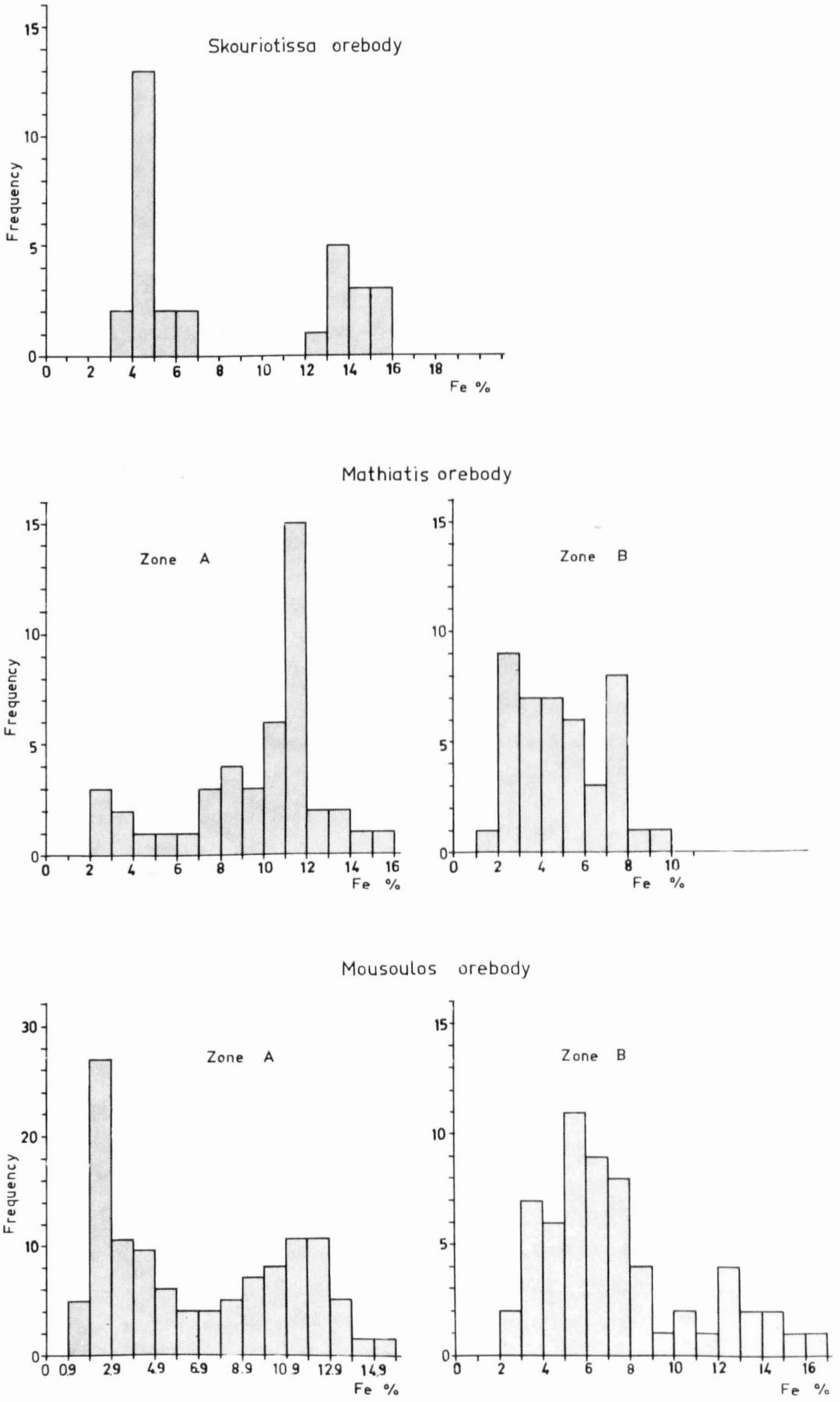
Plates 8-o, 8-p, 8-q. X-ray scanning (FeKa, ZnKa and CuKa) micrographs of pyrite associated with sphalerite Mousoulos orebody.

Area 150x150 microns.



Plates 8-a ... 9-q

Fig 8-1. Distribution of iron in sphalerite from the zones A and B of the Skouriotissa, Mathiati and Mousoulos orebodies.



Pyrrhotite is lacking in the zones B, and in the stockwork. In the massive ores pyrrhotite tends to be more common in their upper levels, particularly in zones of chalcopyrite and sphalerite enrichment (Plates 5.79, 5.80, 5.81, 3.68). Pyrrhotite forms anhedral grains filling cavities in pyrite (Plates 3.68, 3.69, 5.82), and frequently forms inclusions in sphalerite (Plate 3.65, 5.79) and less commonly in chalcopyrite.

Monoclinic pyrrhotites with low temperature stability fields occur only in the narrow composition range 46.35 - 46.90 mole per cent Fe (Carpenter and Desbourough (1965); Clark (1966); Arnold (1969); Yund and Hall (1969); Taylor (1969); Formation of monoclinic pyrrhotite at low temperatures was reported by Clark (1965) who succeeded in synthesizing this mineral by the reaction between iron and sulphur at 45°C; Erd et al (1957) found crystals of highly magnetic pyrrhotite enclosed in calcite crystals. Fluid inclusion thermometry indicates that the temperature of deposition of this pyrrhotite varies from 25° to 40°C. Three electron probe analyses of pyrrhotites in samples from the Skouriotissa orebody were carried out by P. Suddaby (personal communication). The results are listed in Table 8-2 and are plotted in fig. 8-2. Two of the three analyses fall in the narrow compositional range of low temperature, monoclinic pyrrhotite.

It seems highly probable that in general the pyrrhotite in the Cyprus orebodies was formed from aqueous solutions at low temperature. Its formation was probably facilitated by the reducing conditions which developed after the isolation of the orebodies from the open sea when sufficient goethite was precipitated and the olivine basalts were extruded.

7. Chalcopyrite - Sphalerite - Pyrrhotite exsolution textures

Intergrowths consisting of minute inclusions of chalcopyrite and pyrrhotite in sphalerite are common in the upper parts of the Skouriotissa, Mousoulos, Kokkinoyia and Agrokipia B orebodies. Rare intergrowths consisting of minute inclusions of sphalerite or pyrrhotite in chalcopyrite were seen in the same zones of the above orebodies. The shape and boundary relations between including and included phase vary widely in these

Table 8-2. Electron Probe analyses of Pyrrhotite from the Skouriotissa orebody. Formulae calculated on the basis of one Fe atom.

Wt/%	(1)	(2)	(3)
Fe	60.6	62.4	62.3
S	37.9	38.3	38.2
Total	98.6	100.7	100.5
Formulae	$Fe_1S_{1.091}$	$Fe_1S_{1.07}$	$Fe_1S_{1.069}$
Atomic per cent Fe	45.45	46.50	46.55

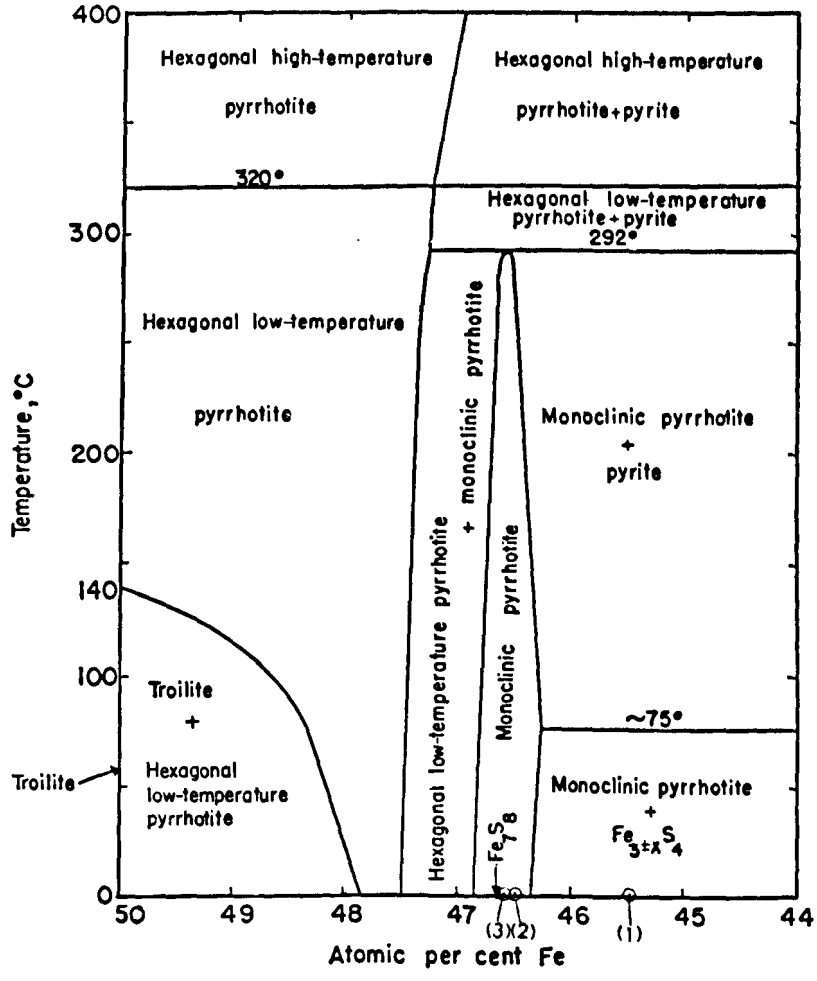


Fig. 8-2. Phase relations at low temperatures in the region from 44 to 50 atomic % Fe in the condensed Fe-S system.
After Taylor (1969)

intergrowths. Mutual boundary textures of chalcopyrite in sphalerite (Plates 3.71, 4.40), of pyrrhotite in sphalerite (Plates 3.63, 5.82) and of chalcopyrite in pyrrhotite (Plate 3.67) are common. Frequently chalcopyrite inclusions exhibit "replacement textures" by the sphalerite host (Plate 4.40). The inclusions may be lamellar or rod like and are randomly distributed in the host, (Plates 5.82, 5.83, 5.84, 5.85). Very fine grained chalcopyrite, non-coherently exsolved in sphalerite (Plates 5.81), is common in the Mousoulos orebody.

These intergrowths are probably produced by unmixing during the crystallization of chalcopyrite-sphalerite-pyrrhotite solid solutions. Edwards (1954) suggested that solid solutions of chalcopyrite in sphalerite unmix at 350° - 400°C, whereas unmixing of sphalerite in chalcopyrite occurs at about 550°C. Brett (1964) investigated the exsolution textures in the Cu - Fe - S system in controlled cooling experiments and concluded that quantitative data on the cooling conditions of natural copper iron sulphides cannot be obtained through studies of exsolution textures. However, he suggested that unmixing at low temperatures would produce fine grained, non-coherent exsolution textures, because of low diffusion rates and a high degree of supersaturation. Yund and McCallister (1969) reviewed the theories on the kinetics and mechanisms of exsolution and concluded that the existing information is not sufficient for practical applications in mineralogy. Nevertheless, because:

(a) intergrowths are restricted to the upper portion of massive ores,

(b) the intergrowths are invariably found in zones of secondary chalcopyrite and sphalerite enrichment, and

(c) pyrrhotite seems to have been formed at low temperatures,

it appears that in the Cyprus massive ores the intergrowths were produced by unmixing of chalcopyrite - sphalerite - pyrrhotite solid-solutions at low temperatures.

8. Conclusions

Sufficient evidence is available to suggest that the marcasite which occurs in some of the orebodies is secondary. Most likely it was produced by the reaction of ferrous sulphate and sodium polysulphide solutions at low temperatures and in an acid environment. Both reactants formed through the dissolution of pyrite during submarine oxidation of the massive ores, and not during supergene oxidation.

Trace amounts of pyrrhotite were identified for the first time in the massive sulphide of the Cyprus orebodies. The distribution of pyrrhotite, combined with mineralogical textural and analytical studies, indicates that it is secondary. The pyrrhotite is sulphur-rich and its chemical composition indicates that it is a low temperature, monoclinic species.

Field, mineralogical, textural and chemical relationships leave little doubt that a considerable proportion of the chalcopyrite and sphalerite present is secondary. Supergene secondary chalcopyrite occurs only in some parts of the Skouriotissa orebody. Remobilization of chalcopyrite and sphalerite probably took place under submarine conditions by chemical and electrochemical dissolution of the primary chalcopyrite and sphalerite in the oxidized portion of the massive ores. However, the proportions of primary chalcopyrite and sphalerite cannot be accurately determined because of the difficulty in distinguishing primary and secondary sulphides. The probable paragenetic position of the various ore minerals found in the massive ores is illustrated in Table 8.3. Many of the exsolution textures, which are commonly observed in the zones of enrichment, were probably formed at low temperatures.

Table 8-3 Probable Paragenetic Position of the ore minerals which were identified in the Cyprus ores

	PRIMARY MINERALS					
	CHALCOPYRITE		PYRITE I	PYRITE II ?	SPHALERITE	
PROCESS OF FORMATION	Directly through leaching	Dissolution and reprecipitation	Directly through leaching	Dissolution and reprecipitation	Dissolution and reprecipitation	Through submarine secondary enrichment
SECONDARY MINERALS	Chalcocite	Chalcopyrite	Collomorphic pyrite	Collomorphic pyrite	Sphalerite	Galena
	Digenite	Bornite	Framboidal pyrite	Framboidal pyrite		Tennantite
	"Permanent blue" covellite	Chalcocite ?		Pyrite II ?		
	Covellite	Tenorite		Marcasite		
	Bornite	Paramelaconite		Pyrrhotite		
	Orange bornite	Delafossite		Mackinawite		
	Idoite	Cuprite (Memi orebody)				

CHAPTER IX

MINOR ELEMENT CHEMISTRY OF THE PYRITES OF THE CYPRUS SULPHIDE ORES AND ITS POSSIBLE GENETIC SIGNIFICANCE

1. General Statement

Attempts have been made for a long time to use the minor element content of sulphides ores as an indicator of metallogenetic provinces and of different periods of mineralization in a single metallogenetic province. Trace element studies have also been used to estimate the temperature of deposition of the sulphide minerals in various orebodies. The concentrations of some trace elements in some sulphide minerals have been considered as indicators of the formative conditions of sulphide deposits. For metamorphosed sulphide ores trace elements have been used as indicators of the grade of metamorphism. A review of the voluminous literature on the minor element studies in some sulphide minerals up to 1955 was given by Fleischer (1955).

Pyrite is the most common sulphide mineral and it is widespread throughout the geological record in a variety of rock types and geological environments: black muds in a variety of recent sedimentary environments contain small amounts of pyrite (Dunham 1961); pyrite is the predominant mineral in a variety of vein-type sulphide deposits Lindgren (1933), Bateman (1952); pyrite is also the predominant mineral in the strata-bound massive sulphide ores throughout the world. The abundance of some minor elements in pyrite, particularly cobalt and nickel and the ratios between these two elements, have been used extensively to deduce the formative conditions of pyrite and the orebodies in general.

In most of the Cyprus orebodies studied, there are two distinct zones, the massive ore (Zone A) and the stockwork (Chapters 4, 5). Between the massive ore and the stockwork in some of these orebodies there is a narrow zone consisting of pyrite and quartz (Zone B). In the Skouriotissa orebody, bands of pyrite are interbedded with ochre and cherts. Thus in the orebodies studied pyrite occurs in a variety of geological environments.

A preliminary investigation of the minor element content in pyrite was undertaken to determine whether the trace elements could be used as indicators of the different formative environments of the various zones of these orebodies.

2. Previous work and present investigation

The trace element content in the pyrites of the Cyprus ores has not been investigated in detail before. The private files of the Mining Companies operating in Cyprus contain a considerable number of analyses of the ores and ore concentrates from the mines. The results of these analyses are of little interest in connection with the present investigation because:

(a) In most cases no description of the analysed samples is given.

(b) The analytical method used and its sensitivity are not described.

Several quantitative analyses of pyrite concentrates from various mines were carried out by Bachfeld (in Wolff 1964). Searle (1965) undertook a preliminary study of the trace element content in the ores of some orebodies in connection with the geochemical investigation of the lavas around the orebodies. Several semi-quantitative spectrochemical analyses of the ore in the Sha orebody were given by Panayiotou (1969).

The distribution of the elements Copper, Zinc, Nickel and Cobalt in the ore from the various zones of the investigated orebodies was discussed in Chapters 3, 4 and 5. The distribution and significance of cobalt determined spectrochemically in fifty four pure pyrite samples is discussed in detail below. Furthermore fiftyfour pure pyrite samples had been analysed spectrochemically for a number of trace elements. The analyses were carried out in the Department of Pure Geochemistry, Imperial College, under the supervision of J.R. Butler and R. Berlin. A summary of the sample preparation and analytical techniques is given in Appendix B. A more detailed description of these techniques is given by Wheatley (under preparation). Most of the analysed samples were taken from the investigated orebodies, but samples from additional orebodies were analysed to determine whether there is any geographical variation in the distribution of any trace element. As the number of analysed samples from each orebody was limited, they were selected

carefully in order to represent all the existing types of ore in each orebody.

3. Results and discussion

The results of the spectrochemical analyses are shown in Tables 9.1 and 9.2 and indicate that:-

(a) Chromium was not detected (<5 ppm) in most of the samples. Low amounts of chromium were detected in some samples but no significant variation of this element exists in pyrites from the massive ore and the stockwork.

(b) Manganese was not detected (<10 ppm) in most of the samples. However low manganese was detected in some samples from both the massive ore and the stockwork, but this element is of no use as a genetic criterion of any particular zone.

(c) Silver (<10 ppm) is generally low and was not detected in most of the samples. However most of the analysed pyrites containing detectable amounts of silver belong to the upper parts of the massive ore and Zone B but the number of these pyrites is so small that no definite conclusions can be drawn.

(d) Lead and Molybdenum are present in all 15 of the samples analysed a limited number of samples. Both elements are present in pyrites from the massive ore and the stockwork. It is interesting to note that although lead was also enriched in the zones of chalcopyrite and sphalerite enrichment of some orebodies, (Figs 4.5a; 4.8) the pure pyrite samples from these zones do not exhibit any significant increase in lead. It seems probable that in these enrichment zones the lead is concentrated in the sphalerite. Pb 25-300 Mo 5-160

(e) Vanadium was not detected (<30 ppm) in most of the pyrite mainly because of the low sensitivity for this element to the method employed. Carstens (1943) (quoted by Fleischer (1955)) on the basis of few analyses reported that vanadium is absent from pyrite of hydrothermal sulphide deposits whereas it is present in pyrite of sedimentary origin. Anderson (1969) suggested the use of the concentrations of vanadium in pyrite as a genetic criterion. In the Cyprus ores vanadium tends to be more common in the pyrite of the massive ore, but in two analyses of samples from the stockwork considerable amounts of

Table 9-1. Spectrographic analyses of pyrites

Plate No	Specimen No	Location	Description of Specimen	Purity	Co 10	Ni 10	Ag 10	Ag* 0.9	Mn 10	Cr 5	V 30	Ti 25	Mo* 2	Pb* 4	Ga* 2
SKOURIOTISSA OREBODY															
3345	SK4/5a	Level 990 ft Coords:-126 665, 33900 ft.	Pyrite mixed with amorphous red silica at the ochre - ore contact.	Very good	440	33	10	N.D.	13	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3340	SK4/6	Level 990 ft. Coords:-126665, 33900ft.	Solid sulphide block enriched in chalcopyrite beneath the ochre-ore contact.	"	250	17	B.S.	N.D.	10	27	B.S.	B.S.	N.D.	N.D.	N.D.
3343	SK/23	Level 1017 ft. Coords:-126 480, 34 015 ft.	Band of massive friable pyrite interbedded with ochre.	"	560	15	10	N.D.	13	13	B.S.	B.S.	N.D.	N.D.	N.D.
3345	SK14/28	Level 810 ft. Coords:-127 398, 33 840 ft.	Solid sulphide block consisting of a mixture of pyrite I and collomorphic pyrite (conglomeratic ore)	"	860	14	B.S.	6	B.S.	B.S.	B.S.	B.S.	130	60	BS N.D.
3342	SK14/31	Level 810 ft. Coords:-127 395, 33 840 ft.	Mixture of pyrite I and collomorphic pyrite (conglomeratic ore)	"	328	B.S.	B.S.	N.D.	B.S.	B.S.	47	B.S.	N.D.	N.D.	N.D.
3342	SK14/2	Level 810 ft. Coords.-127130, 33585 ft.	Hard compact ore consisting of pyrite I and minor pyrite II	"	5500	35	B.S.	2.8	B.S.	B.S.	45	72	90	25	BS N.D.
3342	SK/639	Level 981 ft. Coords-126980, 33300 ft.	As above but more porous	"	1280	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3341	SK11/5	Level 837 ft. Coords.-127030, 33470 ft.	Fracture filling and disseminated pyrite in brecciated and hydrothermally altered lavas (stockwork)	"	140	180	B.S.	N.D.	114	19	B.S.	52	N.D.	N.D.	N.D.
3341	SK5/15	Level 990 ft. Coords:-126775, 33500 ft.	As above	"	355	68	B.S.	N.D.	120	B.S.	B.S.	700	N.D.	N.D.	N.D.
MOUSOULOS OREBODY															
3343	MS3/75	Level 125 m. Coords: -5118, -23542 m	Highly porous solid sulphide block encased in ochre.	Very good	B.S.	B.S.	B.S.	6	27	B.S.	B.S.	B.S.	20	75	BS N.D.
3342	MS3/77	Level 125 m. Coords:-5119, -23545 m.	Porous sulphide block encased in sandy sulphide matrix.	"	92	33	B.S.	N.D.	B.S.	B.S.	48	B.S.	N.D.	N.D.	N.D.
3343	MS3/77a	Level 125 m. Coords:-5119 -23545 m.	Sandy sulphide matrix around the above block.	"	B.S.	20	B.S.	N.D.	B.S.	14	110	B.S.	N.D.	N.D.	N.D.
3342	MS3/78	Level 125 m. Coords.-5122.-23550 m.	Solid sulphide block (conglomeratic ore)	"	B.S.	19	B.S.	3.2	16	11	B.S.	B.S.	35	70	BS N.D.
3343	MS3/79	Level 125 m. Coords:-5122.-23557 m	As above	"	B.S.	11	B.S.	N.D.	13	11	B.S.	B.S.	N.D.	N.D.	N.D.
3343	MS3/80	Level 125 m. Coords:-5124,-23560 m.	As above	"	B.S.	14	11	15	B.S.	B.S.	B.S.	B.S.	45	90	BS N.D.
3343	MS3/82	Level 125 m. Coords:-5125, -23566 m.	Block of sulphide mixed with silica (Zone B)	"	24	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3341	MS3/103	Level 125 m. Coords.-5112, -23571 m.	Fracture filling and disseminated pyrite in brecciated and hydrothermally altered lavas (stockwork)	"	145	B.S.	B.S.	N.D.	B.S.	31	B.S.	325	N.D.	N.D.	N.D.
3341	MS3/105	Level 125 m. Coords:-5114,-23579 m.	As above	"	105	17	B.S.	2.8	B.S.	B.S.	B.S.	B.S.	60	25	70	BS N.D.
3341	MS3/109	Level 125 m. Coords:-5120 -23598 m.	Fracture filling and disseminated pyrite in hyd. altered lavas, with rare pillow structure preserved (stockwork)	"	265	26	B.S.	2.5	B.S.	B.S.	B.S.	B.S.	45	50	BS N.D.
3342	MS1/13	Level 133 m. Coords:-5144, -23565 m.	Solid sulphide block (conglomeratic ore)	"	64	15	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
MATHIATIS OREBODY															
3340	MA/1	Level 330 m. Coords. 2700, -3087 m.	Highly porous sulphide block near ochre-ore contact.	Very good	B.S.	22	20	N.D.	143	17	60	B.S.	N.D.	N.D.	N.D.
3331	MA/8	Level 330 m. Coords: 2665, -3100 m.	As above	"	B.S.	22	B.S.	N.D.	B.S.	B.S.	B.S.	98	N.D.	N.D.	N.D.
3331	MA/9	Level 335 m. Coords: 2726, -3105 m.	Block of massive sulphide (conglomeratic ore)	"	B.S.	27	B.S.	N.D.	B.S.	B.S.	B.S.	145	N.D.	N.D.	N.D.
3331	MA/11	Level 335 m. Coords: 2723,-3187 m.	As above	"	B.S.	23	B.S.	N.D.	B.S.	B.S.	B.S.	450	N.D.	N.D.	N.D.
3340	MA/14	Level 330 m. Coords: 2750,-3182 m.	Pyrite mixed with red jasper (Zone B)	"	B.S.	12	10	5	67	10	B.S.	B.S.	20	75	BS N.D.
3331	MC2/31	Level 330 m. Coords: 2747,-3140 m.	Fracture filling and disseminated pyrite in brecciated and altered lavas (stockwork)	"	B.S.	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	67	N.D.	N.D.	N.D.
3335	MC2/33	Level 330 m. Coords: 2753,-3153 m.	Massive pyrite cementing blocks of mineralised lavas (stockwork)	"	18	20	B.S.	N.D	B.S.	B.S.	B.S.	360	N.D	N.D	N.D.
KOKKINOYIA OREBODY															
3327	B.H.M72/58	Fig. 4-8	Highly porous massive ore enriched in chalcopyrite	Very good	B.S.	16	29	32	29	10	70	76	160	300	7
3327	" M72/61	"	As above but porosity decreases	"	115	B.S.	B.S.	7	B.S.	29	B.S.	B.S.	120	100	BS N.D.
3327	" M72/64	"	Massive sulphide ore consisting mainly of pyrite I	"	135	53	B.S.	11	B.S.	B.S.	B.S.	B.S.	55	230	BS N.D.
3340	" M45/75	"	Massive ore enriched in chalcopyrite	"	B.S.	24	12	N.D.	280	16	33	B.S.	N.D.	N.D.	N.D.
3325	" M45/78	"	Pyrite mixed with quartz (Zone B)	"	100	B.S.	B.S.	N.D.	B.S.	17	58	108	N.D.	N.D.	N.D.
3325	" M45/80	"	Fracture filling and disseminated pyrite (stockwork)	"	B.S.	55	B.S.	N.D.	B.S.	28	B.S.	95	N.D.	N.D.	N.D.
3326	" M45/83	"	As above	"	135	25	B.S.	N.D.	B.S.	B.S.	B.S.	410	N.D.	N.D.	N.D.

Values in p p m, Sensitivity given with each element, N.D. = Not determined, B.S. Below sensitivity, * Elements determined by R. Berlin
Coordinates based on Cyprus Grid

Table 9-2. Spectrographic analyses of pyrites

Plate №	Specimen №	Location	Description of specimen	Purity	Co 10	Ni 10	Ag 10	Ag* 0.9	Mn 10	Cr 5	V 30	Ti 25	Mo* 2	Pb* 4	Ga* 2
AGROKIPIA OREBODY															
3325	B.H.AΓ103/31	Fig 4-5a	Massive ore enriched in chalcopyrite and sphalerite	Very good	B.S.	B.S.	B.S.	N.D.	B.S.	B.S.	58	B.S.	N.D.	N.D.	N.D.
3325	" 34	"	Massive pyritic ore mixed with rare quartz	"	B.S.	B.S.	B.S.	0.9	B.S	37	30	383	5	60	N.D.
3324	" 41	"	Fracture filling and disseminated pyrite (stockwork)	"	140	B.S.	B.S.	2.5	B.S.	B.S.	B.S.	B.S.	5	30	B.S.
3325	" 49	"	As above	"	65	B.S.	B.S.	4	B.S.	54	B.S.	B.S.	15	50	B.S.
3324	" 57	"	As above	"	115	B.S.	B.S.	6	B.S.	B.S.	B.S.	B.S.	40	100	3
3325	AG. B1	Underground workings	Massive ore consisting of coarse grained pyrite	"	B.S.	B.S.	B.S.	N.D.	B.S.	15	36	100	N.D.	N.D.	N.D.
3323	AG. A4	Level 395 m. Coords:-15730, 4395 m.	Massive pyrite filling fracture in mineralized pillow lava (stockwork)	"	315	B.S.	B.S.	N.D.	B.S.	B.S.	54	B.S.	N.D.	N.D.	N.D.
KOKKINOPEZOULA OREBODY															
3340	K Π 4	Level 356 m. Coords:-18350, 3532 m.	Pocket of coarse grained massive pyrite (stockwork)	Very good	1000	18	B.S.	N.D.	B.S.	B.S.	60	76	N.D.	N.D.	N.D.
3327	K Π 3	Level 382 m Coords:-18350, 3590 m.	Fracture filling pyrite in brecciated mineralized lava (stockwork)	"	290	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3328	K Π 2	Level 356 m. Coords:-18318, 3550 m.	Fine grained disseminated pyrite in silicified lava (stockwork)	"	69	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3327	K Π 1	Level 356 m. Coords:-18318, 3550 m.	Massive pyrite filling fracture in silicified lava (stockwork)	"	92	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
MEMI OREBODY															
3328	M M 1	Level 360 m. Coords:-25530, 3765 m.	Fracture filling and disseminated pyrite (stockwork)	Very good	B.S.	B.S.	B.S.	N.D.	B.S.	B.S.	115	230	N.D.	N.D.	N.D.
3328	M M 4	Level 360 m. Coords:-25545, 3761 m.	Fracture filling massive pyrite (stockwork)	"	53	B.S.	B.S.	N.D.	10	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3328	M M 5	Level 360 m. Coords:-25550, 3762 m.	As above	"	44	29	B.S.	N.D.	B.S.	B.S.	B.S.	237	N.D.	N.D.	N.D.
3340	M M 8	Level 360 m. Coords:-25502, 3753 m.	Fracture filling and disseminated pyrite (stockwork)	"	15	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	1200	N.D.	N.D.	N.D.
3345	M M TC	Level 400 m. Coords:-25540, 3750m.	Massive pyrite at the top of the orebody	"	B.S.	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
LIMNI OREBODY															
3345	L	Level 496 ft Limni pit	Fracture filling pyrite (stockwork)	Very good	660	18	35	N.D.	B.S.	17	175	B.S.	N.D.	N.D.	N.D.
EVLOIMENI OREBODY															
3341	EV	Evloimeni prospect	Highly porous friable massive sulphide block	Very good	B.S.	46	13	N.D.	104	33	B.S.	B.S.	N.D.	N.D.	N.D.
KAPEDHES OREBODY															
3345	K.D.	Kapedhes pit	Coarse grained fracture filling pyrite (stockwork)	Very good	B.S.	B.S.	B.S.	N.D.	118	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
KAMBIA OREBODY															
3345	K B.	Kambia pit	Coarse grained fracture filling pyrite (stockwork)	Very good	B.S.	23	B.S.	N.D.	34	11	B.S.	B.S.	N.D.	N.D.	N.D.

Table 9-2a. Spectrographic analyses of chalcopyrite

SKOURIOTISSA OREBODY															
3364	S K 4/9	Level 990 ft Coords:-126665, 33900 ft.	Sulphide block enriched in chalcopyrite underneath the ochre (secondary ?)	Very good	B.S.	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3364	S K 5/1	Level 990 ft. Coords:-126930, 33292 ft.	Supergene chalcopyrite mixed with crystalline pyrite (secondary ?)	"	B.S.	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3365	S K 14/31	Level 810 ft. Coords:-127395, 33840 ft.	Interstitial chalcopyrite in solid sulphide block	"	B.S.	B.S.	34	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
MOUSOULOS OREBODY															
3364	M S 1/139	Level 139 m. Coords: -5150, -23600 m.	Zones in the stockwork enriched in chalcopyrite	Very good	B.S.	B.S.	94	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3365	M S 3/78	Level 125 m. Coords:-5112, -23525 m.	Interstitial chalcopyrite in solid sulphide block (secondary ?)	"	B.S.	B.S.	43	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
KOKKINOYIA OREBODY															
3364	M 72/61	Fig. 4-8	Massive ore enriched in chalcopyrite (secondary ?)	Very good	B.S.	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3364	M 72/64	"	Interstitial chalcopyrite	"	B.S.	B.S.	82	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
AGROKIPIA OREBODY															
3365	AΓ103/31	Fig. 4-5	Massive ore enriched in chalcopyrite and sphalerite (secondary ?)	Very good	B.S.	B.S.	65	N. D.	B.S	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3365	" 33	"	Massive pyritic ore mixed with rare quartz	"	B.S.	B.S.	53	N. D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
LIMNI OREBODY															
3364	L I	Limni mine	Fracture filling chalcopyrite (secondary ?)	Very good	B.S.	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
3365	L 516	"	As above	"	B.S.	B.S.	B.S.	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.
MEMI OREBODY															
3365	M M 642	Level 400 m. Coords:-25540, 3750m	Massive ore enriched in chalcopyrite (secondary ?)	Very good	B.S.	B.S.	160	N.D.	B.S.	B.S.	B.S.	B.S.	N.D.	N.D.	N.D.

Values in ppm, Sensitivity given with each element, N.D. = Not determined, B.S. = Below sensitivity, * Elements determined by R. Berlin

Coordinates based on Cyprus Grid

vanadium were detected. The two samples were taken from pockets of massive pyrite in the stockwork zone. (Table 9-2 samples КП 4, MM_1). Hence in the Cyprus ores vanadium cannot be used as a conclusive indicator of the formative conditions of the pyrite.

(f) Titanium was not detected (<25 ppm) in most of the samples mainly because of the low sensitivity of the analytical method. However there is a definite tendency for titanium to be more abundant in the pyrites from the stockwork zone. This is probably due to the fact that the pyrites impregnating the stockwork lavas frequently contain inclusions of leucoxene (Plate 5.95). Electron probe analyses of magnetites in the unmineralized basaltic lavas indicate that the magnetites contain 3 to 7 per cent titanium, which is distributed uniformly in the magnetite grains. It seems most likely that the pyrites which contain high titanium, were formed through the sulphurization of the titanomagnetite during the mineralization of the basaltic lavas.

(g) Nickel is generally low in the Cyprus ores and exhibits small variation. The abundance of nickel in pyrite was suggested by many investigators as a diagnostic criterion of its formative conditions. Thus pyrite with high concentrations of nickel was suggested to characterize sedimentary ores, (Hegemann (1943); Davidson (1962); Loftus-Hill and Solomon (1967), whereas pyrite with low concentrations of nickel characterises hydrothermal, (Hegemann (1943); Davidson (1962) and subvolcanic ores (Camble and Jarkovsky (1969). In the Cyprus ores, nickel occurs in equal amounts in pyrites from the massive ore and the stockwork. The nickel content of pyrite from bands of sulphides which are interbedded with ochre in the Skouriotissa orebody does not differ significantly from the nickel content of pyrite from the massive ore and the stockwork zones. In the Skouriotissa orebody in particular, nickel is very high in the two samples from hydrothermally altered lavas (stockwork). Hence the nickel content in the pyrite of the orebodies studied cannot be used, in the absence of other evidence, to distinguish the pyrites from the various zones of these orebodies.

determined at 3 and 7 p.m.

(h) Gallium was detected in only two samples, one from the massive ore and one from the stockwork, it is therefore of no genetic significance.

4. Cobalt content in the pyrite of the Cyprus ores

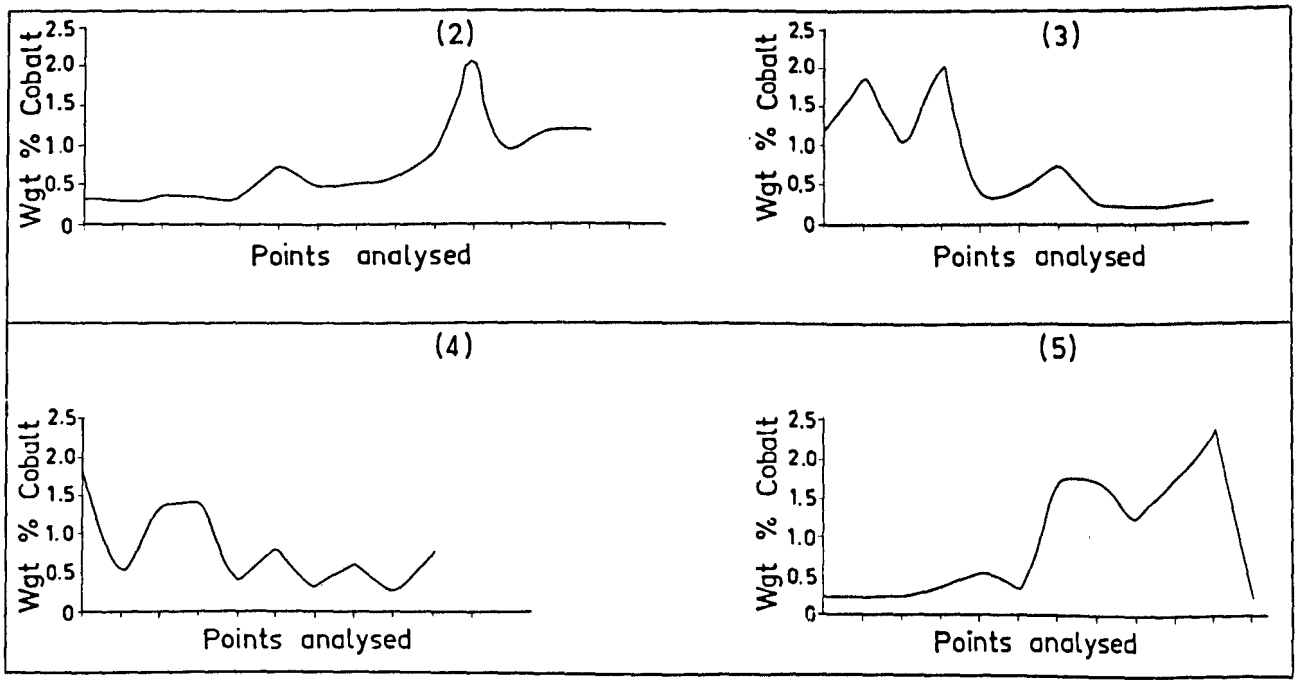
In the pyrite of the analysed samples, cobalt is the most common minor element. The cobalt exhibits a very wide variation not only in the various orebodies but also in different zones of the individual orebodies (Tables 9-1 and 9-2). Cobalt is highly concentrated in pyrite of the ores at Skouriotissa and Kokkinopezoula whereas it is very low or below the detection limit in the pyrite of the ore at Mathiatis. The pyrite of the stockwork of the Mousoulos, Agrokipia A and Agrokipia B orebodies generally contains high cobalt; the pyrite of the massive ore at Mousoulos and Agrokipia B is below the detection limit although there are some erratically distributed high concentrations. In the Kokkinoyia orebody cobalt is erratically distributed in the pyrite of the massive ore and the stockwork. In the Skouriotissa orebody cobalt is substantially higher in pyrite of the hard compact ore than in pyrite of the conglomeratic ore.

The four pyrite samples which contain the highest concentrations of cobalt (SK 14/2, SK 639, SK 14/28 and KΠ 4) (Tables 9-1 and 9-2) were further investigated with an electron probe microanalyser. In the pyrite of SK 14/28, cobalt is below the sensitivity of the instrument; concentration profiles by traversing the electron probe slowly along lines throughout the specimen KΠ 4 have shown that cobalt is uniformly distributed in it quantitative analysis was impossible. X-ray scanning micrographs showed that in the pyrite of SK 14/2 and SK 639 there are zones in which cobalt is highly concentrated (Plates 8.a, 8.b, 8.c). Analyses along 6 concentration profiles intersecting zones of high cobalt in the SK 639, similar to the high cobalt zone shown in plate 8.c are given in the Table 9.3 and are graphically presented in figure 9.2. These analyses indicate that in this specimen in a single traverse cobalt varies from less than 0.2 to as much as 3.5 per cent.

Table 9-3. Electron probe analyses of cobalt in the pyrites of the specimens SK 639 and SK 14/2 both consisting of euhedral zoned pyrite.(description of specimens is given in Table 9-1)

SK 639 Quantitative analyses of cobalt along six concentration profiles. Points analysed, approximately, equally spaced. The profile 6 is illustrated in Plates 8.a, 8.b, 8.c. Analyses in weight per cent cobalt						SK 14/2 Analyses of "high-cobalt spots" contained in two areas (1, 2) 500µm square and in the high cobalt zone illustrated in Plate 8. e		
1	2	3	4	5	6	1	2	3
0.29	0.31	1.26	1.83	0.20	0.20	0.35	1.96	1.50
0.23	0.25	1.87	0.54	0.21	0.24	0.92	6.01	0.92
0.33	0.35	1.06	1.36	0.25	0.21	0.17	4.51	7.98
0.31	0.31	2.07	1.40	0.34	0.21	1.62	0.58	10.17
3.70	0.74	0.36	0.38	0.55	1.31	1.04	3.70	3.47
2.94	0.45	0.46	0.80	0.35	2.57	3.12	3.47	1.85
	0.51	0.74	0.32	1.77	0.72	1.50	3.24	3.81
	0.56	0.20	0.62	1.74	1.88	3.12		6.24
	0.88	0.20	0.26	1.24	2.39	4.62		2.31
	2.10	0.20	0.78	1.77	2.69	2.20		4.28
	0.93	0.30		2.38	3.22			7.17
	1.19			0.20	1.22			1.96
	1.17				0.95			
					3.45			
					2.02			
					1.99			
					0.24			
					0.43			

Fig 9-2. Graphical presentation of cobalt distribution along the concentration profiles 2, 3, 4 and 5 of SK 639



X-ray scanning micrographs showed that in the pyrite of the specimen SK 14/2 there are sporadic zones in which cobalt is highly concentrated (Plate 8.e). More often the cobalt is concentrated in spots less than 3 microns across which are erratically distributed in the pyrite crystals. The cobalt in these spots is much higher than the average cobalt content of the specimen. This is clearly illustrated in figures 9-1 and 9.1a. Quantitative analyses of several cobalt-rich spots contained in two areas 500 µm square of the specimen SK 14/2 are shown in Table 9.3 and indicate that cobalt ranges from 0.2 to as much as 6 per cent. In the same table are shown quantitative analyses of the cobalt rich zone, illustrated in plate 8.e; they indicate that the cobalt in this zone ranges from 0.9 to as much as 1.0 per cent.

Mineralogical studies have shown that the samples SK 639 and SK 14/2 consist mainly of euhedral zoned pyrite I. The detailed electron probe investigations indicate that similar contiguous pyrite crystals contain markedly different concentrations of cobalt. This suggests that pyrite crystals growing under similar conditions contain different amounts of cobalt; it seems therefore probable that the concentration of cobalt in pyrite is largely dependent on the availability of this element during the growth of the various pyrite crystals.

The electron probe investigation failed to identify any discrete cobalt phases in the pyrite of the samples SK 14/2 and SK 639. The high cobalt spots and zones which were observed in the pyrite of the above samples probably represent nuclei of a cobalt solid phase which did not grow to a cobalt mineral because not enough cobalt was available in the mineralizing solutions. The nuclei of cobalt probably occur along the contacts of growth zones. On surfaces of growth zones nucleation is most easily achieved because there the lattice is disordered and the free energy is higher than the average (Brett 1964). As subsequent zones are added to the pyrite crystal, the nuclei of the cobalt solid phase become trapped within it.

It appears that the high-cobalt spots and/or zones, which are erratically distributed in the pyrite of the samples

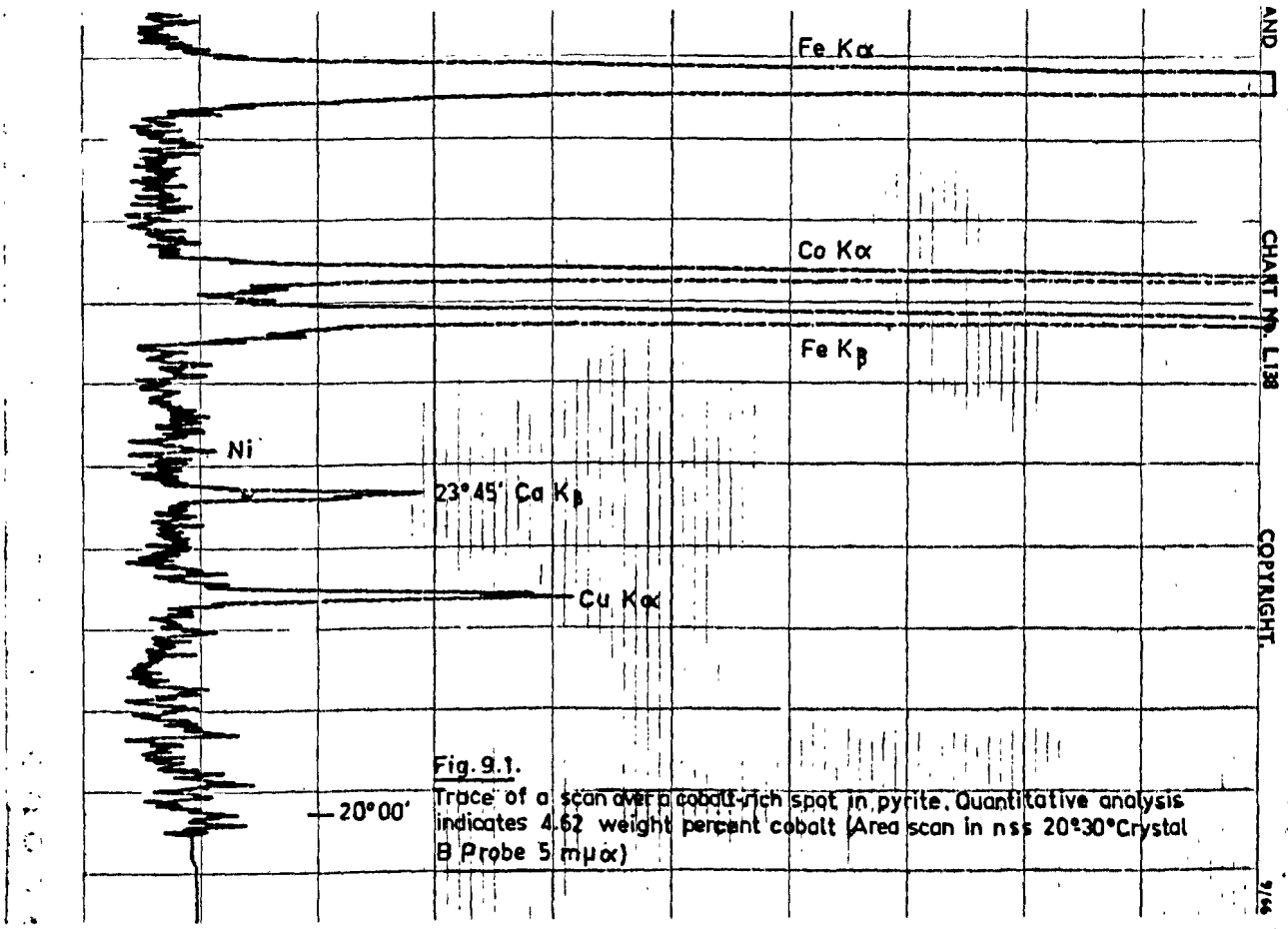


Fig. 9.1.
Trace of a scan over a cobalt-rich spot in pyrite. Quantitative analysis indicates 4.62 weight percent cobalt (Area scan in nss 20°30° Crystal B Probe 5 mμα)

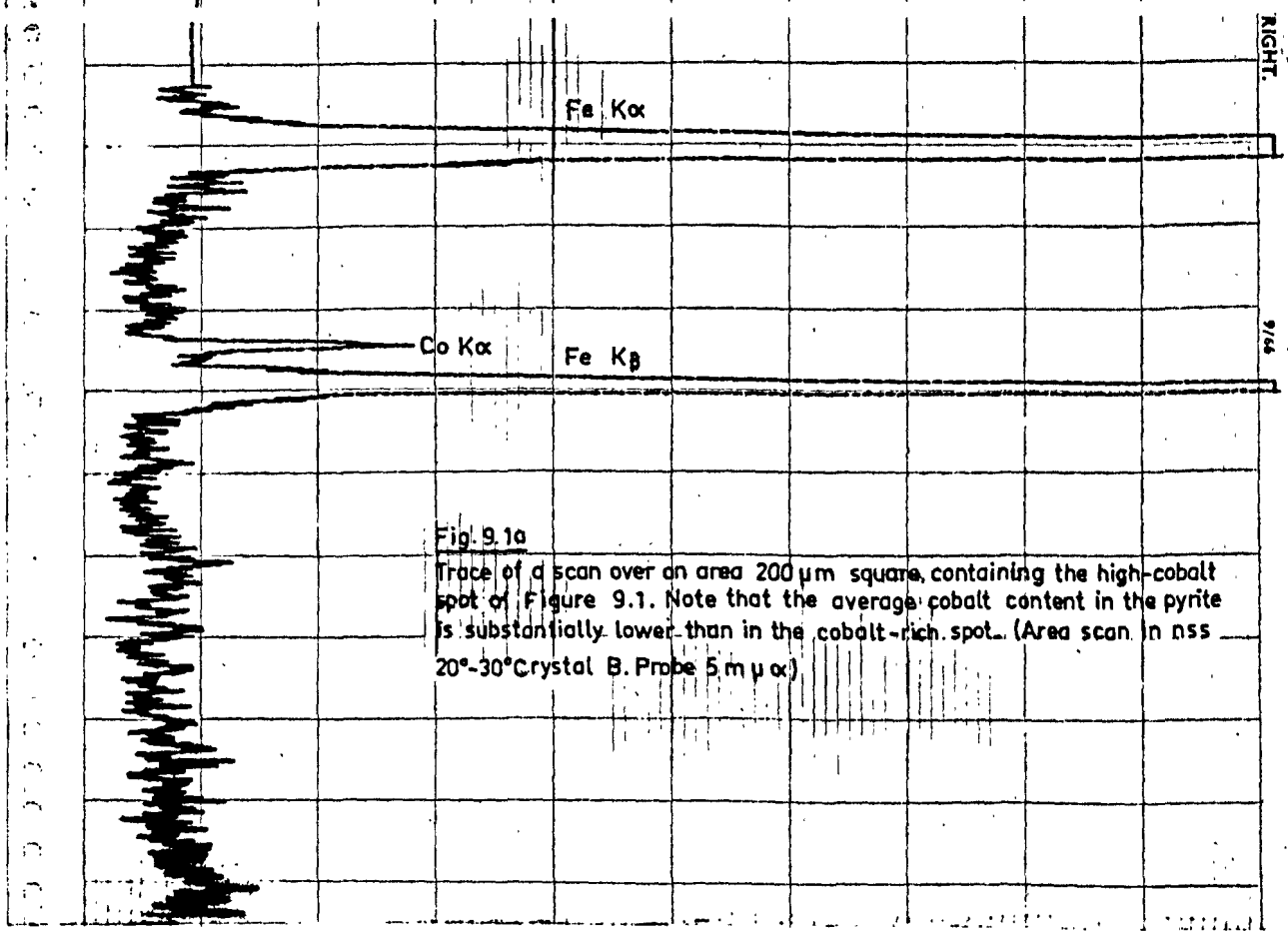


Fig. 9.1a
Trace of a scan over an area 200 μm square, containing the high-cobalt spot of Figure 9.1. Note that the average cobalt content in the pyrite is substantially lower than in the cobalt-rich spot. (Area scan in nss 20°-30° Crystal B. Probe 5 mμα)

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SK 14/2 and SK 639 both taken from massive ore present nuclei of a cobalt phase which were included in the pyrite by means of occlusion (McIntyre, 1963). On the other hand the uniform distribution of cobalt in the pyrite of the sample KΠ 4 (Table 9-2) which was taken from the stockwork probably is due to the inclusion of cobalt in the pyrite by means of solid solution formation (McIntyre, 1963). Thus the different mode of occurrence of cobalt in pyrite of samples taken from the massive ores and the stockwork, probably reflects the different environmental conditions under which the pyrite of the two zones was formed.

5. Cobalt content in pyrite as a possible indicator of its formative conditions.

Many geologists since the early work of Hegemann (1943) have suggested the use of cobalt concentration in pyrite as a clue to the recognition of the formative conditions of the pyrite. Thus pyrite with high cobalt content was considered to be common in ores of volcanic origin whereas pyrite with low cobalt content was considered to characterize ores of sedimentary origin. (Hegemann (1943); Hegemann and Leybold (1954); Roscoe (1965); Loftus-Hills and Solomon (1967)). It was suggested by Hawley (1952) that pyrite in which cobalt tends to predominate over nickel was formed at high temperatures whereas pyrite in which the ratio Co:Ni tends to be a unity was formed at low temperatures. Davidson (1962) suggested that ores with high cobalt are of magmatic-hydrothermal origin whereas ores with low cobalt content are of sedimentary origin. Finally Cambel and Jarkovsky (1966a, 1969) suggested that "subvolcanic pyrites in the volcanite region as a rule have low cobalt and nickel in contrast to plutonogenic pyrites".

The geological setting of the orebodies studied their structure chemistry, mineralogy and textures all clearly suggest that they are genetically connected with the volcanism of the Troodos Pillow Lavas, and that their massive ores and stockwork zones were formed under similar conditions. If however the cobalt content of the Cyprus pyrites (shown in Tables 9-1 and 9-2) is considered to be genetically significant, then a wide spectrum of contradicting genetic environments and sources for the mineralizing

solution is obtained using any of the criteria listed above. Thus it is concluded that the concentration of cobalt in pyrite is ambiguous as a genetic criterion at least for the investigated Cyprus ores and, in the absence of any more reliable evidence, its use should be attempted with the utmost caution.

6. Cobalt concentration in euhedral and collomorphic pyrite

Lampard (1960) reports that in the Avoca orebody, cobalt is absent in colloidal pyrite whereas it is concentrated in crystalline pyrite. This was recently confirmed by the detailed spectrochemical investigations of Wheatley (personal communication). Lampard (1960) analysed also a few samples of colloidal and crystalline pyrite from Rio Tinto, and found that cobalt is absent in the first type whereas it is concentrated in the second one. He suggested that the differentiation of cobalt between the two types of pyrite is primary, and is controlled by the growth mechanism of the two types of pyrite.

The Atomic Absorption Spectrophotometer analyses for cobalt indicate that this element tends to decrease at the top of the Agrokipia B (Fig. 4.5c) Kokkinoyia (Fig. 4.8) Mathiatis (Fig. 4.11) and Mousoulos (Fig. 5-6) orebodies. Mineralogical studies showed that at the top of the above orebodies, the zoned pyrite is characteristically low because, as mentioned in Chapter 7, it dissolved through leaching. Thus, the notable decrease in cobalt in these zones is probably due to the leaching of the zoned pyrite; this suggests that cobalt is relatively more concentrated in the zoned pyrite rather than in the unzoned pyrite and that the concentration of cobalt in the zoned pyrite probably lowers its resistance to chemical and electrochemical leaching.

In the Skouriotissa orebody (Table 9-1) the pyrite from samples of hard compact ore, which consist mostly of euhedral zoned pyrite and no collomorphic pyrite, contains substantially higher cobalt than the pyrite from samples of conglomeratic ore, which contain considerable amounts of collomorphic pyrite. It is worth noting that the euhedral pyrite I and the collomorphic pyrite of the Cyprus ores are similar to the crystalline pyrite and colloidal pyrite respectively which were described by Lampard (1960)

from the Avoca orebody. In Chapter 7 it was suggested that the collomorphic pyrite is secondary and was formed through the leaching of euhedral zoned pyrite. Thus pyrite from samples of conglomeratic ore would contain less cobalt because a proportion of cobalt - rich zoned pyrite is leached. Cobalt would tend to decrease as the proportion of leached zoned pyrite increases. It is concluded therefore that the low cobalt content in pyrites from samples which contain collomorphic pyrite is not a primary feature but has resulted from the partial leaching of cobalt-rich zoned pyrite.

7. Conclusions

The abundance of the elements, Cr, Mn, Mo, Ga, Pb, V and Ag, in the pyrite of the investigated orebodies appears to be inconclusive as indicators of the formative environment of the pyrite. Titanium tends to concentrate in the pyrite of the stock-work zone and its high concentration is most probably due to inclusions of leucoxene in the stockwork pyrite. The inclusions of leucoxene characterize pyrite produced by sulphurization of the titanomagnetite of the basaltic lavas during their mineralization. The abundance of nickel in the pyrites of the Cyprus ores cannot be used to deduce their genetic conditions.

The actual amounts of cobalt in the pyrite of the orebodies studied have no genetic significance. Two samples of pyrite from the same zone at Skouriotissa orebody differ markedly in their cobalt content although mineralogical evidence suggests formation under similar conditions. It seems probable that the main factor controlling the cobalt content in pyrite is the availability of this element during the growth of pyrite. On the other hand, in pyrites formed under different conditions, the mode of occurrence of this element is different: in the massive ore, cobalt is erratically distributed in the pyrite and is included by means of occlusion, whereas in the stockwork the cobalt is uniformly distributed in the pyrite as a result of solid solution. In the massive ore the zoned pyrite contains higher concentrations of cobalt than the unzoned pyrite. The occluded cobalt in the zoned pyrite may cause nonequilibrium conditions resulting in its low resistance during chemical and electrochemical leaching. Hence

cobalt is more concentrated in the pyrite of the hard compact ore, which is the least affected by leaching, than in the pyrite of the conglomeratic ore which had undergone considerable leaching.

CHAPTER X

A DISCUSSION ON THE FORMATIVE CONDITIONS OF ZONE B AND THE STOCKWORK ZONE OF THE CYPRUS ORES.

1. General Statement

After correction for postmineralization faulting and tilting, most of the investigated orebodies are seen to have had initially the shape and structure illustrated in figure 7.1. The upper part of most of the orebodies is occupied by the massive ore which has a saucer-shaped disposition and is variably overlain by unmineralized lavas, ochre and gossan. In some orebodies, (Mousoulos, Mathiatis, Kokkinopezoula), the massive ore is underlain by a narrow but distinct zone (Zone B) which consists of an intimate mixture of sulphide and silica. In other orebodies, Kokkinopezoula, Agrokipia B, the massive ore rests on the mineralized lavas of the stockwork zone, whereas at Skouriotissa the massive ore is resting on unmineralized lavas. In Cyprus stockwork type mineralization was never found overlying massive ore.

The mineralizing solutions that gave rise to the massive ores are believed to have moved through the lava sequence probably along fractures. Lavas through which such solutions moved have undergone extensive chemical and mineralogical alteration. Sulphide veins found extensively in the stockwork zone are believed to represent the paths (fractures) along which the mineralizing solutions passed.

2. Discussion on the probable formative conditions of the silica in Zone B.

The field characteristics as well as the mineralogy and chemistry of Zone B have been described in chapters 4 and 5. Zone B consists mainly of sulphides which are mixed with varying proportions of silica. The sulphide is represented by pyrite and small and variable amounts of chalcopyrite and sphalerite. The silica is represented by variable proportions of quartz, chalcedony and red jasper. In Zone B the pyrite is represented only by intensely corroded pyrite Ithe morphology of which is generally similar to the morphology of the corroded pyrite in the sandy friable massive ore (compare plates 4.80, 4.81, 4.82 with plate

4.67 and plates 5.86, 5.87 with plates 5.45, 5.46).

Mineralogical and textural studies (Chapters 4 and 5) leave little doubt that the silica of Zone B was introduced after the sulphides were formed. In the orebodies in which present, Zone B probably represents the lower part of their massive ore which was partly replaced by silica. In this section only a discussion on the probable formative conditions of silica is attempted; the formative conditions of the sulphides will be discussed in the following Chapter. It is difficult to determine conclusively the source of silica and the processes involved in its transport and deposition. A plausible explanation is that the silica in Zone B was introduced by late silica-rich hydrothermal solutions and that the silica of these solutions replaced part of the sulphides at the base of the massive ore. This hypothesis is supported by the observed persistent corrosion and replacement of pyrite by quartz in the stockwork zone, which represents the channels through which these solutions moved. Against this hypothesis is the observed horizontal and sharp contact between Zone B and the overlying massive ore which contains no silica. The massive ore is fractured and porous and any hydrothermal solutions could move through it up to its higher levels. Against this hypothesis are also the results of a preliminary chemical investigation of the lavas in the stockwork zone which indicate that no considerable amounts of silica were introduced in the mineralized lavas of the stockwork zone (see a later section of this chapter) during their mineralization.

Another plausible explanation is that Zone B originally consisted of conglomeratic massive ore in which was introduced silica and filled all the pore-spaces. The silica was probably leached out of the underlying stockwork lavas; its precipitation at the lower parts of the massive ore was controlled by the physico-chemical conditions which prevailed in this part of the orebodies. Optical and chemical data seem to support this hypothesis. Thus in polished sections of ore from Zone B the surface area covered with silica is generally similar to the surface covered with pore space in the conglomeratic massive ore. Hence equal volumes of conglomeratic massive ore, and ore of Zone B contain the same

amount of sulphide, but Zone B contains also silica whereas in the conglomeratic ore 20 to 40 per cent of the volume of the ore is occupied by pore space. Chalcopyrite and/or sphalerite enrichment which in the massive ore was considered to have taken place during the leaching of the ore is also common in Zone B. This further corroborates the suggestion that Zone B represents conglomeratic ore into which silica was introduced at a later stage.

Not infrequently the quartz in Zone B has an internal zoned structure. Growth zoning is common in quartz, but in Zone B the form and texture of the zoned quartz is very similar to the form and texture of zoned pyrite. This similarity is so striking in polished sections which contain zoned pyrites and zoned quartz, as to suggest that, in Zone B, part of the zoned quartz represents pseudomorphs after pyrite. The tendency of silica to replace other rock material, often preserving the original textures and structures with marvellous fidelity, is well known. Petrified wood (Krauskoph 1967) and partial silicification of chalk fossils (Brown et als 1969) are mentioned as examples. Krauskoph (1967) suggested that the replacement of calcite by silica is probably done through slightly acid solutions, supersaturated with silica, causing the dissolution of calcite and deposition of silica. The replacement of zoned pyrite by silica is probably done through acid leaching. Under such conditions the zoned pyrite dissolves readily (Chapter 7) followed by precipitation of silica which inherits the outward form and structure of the dissolved zoned pyrite.

3. Stockwork zone

a. General Characteristics of the Stockwork zone

In the Cyprus deposits the massive ore is generally underlain by the stockwork zone. The Skouriotissa orebody is the only sulphide deposit investigated by the writer which is not underlain by a stockwork zone. In this orebody stockwork type mineralization occurs only along the 350° trending fault. To the north beyond the Skouriotissa orebody, there is an extensive zone of stockwork type mineralization (Chapter 3). The upper part of

the stockwork zone generally consists of brecciated lava which is downwards succeeded by pillow lavas. Both the brecciated and pillow lavas are hydrothermally altered and mineralized.

The thickness of the stockwork zone is not known because the mining operations and the exploration drill holes, the main sources of information, stopped in low grade ore. In the Tamassos mining area exploration drill holes have shown that, stockwork type mineralization, containing up to 20 per cent sulphur, extends to the depth of 255 metres. In the Skouriotissa mining area, recent exploration drilling indicates that stockwork type mineralization, containing less than 7 per cent sulphur, extends to depths lower than 700 metres. Post-mineralization faulting and tilting, have obscured the original lateral relationship of the stockwork zone to the massive ore and the surrounding lavas. Drilling data however indicate that in the three mining areas of Skouriotissa, Tamassos and Kalavassos stockwork type mineralization extends far beyond the limits of the massive ores and frequently is hidden under a thick cover of unmineralized lavas.

The mineralization in the stockwork zone of all the orebodies studied, is represented by sulphide veins and disseminations of pyrite in the mineralized lavas. The mineralogy of the sulphide veins and the disseminated pyrite in the stockwork of the orebodies studied have been discussed in Chapters 3,4 and 5. In the same Chapters a discussion was also given on the products of hydrothermal alteration which accompanied the mineralization of the lavas of the stockwork zone as well as the distribution of sulphur and the minor elements, copper, zinc, nickel and cobalt.

b. Chemical changes in the lavas of the stockwork zone during mineralization

Eight partial analyses were made of lavas from the stockwork zone from five orebodies for a preliminary study of the chemical changes in the lavas due to hydrothermal alteration. The samples for partial analyses were selected to represent lavas which contain varying proportions of fractures. The analyses were made by the Chemical Laboratory of the Cyprus Geological Survey and the results are shown in Table 10.1. The X-ray diffraction analyses of the

Table 10-1. Partial analyses of hydrothermally altered lavas from the stockwork zone of various orebodies.

Orebody	Sample No	Location	Description	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	S %
Skouriotissa	SK 5/14	Level 990 ft. Cds: -126785 ft. 33485 ft.	Dark green altered lava with disseminated Py.	57.2	12.0	13.7	8.12	0.009	0.14	0.095	4.64
"	SK 11/1	Level 837 ft. Cds: -127110 ft. 33365 ft.	Altered lava with fractures filled with Py.	68.9	6.7	13.0	0.10	0.003	0.11	0.057	10.64
Mousoulos	MS 3/90	Level 125 m. Cds: -5092 m. -23574 m.	Block of altered lava with disseminated Py.	54.1	10.4	21.5	6.47	0.010	0.15	0.089	5.82
"	MS 3/97	Level 125 m. Cds: -5097 m. -23583 m.	As above.	51.9	11.3	21.3	8.46	0.008	0.13	0.051	3.95
"	MS 3/112	Level 125 m. Cds: -5144 m. -23590 m.	As above.	54.1	10.6	20.8	9.28	0.008	0.16	0.057	4.20
Kokkinopezoula	KΠ 2	Level 356 m. Cds: -18318 m. -3550 m.	As above.	56.3	13.5	14.1	4.15	0.1	2.33	0.241	6.36
Memi	MM 8	Level 360 m. Cds: -25502 m. -3753 m.	Altered lava with fractures filled with Py.	59.6	11.6	13.6	0.2	0.003	0.38	2.17	8.86
Agrokipia	AΓ 103/224	Fig 4-5c	Borehole samble.	41.1	13.2	22.0	5.21	0.013	0.47	1.46	14.21
Average of 12 analyses of various rock types (excluding U.P.L.) in the Troodos Pillow Lava series. (Compiled from the Cyprus Geological Survey memoirs.)				54.8	14.5	9.15	5.8	6.7	2.3	1.45	Nil

Table 10-1a : X-ray diffraction analyses of the samples shown in Table 10-1.

Sample No	Plagioclase	Pyroxene	Quartz	Pyrite	Chlorite	Illite	Kaolinite	Mont/nite
SK 5/14	-	-	XXXX	XX	XX	-	X	-
SK 11/1	-	-	XXXX	XXX	-	X	-	-
MS 3/90	-	-	XXXX	XX	XX	X	X	-
MS 3/97	-	-	XXXX	XX	XX	X	X	-
MS 3/112	-	-	XXXX	XX	XX	-	X	-
KΠ 2	-	-	XXXX	XX	XX	-	X	-
MM 8	-	-	XXXX	XXX	-	X	-	-
AΓ 103/224	-	-	XXXX	XXX	X	X	-	-

XXXX = Abundant, XXX = Considerable, XX = Rare, X = Trace, - = Not detected (Coordinates based on Cyprus Grid.)

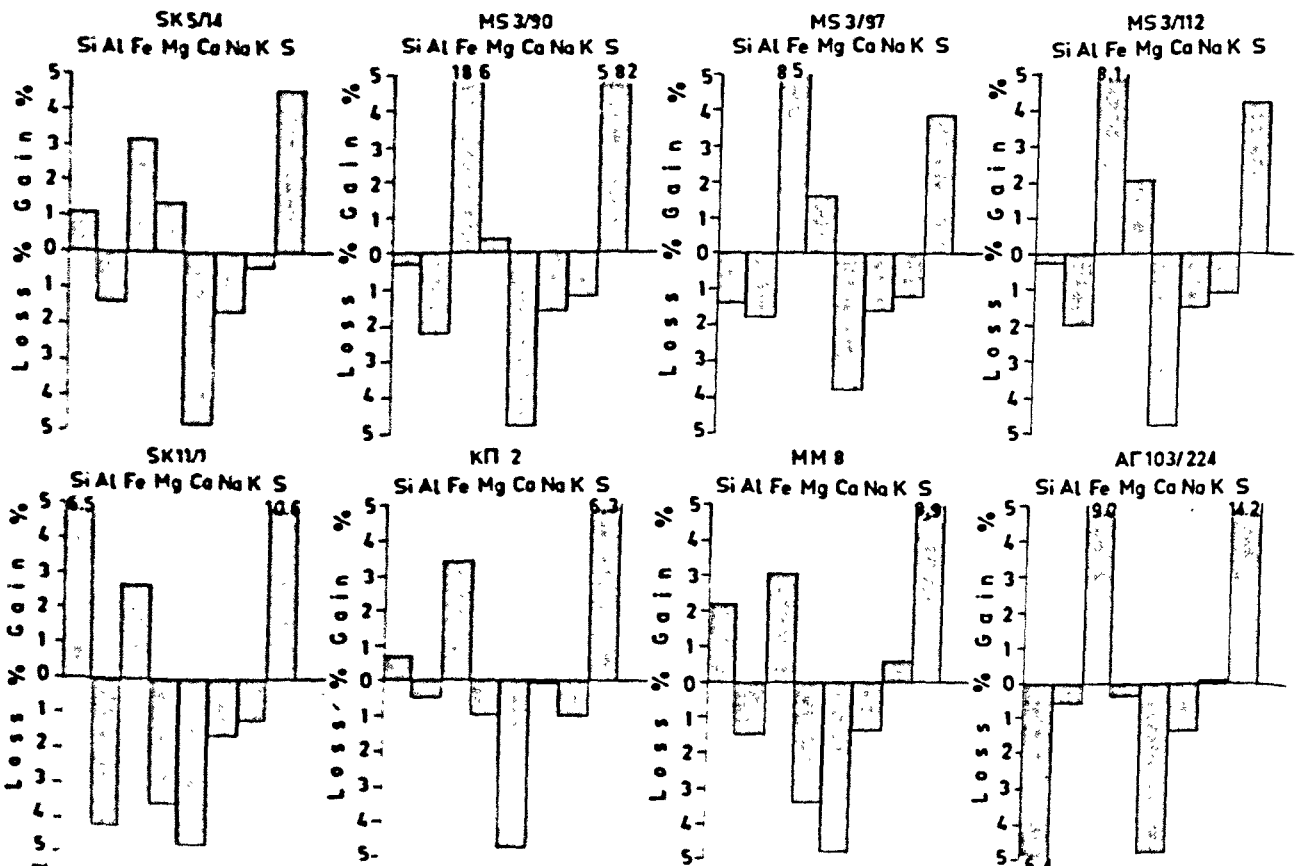


Fig. 10-1 Gain and loss of principal rock constituents through alteration and mineralization in the stockwork zone.

samples are shown in Table 10-1a.

The original petrographic features of the altered lavas, have been obliterated during their mineralization; the interpretation, therefore, of the chemical changes in the lavas, brought about during mineralization, is curtailed by the uncertainty of their original composition. Other sources of uncertainties of the original composition of the mineralized lavas are:

(i) The compositional variations in the Troodos Pillow Lavas brought about during the differentiation of the basaltic magma, and

(ii) compositional variations in the lavas brought about by various grades of burial metamorphism.

To determine any possible gain or loss of the major constituents of the mineralized lavas, each element in all the partial analyses was compared with the average value of the same element from 12 analyses of unmineralized lavas shown in Table 10.1. These 13 analyses were compiled from the memoirs of the Cyprus Geological Survey and represent analyses of a variety of rock types of the Troodos Pillow Lavas. Analyses of Upper Pillow Lavas were not considered since it is highly improbable that stockwork lavas represent mineralized Upper Pillow Lavas; the latter have been extruded after the emplacement of most of the orebodies studied (see Chapters 4 and 5).

The preliminary study of the probable gain and loss of principal rock constituents in the lavas of the stockwork zone during their mineralization is graphically presented in figure 10.1 which indicates that:

(i) Calcium and to a lesser extent aluminium, sodium and potassium have been leached out of the mineralized lavas.

(ii) In some samples of mineralized lavas the magnesium decreased whereas in others it increased.

(iii) Although the mineralized lavas were intensely silicified (Table 10-1a) there was no considerable increase of the silicon in the lavas. It appears that. the silicification

of the mineralized lavas was brought about by selective hydrothermal leaching of bases, leaving behind residual silica (Meyer and Hemley (1967)).

(iv) In the mineralized lavas the iron and sulphur invariably increased. In some samples of mineralized lavas the increase in iron is higher than the increase in sulphur; the excess iron was probably used for the formation of chlorite.

Atomic Absorption Spectrophotometer analyses indicate that the minor elements copper, zinc and cobalt were increased considerably in the mineralized lavas of the stockwork zone of the orebodies studied (see Chapters 4 and 5) compared to the unmineralized lavas (Govett and Pantazis (1971)) whereas nickel decreased.

The stockwork zone represents the channelways of the mineralizing solutions which formed the overlying massive ores. The chief constituents of the massive ores are the sulphur and iron as well as small amounts of copper and zinc. All these elements are invariably increased in the mineralized lavas of the stockwork of the orebodies studied. This suggests that the constituents of the massive ores were not leached out from the underlying lavas, at least, down to depths accessible to observation. The ore constituents probably were derived from deeper zones and were of magmatic origin.

The suggestion of magmatic derivation of the ore constituents is further substantiated by the results of recent sulphur isotopes studies. Sulphur isotopes analyses of pyrites from the stockwork of a number of Cyprus deposits were carried out by M.L. Jensen. The samples were collected by Searle, and the results of the analyses (Searle personal communication) indicate that these pyrites are somewhat enriched in heavy sulphur and have a narrow range of d $S34^{o}/oo$ values (+2.87 - +7.03). Thus their sulphur isotopic composition is similar to that of magmatic hydrothermal pyrite. (Jensen (1967); Smirnov (1968)).

c. Mineralogical Changes in the lavas of the Stockwork zone during mineralization.

The mineralogical changes in the stockwork lavas which were

brought about during their mineralization could be deduced from the comparison of the mineralogical compositions of the unmineralized and mineralized lavas. Optical studies and X-ray diffraction analyses (Table 10-2) indicate that the unmineralized lavas mainly consist of calcic plagioclase and variable amounts of monoclinic pyroxene which are mixed with greatly varying proportions of glassy matrix (Chapters 3,4 and 5). Olivine, where present, is mostly altered whereas small amounts of magnetite are invariably scattered in the unmineralized lavas.

Chlorophaeite is a very common mineral in the unmineralized Upper and Lower Pillow Lavas and appears that it was derived from the alteration of the pyroxene and glassy matrix. Montmorillonite is also a very common mineral of the unmineralized lavas and was produced by the alteration of the plagioclase and the glassy matrix. Celadonite tends to be restricted to the Lower Pillow Lavas and is associated with chalcedony. A great variety of zeolites, including analcite, natrolite, stilbite, scolecite, heulandite and laumontite, is present in the unmineralized lavas. The chlorophaeite, montmorillonite and zeolites, are hydrated minerals and most probably represent products of regional low grade (zeolite-facies) burrial metamorphism. It is worth mentioning that whereas "hydrothermal solutions" and "hydrothermal alteration" were involved in the burrial metamorphism of the lavas, in this investigation, these terms were used as synonymous with the "mineralizing solutions" and "the effects of these solutions on the mineralized lavas".

A source of uncertainties in the study of mineralogical changes in the stockwork lavas during their mineralization is the difficulty to determine if the stockwork lavas had been affected by burrial metamorphism before their mineralization. The Upper Pillow Lavas which were extruded after the emplacement of most of the orebodies studied, as well as the post mineralization basaltic dykes which intersect most of these orebodies, have been affected by the regional burrial metamorphism. This suggests that regional low grade metamorphism of the Troodos Pillow Lavas was still active after the emplacement of the sulphide ores.

Table 10-2 X-Ray diffraction analyses of mineralized and unmineralized basaltic lavas as well as basaltic dykes intersecting various grades of sulphide ore.

	Specimen No	Location	Description of Specimen	Quartz	Pyrite	Chlorite	Illite	Montmorillonite	Kaolinite	Palygorskite ?	Plagioclase	Pyroxene
		SKOURIOTISSA OREBODY										
	SK 5/2	Level 990 ft, Coords -126910, 33345 ft	Intensely brecciated and altered lava	XXXX	XX	XXX	X		X	X	–	–
	SK 5/4	" " " -126880, 33380 ft	As above with common pyrite veins	XXXX	XXXX	–	–	–	–	–	–	–
	SK 5/7	" " " -126850, 33410 ft	As above	XXXX	XXXX	–	X	–	–	X	–	–
	SK 5/10	" " " -126820, 33455 ft	As above	XXXX	XXX	X	X	–	X	X	–	–
	SK 5/13	" " " -126795, 33470 ft	Large blocks of dense mineralized lava	XXXX	XX	XXX	X	–	–	X	–	–
	SK 5 15	" " " -126775, 33500 ft	Intensely brecciated and altered lava with common pyrite veins	XXXX	XXX	XX	X	–	–	X	–	–
	SK10/1	" " " -127070, 33335 ft	Fragment of brecciated mineralized lava	XXXX	X	XXX	X	–	X	X	–	–
	SK10/4	" " " -127035, 33375 ft	As above	XXXX	X	XXX	X	–	X	X	–	–
	SK10/8	" " " -127020, 33405 ft	Dense altered lava impregnated with pyrite	XXXX	X	XXX	–	–	X	X	–	–
	SK10/13	" " " -127008, 33440 ft	As above	XXXX	XX	XXX	X	–	X	X	–	–
	SK10/15	" " " -127000, 33480 ft	Brecciated lava cemented with pyrite	XXXX	XXX(cpy)	XXX	X	–	X	X	–	–
	SK11/5	" 837 ft, " -127030, 33470 ft	Brecciated lava, pyrite filling fractures	XXXX	XX	XX	XX	–	–	X	–	–
	SK1	" " " -127350, 33355 ft	Unmineralized olivine basalt	–	–	–	–	XXX	–	–	XXX	X
	SK2	" " " -126705, 34055 ft	As above	–	–	–	–	XXX	–	–	XXX	X
		MOUSOULOS OREBODY										
	Δ168/156	Fig 5-4	Intensely mineralized lava	XXXX	XXXX	X	X	–	–	–	–	–
	Δ168/162	" "	As above	XXXX	XXXX	X	X	–	–	–	–	–
	Δ168/168	" "	" "	XXXX	XXXX	X	X	–	–	–	–	–
	Δ168/175	" "	" "	XXXX	XXX	X	X	–	–	–	–	–
	MS2/54d	" "	Brecciated and mineralized lava	XXXX	XX	XX	X	–	–	X	–	–
	MS3/103	Level 125m, Coords -5112, -23571 m.	As above	XXXX	XXXX	X	–	–	–	–	–	–
	MS3/109	" " " -5120, -23598 m.	" "	XXXX	XXX	XX	–	–	–	–	–	–
	MS3/31	" " "	Basaltic lava in contact with massive ore	–	–	–	–	XXX	–	–	XXX	X
	MS 1/1	" 133m, " -5157, -23543 m	Basaltic lava in faulted contact with ore	–	–	–	–	XXX	–	–	XXX	X
	MS2/130c	" 130m, " -5185, -23575 m	Margin of dyke intersecting sulphide ore	–	–	–	–	XXX	–	–	XX	X
	MS151/4	" 151m, " -5175, -23502 m	Basaltic lava in faulted contact with ore	–	–	–	–	XXX	–	–	XXX	X
	MS148/d	" 148m., " -5135, -23565 m	Margin of dyke in contact with massive ore	–	–	–	–	XXX	–	–	XX	–
	MS148/d	" " " " "	Centre of dyke in contact with massive ore	–	–	–	–	XXX	–	–	XXX	X
	MS142/d	" 142m, " -5180, -23580 m.	Centre of dyke in contact with medium ore	–	–	–	–	XXX	–	–	XXX	X
	MS4/1d	" 120m, " -5195, -23580 m.	As above	–	–	–	–	XXX	–	–	XXX	X
		KOKKINOYIA OREBODY										
*	M45/220	** Fig 4-8	Pyrite mixed with quartz	XX	XXXX	–	X	–	–	–	–	–
	M45/230	" "	Intensely mineralized lava	XXXX	XXX	X	XX	–	–	–	–	–
	M45/236	" "	As above	XXXX	XXX	–	X	–	–	–	–	–
	M45/242	" "	" "	XXXX	XXX	–	X	–	–	–	–	–
	M45/245	" "	" "	XXXX	XXX	–	XX	–	–	–	–	–
	M45/252	" "	" "	XXXX	XX	–	X	–	–	–	–	–
	M49/216	" "	" "	XXXX	XXX	XX?	XX	–	X	–	–	–
	M49/222	" "	" "	XXXX	XX	XX	XX	–	–	–	–	–
	M49/234	" "	" "	XXXX	XX	XX	XX	–	X	–	–	–
	M72/124	" "	Basaltic lava 56 metres from lava-ore contact	–	–	–	–	XXX	–	–	XX	X
	M72/150	" "	Basaltic lava 30 metres from lava-ore contact	–	–	–	–	XXX	–	–	XX	X
	M72/160	" "	Basaltic lava 20 metres from lava-ore contact	–	–	–	–	XXX	–	–	XXX	XX
	M72/180	" "	Basaltic lava in contact with massive ore	–	–	–	–	XXX	–	–	XXX	XX
		AGROKIPIA 'B' OREBODY										
	AΓ103/155	Fig 4-5c	Pyrite mixed with quartz	X	XXXX	–	–	–	–	–	–	–
	AΓ103/161	" "	As above	XXX	XXXX	–	–	–	–	–	–	–
	AΓ103/167	" "	" "	XXXX	XXXX	–	–	–	–	–	–	–
	AΓ103/173	" "	" "	XXXX	XXXX	–	–	–	–	–	–	–
	AΓ103/179	" "	Intensely mineralized lava	XXXX	XXXX	–	X?	–	–	–	–	–
	AΓ103/185	" "	As above	XXX	XXXX	–	X	–	–	–	–	–
	AΓ103/194	" "	" "	XXXX	XXXX	X	X	–	–	–	–	–
	AΓ103/200	" "	" "	XXXX	XXX	X	X	–	–	–	–	–
	AΓ103/206	" "	" "	XXX	XXXX	X	X	–	–	–	–	–
	AΓ103/212	" "	" "	XXXX	XXX	X	X	–	–	–	–	–
	AΓ103/218	" "	" "	XXXX	XXX	X	X	–	–	–	–	–
	AΓ103/224	" "	" "	XXXX	XXX	X	X	–	–	–	–	–
	AΓ103/230	" "	" "	XXXX	XXX	XX	X	–	–	–	–	–
	AΓ103/236	" "	" "	XXXX	XXX	X	X	–	–	–	–	–
	AΓ103/245	" "	" "	XXXX	XXX	X	X	–	–	–	–	–
	AΓ103/251	" "	" "	XXXX	XXX	X	X	–	–	–	–	–
	AΓ103/257	" "	" "	XXX	XXXX	X	X	–	–	–	–	–
	AΓ103/263	" "	" "	XXX	XXX	X	X	–	–	–	–	–
	AΓ103/269	" "	" "	XXXX	XXX	X	X	–	–	–	–	–
	AΓ103/275	" "	" "	XXX	XXX	X	X	–	–	–	–	–
	AΓ103/288	" "	" "	XXXX	XX	XX	X	–	–	–	–	–
	AΓ103/295	" "	" "	XXXX	XX	XX	X	–	–	–	–	–
	AΓ93/160	'B' orebody. Coords -15425, 4414 m.	Basaltic lava in contact with massive ore	–	–	–	–	XXX	–	–	XXX	XX
		MATHIATIS OREBODY										
	MC1 -11	Level 330m, Coords 2771, -3145 m.	Altered lava with pyrite veinlets	XXXX	XX	–	X	–	–	–	–	–
	MC1 -17	" " " 2748, -3185 m	Dense lava impregnated with pyrite	XXXX	X	XXXX	–	–	–	–	–	–
	MC1 -19	" " " 2760, -3198 m.	As above	XXXX	X	XXXX	–	–	–	–	–	–
	MC2 -33	" " " 2755, -3156 m.	Altered lava with pyrite veins	XXXX	XXX	XX	X	–	X	–	–	–
		KOKKINOPEZOULA OREBODY										
	KΠ3	Level 382m, Coords -18350, 3590 m	Fracture filling pyrite in brecciated mineralized lava	XXXX	XX	X	X	–	–	–	–	–
	KΠ	" 356m, " -18397, 3517 m.	Altered premineralization dyke	XXXX	X	XX	–	–	X	–	–	–
	KΠd	" 403m, " 18403, 3440 m	Fresh basaltic dyke in low grade ore	X	–	–	–	XXX	–	–	XXX	X

* M45 = Number of drillhole
**/220 = Depth in metres

XXXX = Abundant, XXX = Considerable, XX = Rare, X = Trace, – = Not detected
(Coordinates based on Cyprus Grid)

In the mineralized lavas the original structure and textures of the basaltic lavas is frequently faithfully preserved. (Plates 3.82, 5.93, 5.94, 7.18, 7.19). Pyrite is a common mineral in the mineralized lavas whereas it is lacking in the unmineralized lavas. Magnetite is characteristically absent from the mineralized lavas. Frequently in the weakly mineralized lavas the amount and form of the pyrite are similar to the amount and form of magnetite in the unmineralized basaltic lavas. This suggests that a considerable part of the fine-grained pyrite which is disseminated in the mineralized lavas resulted from the sulpharization of the magnetites of the basaltic lava. Thus the formation of pyrite through the sulpharization of magnetite appears to be a characteristic mineralogical change in the mineralized lavas.

Quartz is lacking, or it is rare, in the unmineralized lavas while the mineralized lavas are intensely silicified. The silicification is represented by quartz and chalcedony. The quartz mostly replaces the plagioclase and pyroxene, and very often inherited the outward form of the replaced minerals. (Plates 3.81, 3.82, 5.73, 5.74, 7.18, 7.19). Quartz also occurs in the form of veins filling fractures in the lavas, or it fills vesicles in the lavas. The chalcedony is restricted to the glassy matrix. As mentioned in the previous section of this chapter, the silicification of the mineralized lavas did not involve introduction of considerable silica but probably resulted from the selective hydrothermal leaching of bases from the plagioclase, the pyroxene and the glassy matrix leaving behind the silica.

Chlorite which was not detected in the unmineralized basaltic lavas is a common mineral in the mineralized lavas of the stockwork zone. (Table 10.2). Chlorite is mostly restricted to the glassy matrix where it is intimately mixed with chalcedony. Chlorite tends to decrease in lavas with increased pyrite content, and vice versa. Chlorophaeite was not observed in the mineralized lavas of the stockwork zone.

Montomorillonite is reported to be a very common product of hydrothermal alteration in many mineralized areas throughout the world (Grim (1960); Iwao (1961); Meyer and Henley (1967);

Ellis (1969). Hawkins and Roy (1963) from experiments on hydrothermal alteration of basaltic rocks found that in HCl environment and saline conditions the product of hydrothermal alteration is montmorillonite whereas in CO_2 - saturated aqueous environment illite is produced. They concluded that the role of magnesium is crucial for the formation of montmorillonite. In the Cyprus ores however samples of mineralized lavas which contain considerable magnesium, contain no montmorillonite (Tables 10.1, 10.1a). Ellis (1967) reported that in the Wairakhi geothermal system, in zones in which the temperature of water is about 130°-150°C and its pH about 7, the clay mineral formed is montmorillonite, whereas in zones in which the temperature of the water is 250°-260°C and its pH 6.6-6.8 the clay mineral formed is illite. In the mineralized lavas of the stockwork zone of the orebodies studied, montmorillonite is characteristically lacking whereas small amounts of illite are persistently present (Table 10.2). The persistent lack of montmorillonite and presence of illite in the mineralized basaltic lavas underlying the Cyprus ores most probably reflects the physicochemistry of the mineralizing solutions.

d. Probable formative conditions of the stockwork mineralization.

In the stockwork zone the sulphide mineralization is represented by fine grained pyrite which is disseminated in the mineralized lavas and of sulphide veins, often associated with quartz, which fill fractures in the lavas. The contact of the sulphide veins with the enclosing lava is sharp and the pyrite decreases from massive to rare disseminations over a distance of a few millimetres (Plates 4.6, 4.7, 4.16). Not infrequently the original structure and texture of the mineralized basaltic lava which is in contact with the massive sulphide veins is faithfully preserved (Plates 3.81, 4.81), suggesting that there was no replacement of lava by pyrite.

Mineralogical studies indicate that there are some significant differences between the disseminated pyrite and the sulphide veins. Thus, the sulphide veins contain small and variable amounts of chalcopyrite and sphalerite whereas these two

minerals were not observed in the form of disseminations in the mineralized lavas. The pyrite in the sulphide veins tends to be coarse grained and frequently zoned (Plates 4.12, 7.18) whereas the disseminated pyrite is fine-grained and invariably unzoned (Plates 3.81, 3.82, 4.15, 5.94, 5.75, 7.18, 7.19). Leucoxene, in the form of small anhedral grains is frequently included in the disseminated pyrite whereas it was not observed in the pyrite of the sulphide veins.

The differences between the disseminated pyrite and the pyrite of the sulphide veins listed above, most probably resulted from the different conditions under which these two types of pyrite have formed. The disseminated pyrite was formed through the reaction of sulphur which was introduced by the mineralizing solutions with the iron contained in the magnetite of the unmineralized lavas. The titanium which is present in the sulphurized magnetite forms the commonly observed leucoxene inclusions in the resultant disseminated pyrite. The iron contained in the ferromagnesian minerals and the glassy matrix is probably used for the formation of chlorite. In the lavas which were more intensely mineralized, the chlorite decreases; the iron which was released from the decomposition of part of the chlorite was used for the formation of disseminated pyrite.

The sulphur was probably transferred in the mineralized lava through diffusion. The lavas are ramified with fractures and are commonly vesicular, therefore the distance of diffusive transfer of sulphur from open spaces (zones of circulation of solutions) into solid rock, is short and lies in the limits which are anticipated by experiments (Verhoogen (1952); Naughton and Fujikawa (1959); Sippel and Foster (1963)). The experiments indicate that the rate of diffusion is largely dependent on the concentration of the diffused material. It appears that in the Cyprus ores the concentration of sulphur in the mineralizing solutions was sufficient and sulphur diffused into the mineralized lavas. The consistent lack of chalcopyrite and sphalerite in the form of disseminations in the mineralized lavas is probably due to the low concentrations of copper and zinc, in the mineralizing solutions and the insufficient diffusive transfer of these metals

into the mineralized lavas. It is also due to the fact that the basaltic lavas which were mineralized did not contain enough copper and zinc, to react with sulphur to form disseminated chalcopyrite and sphalerite.

In the stockwork zone the sulphide veins fill fractures and other open spaces in the mineralized lavas. The frequency and the width of the sulphide veins tend to decrease with depth probably because the proportion of fractures and open spaces decreases with depth. In the sulphide veins the mineralogy and textures are generally similar to the mineralogy and textures of the overlying massive ore. These similarities are more clear in the upper parts of the stockwork zone where the sulphide veins are more wide (Plates 4.11, 4.12, 4.17, 4.30, 4.31). The pyrite in the sulphide veins is generally coarse grained and frequently zoned. Chukrov (1966) suggested that large crystals cannot develop from a gel of colloidal particles without going through a solution stage. He also suggested that large crystals can form when the concentrations of reactants are low and the rate of crystallization exceeds the rate of precipitation. These suggestions were substantiated by the experimental work of Rickard (1968) who reported that by using reactants with concentrations ranging from 10^{-1} to 10^{-2}M the synthesized iron sulphides invariably were of submicroscopic colloidal dimensions. He concluded that, in order to obtain single large crystals of iron sulphides, the concentration of reactants would have to be much lower than 10^{-2}M. Thus field relationships and mineralogical and experimental data suggest that the pyrite of the sulphide veins was precipitated from mineralizing solutions which moved through fractures in the stockwork lavas and the concentration of the constituents of pyrite in these solutions was much lower than 10^{-2}M.

4. Conclusions

Zone B consists of sulphides which are intimately mixed with varying proportions of silica. Mineralogical and textural data leave little doubt that the silica in the zone was introduced after the sulphides had been formed. The source of silica

and the processes involved for its restriction to the base of the massive ore and the top of the stockwork zone are not definitely known. Mineralogical and Chemical data suggest that Zone B, in the orebodies in which it is present, represents the lower part of their massive ore.

The silica of Zone B was probably leached out of the underlying stockwork lavas and was precipitated in the cavities which were formed by leaching of the pyrite of the massive ore. An alternative, but less probable, explanation is that the silica of Zone B was introduced by late silica-rich hydrothermal solutions which replaced part of the lower part of the massive ore.

The stockwork zone persistently underlies the massive ore and extends downwards to depths exceeding 700 metres. The stockwork zone represents the roots of the massive ore and the channels through which the ore forming solutions of the massive ore had moved. A preliminary comparative chemical study of the mineralized stockwork lavas and the unmineralized Troodos Pillow Lavas suggests that sulphur and iron were invariably introduced into the mineralized lavas. The general enrichment of the stockwork lavas in sulphur and iron down to great depths and the sulphur isotopes data suggest that these two elements were derived from magmatic sources. Mineralogical studies indicated that during the mineralization of the stockwork lavas, the minerals pyrite, chlorite, quartz and illite were invariably formed. Montmorillonite was not detected and appears to characterise the unmineralized lavas in which it is a very common mineral.

In the stockwork zone the sulphide mineralization is represented by sulphide veins, and disseminations of pyrite in the mineralized lavas. Mineralogical and textural data, combined with experimental data, suggest that the pyrite of the sulphide veins formed in open spaces through the reaction of sulphur and iron in solution. The concentration of the two metals in the ore forming solutions probably were much lower than 10^{-2} M. The pyrite which is disseminated in the lavas appears to have been formed through the reaction of diffused sulphur with the iron contained in the mineralized basaltic lavas. Chalcopyrite and sphalerite were not observed as disseminations in the mineralized lava. This is probably

due to the low concentrations of copper and zinc in the mineralizing solutions and the diffused amounts of these metals in the lavas were not sufficient to form disseminated chalcopyrite and sphalerite.

CHAPTER XI

A DISCUSSION ON THE GENESIS OF THE MASSIVE ORE

1. General statement

The massive ore because of its high sulphur and copper content constitutes the economically exploited part of the Cyprus deposits. It was more intensely exploited and studied than the low grade ore of the stockwork zone. Most of the postulated theories with regard to the origin for the Cyprus sulphide ores deal with the massive ore. In the literature there is unanimous agreement that the Cyprus ores are genetically related to the volcanic activity which produced the Troodos Pillow Lavas; but the process of emplacement of the massive ore is, **controversial.**

Hydrothermal replacement of the pillow lavas, agglomerates and volcanic breccias by sulphide, was the most widely accepted process for the genesis of the Cyprus massive ores. (Cullis and Edge (1923); Lespineux and de Magnee (1935); Jarrel (1947); Harris (1956); Mousoulos, (1957); Ingham (1959); Gass (1960); Bear (1960, 1963), Kattamis (1962); Wolff (1964); Gordon-Smith (1963, 1968); Vokes (1964, 1966a); Kinkel (1966); Pantazis (1967, 1969)).

The hydrothermal origin of the Cyprus massive ores was rejected by Thomas (1923) who postulated that the massive ore at Skouriotissa was formed through the intrusion of a concentrated sulphide melt which was consolidated under the sedimentary cover. Hutchinson (1965) prefers a subaqueous extrusion of the concentrated sulphide melt which formed the Cyprus massive ores.

Searle and Panayiotou (1968) suggested that the massive ore at Mathiatis was formed by exhalative sedimentary processes; Searle (1968) suggested a volcanic-bacteriogenic origin for all the Cyprus massive ores. Finally more recently Hutchinson and Searle (1970) suggested that the Cyprus massive ores had been formed from exhalations of metal bearing brines which precipitated as brine saturated muds, in local basins of restricted circulations and in which strongly reducing conditions prevailed.

However, conclusive determination of the formative conditions of the Cyprus massive ores is difficult, because only

speculative suggestions could be made about the physicochemistry of the ore forming solutions, and the mechanisms of transport, local concentration and precipitation of these solutions.

2. Source of the ore-forming constituents

A critical examination of the data obtained from the present investigation reveals the following facts.

(a) Massive ores consisting mostly of pyrite and minor amounts of chalcopyrite and sphalerite were deposited at the top of the various stratigraphic horizons in the Troodos Pillow Lavas. Apart from the massive ores and the ochreous sediments which overly some of the massive ores no other sediments were found between the various stratigraphic horizons in the lava sequence.

(b) The massive ore in most of the deposits is underlain by the stockwork zone consisting of hydrothermally altered lavas which extend to considerable depths. Field chemical and mineralogical relationships suggest that the stockwork zone represents the channels through which the ore-bearing fluids have ascended to form the massive ore.

(c) All the massive deposits consist of basaltophylic elements, and their composition is generally similar, irrespective of their stratigraphic or geographic position in the Troodos Pillow lava sequence.

(d) Preliminary chemical investigation (Chapter X) has shown that the elements, sulphur, iron, copper and zinc which are the chief constituents of the massive ores, were not leached out of the underlying hydrothermally altered lavas of the stockwork zone. On the contrary these lavas were enriched in the above elements down to depths accessible to observations.

(e) Sulphur isotopes analyses of pyrites from a number of massive ores (Searle personal communication) indicate that these pyrites are somewhat enriched in heavy sulphur, and have a narrow range of $d S34^{o}/oo$ values (+1.85 - +5.25) similar to the isotopic composition of magmatic hydrothermal pyrites (Jensen 1967).

The available facts leave little doubt that the sulphur of the massive ores was derived from volcanic or plutonic sources.

From the same sources were derived most of the iron, copper and zinc of the massive ores. The massive ores are restricted to the top of the various stratigraphic horizons in the lava sequence and probably were formed through subaqueous fumarolic activity which was associated with the waning stages of the various volcanic cycles.

3. Mechanism of Transport of the ore-constituents

The geological literature is replete with discussions on the physicochemistry of the ore forming solutions and the mechanism of their transport from the source to the site of deposition. Speculative suggestions were primarily based on the studies of stability relationships among ore minerals and the products of the wallrock alteration associated with the emplacement of the orebodies. Recent studies of hot springs and fluid inclusions provided quantitative data, partly confirming the speculative suggestions but in many cases contradicting the geological evidence.

Data obtained from studies of hot springs and fluid inclusions indicate that the ore forming fluid is a dominantly aqueous solution concentrated in Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4 (Roedder 1967). The same author, relying on the general scarcity of precipitated sulphides in the fluid inclusions, concluded that metal concentrations, in the range of 1-100 mg/litre, are most likely in the ore forming solutions. Fluid inclusion studies indicate that the content of total sulphur in the ore-fluids is generally low, often 0.03M or less, the sulphur mostly being oxidized (Barnes and Czamanske 1967). From analyses of fluid inclusions and hot spring water, and phase relations, Barton (1957) concluded that in the ore-fluid the CO_2 is from one to three orders of magnitude more abundant than H_2S.

On the other hand there is compelling geological evidence suggesting high concentrations of sulphur and iron in products of volcanic activity and fumaroles connected with the after effects of volcanic activity. Well known examples are (a) the melted flow of sulphur mixed with hot salty water and steam (Watanabe 1940 quoted by Anderson 1969), (b) the magnetite-hematite flow at

El Laco in Northern Chile (Park 1961) and (c) deposits of native sulphur and massive pyrite formed in craters on the slopes of still active volcanoes in Japan. In Japan the volcanic sulphur deposits and the large scale solfataric areas are practically confined to zones of basic volcanic rocks (Mukaiyama 1959, 1970). In the same country many workable limonite deposits were formed and in some places are still being formed, from ferruginous spring waters which originated in connection with the after effects of the volcanic activities involving andesitic and basaltic magmas. (Shiikawa 1970).

Native sulphur deposits associated with pyrite and marcasite and genetically related to late Tertiary early Quaternary volcanism in Almeria Spain were described by Williams (1936, 1965). Good examples indicating high concentrations of iron in volcanic emanations, is the filling, in ten days, of a fissure 3 feet wide, with hematite formed by the reaction between iron chloride and water vapour, during an active phase of Vesuvius in 1817 (Breithaupt quoted by Oftedahl (1958) and the incrustations of fumarolic magnetite and hematite in the Valley of Ten Thousand Smokes which were formed from iron transported as a halide in a vapour phase (Zies 1929). In the Cyprus ores the extensive sulphurization of the iron of the mineralized basaltic lavas, as well as the sulphide veins in the stockwork zone, and the large accumulations of massive sulphide ores, suggest that the concentration of sulphur and iron in the mineralizing solutions was much higher than that suggested by fluid inclusion studies.

The question whether the sulphide ions and metal ions are transported in the same or separate solutions is not answered yet. Lovering (1961) suggested that the metal ions are transported in a sulphur deficient chloride-rich solution, and react with a separate earlier sulphide-rich solution. Barnes and Czamanske (1967) questioned this hypothesis and suggested that complexing by all aqueous species stable in the ore forming environment within the system S-O-H-Cl-N-C must be considered as possible mechanisms of transport. Furthermore the complexes responsible for transport must be stable in the presence of sufficient concentrations of sulphide species to form sulphide deposits, Krauskoph (1967)

suggested that the most likely carrier of the ore metals, at moderate and low temperatures, is a neutral or near neutral solution containing abundant chloride ion and H_2S.

4. Possible loci of concentration of ore constituents

As mentioned in the previous chapter, in the stockwork zone there is no evidence of substantial replacement of lava by the sulphides of the veins. It was suggested that the sulphide veins were formed by precipitation of sulphides in open spaces. Optical studies indicate that the mineralogy and textures of the massive ore while generally similar to the mineralogy and textures of the sulphides in the stockwork veins they are distinctly different from the mineralogy and textures of the sulphide which is disseminated in the lavas. This suggests that the sulphides of the massive ore similar to the massive veins of the stockwork were formed in an open space. The massive ores are restricted to the top of the various volcanic horizons in the lava sequence and persistently have a s ucar-shaped disposition. This suggests that the massive ore was probably accumulated in local depressions on the lava surface.

In many orebodies the upper part of the stockwork on which the massive ore is resting consists of brecciated lava. It is probable that the local depressions in which the massive ores were concentrated represent fumarolic vents. Notwithstanding the observations that (a) the massive ore in a number of deposits is overlain by ochreous sediments which in turn are overlain by olivine basalts (b) the massive ore in other orebodies is overlain directly by olivine basalts and (c) both the ochreous sediments and the basalts were accumulated in a marine environment; still it is difficult to determine conclusively whether these fumarolic vents, during the accumulation of the massive ore in them, were part of the sea floor.

This difficulty is emphasized by the fact that beyond the limits of the massive ore in the Mousoulos, Mathiatis, Kokkinoyia, Agrokipia A and Agrokipia B orebodies no sediments were found underneath the basaltic pillow lavas. If the fumarolic vents were on the sea floor it is difficult to envisage a mechanism involving

the precipitation of pure massive sulphide, up to 100 metres thick, at the same time arresting any sedimentation beyond the limits of the fumarolic vents. A speculative explanation for the lack of sediments, contemporaneous with the massive ore, is because the latter was accumulated in caldera-like depressions probably / not connected with the sea, but filled with volcanic water. These depressions after the precipitation of the massive ore probably had undergone volcano-tectonic sinking (Rittmann 1962) and were brought below the sea level. The sinking of the caldera-like depressions probably had occurred prior to the extrusion of the olivine basaltic lavas.

5. A possible mechanism of deposition of the Cyprus massive sulphide ores.

In the geological literature there are numerous descriptions of, and genetic hypotheses for, the Stratiform massive sulphide deposits. A total of over 400 pertinent references which give essential information on, and discuss the genesis of these deposits can be obtained from the papers of Williams (1960, 1965) Kinkel (1966) Anderson (1969) Smirnov (1970). In these papers the Cyprus sulphide ores are cited and discussed at varying lengths. In the last two decades, in Europe, particularly in Germany the long controversy between epigeneticists and syngeneticists which had started in the first two decades of this century came to an end in favour of the syngeneticists. In the last decade it was realized that the influence of volcanism in ore deposition was underestimated and a volcanic-exhalative sedimentary origin was widely accepted for most of the conformable massive ores throughout the world.

Stanton (1960) stressed the interplay between volcanic and bacteriological factors in the concentration of the conformable pyritic ores, and suggested that the absence of either factor precludes any significant concentration of sulphide. A combination of volcanic and biogenic processes was suggested by Williams (1965) and Searle (1968) to be responsible for the deposition of the massive ores at Rio-Tinto and Cyprus respectively. The results of the sulphur isotopes analyses of pyrites from the Cyprus massive ores clearly suggest that their precipitation was strictly inorganic and did not entail any bacteriogenic factors. This suggestion is also supported by the fact that pyrite was precipitated in open

spaces to form massive veins, in great depths in the stockwork zone, where it is most unlikely that biogenic contribution had occurred.

The importance of biogenic contribution in the formation of massive sulphide ores was also questioned by the experimental work of Rickard (1968). A survey of the literature indicates that, in the available organic analyses of shales, including bituminous shales, the organic matter rarely exceeds 10-12 per cent. Rickard (1968) had calculated that if all the organic matter in these shales were lactate, and all was utilized by bacteria, and that all sulphide produced by these bacteria reacted to form pyrite, only 2.5 per cent pyrite could be formed biogenically in these sediments; hence 60 to 120 feet of sediment would be necessary to form one foot of pyrite. These calculations are in agreement with the reported pyrite content (1-5 per cent) in black muds in a variety of sedimentary environments (Dunham 1961).

In Cyprus the precipitation of the massive ore was brought about inorganically and probably involved rapid formation of pyrite from aqueous solution. Recent experiments indicate that pyrite forms rapidly from aqueous solutions when oxygen is excluded from the environment and the pH of the latter is not higher than 6.0 (Roberts et al 1969). These experiments indicate also that the effective reagents bringing about rapid formation of pyrite are the ferrous iron and the disulphide ion. The latter is formed by the action of H_2S in aqueous solution on elemental sulphur which is produced by the oxidation of H_2S by ferric iron. Thus the requirements for rapid deposition of pyrite are: (a) slightly acid and oxygen deficient environment and (b) sufficient supply of ferric iron and hydrogen sulphide.

In Cyprus such conditions are not unlikely to have had prevailed in the subaqueous fumoralic vents which are the probable loci of deposition of the sulphide ore. The main difficulty involved is the transportation of ferric iron in solution which is stable only in highly oxidizing and highly acid conditions (Garrels and Christ 1965). A plausible explanation is that the ferric iron was transported as chloride complexes. This hypothesis is supported by data from fluid inclusions, recent fumaroles and geothermal springs which indicate that the ore fluids contain

considerable amounts of chloride.

In ChapterVIIit was suggested that the Cyprus massive ores originally consisted of ore similar to the hard compact ore of the Skouriotissa orebody. These ores were made up of zoned and to a lesser extent unzoned pyrite I which contained anhedral grains of chalcopyrite and sphalerite. Thus for the understanding of the formative conditions of these ores the understanding of the mechanism of deposition of the Pyrite I is crucial. Using mineralogical and tectural observations as well as experimental data on the chemistry of pyrite formation, some speculative suggestions are made about the formation of pyrite I of the Cyprus massive ores.

The coarse grained nature of pyrite I suggests that it was not formed from colloidal dispersions but from reactants in solution (Chukrov 1966) and that the concentration of the reactants was much lower than 10^{-2}M (Richard 1968). Textural studies have shown that in many cases in a single zoned crystal there are zones of collomorphic pyrite sandwiched between zones of euhedral pyrite (Plates 3.47, 3.54). The collomorphic pyrite probably was precipitated from reactants with higher concentration than the concentration of reactants which formed the euhedral pyrite. This suggests that during the formation of the massive ore there was a fluctuation in the concentration of the ore forming solutions. Changes in the concentration of the reactants seem to be also responsible for the commonly observed changes from cubic to octahedral habit of the euhedral zones in single zoned pyrite crystals (Plates 3.47, 3.54).

The forms and textures of the zoned pyrite in the Cyprus ores are similar to those of the zoned pyrite in the Rio Tinto ores. For the Rio-Tinto ores the mechanism of growth of the zoned pyrite was thoroughly discussed by Read (1968) and the proposed mechanism appears to be also applicable to the growth of zoned pyrite in the Cyprus ores; Read (1968) reported differences in the copper content of the individual growth zones of single pyrite crystals. Detailed electron probe investigations have shown that such differences are not detectable in the zoned pyrite of the Cyprus ores.

Mineralogical and textural studies indicate that in the Cyprus ores the growth of zoned pyrite commonly has a complex history. Thus the growth of the individual zoned pyrite crystals was frequently interrupted and already formed pyrite was partly dissolved. This suggests that during the precipitation of the massive ore the physicochemical conditions of the formative environment were changing to such an extent that already formed pyrite was not in equilibrium with this environment and dissolved. New favourable conditions resulted in the precipitation of new zones of pyrite which trapped within them the partly dissolved zones of pyrite and produced . pyrite crystals similar to that illustrated in plate 3.48.

Conclusions

Notwithstanding the fact that the Cyprus massive ores, spatially and genetically, constitute an integral part of the prolonged and episodic submarine volcanism of the Troodos Pillow Lavas, their formative conditions are not conclusively determinable. The structural, chemical, mineralogical and textural alteration which the massive ores had undergone during their submarine leaching made the conclusive determination of the nature of the original massive ore difficult. Uncertainties also arise from the difficulty to determine the mechanism of transport of the ore forming solutions, the physicochemical features of these solutions, and the physicochemical conditions which prevailed in the loci of concentration of the sulphide ores.

Data obtained from the present investigation suggest that the most probable original structure of the Cyprus massive ores is that of the hard compact ore found at Skouriotissa. Both the iron and sulphur of the massive ores have a magmatic source, and were supplied through fumarolic activity during hiatuses in the volcanicity of the Troodos Pillow Lavas. The fumarolic activity was subaqueous and most probably took place in caldera-like depressions not connected with the sea but filled with water. The most likely carrier of the ore metals was a near neutral solution containing abundant H_2S and chloride. The iron most probably was

transported in the form of aqueous chloride complexes.

The accumulation of the massive sulphide ores was strictly inorganic and did not entail any biogenic processes. The formation of pyrite most probably was brought about by the reaction of ferrous iron with disulphide in aqueous solutions and under reducing and slightly acid conditions. Mineralogical and textural data suggest that the concentration of reactants was generally low but fluctuating. The same data also suggest that during the accumulation of the massive ore the formative conditions were changing and frequently already formed pyrite was not in equilibrium with the formative environment and was partly dissolved.

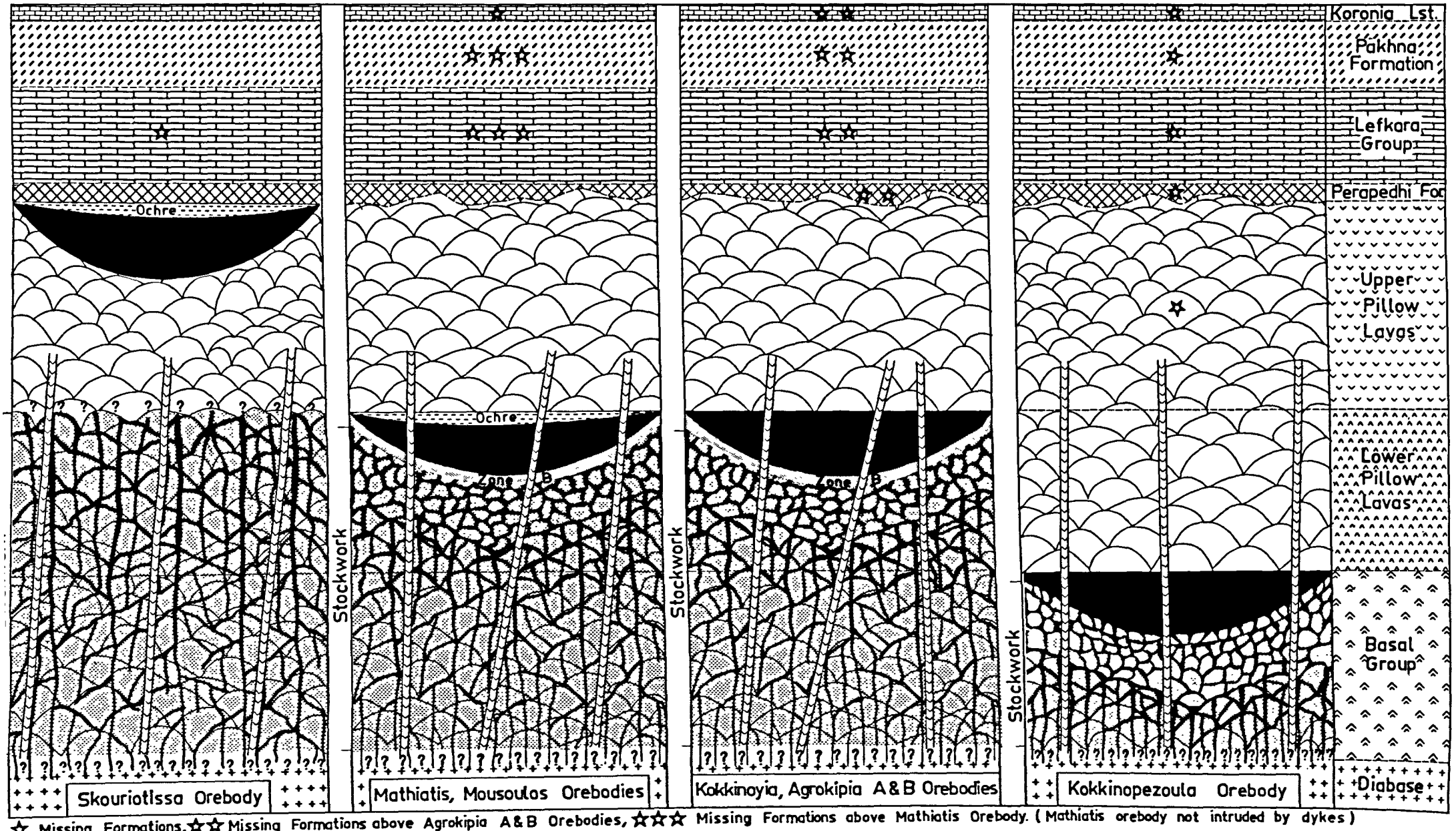
CHAPTER XII

SUMMARY AND CONCLUSIONS

The seven orebodies studied, e.g. Skouriotissa, Kokkinopezoula, Agrokipia A, Agrokipia B, Kokkinoyia, Mathiatis and Mousoulos occur in the Skouriotissa, Tamassos and Kalavassos Mining Areas. The above orebodies and the other massive sulphide deposits of Cyprus are restricted to the Troodos Pillow Lavas that flank the Troodos Igneous Complex and are flanked by younger Upper Cretaceous to Recent sedimentary rocks. The Troodos Pillow Lavas represent products of a Mesozoic submarine basaltic volcanism that probably took place by fissure eruptions. These lavas in ascending sequence have been divided into three stratographic units:- The Basal Group, the Lower Pillow Lavas and the Upper Pillow Lavas. The Cyprus sulphide ores occur at different stratigraphic horizons and constitute an integral part of this submarine volcanic sequence (Fig. 12-1).

Among the seven orebodies considered here, Kokkinoyia, Agrokipia A part of Agrokipia A, Mathiatis and Mousoulos are overlain by unmineralized olivine basaltic Upper Pillow Lavas; Kokkinopezoula is partly overlain by unmineralized Lower Pillow Lavas whereas Skouriotissa overlies unmineralized olivine basaltic Upper Pillow Lavas. Many of these orebodies are intersected by unmineralized dykes similar in composition and texture with the feeder dykes to the olivine basaltic Upper Pillow Lavas. Field and laboratory data obtained from this research indicate that the unmineralized basaltic dykes had intruded into these orebodies after their formation. This suggests that after the formation of many sulphide ores there was a renewal of volcanic activity and younger olivine basaltic Upper Pillow Lavas were deposited over many sulphide ores. This is important for future exploration and suggest that concealed sulphide deposits should be sought beneath the olivine basaltic Upper Pillow Lavas which are post-mineralization in age.

Umber is the first sediment deposited after the extrusion of the Troodos Pillow Lavas. It constitutes the base of the Perapedhi Formation (Fig. 12-1) and overlies unconformably the lavas. The umber forms sporadic outcrops which fill irregularities on the lava surface. It is generally massive, fine grained and soft and has a chocolate-brown colour. The umber is commonly associated with radiolarian cherts, silts, grits and conglomerates but in the three mining areas considered



☆ Missing Formations, ☆☆ Missing Formations above Agrokipia A&B Orebodies, ☆☆☆ Missing Formations above Mathiatis Orebody. (Mathiatis orebody not intruded by dykes)

Fig. 12–1. Schematic sections showing the vertical zoning of the ore in the orebodies studied and their probable relationship to the Troodos Pillow Lavas and the overlying Sedimentary succession

the umber is not associated with radiolarian cherts. Chemically the umber consists mostly of iron and manganese oxides, silica and alumina. Optical studies and X-ray diffraction analyses indicate that the umber contains very little crystalline material, mostly goethite.

In the past, many geologists suggested that the umber is genetically related to the sulphide mineralization. However, the unconformable relation between the olivine basaltic Upper Pillow Lavas and the umber as well as the evidence of pre-umber erosion of these lavas indicate that there is a considerable time-interval between the end of volcanicity and the commencement of umber sedimentation. Moreover most of the orebodies considered were definitely formed before the extrusion of the olivine basaltic Upper Pillow Lavas. Therefore field evidence leave little doubt that the umber is post-mineralization in age. Furthermore the trace element assemblage of the umber is clearly related to the volcanic rocks and not to the sulphide ores. This suggests that the metals of the umber were essentially derived from the lavas and not from the sulphide ores.

Ochre is a manganese-poor, iron-rich sediment which directly overlies the Skouriotissa, Mathiatis and Mousoulos orebodies and is locally associated with other sediments such as cherts, tuffs and silicious limestone. It is normally restricted to the boundaries of the sulphide deposits and contains sulphides in the form of layers, fine bands and disseminations. It is commonly well bedded and locally exhibits graded banding and washouts. The ochre consists mainly of poorly-and well-crystalline goethite, traces of maghemite and variable amounts of quartz. Optical studies indicate that the ochre-sulphide ore contact is invariably gradational and the goethite and maghemite of the ochre are replacing the pyrite of the sulphide ores. The trace element assemblage in the ochre is very clearly related to the underlying sulphide ores. This relation becomes less distinct with increasing distance from the sulphide ore-ochre contact.

The terms umber and ochre have long been confused in Cyprus, but in the present research is shown that these two sediments have distinctly different field dispositions, petrological and mineralogical characters as well as major and minor element assemblages. Field evidence suggest that there was a considerable time-interval between their deposition, in some places represented by the volcanic phase of

basaltic lavas (Fig. 12-1).

It is suggested that the ochre at Skouriotissa, Mathiatis and Mousoulos were essentially derived from submarine oxidative leaching of the underlying sulphide ore. Seawater, even with very low partial pressure of oxygen is an oxidizing solution and its oxidation potential is higher than the upper immunity domain of pyrite. Thus when these deposits were exposed on the sea floor the pyrite was liable to oxidation. Two distinct mechanisms of oxidation are suggested. The first mechanism involved dissolution of pyrite followed by precipitation of hydroxides and oxyhydroxides from solution. The second mechanism involved alteration of pyrite to oxide via a solid-state, probably topotactic reaction. The close spatial and genetic association of the ochre with the sulphide ores makes its identification a very useful exploration procedure in the search for new sulphide deposits.

The sulphide deposits considered, lie mostly on mineralized and hydrothermally altered lavas which extend downwards to considerable depths. They are surrounded by unmineralized lavas which are in faulted contact with them and are variously overlain conformably by ochreous sediments and/or lavas. Some of them are partly overlain by gossans. When account is taken of post-mineralization faulting and tilting most of the deposits have a saucer-shaped disposition and are characterized by a distinct vertical zoning. Their upper part is occupied by a zone of massive ore containing more than 40 per cent sulphur, underlain by a zone of sulphide with quartz containing 30-40 per cent sulphur which in turn is underlain by the stockwork zone containing less than 30 per cent sulphur (Fig. 12-1).

At Skouriotissa, two distinctive structural types of massive ore have been recognized. The first type has a conglomeratic structure and is characteristic of the massive ore of the other investigated deposits. It consists of blocks of solid sulphide (angular, spheroidal or pillow-shaped) embedded in a matrix of sandy friable and highly porous sulphide ore. The solid sulphide blocks are porous and are characterized by colloform banding. The second type consists of large blocks of hard compact ore separated by fractures which are filled with sandy friable ore. The compact ore is much less porous than the conglomeratic ore and is devoid of colloform banding.

The predominant mineral in the massive ore is pyrite. Three paragenetic types of pyrite have been recognized designated Pyrite I, II and III. Pyrite I is euhedral to subhedral and is mostly zoned. It is the most common type of pyrite in the hard compact ore while in the conglomeratic are it is found in greatly varying proportions. Pyrite II is subhedral to anhedral. It is found in both structural types of massive ore and truncates the pyrite I. Pyrite III is found in the form of continuous or discontinuous colloform bands, simple and composit spheres as well as framboids. It is restricted to the solid sulphide blocks of the conglomeratic ores and truncates both Pyrite I and Pyrite II.

Marcasite is highly variable in the massive ores. In some deposits it is very common in others it is very rare and in some it was not identified. It appears to be contemporaneous with or later than Pyrite III. Chalcopyrite is invariably present in the massive ores but its concentration is highly variable. In the upper parts of some deposits it is highly enriched where it fills cavities in pyrite frequently enclosing or cementing together corroded pyrite. Small proportion of chalcopyrite occurs in the form of anhedral inclusions in pyrite I. Sphalerite is less common than chalcopyrite but is invariably present in the massive ore. Its mode of occurrence is similar to that of chalcopyrite. Rare pyrrhotite and variable amounts of covellite, digenite, chalcocite and bornite were identified in the massive ores of most of the investigated orebodies. Trace amounts of galena and tennantite were identified only at Agrokipia B whereas idaite, paramelaconite, tenorite, mackinawite and delafossite were identified at Skouriotissa.

It is suggested that the massive ore of the Cyprus deposits initially was made up of compact pyritic ore. It mostly consisted of zoned pyrite I which contained inclusions of anhedral chalcopyrite and sphalerite. The compact pyritic ore was probably formed in caldera-like depressions through subaqueous fumarolic activity during hiatuses in the volcanism of the Troodos Pillow Lavas. The ore forming constituents have a magmatic source and probably were transported by near neutral solutions which contained H_2S and aqueous chloride complexes of iron. The accumulation of pyrite was inorganic and was probably brought about by the reaction of ferrous iron with disulphide in aqueous solution under reducing and slightly acid conditions. The growth of Pyrite I was

a complex procedure and involved fluctuations of the concentration of the reactants and periods of growth interrupted by periods of dissolution.

At a stage of their geological history the compact pyritic ores were exposed on the seafloor. The contact of the sulphide ore with the oxygenated seawater caused the oxidation of the zoned Pyrite I and the production of ferric sulphate via ferrous sulphate and sulphuric acid. The ferric sulphate was carried down to lower levels in the orebodies and caused the oxidative leaching of zoned pyrite and the included chalcopyrite and sphalerite. Leaching of the pyritic ore probably was also caused by electrochemical processes. The products of leaching were partly lost in the sea or took the form of precipitates of iron hydroxides and oxyhydroxides (ochre) or were transported downwards in solution to be precipitated as sulphides.

The conglomeratic structure of the massive ore, the high porosity and colloform texture are considered to be secondary features which resulted from the submarine leaching of compact pyritic ore. The sandy friable matrix of the conglomeratic ore is considered to represent the extreme effects of dissolution whereas its solid sulphide blocks represent remnants of compact ore which have developed in the same manner as spheroidal weathering.

Pyrite II, marcasite and pyrrhotite are believed to have been precipitated from secondary solutions. Pyrite III is essentially a remnant form of Pyrite I, although some of it probably represents secondary precipitate from solution. The high but erratic concentrations of copper and zinc which occur in the conglomeratic ore of some orebodies are considered to have been derived from leaching of chalcopyrite and sphalerite in Pyrite I and represent a submarine secondary enrichment zone.

Among the seven orebodies considered here the Zone B is well developed at Mousoulos, Mathiatis and Kokkinoyia. This zone consists of very hard medium grade ore containing 30-40 per cent sulphur and variable amounts of copper and zinc. The

sulphides are intimately mixed with silica. The most common sulphide is Pyrite I, mostly unzoned, intensely corroded and replaced by silica. Chalcopyrite is the second most common sulphide but at Mathiatis sphalerite is more common than chalcopyrite. Structural and textural relations suggest that silica is later than all the sulphides and most probably the zone B owes its character to replacement by silica of the lower parts of the massive ore.

Most of the orebodies studied are underlain by a stockwork zone which extends downwards to depths exceeding 700 metres. Skouriotissa is the only orebody which has no stockwork zone under the massive ore although such a zone occurs at the southwestern end of the orebody. The upper part of this zone consists of mineralized brecciated lavas whereas its lower parts consist of mineralized lavas with preserved pillow structure (Fig. 12-1).

In the stockwork zone the sulphide mineralization is represented by sulphide veins and disseminations of pyrite in the mineralized lavas. In the veins the character of the sulphides is similar to that of the primary sulphides in the massive ore. The contact of the veins with the enclosing lavas is sharp and there is no evidence of replacement of the lavas. Very often the original texture of the mineralized lava is preserved with marvelous fidelity even at its contact with sulphide veins. Plagioclase and pyroxene are pseudomorphed by quartz and the glassy matrix is replaced by chalcedony chlorite and illite. It is believed that the sulphide veins filled fractures and cavities in the lavas and represent feeder channels for the overlying massive ore.

The mineralized lavas are impregnated with fine grained pyrite which very often is similar in form and amount with titaniferous magnetite in unmineralized basaltic lavas. The mineralized lavas contain no magnetite but inclusions of leucoxene are common in the disseminated pyrite. It is believed that most of the pyrite impregnating the lavas was produced by sulphurization of magnetite and from iron released from the ferromagnesian minerals and the glass in the lavas. No chalcopyrite or sphalerite were observed impregnating the lavas. The mineralized

lavas in addition to pyrite contain abundant quartz and variable amounts of chlorite and illite. Montmorillonite is invariably absent and is believed to characterize the unmineralized basaltic lavas in which it is very common and is associated with zeolites and chlorophaeite.

APPENDIX A

Impregnation of umber, ochre and soft friable sulphide ore for the preparation of polished sections.

In the past the preparation of polished sections for the optical study of ochre, umber and soft friable sulphide ore was difficult. In the present research the optical study of these rock types was considered to be of great importance. Various techniques were tested by Mr. B. Foster of the Laboratory of Ore Mineralogy for the impregnation of these rocks to prepare polished sections. The technique described below is considered to be the most effective.

For the impregnation of samples of ochre and umber was used a mixture of Araldite resin AY 18 and Araldite hardener HZ 18. The mixing ratio of resin and hardener is 100:75 by weight; the viscosity of this mixture at 21°C is 0.2 poises. The specimen is heated in an oven at a temperature of about 40°C for the removal of moisture. Then the specimen is submerged in the araldite mixture and the container is placed in vacuum decicator and evacuate for 13-30 minutes depending on the individual specimen. To avoid boiling we evacuate for one minute and stop until the bubblesin the araldite mixture disappear. Then the specimen is placed in silver foil and is cured in an oven for 3-4 hours at about 60°C. When the specimen is set the normal procedure of polishing is followed.

For the impregnation of sandy friable as well as highly porous solid sulphide ore was used a mixture of Araldite resin AY 103 and Araldite hardener HY 951. The viscosity of this mixture at 21°C is 18 poises, and if it is needed it can be thinned with acetone but in this case it boils readily under vacuum. The impregnation procedure is similar to that described above for samples of umber and ochre.

APPENDIX B

Spectrochemical analyses of pyrite and chalcopyrite

1. Sample preparation

All the samples were crushed down to -150 +200 B.S. mesh. In the samples of the massive ore the rare quartz was removed with Tetra-Bromo Ethane (T.B.E.) (sp. gr. 2.95 gr/cm^3) heavy liquid, which has a specific gravity 2.95 gr/cm^3. The chalcopyrite sphalerite and covellite were removed from the pyrite with the Franz Isodynamic magnetic separator. In the samples of Zone B the separation of the pyrite from the finely intermixed quartz was more difficult and was done with repeated heavy liquid separations. The rest of the chlorite was removed with the electromagnetic separator.

Examination of the separated samples with the binocular microscope indicated that their pyrite was very pure. X-ray diffraction analyses of several samples indicated that only pyrite was present. Furthermore the pyrite of the samples was investigated microscopically in several polished sections of pure pyrite samples. This investigation showed that only rare chalcopyrite and sphalerite were present as minute inclusions in the pyrite. Because of these inclusions, the copper and zinc contents in the pyrites were not determined.

The chalcopyrite grains for the spectrochemical analysis were first handpicked with the aid of binocular microscope. The handpicked grains were crushed down to -150 +200 mesh; the quartz was removed with heavy liquid (T.B.E.). Finally the chalcopyrite was separated from the pyrite with the Franz isodynamic magnetic separator.

2. Analytical method

The trace elements Cr, Mn, Ti, Co, Ni etc. were determined quantitatively using the Hilger Large Quartz spectrograph (E 742). The method used is a modification of that proposed by Brey (1942) employing a cathode layer technique with Pd as internal standard.

Finely-ground pure pyrite samples were mixed with an equivalent weight of high purity carbon powder containing 0.04% Pd as internal standard. Pyrite samples were preheated for 20 seconds in a Bunsen burner after loading into electrode to stabilize the burn and prevent sample loss. Samples were burnt to completion and spectra recorded on Kodak B10 plates under conditions shown in Table 1.

Line densities were measured on an A.R.L. microphotometer and converted to relative intensities by means of the self-calibration procedure of Ahrens and Taylor (1961). A transformed density function was used to correct for lines of low intensity and background corrections were made for all analytical lines. The relative intensities thus obtained were related to those of standards by means of working curves.

Standards for use in the analyses of pyrite and chalcopyrite were made by successive dilutions of a ZnS standard with Fe_2O_3. No matrix effects were encountered as a result of the variation in the Zn/Fe ratio of the standards. The precision of the method expressed as a relative deviation is found to be within $\pm$ 15%. (Check sample was the C.A.A.S., standard sulphide ore number 1).

The volatile elements Ag, Mo, Ag and Ga, which were below sensitivity for most of the samples, were redetermined by R. Berlin (Pure Geochemistry Department, Personal Communication) in a selection of samples using a highly sensitive volatile technique (Tennant 1967). Samples are mixed with an alumina-lime buffer containing Re as internal standard and the mixture is arced as an anode in a graphite cup electrode. Arcing conditions are carefully controlled to allow distillation of the volatile elements only. Concentrations in the unknown samples were determined by comparison with a synthetic pyrite standard and the Canadian Standard Sulphide ore. By this method the detection limit was lowered to the values shown in Tables 9-1 and 9-2 (Chapter 9).

Table 1

ARCING CONDITIONS

Slit width	12 microns
Slit height	11 mm
Electrode Gap	10 mm
Step Sector 7 steps	7 steps Ratio 1:2
Current	9 amps D.C.
Electrode Carbon	Ringsdorft Grade R.W.203 Cathode 8 mm (depth) x 2.8 mm ext. diameter x 0.8 mm internal diameter Anode Flattened carbon rod R.W. 203.
Arcing time	To completion Approx. 2 min. 30 secs.
Internal Standard	0.04% Pd in Ringsdorft R.W.B. Carbon.
Sample Preparation	Samples mixed with equal weight of carbon powder with internal standard.
Optics	Cathode layer portion of arc imaged on collimating lens.
Plate Development	Kodak B.10 plates developed for 3 min at 20°C in Kodak D19B developer and fixed in Kodak Unifixer.

Table 2.

WAVELENGTH IN A° USED FOR EACH ELEMENT

Element	Wavelength A°
Mn	2798.27
V	3185
Ni	3050
Co	3453
Ag	3382.89
Cr	4254.35
Ti	3168.52
Mo	3170.35
Pb	2833.07
Ga	2943.64

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