GEOLOGICAL AND MICROSCOPICAL STUDY OF SOME COPPER DEPOSITS OF CHINA.*

BY C. Y. HSIEH 謝家榮

I. INTRODUCTION.

Our knowledge on the Chinese mineral deposits becomes greatly enhanced since the publication of Dr. W. H. Wong's monograph "The Mineral Resources of China"(1) which appeared in the year 1919. Besides a systematic description of different resources of China, this work deals also in a concisive way the relationship between geology and ore deposits and discusses very eminently the metallogenic epochs and metallogenic provinces. It lacks, however, detailed investigation of the mineral deposits along the petrographical and chalcographical ways, which in the light of modern economic geology are indispensable for a better understanding of their genesis and classification. The present communication is intended therefore to make a little contribution along these lines which until now have not yet been seriously considered by the workers of Chinese geology.

The material for the present investigation consists of a collection from E. Yunnan and S. Szechuan by V. K. Ting in 1914, and the writer's own collection (together with C. C. Liu) from S. E. Hupeh during the year 1923. A preliminary study on these two collections has already been made by H. T. Lee and a part of his result is published(2) recently in the Bulletin of the Chinese Geological Survey.

The writer wishes to take this opportunity to thank Directors W. H. Wong and H. T. Chang of the Chinese Geological Survey for their inspiration and help of various ways. To Dr. V. K. Ting, the writer is indebted for his note on the Geology of E. Yunnan and S. Szechuan and to Mr. Lee for the using of the polished sections of ore specimens which were prepared under his direction.

My hearty thanks are also due to Prof. Schneiderhöhn and Dr. Cissarz of the mineralogical department of the University of Freiburg i. B. Germany for their valuable suggestions and criticism throughout the work.

---

* Research supported by the Sino-Japanese Indemnity fund and is conducted partly in the Microscopical Mineralogical Department of the University of Freiburg i. B. Germany

II. COPPER DEPOSITS OF TA YEH AND YANG SIN IN S. E. HUPEH.

(1) GENERAL GEOLOGY*

In the southeastern part of Hupeh within the great elbow of Yangtze, there rises a series of old to maturely dissected mountains which trend approximately from east to west and are roughly parallel to each other. The geology (See Pl. I, geological sketch) consists of a mighty series of sedimentary rocks ranging in age from Ordovician to Jurassic.[1] The series has been intensely folded, the axis of folding running roughly from east to west, i.e. in close accord with the mountain system of the region. Two intrusive masses of grano-diorite, both of which occupying a rather wide area are found. The northern mass occurs at south of O-Cheng and north of Ta Yeh. It extends from the western bank of Yangtze to as far as about 20-30 km. further west into the inland. At its contact with the Permian limestone, this igneous magma has furnished and formed a valuable ore deposit, i.e. the famous iron deposit of Ta Yeh which has since earlier time been extensively mined and formed until now one of the most important mining enterprises of China. The southern mass is found between Ta Yeh and Yang Sin, being situated about 30 km. from the bank of Yangtze. The areal distribution of this mass is more scattered as compared with the northern one, and moreover, the rock is more weathered and decomposed and consequently it forms generally low and rolling hills. The igneous rock is seen here to intrude into both the Carboniferous limestone, and the sandstone and shale series of Lower Silurian age. At its contact with the limestone and the sandstone and more rarely also with the sandstone, the igneous after effect has originated a deposit of another nature as compared with the northern mass, although the geological and physical conditions under which the two deposits were formed, must have been nearly the same. It is the copper deposit of Ta Yeh and Yang Sin which forms the topic of the present chapter.

(2) DISTRIBUTION OF DEPOSITS.

Copper deposits in the forms of irregular replacement bodies or veins are widely distributed in S. E. Hupeh. They are found at the contact zone between mostly limestone and grano-diorite, but less

---

* Based on author's own observation.

Since the present manuscript was written, the writer has received from the Institute of Geology, Shanghai, the report of L. F. Yih and K. P. Chao (18) on the geology and mineral deposits of the same region as is here described. This work contains a geological map on the scale of 1:100,000. It has added undoubtedly a great deal to our knowledge of the geological condition of this deposit.

frequently they occur also exclusively either in diorite or in limestone. A well defined contact zone consisting of solid garnet mixed with some pyroxene and amphibole is observed in most of the deposits investigated. Until now the following districts have been known to contain copper deposits and some of them have been already prospected:

Niu Tou Shan (牛頭山): This deposit is situated at about 2 km. S. E. of Pei Sha Pu (白沙舖), one of the principal towns of the Yang Sin district. The main range of Niu Tou Shan and its vicinity are composed in the main of grano-diorite, while limestone which crops out only in the neighbourhood of the deposit, is found to occupy a very limited extent. Most probably the limestone forms here a cap floating on the dioritic lacolith. Copper deposits consisting chiefly of bornite and chalcopyrite are found almost exclusively in the contact zone between limestone and diorite, the contact line running approximately from S. W. to N. E. From Niu Tou Shan toward N. E. and then to N. W. the contact metamorphic zone continues almost without interruption to as far as Liu Hsü Shan (劉許山) and Han Chia Shan (韓家山). The whole of the cantact zone measures about 15 km. or more in length.

At the time of visiting in 1923, the copper deposit of Niu Tou Shan was worked by the Kai Yang Mining Co. A tunnel about 15 m. long has been opened lying entirely in the contact zone and several side drifts directing toward the dioritic body. Inside of the tunnel, a shallow pit about 7m. deep has been sunk with the object to prospect ore in deeper horizon, but it was soon abandoned, evidently because of the lack of promising indication. The whole work of the Kai Yang Mining Co. was abandoned during 1924, after a year's prospecting, during which period a little amount of ore of about several thousand tons was produced.

Liu Hsü Shan (劉許山): This deposit is located about 5 km. N. E. of Pei Sha Pu, being on the slope of Chih Ma Shan (七馬山), a lofty hill composed chiefly of Carboniferous limestone. Grano-diorite crops out on the western foot hills of the range. Right at the contact between limestone and diorite, there occurs a garnet zone measuring 6-8 m. in width and maintaining a direction from N. W. to S. E. Chalcopyrite with abundant specularite and magnetite are found as disseminations in the garnet rock which is also accompanied by actinolite and other amphiboles.

From Liu Hsü Shan the contact zone continues a few km. further to the N. W. and forms there the copper deposits of Li Chia Shan (李家山) and Han Chia Shan which were however not visited by us.

Ou Yang Shan (歐陽山): This is a deposit which represents mineralization almost exclusively in grano-diorite. It is located at about 2 km. west of Pei Sha Pu. Behind the mine building is a high range called Chih Feng Shan or seven peak hill. Only grano-diorite is found, but near to the mine building, a little limestone was also seen. This deposit was prospected before 1919 by the Hupeh Provincial Mining Administration. At that time one pit and one tunnel were opened up, the former being located near to the contact between a limestone in the north and a grano-diorite in the south. The igneous rock here has been profoundly altered to a greenish chloritic and sericitic rock (see below). The mineralized zone seems to trend about N.60°W. Ore is said to be very rich and formed at that time one of the most promising prospects. It consists of malachite, azurite, chalcocite, bornite associated with quartz, calcite and some other minerals. The shaft is said to be about 60 m. in depth.

Lung Chiao Shan (龍角山): Lung Chiao Shan is a high and steep hill lying about 13 km. N. W. of Pei Sha Pu and being about 500 m. above the adjacent valley. The top of the hill and a part of its upper slope is composed of Carboniferous limestone, under which comes an alternation of quartzitic sandstone and phyllite of Lower Silurian age. A small outcrop of grano-diorite is found at about half a kilometer S. W. of the house of the former mining building which is located on the upper middle part of the main range. The diorite is coarse grained, containing feldspar, mica and hornblend and is spotted throughout with grains of pyrite.

Copper deposits in the forms of irregular pockets are found near the contact between limestone and quartzite. It contains a great amount of pyrite besides some bornite and chalcopyrite. The deposit was worked some ten years ago by the Hupeh Mining Administration with the development of four prospects all lying near to the contact zone. One of the prospects, a shaft of about 30-50 ft. in depth, was sunk in an area of profoundly altered limestone, which is a marble rich in garnet and other contact métamorphic minerals. All the prospects are distinctly marked by 'Eisener Hut' which is composed of limonite and quartz in cellular structure and occasionally also copper stains.

(3) THE GRANO-DIORITE.

The grano-diorite,* to which the origin of the copper deposits of Ta Yeh and Yang Sin is chiefly to be accounted for, is found in the ore bearing district to be intruded into both Silurian and Carboniferous formations. In the iron range of Ta Yeh, the same igneous rock has been found to intrude into the Upper Permian limestone, while in still another place, for instance at south of O-Cheng, where the igneous rock is in contact with Jurassic coal series, the latter is seen to be distinctly metamorphosed by the former. These relationships indicate the age of the grano-diorite to be at least Post Jurassic.

To the naked eye the grano-diorite is a medium to coarse grained rock exhibiting a gray to pinkish color, the latter phenomenon is evidently due to the presence of orthoclase. Hornblende is very abundant, and in some cases also biotite, both being clearly discernable by examining with a lens. Quartz is certainly present, but rarely visible in hand specimens.

In most cases the rock has been profoundly altered and weathered to form in its superficial portion a loose, disintegrated mass, or in its extreme case, a laver of sand. On account of its easily disintegrated nature, the topograpy which is distinctly in contrast with the lofty aspect exhibited by both the Carboniferous limestone and the Silurian sandstone and shale series. It is to be noted that the two principal highways from north to south of this region, during their crossing of the watershed, have chiefly followed the much more decomposed, low lying areas of the grano-diorite. (see Pl. I geological sketch).

A specimen of fresh grano-diorite from Ou Yang Shan when examined under the microscope is seen to contain the following minerals:

Plagioclase : It occurs in large tabular or prismatic form and constitutes the most abundant mineral in this rock. It is commonly twinned according to albite law, the twinning lamellae being not so broad and are rather equally

* According to C. L. Ho (19) the igneous intrusions of Ta Yeh and Yang Sin vary from granite to diorite. The northern mass which is in genetic relation with the Ta Yeh iron deposit is believed to be distinctly more basic than the southern one, the latter is the mother rock of the copper deposits. Consequently L. F. Yih seems to think that the difference in mineralization may be explained chiefly by a difference in their original magmatic composition, Whether this is really the case, it is certainly difficult to decide. On the other hand, the microscopical as well as chemical study of the rock—at least the specimen from Ou Yang Shan—all point to a grano-diorite of the basic rather variety. H.T. Lee reached in his report of the same conclusion. Can a rock of such composition be very much different from the intrusion at Ta Yeh ? For a satisfactory solution of the problem, accurate chemical analysis of the rock must be made besides a merely microscopical investigation.

spaced. Sections approximately perpendicular to α. shows an extinction angle (referring to twining lamellae) varying from 66°-76°, while that perpendicular to γ the extinction angle is only about 1°-3°. In the sections approximately lying in the zone perpendicular to 010, it shows an extinction angle about 10° or more. From these optical determinations, we are convinced that the plagioclase in question is an oligoclase-andesine. Even in the most fresh rock, the plagioclase shows some slight signs of alteration; it is partly coated with kaolin and along the cracks small veinlets of sericite can often be seen when carefully studied. The plagioclase seems to contain little inclusions, with the exception of some small crystals of apatite.

Orthoclase: Orthoclase is also common in this rock, but it is not so abundant as the plagioclase. It occurs usually in allotriomorphic massive forms. In sizes it varies from large masses to small irregular fragments, in the former case well formed plagioclase crystals are often seen to be embedded in it forming the characteristic poikilitic structure. The orthoclase contains numerous inclusions such as quartz, apatite and perhaps other minerals. Graphic intergrowth of quartz in orthoclase is commonly seen. The orthoclase is also slightly altered, being coated partly with a thin layer of kaolin, and traversed here and there by small veins of iron stains and sericite.

Quartz: Quartz is certainly present but only in small quantity. It occurs generally as interstitial filling and to represent evidently the last product of crystallization.

Hornblende: Hornblende is the most abundant mineral among the colored constituents of this rock. It occurs in large tabular but frequently more or less corroded forms and shows a green color with distinct pleochroism. Numerous inclusions such as apatite and less frequently also quartz and small crystals of plagioclase are found in hornblende. Even in the most fresh specimen, the hornblende is more or less altered, it shows a bleaching of color, chiefly due to the leaching of iron or to be coated partly with iron stains. In some cases it is seen that hornblende has been partly altered into biotite.

Biotite: Biotite is rather rare in this rock. It is brown in color but in most cases the color is considerably bleached as result of an alteration.

Among the accessory minerals, apatite is the most abundant one forming usually well formed idiomorphic crystals. Besides, there is some titanite occurring in the usual characteristic lozenge shape, and it seems to be always in close association with hornblende.

Pl. II, Fig. 1 shows a microphoto of thin section of the fresh grano-diorite in which practically all the constituents described above can be roughly made out.

A specimen of fresh grano-diorite collected from Liu Hsü Shan shows under the microscope, instead of hornblende, a fair amount of augite and moreover more biotite. Augite is slightly greenish colored, faintly pleochroic from light green to light brown. In addition to the prismatic cleavage, this appears in many cases another system of fine lines parallel to bases. On the border it is often altered to hornblende which is green and distinctly pleochroic. This is the well known process of uralitization. The optical study of plagioclase shows it also to be an oligoclase-andesine. It is however rarely twinned. There seems to be little orthoclase. A few interstitial quartz is present. Graphic intergrowth of myrmekitic quartz in orthoclase is also found. Inclusions of apatite in both augite and plagioclase are commonly observed.

Alteration of grano-diorite. From the old mine dump of Ou Yang Shan, the writer has collected a very interesting specimen of mineralized grano-diorite. It is most unfortunate that we could not know its exact location. The rock is an extremely altered grano-diorite exhibiting a pseudo-gneissic texture. To the naked eye the rock is composed of alternating layers of quartz and a pink colored mixture, evidently the alternation product of feldspar. Chalcocite veinlets, nests, or disseminations are seen to distribute throughout the whole mass, but it seems that they have a special tendency to follow closely the quartz layers. That mineralization taking place here after silicification is made clear from this relationship. Besides there are small and irregular veinlets of calcite cutting across the rock.

Under the microscope, the parallel arrangement of the quartz layers is still more apparent (Pl. II, Fig 2). The layer varying from 2-4 mm. or more in thickness is composed chiefly of granular quartz, but in which some altered biotite, and a fine mixture of sericite, chlorite and calcite are also found. Here and there are seen chalcocite disseminations or veinlets either to replace or to cut through the quartz layers. It is no doubt that here the quartz just as chalcocite were of secondary origin, i. e. to say they were introduced into the rock during the period of mineralization.

Practically no original minerals can be seen in this specimen except some small crystals of apatite which remain however in an entirely unaltered state. Biotite, though considerably bleached of its color and in some cases bended can still be recognized by its forms. It is light green to almost colorless. Feldspar and hornblende have been entirely altered and disappeared, and in their place is found now a fine mixture of sericite, chlorite, calcite and quartz. In some cases the original outline of feldspar (evidently plagioclase) is still preserved, though its interior has been entirely altered. Both sericite and chlorite are seen under higher magnification, to occur in small plates or scales, the latter mineral exhibiting usually a spherulitic extinction.

In another specimen of the altered grano-diorite from Ou Yang Shan which was collected from the surface and had evidently no ore deposits in its neighbourhood shows still more advanced degree of alteration. It is a fine grained, yellow colored rock. Under the microscope the rock appears to be composed almost entirely of an aggregate of chlorite, sericite and quartz with here and there isolated quartz and a few siderite. All minerals including biotite have been wholly altered; the only fresh original constituent in this specimen is apatite. The section is again coated in many cases with kaolin which is evidently a product of weathering.

Chemical Composition of Grano-diorite: A specimen of fresh grano-diorite from Ou Yang Shan in Yang Sin district has been analysed by Mr. K. Y. King of the Chinese Geological Survey who gives the following composition:

SiO_2	58.19	K_2O	3.27
Al_2O_3	19.74	H_2O+	0.49
Fe_2O_3FeO	6.18	H_2O-	0.15
MgO	1.24	TiO_2	1.89
CaO	5.62	P_2O_5	0.82
Na_2O	2.94	Total	100.53

Recalculating* the above composition according to the method of Niggli [4] we have the following values:

al = 40	si = 200	si' = 164
fm = 22.	k = 0.42	si-si' = +36 = Number of quartz molecules.
c = 20	mg = 0.28	
alk = 16		

The proportion of *c: fm* is 0.90. Therefore this rock should fall to "Schnittebene" No. 5 of Niggli's "Tetraederprojection."

* The same analysis has been calculated by H. T. Lee according to the method of the American investigator.

The above values coincide closely with some of the grano-diorite listed in Niggli's table. The similarity of *c* and *fm*, the moderate amount of *al* and *alk* and rather high amount of *k* are all characteristics for that rock. Further we can see that here *al* is distinctly greater than *fm*, the difference amounting to +18. The only divergence is perhaps a little too low in silica which for ordinary grano-diorite from 212-330. The number of quartz molecules reaches in this case therefore only +36 which means a weak acid rock. Accordingly, I shall call this rock as a grano-diorite of less acid variety.

(4) The Contact and Hydrothermal Metamorphism

One of the most conspicuous features observed in the Ta Yeh and Yang Sin copper deposit is the phenomenon of contact metamorphism as effected by the intrusion of grano-diorite in Carboniferous limestone. Almost in every deposit, the ore bearing zone is distinctly marked by numerous contact metamorphic minerals. So far as is known at present, the following minerals of undoubtedly contact metamorphic origin have been observed, namely garnet, wollastonite, tremolite, actinolite and diopside. It is quite sure that more may be discovered, when a further detailed and more urgent search is made.

Garnet: Garnet occurs in almost all the ore bearing zone, and forms without doubt the most abundant mineral. In fact it forms in many cases a solid rock reaching an extent of over 7-8 m. in width. According to the determination of Mr. Lee, the garnet of Niu Tou Shan is mostly grossularite, while in Liu Hsü Shan and Lung Chiao Shan is andradite. As will be seen from the following description, the ore of Liu Hsü Shan is rich in magnetite and hematite while the ore of Lung Chiao Shan is exceptionally rich in pyrite, all indicating an excess of iron in the original magmatic solution. The formation of an iron bearing garnet, i.e. andradite in both of these regions, where iron formed a conspicuous part in the magmatic solution, can therefore be easily explained. If this be true, then we can take this evidence as to indicate that the contact zone here must have been formed not only from a recrystallization of the original constituents of the sedimentary rocks, but a considerable part, for instance iron must have been introduced from the magmatic solution.

The thin section of the contact zone from Lung Chaio Shan shows large, irregular crystals of garnet embedded in a ground mass of calcite and quartz, the former occurs in large, allotriomorphic forms. At the boundary between garnet and calcite, there shows no slight disturbance in cleavage of the embedded mineral.

Along the cracks or in the ovoids of the garnet there occurs frequently idiomorphic formed quartz, needles of actinolite, biotite, chlorite and calcite. Copper ores in forms of disseminations or veinlets are also common in the garnet ; it seems that mineralization has taken advantage of the cracks or ovoids of the latter minerai.

Wollastonite : The contact zone of Niu Tou Shan is very rich in wollastonite which forms commonly a massive rock and is in intimate association with garnet, diopside, actinolite and apatite. Under the microscope the wollastonite is seen to occur in long, tabular crystals. It is colorless and exhibiting a moderate refringence and rather high birefringence. Pl. III, Fig. 3 represents microphoto of a thin section from Niu Tou Shan in which replacement of wollastonite by the copper minerals (bornite and chalcopyrite) is distinctly shown. Replacement seems to follow frequently along the cracks or boundaries of different crystals, less frequently it goes also along the cleavage. One noted feature is the presence of an appreciable amount of apatite occurring as inclusions in the wollastonite, the latter is crossed in many cases also by calcite veinlets.

Diopside (Heden bergite): This mineral is rather rare in the specimens studied. It is found only in Niu Tou Shan being in close association with wollastonite. It is most probable that both of these minerals were crystallized at about the same time.

Tremolite : Tremolite occurring in the usual acicular forms and often radially aggregated is found in the contact zone at Lung Chiao Shan. The aggregates form pockets or veinlets in a fine grained marble. Patches or irregular grains of ore (mostly pyrite) are seen to replace both tremolite and calcite as are clearly shown in Pl. III, Fig. 4.

Actinolite : Actinolite in small amount is present in all the districts investigated, it occurs usually as ovoid filling in garnet (Fig. 5) or as small veinlets or inclusions in other contact metamorphic minerals. It seems that this mineral together with tremolite were the last one formed and represent product of the last phase of the formation of heavy silicate by the contact metamorphic action. On the other hand, actinolite was formed evidently before the deposition of ore, because the former is seen in many cases to be replaced by the latter. Pl. IV, Fig. 5 shows microphoto of a thin section of an actinolite veinlet from Liu Hsü Shan, in which acicular and radiating crystals of actinolite are abundantly embedded in a ground mass of garnet and calcite. The mineral is green in color and is distinctly pleochroic.

Besides the minerals described above, there occurs also in the contact zone, especially in close association with garnet, nests of chlorite and patches of biotite, the former occurs in radiating aggregates and exhibiting a distinct spherulitic extinction, while the latter is brown in color and showing no evidence of alteration. They were formed evidently much later than the other contact metamorphic minerals and represent products of hydrothermal alteration. The occurrence of apatite has already been mentioned. Whether this mineral was formed as a result of contact metamorphic action or it represents a product of late process is at present difficult to decide.

Distinct evidence of hydrothermal metamorphism can be best seen in the altered or mineralized grano-diorite from Ou Yang Shan, a petrographical description of it has already been given in the foregoing paragraph. That this alteration is clearly of hydrothermal origin is evidenced by the occurrence of numerous chlorite and sericite, and the formation of abundant secondary quartz. The last named mineral, on account of certain unknown reasons, has arranged roughly in a parallel position, thus giving rise to a pseudo-gneissic texture of the rock. Some chlorite and secondary quartz are also found in the marble of Lung Chiao Shan in which chlorite often forms small veinlets in pyrite or to send projections into it indicating clearly that pyritization preceeds chloritization.

From the above description based chiefly on microscopical study of the country rocks, we can conclude that as an igneous after effect of the grano-diorite intrusion in Ta Yeh and Yang Sin there have occurred two distinct processes of alteration, namely: an older one formed under the high temperature and pressure and is of contact metamorphic origin, and a younger one of hydrothermal action. The latter phenomenon, so far as is known in the present, is best developed in the grano-diorite of Ou Yang Shan though to some extent it can also be seen in the Lung Chiao Shan and Niu Tou Shan. Besides recrystallization of limestone into marble, the contact metamorphism has accompanied with an appreciable introduction of foreign material from the magmatic source. The relative order of crystallization between the different contact metamorphic minerals, so far as can be determined, is roughly as follows: garnet, diopside and wollastonite, tremolite and actinolite. A superimposing of hydrothermal action upon contact metamorphism is observed in the deposits of Lung Chiao Shan and Niu Tou Shan, where chlorite and biotite are intimately in association with garnet.

(5) MICROSCOPICAL STUDY OF THE ORE MINERALS.

The investigation on the igneous rock and its accompanied phenomenon of metamorphism and alteration has already been discussed in the foregoing pages. Now in order to understand more clearly about the genesis and paragenesis of the deposit in question, a close study of the ore itself is inevitable. By the method of examining polished ore specimens under vertical illumination, the geologist is now in a position to investigate the opaque minerals in all details what he wants. Similar method has been used to study the copper deposit of Ta Yeh and Yang Sin, and the following in some of the result obtained.

Pyrite: Pyrite is found as an important constituent in the deposits of Lung Chiao Shan and Tien Tai Shan, as subordinate mineral in Liu Hsü Shan but none of it has yet been seen in Niu Tou Shan or Ou Yang Shan. It occurs usually in idiomorphic to hypiomorphic forms of a size ranging from 1 to 1.5 mm. in diameter. In the case of Lung Chiao Shan, pyrite is in association with chalcopyrite and magnetite, the latter two minerals play here only a subordinate role and and occurring generally as interstitial filling. The gangue mineral is either garnet, or calcite or more rarely tremolite.

The ore of Tien Tai Shan contains essentially the same mineral composition as that of Lung Chiao Shan, namely a mixture of pyrite, chalcopyrite and magnetite. Pyrite occurs in idiomorphic aggregates and is much more abundant than the other two minerals. In another specimen from the same district the sulphide has been extensively oxidized to limonite and malachite, while the original pyrite being left only as residual grains.

Magnetite: In the deposit of Liu Hsü Shan, magnetite is abundantly present, which occurs either as filling in microlitic druses, in that case often crystallizing in perfect octahedral and dodecahedral forms or as disseminations in garnet rock. In the druse filling the magnetite is often accompanied with well crystallized quartz, both of them attaining sometimes a size of several centimeters. Under the microscope the magnetite shows an exceedingly interesting feature, namely the process of martitization. According to the recent investigation, martite is not a definite mineral, but an unhomogenous mixture of magnetite and hematite and moreover the former is replaced by the latter. That here we have really a case of replacement is shown by the irregular occurrence of hematite which frequently cuts through or intrudes into the magnetite. In many cases the magnetite has been extensively replaced by hematite, the former being left in a spongy or reticulated mass, a form clearly of residual origin. Pl. IV, Fig. 6 is a microphoto of polished section from Liu Hsü Shan showing a dodecahedral section of magnetite partly replaced by hematite. The octahedral form of martite has been repeatedly observed, but the dodecahedral form, so far as known, is of rare occurrence. The replacement has followed roughly the crystallographic direction of the mineral and consequently a zonal arrangement of alternating layers of magnetite and hematite is resulted. Under the vertical illumination hematite is bright and white, while magnetite is gray with tints of brown and more dull in luster. In this way the two minerals can easily be distinguished one from the other.

In another specimen from Liu Hsü Shan, the magnetite shows in like manner the process of martitization, but it occurs usually in long prismatic form. Now the question arises, why the magnetite should take up this form, which is crystallographically impossible for that mineral. Under the microscope the mineral shows exactly the same kind of relationship; i.e. magnetite is replaced by hematite. Admitting that here magnetite formed before hematite, the only possible explanation is that the prismatic form of magnetite is not its own form, but a pseudomorphism after certain other mineral, for example actinolite. Another possibility is that the mineral was originally a hematite crystallizing in prismatic forms, afterwards it has been entirely transformed into magnetite and now it begins again to be changed into hematite. In other words we have here a change from hematite to magnetite and then to hematite again which according to recent investigation of P. Ramdohr (5) on this subject is quite possible.

Magnetite forms an important constituent of the ore of Tung Lu Shan, about 5 km. S. W. of Ta Yeh city. Under the microscope the ore is composed chiefly of massive magnetite which is traversed by numerous veinlets of either hematite or limonite or what is more common, a mixture of the two. In the last case, limonite occupies always a central position, indicating a reopening of the fissure with the filling of the later formed mineral. Hematite veinlet is also frequently cut across or replaced by limonite. From what has been said, it is clear that the magnetite of Tung Lu Shan indicates also the phenomenon of martitization which in this case is only in the beginning of development as compared with that found in Liu Hsü Shan.

Magnetite with fine veinlets of chalcocite is found in the ores from Niu Tou Shan and Lung Chiao Shan. It occurs in association with pyrite, the latter seems in many cases to be intruded by the former, so that the magnetite is distinctly younger than the pyrite. After it is etched with concentrated

HCl, the magnetite yields two or three systems of twinning lamellae arranged in octahedral directions.

The process of martitization has been held by many authors particularly by Ramdohr (5) as of hypogenic origin, i. e. a product accomplished by the ascending solution. No evidence is found here as to against such an explanation.

Bornite. Bornite forms an important constituent in the copper deposit of Hupeh, especially in the case of Niu Tou Shan, where it occurs either as dissemination or as veinlets in wollastonite, garnet or other gangue minerals. When examined under the microscope, the polished section of bornite shows always a distinct anisotropic character as a consequence of strong circular polarisation. By careful examination under higher magnification by immersion objectives, it is found that the bornite in many cases is not a homogenous mineral, but containing numerous fine lines or lamellae of chalcopyrite as inclusions. The chalcopyrite inclusions which are intersected at 60° or 90° to each other. Generally two or three or more rarely four directions have been observed. (see Pl. V, Fig. 7-9).

This inclusion of regularly arranged chalcopyrite lines in bornite, according to recent investigation at first by H. Schneiderhöhn (6) is to be regard as a phenomenon of unmixing, i. e. to say separation of mineral constituents from a solid solution of another composition brought about chiefly by lowering of temperature. Minerals formed at high temperature contain frequently in solid solution, various other constituents; upon gradual cooling to certain temperature these may suddenly crystallize out within the mass of the original mineral. Being crystallizing in a solid state, the only space that the mineral can make for itself, is the molecular space of the embedding mineral. The newly separated mineral would therefore dispose itself according to the molecular structure of the medium, which is at the same time the crystallographic direction. This is the explanation why the gashes or dots of lately separated minerals should take up generally a regular arrangement which is in most cases, parallel to the crystallographic directions of the original mineral. Many examples of unmixing are found in metallic alloys and according to recent investigation they are also widely distributed in mineral deposits. Careful study of this subject throws not only light on the genesis of the deposit and its condition of formation, but considerable information of practical value, such as ore dressing and smelting etc. can be obtained.

Essentially the same kind of structure of chalcopyrite inclusions in bornite has been figured and described by Overbeck in Patapsco mine, Maryland; Tolman in Apache mine, Plumes county, Arizona; Bateman and McLaughlin in Jumbo mine, Kennekott, Alaska; and Schneiderhöhn in Tsumeb mine, S. Africa; and Geijer in Kirūnavara, Sweden, etc.

The bornite of Niu Tou Shan with its characteristic inclusions of chalcopyrite is in many cases cut and replaced by a chalcopyrite of second generation. This relationship is very clearly shown in Pl. V, Fig. 8. Another microscopic feature to be mentioned is that nearly every piece of bornite is surrounded by a thin layer of blue chalcocite, the latter is sometime again changed into fibrous covellite.

The ore of Ou Yang Shan contains also some bornite, but it is only in a small amount and found in intimate intergrowth with chalcocite. Its occurrence is shown in Pl. VI, Fig. 10 and 11. The form of bornite is most characteristic as it exhibits in one case irregular myrmekitic grains, while in other roughly orientated lamellae are shown. The lamellae are arranged in one or two or three directions which corresponds evidently to the cubic or octahedral planes of the bornite. When studied more closely, we can see that the lamellae are often cut across by small, irregular veinlets or gashes of chalcocite, representing so to say a corroded skeleton of bornite in a mass of chalcocite; a structure what is most characteristic of replacement origin. From these arguments, the writer inclines to think, in following the views of Rogers, (7) and others that the intimate intergrowth of bornite and chalcocite in Ou Yang Shan is of replacement origin and that bornite was formed earlier than chalcocite. Same kind of intergrowth of bornite in chalcocite or chalcocite in bornite is to be seen in the ores of Tung Chuan, E. Yunnan, to be described later.

On the other hand, recent experimental study of Schneiderhöhn * has led him to believe that the paragenesis between the minerals chalcopyrite, bornite and chalcocite is not so simple as first thought. When, a mixture of $Cu_xFe_yS_z$ is allowed to cool to certain temperature, it will break down (Zerfallen) and crystallize into bornite and chalcocite, if the mixture contains more copper than iron, while bornite and chalcopyrite will be formed, if iron exceeds copper. The relation can be expressed in the following formula.

$$Cu_xFe_yS_z \ (x>y) \longrightarrow Cu_3FeS_3 \quad Cu_2S$$

$$Cu_xFe_yS_z \ (x<y) \longrightarrow Cu_3FeS_3 \quad CuFeS_2$$

* Not yet published.

The so formed mixture of bornite and chalcocite indicates exactly the same kind of graphic structure as has been so commonly observed among the natural occurrences of copper deposits. For this reason, Schneiderhöhn inclines to believe that the so called graphic structure of bornite and chalcocite is neither of replacement origin nor of eutectic intergrowth, but a case of break down from a mixture of sulfides of copper and iron, in which copper is in excess of iron. However, the evidence so far as obtained is not yet ample enough, so that Schneiderhöhn still maintains the question as unsettled.

In view of the profound hydrothermal altetation observed in the ore bearing rock, the writer believes that the bornite and chalcocite of Ou Yang Shan are of hydrothermal origin and are distinctly younger than the deposits of other districts. It is worthy to note that the ore of the said region shows an almost complete absence of chalcopyrite inclusions in bornite.

Small amount of bornite in which occurring numerous veinlets of limonite and other oxidation products is found in the ore of Liu Hsü Shan. The bornite occurs here merely as a residue in an altered mass. On close examination it is seen that the boundary between the unaltered bornite and the altered mass is marked by a zone of fibrous mineral which seems to arrange at certain definite direction. The fibrous mineral is dark and gray in color evidently belonging to some variety of the gangue, but when seen under higher magnifcation, this gangue seems to be the alteration product of a preexisting chalcopyrite needles, because traces of the latter mineral can still be seen at the edge of the altered mineral. From this observation we can conclude that here exists again unmixing of chalcopyrite in bornite, the former frequently occurs at the border of the latter. Same kind of structure is observed also in the deposit of Tung Chuan, E. Yunnan, to be described in the following pages.

Chalcopyrite: Chalcopyrite is present in all the ores investigated, except Ou Yang Shan, in that case not a trace of chalcopyrite has yet been observed among the collected material. In the deposit of Niu Tou Shan, as has been already said, chalcopyrite occurs in two generations: (1) As inclusions in bornite forming fine lines and lamellae which have been separated out from bornite as a result of unmixing; (2) massive chalcopyrite of a younger generation which cuts and replaces the bornite. The later formed chalcopyrite seems in many cases to have taken advantages of the older chalcopyrite lines as channel of deposition, so that a superimposing of younger chalcopyrite to an older one is resulted. Pl. V, Fig, 7 shows clearly such a relationship, in which several broad needles of chalcopyrite have been evidently formed in this way.

The channel was gradually enlarged and more chalcopyrite deposited as the process went on and the result was a broad arm of chalcopyrite protruding into bornite as is shown in Pl. V, Fig. 8. In fact all different stages of formation of the younger chalcopyrite may be observed in the ore of Niu Tou Shan; they vary from small and narrow superimpos d needles to broad arms and finally almost the whole bornite being altered and replaced by chalcopyrite, while the original mineral being left merely as irregular residue. In many cases it is seen that the residual bornite is still bounded by sharp and definite boundaries of cubic or octahedral outline, a direction taken also by the chalcopyrite inclusion. The structure gives further evidence as to indicate that the deposition of chalcopyrite has followed essentially the directions of the inclusion which are at the same time the crystallographic directions of the bornite.

Chalcopyite occurs also in two generations in the ore of Liu Hsü Shan, namely, an older one as inclusion in bornite and a younger one of massive form is seen to replace both bornite and the prismatic formed martite. In the latter case one can clearly see small veinlets of chalcopyrite projecting into martite, or the latter mineral is partly replaced by the former, but still maintaining the prismatic forms. The structure indicates a distinct later origin of the chalcopyrite as compared with martite.

The ore of Tien Tai Shan contains a small amount of chalcopyrite which is frequently bordered by a thin fringe of blue chalcocite in which fibrous covellite is usually intergrown. A small amount of chalcopyrite is also found in the ore of Lung Chiao Shan, but there it shows no sign of alteration.

Chalcocite: Two generations of chalcocite seem to be present in the ore of Ta Yeh and Yang Sin, namely an older one of hypogenic origin formed most probably under the influence of hydrothermal action, and a younger one of supergenic origin. The latter chalcocite occurs either as little veinlets to cut through the primary ore or to form thin border fringing upon the ores of older epoch.

The only hypogenic chalcotite, so far as is known, is found at Ou Yang Shan, where it forms the principal mineral. In occurs as pockets, nuggets, or as irregular disseminations in an extremely altered grano-diorite. The chalcocite contains numerous rests of bornite occurring in myrmekitic or roughly lamellar forms. The origin and significance of this bornite intergrowth has already been discussed. On etching with conc. nitric acid, the chalcocite yields a distinct etching structure similar to that shown in Pl. XI,

Fig. 24. The etching structure consists of two systems of lines nearly perpendicular to each other, in which one system is more prominent and continuous than the other. Exactly the same kind of etching structure has been figured described by Tolman (8), who considered it as an orthorhombic chalcocite of hypogenic origin. Recently the same etching structure has been observed by Moritz (9) among the ores of the Tsumeb mine in S. Africa. The etching figure exhibits usually an allotriomorphic massive structure granular aggregate is only rarely observed.

Supergenic chalcocite is abundantly represented in the ores of Niu Tou Shan as well as in Liu Hsu Shan and Tien Tai Shan, but so far it has not been observed in Lung Chiao Shan. In all the cases, the secondary chalcocite forms merely small veinlets or thin coatings occurring among the masses of primary ores. It is therefore entirely hopeless to expect any considerable enriched body of supergenic origin in this region.

Detailed microscopical study of the ore of Niu Tou Shan shows clearly that formation of secondary chalcocite has certain tendency to be confined more in bornite than in chalcopyrite. So it is observed that a piece of bornite has been replaced along its border by chalcocite, but its fine inclusions of chalcopyrite needles remained practically unchanged. The structure indicates at first sight as if chalcocite were formed earlier than chalcopyrite, but more careful study reveals at once the true relationship. This selective replacement, as it may be called, is a very common phenomenon which is again observed in the deposits of Yunnan as will be described later. On the other hand, replacement of chalcopyrite by chalcocite is also present as is clearly shown in the ore of Tien Tai Shan, in which almost every piece of chalcopyrite is bordered by a zone of chalcocite and sometimes also covellite. These two minerals seem here to be intimately mixed.

Hematite: Again two generations may be distinguished; the older one participating in the formation of martite, while the younger one was formed as a consequence of alteration of bornite into chalcocite by which process excess iron was separated and crystallized into hematite. The older one was evidently formed at higher temperature than the younger one.

Covellite: Covellite occurring in fibrous forms is the deposits of Niu Tou Shan and Tien Tai Shan: in other regions this mineral is extremely rare. It is a mineral most characteristic of the cementation zone and is formed without doubt by the descending solution. Bornite with fine inclusions of chalcopyrite seems to be more easily replaced by covellite than the chalcopyrite of the second generation ; this is another case of selective replacement which can very well be observed in the ore of Niu Tou Shan as well as the ore of Tung Chuan to be described later. In all of the specimens studied, covellite is distinctly younger than chalcocite, and it constituting therefore the youngest mineral of the cementation zone.

Limonite and malachite: Distinct oxidation zone marked by the presence of limonite, malachite and perhaps other minerals is found at Liu Hsü Shan and Tung Lu Shan, in the last named region, beautiful crystals of fibrous malachite are frequently observed. In other districts, oxidation process seems to have played only a subordinate role.

Other minerals: The ore of Niu Tou Shan contains a small amount of galena which is white and isotropic and occurs commonly on border of bornite being in close association with blue chalcocite. (Pl. V, fig. 9). In the bornite there exists very rarely some small grains of native gold, which is easily recognizable from its brilliant yelow color. In the chalcocite of Ou Yang Shan, it is found a very small amount, thread-like minerals of brilliant light yellow color. It is probably pendlandite.

(6) GENESIS AND PARAGENESIS.

From a geological as well as microscopical study of the ore deposits of Ta Yeh and Yang Sin, it is possible to conclude that there are two distinct types of copper deposits, namely : (1) Contact metamorphic deposits of pyrite, magnetite, hematite, bornite and chalcopvrite formed immediately after the intrusion and consolidation of the igneous magma and the crystallization of most of the heavy silicate minerals such as garnet, wollastonite etc. The bornite of this formation is generally characterized by fine inclusions of chalcopyrite needles which are to be regarded as a result of unmixing and is usually characteristic for deposits formed at high temperature. The deposits of Lung Chiao Shan, Niu Tou Shan, Liu Hsü Shan are of this origin. (2) Hydrothermal deposit of bornite and chalcocite formed much later than type No. 1, and is following the processes of sericitization, chloritization, and silicification of the country rocks. Bornite is distinctly seen to be replaced by chalcocite, though the two exhibiting an interesting graphic texture. So far as can be determined, no inclusion of chalcopyrite is observed in bornite, which fact probably indicating a much lower temperature for its formation. The deposits of Ou Yang Shan and probably Siao Chih Shan (not visited by us) blong to this type.

It is almost an universal feature that minerals were not formed at one time, but successively one after the other, so that the first formed one is often replaced by the later ones and so on. A detailed account on the paragenetic relations among the minerals of the tin, wolfram and molybdenum deposits has been recently given by Cissarz (10). The succession of formation of different minerals in Ta Yeh and Yang Sin districts has been fully discussed, an outline of the same is embodied in the following table.

Table I. Genetic distribution of minerals of Ta Yeh, Yang Sin Copper Deposits, S. E. Hupeh

Origin	Minerals	Niu Tou Shan	Liu Hsü Shan	Tien Tai Shan	Lung Chiao Shan	Tung Lu Shan	Ou Yang Shan
Oxidation	Malachite		×	×		×	
	Limonite		×	×		×	
Downward Cementation	Covellite	×		×			
	Chalcocite (blue veinlets)	×		×			
Hydrothermal	Hematite						××
	Chalcocite (white, massive)						××
	Bornite (without chalcopyrite inclusion)						××
	Chloritization, Sericitization, Silicification				×		××
Contact-Pneumatolytic	Chalcopyrite	××	××	×	×		
	Bornite (with chalcopyrite inclusion)	××	×				
	Hematite		××			××	
	Magnetite	×	××	×	×	××	
	Pyrite		×	××	××		
	Formation of heavy Silicates	××	××	××	××	×	×

× Presents in small quantity
×× Presents in appreciable quantity

III. COPPER DEPOSITS OF TUNG CHUAN IN E. YUNNAN.

(1) Geological Occurrence

The famous Tung Chuan copper mines which have been worked since 1697 and have produced at one time no less than 8000 tons of copper annually, are situated at the N. E. part of Yunnan, near to the boundaries between the three provinces Yunnan, Szechuan and Kueichow. The geology of the region, according to V. K. Ting (11) consists of sandstone, shale and limestone ranging from Carboniferous to Cambrian in age. The sedimentary formations are intruded by numerous gabbro masses which are intimately associated with the copper ores and have, no doubt, a genetic relation with them. Besides there

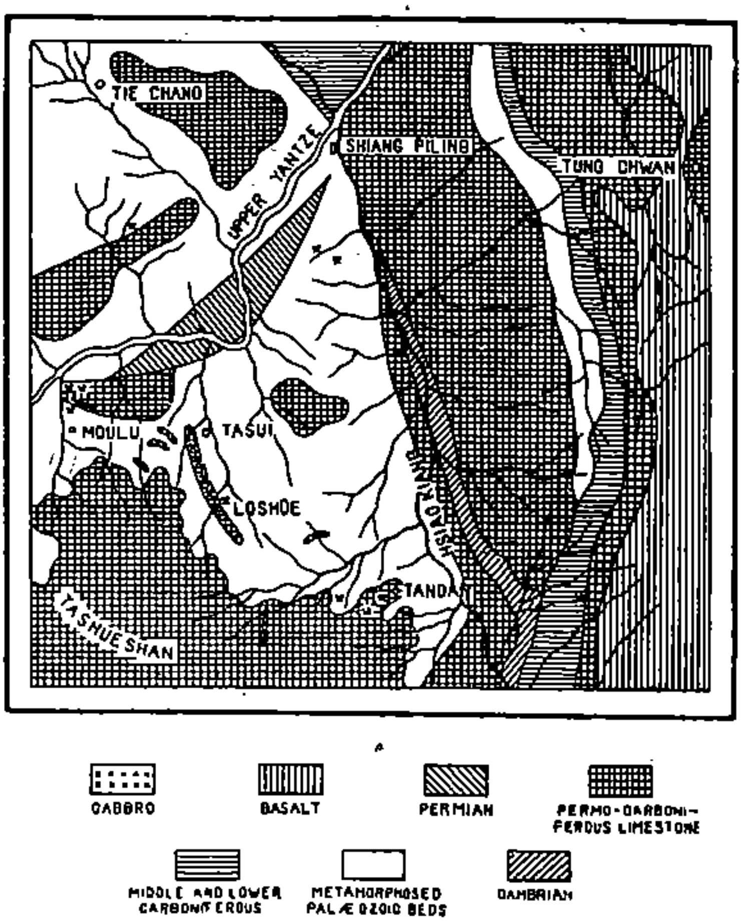


Fig. 1. Sketch map of the Tung Chuan Fu Copper Mines, Scale 1:500,000 (After V. K. Ting).

occurs basalt of Tertiary or Quaternary age which forms usually caps on the older formation. The mines are divided into five groups, namely: Tandan (湯丹), Loshüe(落雪), Tasui (大水), Moulu (茂麓), and Tiechang (鐵廠). Except the last locality which is on the west side of the Upper Yangtze, near the Szechuan border, the four other groups are situated between the Yangtze and its tributary, the Hsiao Kiang, to the S. E. of Tung Chuan Fu city.

The deposits are found either in metamorphosed sandstone and shale of Lower Palaeozoic age or in limestone of Carboniferous formation. About 80 % of the ore now worked comes from the latter source. The deposit at Tandan is an irregular stockwork with occasional concretionary masses of barite.* One single vein varies from 10 cm. to 1.5 m. in width, with 60 cm. as an average. The original ore is chalcopyrite which is often altered into carbonate with a considerable increase of the percentage into as much as 15%. Gangue minerals are quartz, calcite and siderite. Because of its favorable location, Tandan forms one of the most developed mines and it yields more than 45% of the total copper now produced in Tung Chuan. Present mining seems to be confined mostly to the uppermost oxidized zone which reaches to 15-25 m. in depth. In Loshüe and Tasui, ores occur in irregular masses varying from 4 ft. to a few inches in width. The chief minerals are bornite and chalcocite, often extremely rich. The other two mining centers, namely Tiechang and Moulou consist of impregnation ores in the metamorphosed beds. It is mostly chalcopyrite with some mixture of silicates which make the ore more difficult to smelt. The region at Moulu is said to be too crushed to contain extended fissures and the minerals form scattered deposits without continuity. The accompanied map shows the general geology and distribution of mines in the Tung Chuan Copper deposits.

(2) Description of Specimens

No. 1. *Sin Shan* (新山), *Tandan, Tung Chuan.* This specimen represents a product of the oxidation zone, but the oxidation process has not been advanced enough so that remnants of the primary ore are still to be found.

* Leclere, Deprat, Brown and Ting all mentioned the existence of the mineral barite, but among the material investigated, the writer has not yet seen any trace of this mineral Brown mentioned also, in his report (12), the mineral phillipsite occurring with carbonate ore in Loshüe mine. Should the observation of these authors be correct, it tends to indicate a rather lower temperature and medium depth for the formation of thi rsemarkable deposit, because both barite and phillipsite are generally known to be formad under such conditions.

It is composed in the main of the chalcopyrite and bornite, both of which being traversed by a sytem of veinlets of oxidation products.

Both bornite and chalcopyrite often exhibit allotriomorphic forms and are being intimately associated together. While in certain cases bornite may form small grains or irregular fragments included in chalcopyrite, but in other instances, the relationship seems to be just the reverse. No clear evidence of replacement can be seen from which to ascertain the relative age between chalcopyrite and bornite.

The ore is traversed by an immense system of fine to rather broad veinlets which is composed of a gangue mineral, probably calcite in the center, a layer of limonite comes next and on the border is found blue colored covellite often occurring in short prismatic or fibrous crystals. By examining in crossed nicols and under oil immersion, the covellite shows a bright purple color. The limonite shows in this instance a brown to brownish red color which is characteristic enough to distinguish it from other oxidation products.

In the center of some of the broad oxidation veinlets is found another mineral, i. e. malachite which occurs in the usual fibrous and concentric structure. Irregular masses of malachite of different sizes are also found. Undoubtedly the malachite is the latest mineral formed in the oxidation zone, because it occupies always the central portion of the oxidation veinlets.

On close examination it is found that there exists in the bornite another system of veinlets of a light blue colored mineral which shows however no polarization color or "Innere Reflexion" phenomenon as is to be expected if it is a covellite. The veinlet is much finer and more discontinuous as compared with the oxidation veinlets and the color is a little lighter than covellite. This is the blue chalcocite. What is of most significant is the fact that the chalcocite veinlet occurs only in bornite and not in chalcopyrite, and wherever it comes in contact with chalcopyrite, the little veinlet ceases rather rapidly. Instances are common which tend to show as if chalcocite veinlets in the bornite were cut across by chalcopyrite ; in the latter mineral only fine fissure can sometimes be seen indicating evidently the former position of chalcocite veinlets in an already disappeared bornite, but no real continuation of chalcocite in chalcopyrite can ever be seen (Pl. VII, Fig. 13). On etching with concentrated nitric acid, the chalcocite gives a deep blue color, but no characteristic etching structure can be seen ; this is perhaps due to the fact that the chalcocite veinlets being too small to show a clear etching figure.

The above relationship between the minerals of chalcocite and chalcopyrite shows at first sight as if chalcopyrite is younger than chalcocite. because the latter is cut across by the former. But we must remember at the same time the phenomenon of selective replacement which has already been noted among the copper ores of S. E. Hupeh, admitting the principle of selective replacement, then we may explain the above structure by saying that because chalcopyrite is more resistant to chalcocitation than bornite, so the veinlets of chalcocite are found only in the latter mineral. It is to be noted that among numerous specimens from the same Tung Chuan district, only covellite but not chalcocite veinlets are found in chalcopyrite, while in bornite both minerals are equally represented.

Frequently in bornite and also in chalcopyrite there occurs a gangue mineral of long and prismatic form. After optical study under the polarization microscope this mineral is determined to be tourmaline. It shows a rather high birefringence and refringence, a negative elongation and a positive character. The long prism is almost always cut across by several horizontal fractures, and in some cases the mineral has even been displaced. A thin layer of chalcocite is almost always present to surround the border or to fill the fracture of the tourmaline which usually embedded in bornite. Besides the prismatic form, numerous basal sections are found which exhibit a roughly triangular outline, a form most characteristic for tourmaline.

In connection with the etching study of the chalcopyrite, the writer has incidently found a good etching reagent which has never been used by any one before in the microscopical study of the metallic ores. This is the well known so called Schulze's reagent which has been used in Plaeobotany as well as in coal research for maceration. Schneiderhöhn mentions in his text book, (13) acid or alkaline potassium permanganate solution as the suitable etching reagent for chalcopyrite and recently Fackert (14) recommends an etching solution of the following composition :

2 parts and half (volume) HNO_3 Sp. Gr. = 1.2

4 parts (volume) HCl Sp. Gr. = 1.19

10 parts (volume) water

a little $KClO_3$

Moritz used the above solution for the etching study of some chalcopyrite from S. Africa, but could get good result only when a few drops of fluoric acid is added. The writer has tried also the solution of Fackert, but no structure is obtained. On the other hand, when the Schulze's reagent, i. e. a mixture of concentrated nitric acid (Sp. Gr. 1.4) and potassium chlorate is used, structure of every detail can be developed with an etching interval of about one minute or half. Structure of the same intensity can also be obtained by the method of Moritz. However, in view of its simplicity in composition and easy to handle, the Schulze's mixture is strongly recommended as the best etching reagent for chalcopyrite.

When etched with the Schulze's reagent, the chalcopyrite of Pei Sing Shan shows a distinct structure of allotriomorphic granular forms. The grains are medium sized (0.6-1.4 mm or more) and are nearly equidimensional. Twinning lines of two or three directions are frequently observed among some of the grains. Pl. VII, Fig. 14 shows microphoto of the granular structure as developed by etching.

No. 2. Shui Kou (水濡), *Mou Lu Chen* (茂麓鎮), *Tung Chuan.* This is a sample from the oxidation zone by which the ore has been much altered and practically no original material can be seen. It is composed in the main of cuprite scattered here and there with veinlets or irregular masses of malachite. In cuprite small grains of native copper are almost always included. Certainly the native copper here was formed from the oxidation of cuprite, most probably at a time when the latter altered to malachite by which process a certain amount of copper must be separated out. Between cuprite and malachite there occurs frequently a banded zone in which spherical or wavy shaped layers of limonite, malachite and tenorite are beautifully arranged one after the other (Pl. VIII, Fig. 15). Such a structure is called by the German mineralogists as the "Glaskopf-struktur" and is most characteristic for the ore in the oxidation zone. It is supposed that minerals exhibiting such forms were formed in colloidal condition. On close examination it is seen that each layer of the bands consists of radially arranged minerals of fibrous limonite which constitutes here the predominant part, while malachite is the least abundant.

No. 3 Lou Sing Shan (老新山), *Ta Sui* (大水), *Tung Chuan.* The polished section is composed principally of massive bornite in which occurs a dense system of fine veinlets of blue chalcocite. The veinlet is extremely narrow and often discontinuous, being rarely over 0.02 mm. in width and 1 mm. long. No other mineral is found in the veinlet beside chalcocite, the latter gives at first the appearance of covellite, but one can distinguish from it by the lack of a purple polarization color under the crossed nicols. Crystals of tourmaline are abundantly distributed in bornite occurring in the usual prismatic form. Basal sections of tourmaline showing a triangular outline are also abundantly represented. Around the border of tourmaline is commonly seen a thin layer of chalcocite (Pl. VIII, Fig. 16).

No. 4. Hou Shan (後山), *Tung Chuan.* This specimen derives evidently also from the oxidation zone but in which traces of original minerals are still abundantly represented. The rock is a more or less silicified dolomite in which occur nodules, nests or irregular masses of bornite. The whole rock is cut across by a dense system of malachite veinlets and other oxidation minerals.

Under the microscope the thin section of the rock shows to be a rather finely crystallized marble with many idiomorphic formed quartz and several residual crystals of tourmaline. Ores occur in patches or irregular masses but they have been mostly altered to limonite and malachite. Quartz is also more or less altered as is shown by the existence of numerous fine veinlets of calcite and chlorite. Many basal sections of both quartz and tourmaline have been entirely altered to a mixture of chlorite and calcite. Chlorite occurs also as interstitial filling in the dolomite

Now let us study the polished section of the opaque minerals of this specimen. The ore is composed in the main of bornite, but in it occur as inclusions numerous fine needles or lamellae of chalcopyrite either along the border or nearly reaching the middle of the bornite mass. The chalcopyrite needles are usually regularly arranged among which two directions interesect-ing nearly at 90° to each other can be recognized (Pl. VIII, Fig. 17). While in most cases the chalcopyrite needles form only a thin fringe along the borders of bornite, sometimes the whole mass of bornite is covered with such needles leaving only a small unaltered bornite in the center as nucleus. Closely associated with chalcopyrite there occurs an appreciable quantity of covellite in fibrous forms.

From the fact that chalcopyrite needles are intimately inter wn in bornite and moreover, that the needles are oriented according to certain crystallographic directions of bornite, we can conclude without hesitation that the said intergrowth being a phenomenon of unmixing. In other words the chalcopyrite needles were formed as a result of crystallization in solid solu-tion of the bornite mass. Consequently the chalcopyrite must have been formed at about the same time as bornite and owed its origin also to ascending solution.

Although covellite is intimately associated with chalcopyrite but it is not necessary that the two were formed at the same time. It is most probable that covellite was formed much later and owed its origin to the descending solution. As most of the bornite thowing the phenomenon of unmixing has been more or less replaced by covellite, it appears as if the intergrown part has a tendency more to replacement. Exactly the same phenomenon has been observed in the copper deposits of S. E. Hupeh.

No. 5. Tandan (湯丹), *Tung Chuan*. The specimen represhnts a slightly silicified dolomite in which occur grains or irregular masses of bornite and chalcopyrite together with oxidation products like limonite and malachite.

The thin section of the rock shows under the polarization microscope to be a crystalline marble with some degree of silification. Calcite occurs mostly in fine and irregular grains, but large crystals are also found. Quartz occurs either in irregular grains or in large plates; sometimes a great number of quartz crystals are aggregated together to form a big mass. The latter phenomenon indicates an advanced degree of silicification. Most of the large crystals of quartz contains some inclusions of small, prismatic crystals, evidently tourmaline. But in the rock itself, prismatic crystals of tourmaline are very rare, even if they are not absent. Some chlorite is present which shows a weak birefringence and a spherulitic extinction. It forms generally small veinlets crossing quartz, or to occur as small druses in the rock. Malachite is present and is often in association with hematite.

The study of polished section reveals some residues of unaltered pyrite which occurs generally in rounded grains, being surrounded either by bornite and chalcopyrite or by oxidation products. Bornite occurs usually in allotriomorphic forms. Two generations of chalcopyrite may be distinguished; namely, an older one occurring as inclusions in bornite and a younger one of allotriomorphic forms. By examining under crossed nicols, we soon reveal the existence of numerous fibers of covellite which is intimately associated with chalcopyrite. Consequently we have here the same type of structure as been in the specimen from Hou Shan, Tung Chuan just described, namely an intimate intergrowth of chalcopyrite and bornite due to unmixing and which was again replaced by covellite of supergenic origin.

Aside from the minerals just described, the polished section contains many grayish colored, idiomorphic formed mineral showing a rather bright luster. The form represents evidently sections of isometric system. Under crossed nicols the mineral is nearly dark, but along the fracture or depresion, a deep red color is shown. In certain rare cases can we still see small fragments of pyrite occurring in the center of this mineral. From all these characters mentioned, it is no doubt that the mineral in question is a hematite maintaining, however, the form of pyrite; in other words, it is pseudomorphism after pyrite. The hematite is sometimes surrounded by a layer of limonite which shows also a grayish white color but darker in luster.

No. 6 Sing Shan (新山), *Tandan, Tung Chuan*. This specimen is composed in the main of chalcopyrite in which occur numerous residual crystals of pyrite showing frequently a reticulated form of residual origin. The chalcopyrite is in turn crossed by a system of veinlets of covellite and other oxidation products, (Pl. IX, Fig. 18) the structure of which is exactly similar to specimen No. 7 to be described in next paragraph. When etched with Schulze's mixture, the chalcopyrite shows an allotriomorphic granular to massive structure, the grains are sometimes bounded by sharp and straight edges. Twinning lines of one or two directions are observed, but not so frequently as in the other cases.

No. 7 Tung Chuan. Exact locality of this specimen is unknown. It contains chiefly massive chalcopyrite with little gangue. In the chalcopyrite one can see under the microscope a dense system of veinlets composed of limonite and other oxidation products in the center and fibrous covellite on both sides (Pl. IX, Fig. 19). The fibers measure generally 0.01 mm. in length, being irregularly arranged with respect to the direction of the veinlets. It is to be noted that covellite is a mineral characteristic of cementation zone or at the transition between oxidation and cementation. It is therefore much older than limonite and other oxidation minerals.

The chalcopyrite from this locality when etched with Schulze's reagent yields a very interesting etching structure. It shows in the main an allotriomorphic massive structure, being different therefore from the granular aggregates observed under spec. No. 1. Almost every piece of the chalcopyrite represented in the section is twinned; two types of twinning may be distinguished: a) Narrow to broad spaced fine twinning lines usually of three directions and intersecting at 60°-70° to each other. The surface is little tarnished. b) An alternation of narrow and broad bands, each band exhibiting a rather densely spaced polysynthetic twinning; the twinning lamellae being more densely spaced in the narrow band than in the broad ones, are intersected at an angle of about 60° to each other. An example of this complicate twinning is shown in Pl. IX, Fig. 20. It is believed that the structure as just described represents a combination of two kinds of polysynthetic twinnings resembling somewhat the twinning law observed in microcline. According to Schneiderhöhn (13) chalcopyrite showing polysynthetic twinning similar to the Spinel law is widely distributed ; in fact it is rare to observe a chalcopyrite which shows no twinning line when etched.

No. 8 *Tung Chuan*. This specimen represents irregular masses of bornite and other ore in limestone. Under the microscope the ore is seen to be composed mainly of bornite and some hematite, the latter occurring generally inaggregated grains. The bornite is extensively crossed by veinlets or irregular masses of chalcocite, the latter is light blue in color and is distinctly anisotropic. When etched with conc. nitric acid, some of the large masses show a distinct etching structure similar to that observed in other specimen.

The chalcocite exhibits in some cases a beautiful myrmekitic structure which is shown in Pl. X, Fig. 22. It is exactly the same structure such as observed under the so called graphic intergrowth between bornite and chalcocite, commonly described among the literature of ore deposits. But the interesting feature is that here we have, instead of bornite, but chalcocite which exhibiting this characteristic form and being occurred among a groundmass of bornite. In other words, the relative position between bornite and chalcocite is here just reversed. In Pl. X, Fig. 22 one can clearly see that the same chalcocite is found to occur in two ways, namely either in small irregular veinlets cutting through bornite or as myrmekitic forms. The origin of these occurrences can either be explained as replacement or as breakdown, and owing to lack of enough evidence, the question is left for the present undecided.

The occurrence of numerous grains of hematite is a noteworthy feature and which can be explained in this way. As we know from the chemical composition of the minerals, when bornite alters to chalcocite, a certain amount of iron must be separated, and it was this iron which has probably contributed to form the hematite grains which occur especially abundant along the veinlets of chalcocite (Pl. X, Fig. 21). That this phenomenon is a very common one among the Chinese copper deposits is evidenced by its frequent occurrence in the deposits of Yunnan and Hupeh.

No. 9. Lou Sui Chang (落雪廠), *Tung Chuan.* This is composed essentially of chalcocite with residues of bornite and aggregates of hematite. Chalcocite occurs in massive forms in which are often seen rests of bornite, occurring in the characteristic myrmekitic forms (Pl. XI, Fig. 23). It is no doubt that here chalcocite replaces bornite while the latter is only preserved in its residual forms.

On etching with concentrated nitric acid, the Chalcocite yields a distinct etching figure as shown in Pl. XI, Fig. 24. This figure is characteristic of most chalcocite found in south and southwest China.

Hematite occurs either as small grains or fine prismatic crystals embedded in both bornite and chalcopyrite. Numerous crystals of hematite are often aggregated together. They are evidently the product of decomposition formed during the alteration of bornite to chalcocite.

No. 10. Tung Chuan. This is an ore from the primary zone. Under the microscope the polished section shows chiefly allotriomorphic chalcopyrite in which are embedded aggregates or isolated crystals of pyrite in idiomorphic to hypidiomorphic forms. No veinlets of either covellite or chalcocite can be seen in this specimen.

The etching structure of the chalcopyrite exhibits some very interesting feature. It is in fact a mixture of allotriomorphic granular and allotriomorphic massive forms, the relation of the two can be compared with the phenocrys and ground mass in ordinary rock section. Small veinlets or arms of granular chalcopyrite are often seen to cut into the large, massive one. It is probable that these two different shaped chalcopyrites were formed one after the other and the granular one is distinctly younger. I do not postulate, however, that they are products of widely separated generations or were formed under widely different origin or conditions, because both constitute together an homogenous mass before the etching. The massive chalcopyrite represents simply product of first period of crystallization when the rest was still in a liquid state. Two or three directions of twinning lamellae are often seen in the massive chalcopyrite, while in the granular one, they are rarely observed. Schneidershöhn (15) has already made the suggestion that twinning of chalcopyrite seems to be more common in the higher temperature deposits than in the lower one. I do not know whether the present case could be cited as an example to support his idea because the massive chalcopyrite must have been formed under comparatively higher temperature than the granular one.

No. 11. *Ma Lung Chang* (馬龍廠), *Hsiu Na Hsien* (休納縣). This specimen shows some small veinlets of chalcocite in a dolomite. On close microscopic examination it reveals again numerous rests of bornite in chalcocite such as has been described under specimen No. 9 from Lou Sui Chang in Tung Chuan. The form of bornite is here much more regular approaching in some cases a skeleton form. In Pl. XII, Fig. 25 one can see besides the skeleton structure, the chalcocite forms also veinlet to cut through bornite.

The other metallic mineral in the specimen is a prismatic, often well crystallized hematite which occurs frequently in aggregated forms. It is probable that this hematite, just like in other occurrence, was formed as a consequence of the alteration process from bornite to chalcocite. On etching with conc. nitric acid, the chalcocite shows a type of etching structure similar to the one described under specimen no. 9.

No. 13. *Ta Tun.* (大屯) *Hsüan Wan* (宣威縣). The specimen represents some solid massive chalcocite which shows under the microscope to contain numerous veinlets of hematite and malachite. Without etching the polished section of chalcocite shows already some distinct structure which consists of several systems of parallel lines such as shown in Pl. XII, Fig. 26. These lines are believed to be the cleavage of the mineral. Under the vertical illumination the mineral is white and bright but is distinctly anisotropic when examined with the polarisator. On close study it is seen that the chalcocite has been partly altered to covellite, the alteration goes chiefly along the direction of cleavage. (Either a part or the whole of the cleavage can be altered into covellite. Sometimes only a single lamella is altered, while the rest remained unchanged.) By careful study especially when examined under higher magnification, it is possible to see some little trace of bornite embedded in chalcocite. This bornite represents no doubt the survival of an original occurrence from which as a result of hypogenic alteration, it has been almost entirely changed into chalcocite. During the alteration iron oxide was separated out to form hematite veinlets.

(3) Genesis and Paragenesis

Because of the lack of sufficient material to show all its geological relations, especially the character of alteration of the country rocks, it is not yet possible after a merely microscopical work like this to draw definitely conclusions on such important questions such as genesis and paragenesis. However, something can already be said even it should naturally be in a very superficial way.

From the existence of the mineral tourmaline in many of the copper deposits of Tung Chuan, it is justified to think that the deposit in question belongs perhaps to the pneumatolitic type. However owing to lack of suffici-

Table II. Genetic Distribution of Minerals of the Tung Chuan Copper Deposits, E. Yunnan

Origin	Minerals	Pei Sin Shan	Shui Kou, Mao Lou Chen	Lou Sing Shan, Ta Shui Hsien	Hou Shan	Tang Tan	Sing Shan	Tung Chuan	Tung Chuan	Lou Sui Chang	Tung Chuan	Ma Lung Chang, Hsiu Na Hsien	Ta Tun, Hsuan Wan Hsien
Oxidation	Malachite	×	×		×	×							×
	Limonite	×	×		×	×		×					×
	Tenorite		×										
	Native copper		×										
Downward Cementation	Cuprite		×										
	Covellite	×			×		×	×					×
Pneumatolytic-Hydrothermal	Chalcocite (blue veinlets)	×		×									
	Hematite								×	×		×	×
	Chalcocite (white, massive)								×	×		×	×
	Chalcopyrite	×			×	×	×	×					
	Bornite (Occ. with chalcopyrite inclusions.)	×		×	×				×	×	×	×	×
	Pyrite					×	×						
	Chloritization	×		×	×	×			×				
	Tourmalinization, Silicification	×		×	×	×			×				

ent material to show a clear evidence of pneumatolitic alteration, this question, for the time being, is left as not definitly settled.

The succession of ore mineral so far as can be determined is embodied in the accompanied table. There are many questions, however, still not yet definitely solved, chief among which are : (1) The relative age between bornite and chalcopyrite, owing to lack of clear evidence is not definitely known. It is quite possible that they were formed at about the same time. (2) The origin of chalcocite is a most complicate subject which can only be solved by further field and laboratory study. Most of the massive chalcocite containing myrmekitic or lamella rests of bornite is certainly of hypogenic origin due to breakdown or replacement, while the other forms occurring as small veinlets or thin fringe on bornite and assuming a light blue color are most probably the products of descending cementation. However as is shown in spec. No. 15 in which both veinlets and small masses of chalcocite are found and moreover the latter shows a graphic intergrowth with the bornite just as in the other cases. Similar to other processes of chalcocitization, it is here also marked by separation of considerable amount of iron to form rather idiomorphic crystals of hematite. For these reasons, it is a question whether this chalcocite should be considered as hypogenic or supergenic. (3) The fine inclusions of chalcopyrite which is so characteristic for the contact metamorphic deposits of Ta Yeh and Yang Sin are observed here in only one or two specimens.

IV. COPPER DEPOSIT OF HUI LI IN S. SZECHUAN.

(1) Geological Occurrence.

The material for the present investigation consists of only a few pieces of ore collected mostly from Chiang Chün Shih, Tung An in Hui Li (會理) district. Two or three pieces of ore come also from Yi Wan Shui (一碗水) and Hsiang Pao Shan in the same district.

The specimens have been collected by Dr. V. K. Ting, formerly Director of the Geological Survey. No report has been so far published. From oral communication the field relations are approximately as follows :

At Tien Pao Shan (天寶山) of Lu Chang (鹿厰) in Huili district, an intrusion of gabbro is found in Permian sandstone beds. Copper sulphides occur at the contact of the gabbro. The ore as usually worked by the native industry averages at 3-4% Cu. At Tung An of the same district, copper ores occur in a metamorphosedsandstone more distant from the contact zone. The average percentage is higher, about 10%.

(2) MICROSCOPICAL DESCRIPTION.

Chiang Chün Shih (將軍石), *Tung An* (通安). The ore of this region consists mainly of pyrite and chalcopyrite in a dolomitic rock. According to its color and composition, the ore is differentiated by the local people into several kinds, each receiving a special name such as Hei Chin Tu Chu Sha Kuan (黑青土硃砂礦). Pa Chiao Ching (芭蕉青), etc., the exact meaning of which is not yet known. The first named variety represents a primary ore consisting of pyrite and chalcopyrite in dolomite. Under the microscope the polished section shows clearly that pyrite is replaced by chalcopyrite. The Pa Chiao Ching is a massive chalcopyrite in which an extensive system of secondary veinlets are found. The veinlets are composed of limomite or malachite in the center and fibrous covellite as thin lining on the wall. In some of the more oxidized specimens, the whole piece is crossed by secondary veinlets while the chalcopyrite being left merely as residual masses of the network. In some specimens the chalcopyrite is intimately associated with several idiomorphic crystals of quartz and in rare cases, one can notice the occurrence of a few tourmaline. From this fact it can possibly be concluded that the deposits of Hui Li are genetically somewhat similar to that of Tung Chuan, i.e. probably of pneumatolitic origin. Extensively oxidized ore is represented by only one specimen which consists in the main of cuprite with numerous inclusions of native copper. The cuprite here is extensively replaced by malachite. The alteration goes on generally along the boundaries of the cuprite grains which assume usually a cubic form.

The chalcopyrite when etched with the Schulze's reagent, i. e. a mixture of conc. nitric acid and potassium chlorate, very beautiful etching structure is developed. It shows on the whole an allotriomorphic massive structure, among which some masses are more tarnished than the other. This is evidently due to a difference of orientation of the different masses. Twinning is commonly observed, one of which showing three directions of twinning lamellae intersecting at an angle of 60°-70° is illustrated in Pl. XII, Fig. 27. The twinning lamellae which measure from .01-.02 mm. in width is bright and untarnished, while the rest which represents sections of other orientation is tarnished by the solution. Distance between one lamella to another varies from 0.05 to 0.25 mm. As a result of deformation, the lamellae are slightly curved as is shown in the accompanied illustration. In some masses the twinning is indicated by fine lines of one direction, widely separated one from the other ; no lamellar structure as just described can be seen.

Yi Wan Shui (一碗水): The ore of Yi Wan Shui contains besides chalcopyrite and pyrite, also a fair amount of sphalerite and tetrahedrite, a little galena and some safflorite which is a rare mineral but rather common in this specimen. Both sphalerite and tetrahedrite are found as irregular masses and patches in chalcopyrite. They are both characterized by a gray color under the microscope, but tetrahedrite is mere light gray as compared with sphalerite. Galena is white and bright as compared with the other two minerals. Safflorite exhibits a bright luster and white color somewhat similar to hematite, but it shows distinctly a tint in yellow. It occurs in small idiomorphic crystals of rhombic forms. The determination of this mineral as safflorite is based on a micro-chemical test for nickel and further confirmation by spectroscopic examination for cobalt and arsenic.

The microchemical and spectrographic investigations of the mineral were carried on in the following way. As the mineral occurs in such a fine crystallization and minute distribution in the chalcopyrite, it was very difficult to obtain a sample of it in appreciable quantity. In order to accomplish this, the boring method of Moritz (16) who recommended the use of a dentist's roatry borer driven by a small motor is very serviceable. In this connection, I wish to thank Mr. Moritz of the mineralogical department of the University of Freiburg for his kindness in allowing me to use his instrument and at the same time for the guidance of the spectrographic investigation.

The boring was carried on under the microscope ; with a little practice and attention, one is able to obtain a sample of appreciable quantity and meanwhile of the desired pureness. The sample so obtained was dissolved in aqua regia. A few drops of the solution were then taken out ; after diluted with a little water and acidified with some citronic acid, the solution was brought to react with a few drops of alcoholic solution of dimethylglyoxine which gave instantly a precipitate of scarlet red color of nickel dimethylglyoxine. Therefore the presence of nickel in the mineral is confirmed. The same solution was then investigated again with the emission method. The spectrum so obtained indicates a very distinct development of cobalt lines, but rather weak representation of nickel lines, only some trace of them is to be seen. This means that the chief constituent of the mineral is cobalt with only some trace of nickel. The presence of arsenic is indicated by some very weak lines which are in fact always not so distinct in the spectrum.

Safflorite is a rhombic modification of the mineral smaltite which crystallizes in isometric system, while both having about the same chemical composition. (Co, Ni) As_2. Analysis by various authors (17) shows that the chemical composition of safflorite varies in wide extent as follows :

Ni = 0—1.90%, Co = 9—23%, As = 61—71%, Fe = 4—18%.

Safflorite is a typical vein mineral but is of rare occurrence. It occurs fairly abundant in the mine of Schneeberg, Sachsen; Bieber near Hanau ; Wittichen, etc. In the Kupferberg in Schlesien, Schneiderhöhn* has recently found similar occurrence of safflorite in association with sphalerite, tetrahedrite, and galena.

After etched with concentrated nitric acid and potassium chlorate, the chalcopyrite of Yi Wan Shui shows an allotriomorphic granular structure, the grains being inequidimensional. They vary from 0.25-1.75 mm. in size. Some grains are easily attacked by the reagent, showing a rough, tarnished surface, while others being smooth and bright. The tarnished surface shows in addition a distinct system of twinning lamellae of two directions intersecting at about 74°. The less attacked grains show in some cases, also fine twinning lines of one or two directions. No deformation phenomenon is observed. In another specimen from the same district, the chalcopyrite shows an exceedingly interesting structure. It consists in the main of an allotriomorphic granular structure, but among which evidently two generations of grains occurring in different sizes may be distinguished. The coarse grained chalcopyrite measures from 0.6-1.5 mm or more in diameter, being slightly tarnished and showing only in rare cases twinning lines of one or two directions. The fine grained variety has a size varying from 0.025-0.07 mm in directions. It is subangular and is nearly equidimensional. The fine grained variety is seen at one place to be cut through by the coarser one, indicating probably that they were formed not at the same time, but the latter is distinctly younger than the former. This relationship is shown in Pl. XIII, Fig. 30. The boundary between the fine grained and the coarse chalcopyrite is in some places marked by a sharp contact, while in another case a very interesting zone of narrowly and polysynthetically twinned chalcopyrite is observed. This zone is about 0.9 mm. in width.

(3). GENESIS AND PARAGENESIS.

Very little can be said about the genesis of this deposit on account of lack of sufficient material for study. For the occurrence of a few tourmaline

* Oral Communication

in this ore, it seems as if it could be compared with the deposits of Tung Chuan. In fact these two deposits are located rather near together, so that a resemblance in both geological and metallogenetic condition is quite possible.

The primary ore consists of pyrite, sphalerite, tetrahedrite, galena, chalcopyrite and safflorite, named approximately in their order of deposition. Oxidation zone is marked by the presence of cuprite, native copper, limonite and malachite. The only mineral of supergenic origin is covellite; no chalcocite is observed among the collected material. The following table gives some idea about the distribution of the different minerals.

Table III. Genetic distribution of Minerals of Hui Li Copper Deposit, S. Szechuan

Origin	Minerals	Hei Ching Tu, Chu Sha Kuan,	Pa Chiao Ching	Chiang chun Shih, Tung An	Chiang Chun Shih, Tung An	Hsing Pao Shan	Yi Wan Shui	Tung An
Oxidation	Malachite		×	×				×
	Limonite		×	×			×	×
	Native Copper							×
	Cuprite							×
Downward Cementation	Covellite		×	×				
Pneumatolytic to Hydrothermal	Safflorite						×	
	Chalcopyrite	×	×	×	×	×	×	
	Galena							
	Tetrahedrite							
	Sphalerite							
	Pyrite							

V. SUMMARY AND CONCLUSION.

1. The copper deposits of Ta Yeh and Yang Sin in S. E. Hupeh, Tung Chuan in E. Yunnan and Hui Li in S. Szechuan are investigated microscopically with a view to determine their mineralogical composition, structure, genesis and paragenesis.

2. Two types of deposits may be distinguished in S. E. Hupeh, : (1) The contact metamorphic deposits of Lung Chiao Shan, Liu Hsü Shan, Niu Tou Shan and Tien Tai Shan. (2) The hydrothermal replacement deposit of Ou Yang Shan.

3. The copper deposits of Tung Chuan and Hui Li belong probably to the same type of intrusive pneumatolitic-hydrothermal origin as is evidenced by the existence of tourmaline.

4. The Schulze's reagent, i. e. a mixture of conc. nitric acid and potassium chlorate is used with some success as etching reagent for chalcopyrite. It is superior to any other reagent that has been used for this mineral.

5. Two types of etching structure in chalcopyrite may be distinguished : (1) Allotriomorphic granular, generally slightly twinned. (2) Allotriomorphic massive, frequently twinned after the most complicate manner. In some cases both types are shown, in one specimen and the latter is distinctly seen to be cut by the former. It is suggested that the more twinned variety may indicate one that was formed under higher temperature than the not twinned one.

6. The graphic intergrowth of bornite and chalcocite can either be explained by replacement or by breakdown from a mixture of sulfides of iron and copper ; the latter explanation is based on the synthetical study of Schneiderhöhn (not yet published). In view of the complicate nature of the system Fe-Cu-S, further evidence is needed before an adequate explanation can be advanced.

7. The inclusion of chalcopyrite lines in bornite (due to unmixing) is found to be a common structure amony the contact metamorphic deposits of S. E. Hupeh ; it is present to some extent also in the pneumatolitic-hydrothermal deposits of Tung Chuan. No such structure is observed in the ore of Ou Yang Shan, which is of hydrothermal origin. From this we may conclude that unmixing is perhaps a phenomenon most characteristic for deposits formed at higher temperature.

BIBLIOGRAPHY

(1) W. H. Wong: The mineral resources of China, Special Report, Geological Survey of China, 1919. (in Chinese)

(2) H. T. Lee: Copper ores of S. E. Hupeh. Bull. Geol. Sur. China, No. 12. April 1929.

(3) C. Y. Hsieh: Stratigraphy of S. E. Hupeh, Bull. Geol. Soc. China, Vol. 3, No. 2, 1924.

(4) Paul Niggli: Gesteins-und Mineralprovinzen. Berlin, 1923, p. 51.

(5) Paul Ramdohr: Beobachtungen an Magnetit, Ilmenit, Eisenglanz und Überlegungen über das system FeO, Fe_2O_3, TiO_2. Neues Jahrb. f. Miner. etc. Beilage Bd. LIV, 1926, p. 320.

(6) H. Schneiderhöhn: Entmischungserscheinungen innerhalb von Erzmischkristallen und ihre Bedeutung für Lagerstättenkunde u. Aufbereitung, Metall u. Erz, XIX, Heft 22-23, 1922, p. 501.

(7) A. F. Rogers: The so-called graphic intergrowth of bornite and chalcocite. Econ. Geol. 1916, Vol. 11, p. 585.

(8) C. F. Tolman: Observations on certain types of chalcocite and their characteristic etch paterns. Trans. A. I. M. E. Vol. 45, p. 402, 1917.

(9) H. Moritz: Die sulfidischen Erze der Tsumebmine vom Ausgehend bis zur tiefsten Sohle (..160m). (In press).

(10) A. Cissarz: Übergangslagerstätten innerhalb der intrusiv-magmatischen Abfolge. Neues Jahrb. f. Miner. etc. Beilageband LVI, Abt. A. 1927.

(11) V. K. Ting: Tungchuanfu Copper mines, Yunnan. Far Eastern Review, Vol. 12, No. 6, 1915.

(12) J. Coggen Brown: The mines and minerals of Yunnan. Mem. Geol. Surv. India, Vol. 47, p. 1. Also in Far Eastern Review 1921.

(13) H. Schneiderhöhn: Anleitung zur Untersuchung u. Bestimmung von Erzen von Aufbereitungsprodukten besonders im auffallenden Licht. Berlin, 1922.

(14) W. Fackert: Ein neues Kupferkiesätzmittel. Metallwirtschaft, Heft 43, Oct. 1928.

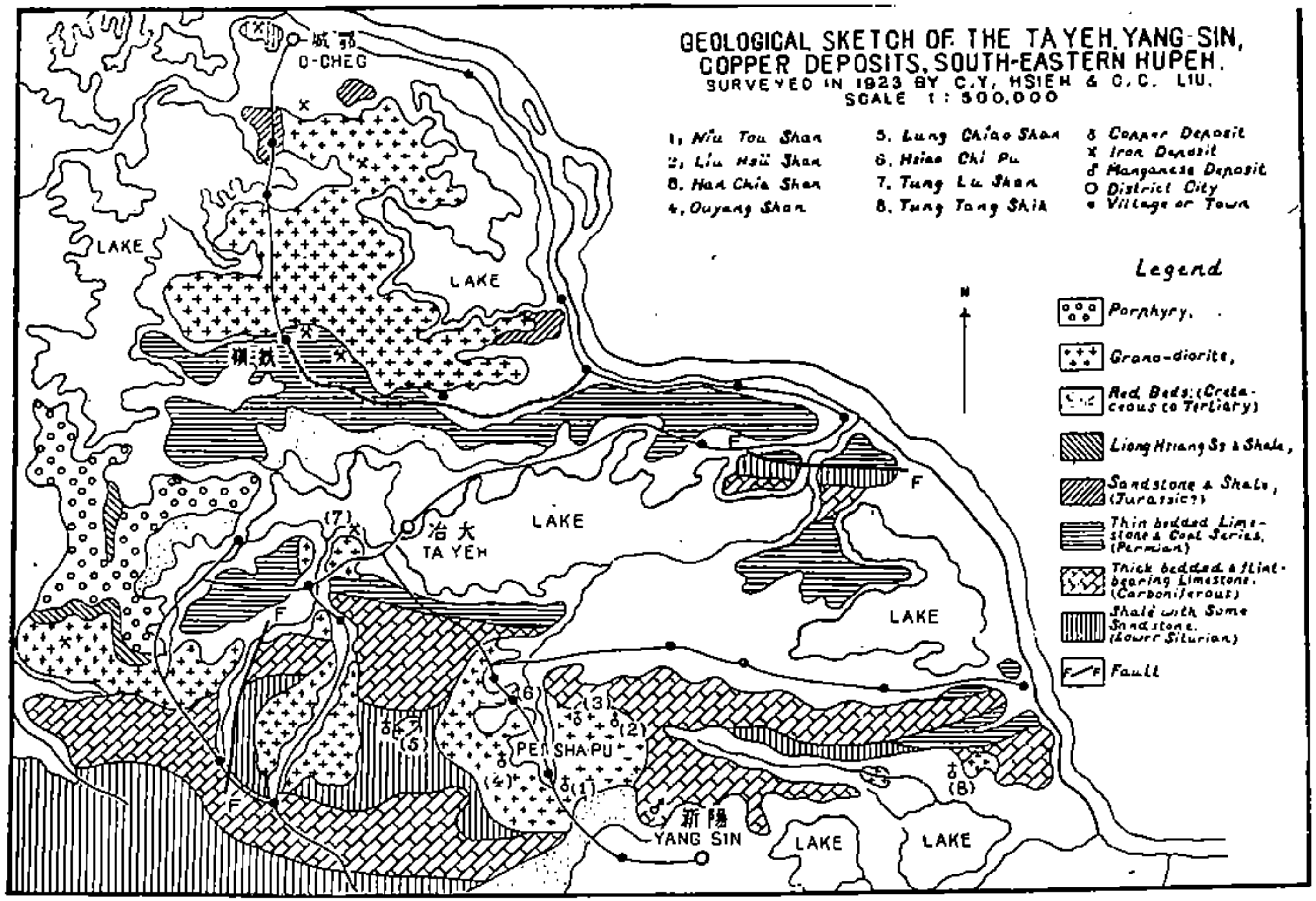
(15) H. Schneiderhöhn: Genesis und Paragenesis der Sulfidmineralien, in Doelter's Handbuch der Mineralchemie, Bd. IV, p. 911.

(16) H. Moritz: Eine Vorrichtung zum Ausbohren analysenreiner Mineralteilchen aus Anschliffen unter dem Erzmikroskop. Centralblatt f. Miner. etc. 1929, Abt. A, No. 7, p. 251-254.

(17) C. Doelter: Handbuch der Mineralchemie, Vol. IV, Part 1, 1926, p. 671, Chapter on Safflorite by M. Henglein.

(18) L. F. Yih & K. P. Chao: Geology and Mineral deposits of Yang Sin Ta Yeh & O Cheng districts, Hupeh Province, Mem. Inst. of Geology No. 1. Shanghai.

(19) C. L. Ho: The igneous rocks of Yang Sin, Ta Yeh and O Cheng districts, Hupeh Province. Mem. Inst. Geology No. 2. Shanghai.


GEOLOGICAL SKETCH OF THE TAYEH, YANG-SIN, COPPER DEPOSITS, SOUTH-EASTERN HUPEH.
SURVEYED IN 1923 BY C.Y. HSIEH & C.C. LIU.
SCALE 1 : 500,000
1, Niu Tou Shan
2, Liu Hsü Shan
3, Han Chia Shan
4, Ouyang Shan
5, Lung Chiao Shan
6, Hsiao Chi Pu
7, Tung Lu Shan
8, Tung Tang Shia
♁ Copper Deposit
x Iron Deposit
♂ Manganese Deposit
O District City
• Village or Town
Legend
Porphyry,
Grano-diorite,
Red Beds; (Cretaceous to Tertiary)
Liang Hsiang Ss & Shale,
Sandstone & Shale, (Jurassic?)
Thin bedded Limestone & Coal Series, (Permian)
Thick bedded & flint-bearing Limestone. (Carboniferous)
Shale with Some Sandstone. (Lower Silurian)
Fault
N
LAKE
LAKE
LAKE
LAKE
LAKE
LAKE
LAKE
O-CHEG
冶大
TA YEH
PEI SHA PU
新陽
YANG SIN
F
F
F
F
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)

Explanation of
Plate II

PLATE II.

Fig. 1. Thin section of a fresh grano-diorite, Ou Yang Shan. x 42. f, feldspar; h, hornblende; b, biotite; a, apatite; t, titanite.

Fig. 2. Mineralized grano-diorite assuming a pseudo-gneissic structure, Ou Yang Shan. Thin section. x 42. q, quartz; b, biotite, bleached; c, calcite; sc, sericite and chlorite; black area, chalcocite with rests of bornite (not distinguishable in thin section).

Fig. 1. × 42.

Fig. 2. × 42.

Explanation of
Plate III

PLATE III.

Fig. 3. Bornite occurring along cracks, cleavage or crystal boundaries in wollastonite, Niu Tou Shan, thin section. X 42.

Fig. 4. Pyrite replacing tremolite, thin section, x70. Lung Chiao Shan.

Fig. 3. × 42.

Fig. 4. × 70.

Explanation of Plate IV

PLATE IV.

Fig. 5. Garnet with filling of actinolite in a ground mass of calcite, thin section, Liu Hsü Shan, x42.

Fig. 6. Magnetite replaced by hematite forming the well-known process of martitization. Replacement seems to have followed along the crystallographic directions of the magnetite, so that a characteristic zonal arrangement is produced. Liu Hsu Shan. x135.

Fig. 5. × 42.

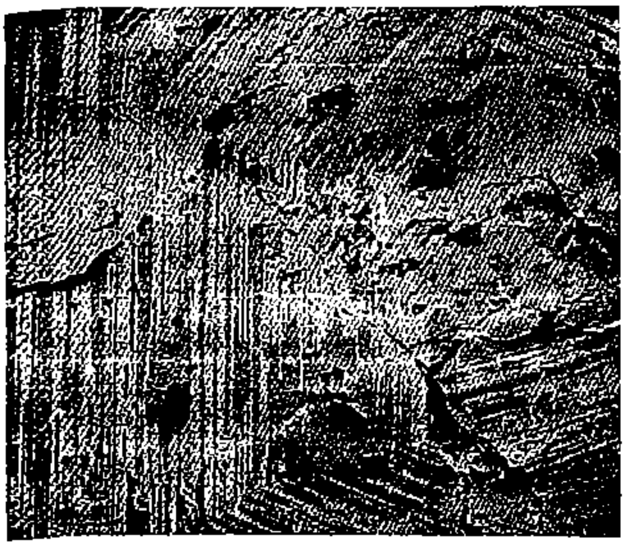


Fig. 6. × 135.

Explanation of

Plate V

PLATE V.

Fig. 7. Bornite (dark groundmass) with inclusions of chalcopyrite lines (white), the latter arranged in cubic directions of the embedding mineral. In the center it is crossed by a veinlet of blue chalcocite (light gray) and covellite (fibrous and grayish black). Niu Tou Shan. Polished section. x360.

Fig. 8. Bornite with chalcopyrite lines arranged in octahedral directions. It is crossed by an irregular veinlet of blue chalcocite (light gray) which has been partly altered to covellite (dark gray). A little galena (white) is shown. Polished section. Niu Tou Shan. x300.

Fig. 9. Bornite with inclusions of chalcopyrite is cut again by chalcopyrite of second generation. Polished section, Niu Tou Shan. x300.

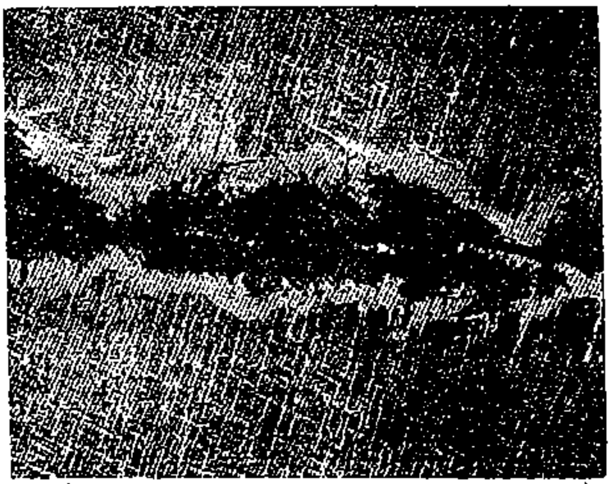


Fig. 7. × 360.

Fig. 8. × 300.

Fig. 9. × 300.

Explanation of Plate VI

PLATE VI.

Fig. 10. Irregular grains and lamellae of bornite (black) more or less regularly arranged in chlacocite (light gray). Ou Yang Shan. Polished section. x115.

Fig. 11. Bornite lamellae (dark gray) roughly arranged according to the octahedral directions in chalcocite (light gray). Ou Yang Shan. Polished section. x225.

Fig. 12. Heat etching structure of chalcocite showing lamellae of three directions. Ou Yang Shan. x21c

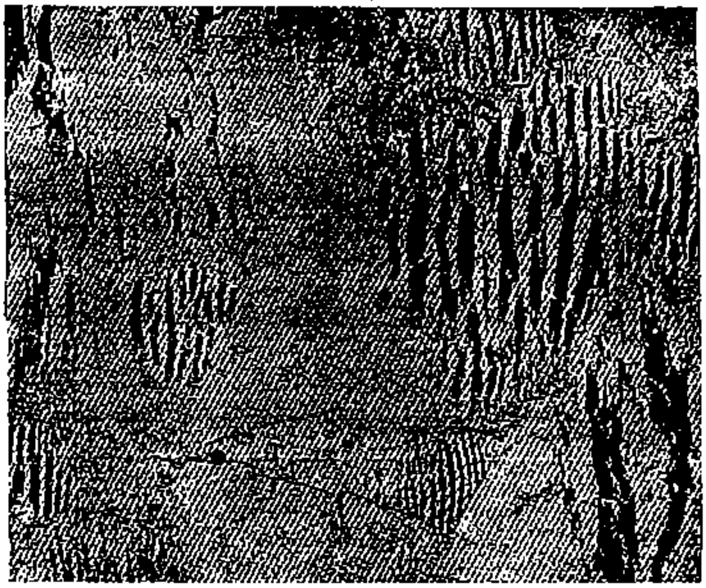


Fig. 10. × 115

Fig. 11. × 225.

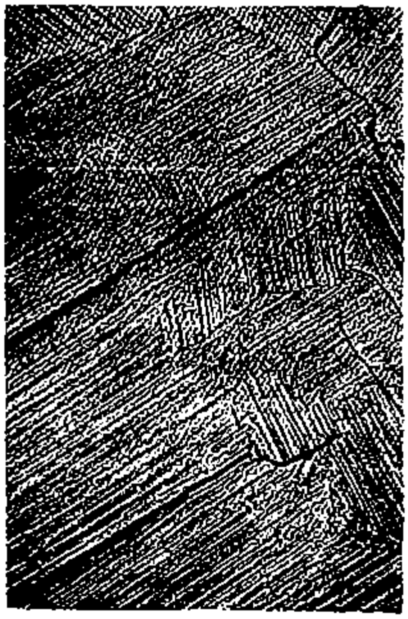


Fig. 12. × 210.

Explanation of Plate VII

PLATE VII.

Fig. 13. Polished section of ore from Sin Shan, Tung Chuan, showing bornite (dark gray), chalcopyrite (white), veinlets of chalcocite (light gray) and covellite (grayish black) and prismatic crystals of tourmaline (dark gray). Characteristic is that here chalcocite replaces only bornite, but not chalcopyrite (selective replacement). x275.

Fig. 14. Chalcopyrite etched with conc. nitric acid and potassium chlorate showing allotriomorphic granular structure. Sin Shan, Tung Chuan x 155.

Fig. 13. × 275.

Fig. 14. × 115.

Explanation of Plate VIII

PLATE VIII.

Fig. 15. "Glaskopf" structure in the ore of Mou Lu Chen, Tungchuan. In the center: Malachite (dark gray) with nucleus of cuprite (white), the latter contains grains of native copper (bright and with relief). In the concentric bands: limonite (gray), tenorite (white and bright) and malachite (dark gray). Polished section. x84.

Fig. 16. Groundmass of bornite (gray) containing small veinlets of blue chalcocite (light gray) and prismatic crystals of tourmaline (dark gray). Notice the horizontal fissures in tourmaline. Lou Sin Shan, Tasui, Tungchan. x84.

Fig. 17. Needles of chalcopyrite (white) in bornite (gray) formed as a consequence of unmixing. The chalcopyrite is partly altered into covellite (dark gray). Hou Shan, Tungchuan. Polished section. x1,000.

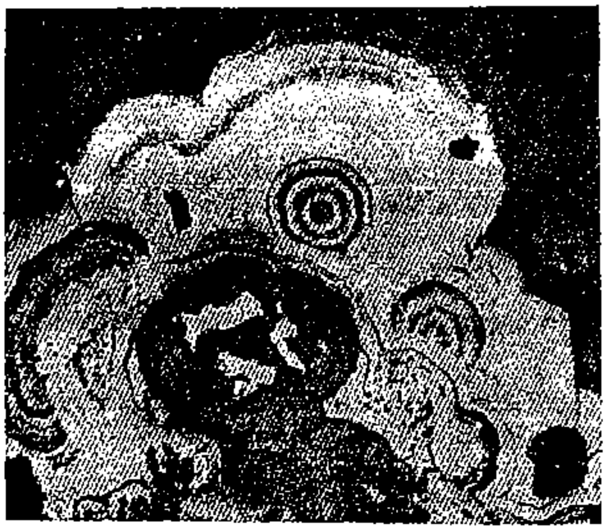


Fig. 15 × 84.

Fig. 16. × 84.

Fig. 17. × 1,000.

Explanation of Plate IX

PLATE IX.

Fig. 18. Residual pyrite (grains with high relief) in chalcopyrite (white) both being crossed by veinlets of covellite (gray). Sin Shan, Tungchuan. x38.

Fig. 19. Veinlets consisting of covellite (fibrous), limonite (gray) and gangue (dark gray) in the center. The groundmass is chalcopyrite. Tungchuan. x193.

Fig. 20. Combination of two systems of polysynthetic twins in chalcopyrite as developed by etching with conc. HNO_3 and $KClO_3$. Tung Chuan. x200.

Fig. 18. × 38.

Fig. 19. × 193.

Fig. 20. × 200

Explanation of Plate X

PLATE X.

Fig. 21. Hematite grains (white with relief) separated along irregular veinlets and grains of chalcocite (light gray) in bornite (dark gray). Tung Chuan. Polished section. x250.

Fig. 22. Chalcocite (gray) occurring either as little veinlets or as irregular myrmekitic forms in bornite (dark gray). Black crystals of prismatic and triangular shape are tourmaline. Tung Chuan. Polished section. x225.

Fig. 21 × 250.

Fig. 22 × 225.

Explanation of

Plate XI

PLATE XI.

Fig. 23. Myrmekitic bornite (gray) in a ground mass of chalcocite (light gray). Idiomorphic crystals with relief are hematite. Lou Sui Chang, Tung Chuan. x210.

Fig. 24. Etching structure of chalcocite (by conc. HNO_3). Lou Sui Chang Tungchuan. Polished section. x210.

Fig. 23. x 210.

Fig. 24. x 210.

Explanation of Plate XII

PLATE XII.

Fig. 25. Intergrowth of chalcocite and bornite (dark gray) forming at one place veinlet and at other skeleton-like structure. Ma Lung Chang, Hsiu Na district, Yunnan. Polished section. x225.

Fig. 26. Cleavage in chalcocite recognizable already before etching. Ta Tun, Hsuan Wan, Yunnan. x58.

Fig. 27. Twinning lamellae in chalcopyrite, more or less deformed. Etched with conc. HNO_3 and $KClO_3$. Chiang Chun Shih, Tung An, Hui Li district, Szechuan. x115.

Fig. 25. × 225.

Fig. 26. × 58

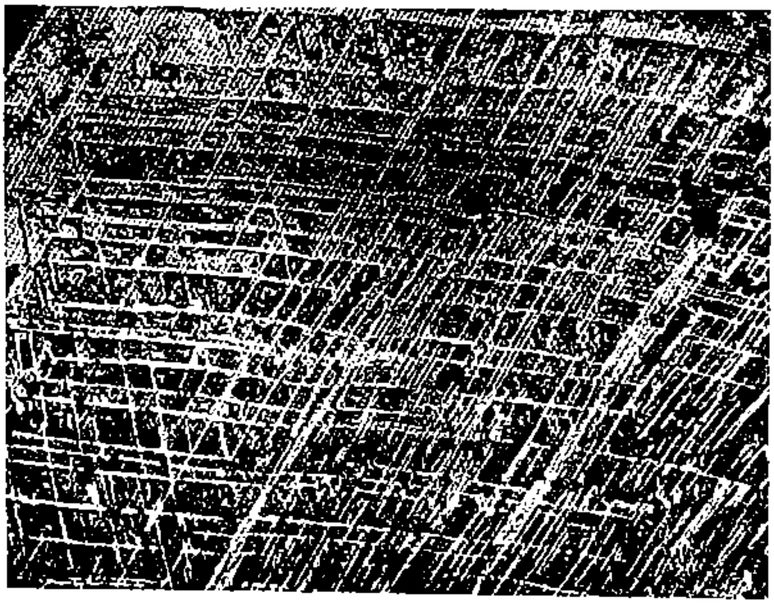


Fig. 27. × 115.

Explanation of Plate XIII

PLATE XIII.

Fig. 28. Polished section of the ore from Yi Wan Sui, Hui Li District, Szechuan showing chalcopyrite (light gray), spherulite (dark gray) and safflorite (small rhombohedral crystals). x135.

Fig. 29. Etching of chalcopyrite showing granular structnre. Yi Wan Sui, Hui Li, Szechuan. x115.

Fig. 30. Etching structure of chalcopyrite showing fine granular variety cut by coarser one. Yi Wan Sui, Hui Li, Szechuan. Polished section. x200.

Fig. 28. × 135.

Fig. 29. × 115.

Fig. 30. × 200.

ERRATA

Page 263 foot note delete *microscopical* before *mineralogical* & inserting *microscopical* before *research.*
,, 264 line 23, delete *and the sandstone.*
,, 265 line 17, for *cantact* read *contact.*
,, 267 line 18, add *grano-diorite of this region is generally characterized by a low & gentle* after *the.*
,, 267 line 19, for *topograpy* read *topography.*
,, 267 foot note line 8 place *rather* before *basic.*
,, 268 line 32. delete *an.*
,, 269 line 7, for *this* read *there.*
,, 269 line 20, for *alternation* read *alteration.*
,, 274 line 9, for *in* read *is.*
,, 274 line 10, for *result* read *results.*
,, 274 line 26, for *microlitic* read *miarolitic.*
,, 276 line 15, delete *which.*
,, 279 line 3, for *Fig.* 8 read *Fig.* 9.
,, 280 line 4, add *and* after *figured.*
,, 280 line 33, add *found in* after *is.*
,, 283 line 10, for *hosides,* read *besides.*
,, 285 line 31, for *bornitc,* read *bornite.*
,, 287 line 11, delete *Pei.*
,, 288 line 24-25 for *interesecting* read *interesting.*
,, 289 line 6, for *thowing* read *showing.*
,, 289 line 10, for *represhut* read *represents.*
,, 289 line 33, for *been* read *seen.*
,, 290 line 2, for *deprcsion* read *depression.*
,, 292 line 22, for *phenocrys* read *phenocrysts.*
,, 293 line 21, for *polarisator* read *polariser.*
,, 294 table II shift *downward cementation* one column below so to include *cuprite* in *oxidation.*
,, 294 table II for *Tang Tan* read *Tandan.*
,, 294 table II delete *Pei* before Sin shan.
,, 294 table II add × under *Tandan* & *hematite.*
,, 297 line 9, for *mere* read *more.*
,, 298 line 25, for *directions* read *diameter.*
,, 298 last line for *For* read *From.*
,, 299 table III add × indicating the presence of galena, tetrahedrite & sphalerite under *Yi Wan Shui* and add × corresponds to *pyrite* for the first four localities except the second.

Plate V. for Fig. 8 read Fig. 9 & for Fig. 9 read Fig. 8.

Explanation of Plate XIII line 2 for *spherulite* read *sphalerite.*