国立中央研究院地質研究所

# 叢　刊

第四号

CONTRIBUTIONS

FROM

THE NATIONAL RESEARCH INSTITUTE OF GEOLOGY

ACADEMIA SINICA

No. 4.

地質研究所印行

中华民国二十二年六月

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## 目　錄

# MAGNETITE DEPOSITS OF THE TUNGKUAN-SHAN, TUNGLING, ANHUI.

BY

H. M. MENG AND K. CHANG

(With 9 Plates, 2 Text-figures and a Geological Map)

## INTRODUCTORY.

Ever since von Richthofen's[1] time the Tungkuan-shan has been made known to, and been visited by many a geologist and mining engineer. Among them some[2] have published brief reports chiefly dealing with the iron-ore reserve and very few[3] have made detailed study on the genesis of the ore. In connection with the contact metamorphism of the quartz diorite in the region, none has paid attention to the well exposed contact zone composed of wollastonite, diopside, salite and grossularite at Tien-o-pautan, about 2 km. northeast of Tungkuan-shan-miao, and that composed of tremolite at Tsienhsui-lao a little southward from Tien-o-pautan about 1 km. Hence in the present report particular stress is laid on the ore genesis of the Tungkuan-shan magnetite deposits and the associated contact silicates. Lastly an attempt is made to calculate the ore reserve of the region so as to compare with other estimates.

The writers wish to express their indebtedness to Prof. J. S. Lee, Director of National Research Institute of Geology, and Prof. L. F. Yih for their advice and encouragement during the study of the Tungkuan-shan magnetite deposits and particularly to Prof. Lee for his critical reading of the manuscript and many invaluable suggestions. The total or partial chemical analyses of the rock and mineral specimens contained

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[1] Richthofen, F. v., China, Band III, pp. 562-3.

[2] Wong, W. H., Mineral Resources of China, Mem. China Geol. Survey, Ser. B, No. 1, pp. 144-6.
Tegengren, F. R., The Iron Ores and Iron Industry of China, Mem. China, Geol. Surv. Ser. A, No. 2, Part II, pp. 207-11.

[3] Yih, L. F., Bull. Geol. Soc. of China, Vol. IV, p. 113; Vol. V, pp. 65-66.
Hsieh, C. Y., Bull. Geol. Soc. of China, Vol. X, pp. 336-7.

herein were made by Messrs. H. Li, C. Chiu and I. Li, Chemists of National Research Institute of Geology, to whom the writers should acknowledge their appreciation.

## GENERAL FEATURES.

Tungkuan-shan, though only about 460 metres above the plain, constitutes one of the several quartzite peaks which tower above the red clay terraces and the recent flood plains along the eastern banks of the Yangtze River between Tatung and Tungling. It is situated about 11 *li* south of the city of Tungling and about 35 *li* north-northeast of the river-port, Tatung. Most of the magnetite deposits crop out along its northern foothills. Of the mining history of the region, an excellent account was given by Tengengren.[1]

Several hundred meters north-northeast of the main Tungkuan-shan, there rises the Pi-shan to an altitude of about 140 meters. Its northern end consists of the Lungtan Coal Series which is metamorphosed into a dark grey, massive slate. In its southern part, the Chihsia Limestone becomes dominant, though faulted in certain places. This Limestone is also locally metamorphosed, presenting a somewhat schistose structure, and the cherty nodules included therein are mostly bleached to white masses. The southwestern part of the hill is composed of a garnetiferous rock—chiefly andradite—and iron ore which are less resistant to erosion than the enclosing sedimentary formations. Numerous boulders and irregularly shaped pebbles of magnetite, hematite, and andradite are scattered over the hill slopes. Further on the southern end of the Pi-shan, the quartz-diorite crops out.

On the northwestern part of the Tungkuan-shan is a dome-shaped hill named the Pau-shan. On its northern slope, some quartz-diorite is exposed, but highly weathered and decomposed. Between the quartz-diorite and the quartzite, which latter constitutes the greater part of the Pau-shan, lies a garnetiferous iron ore lode. To the east of this is the Lau-shan, a foothill of the Tungkuan-shan. Here similar conditions to those of the Pau-shan prevail. Along the lower portion of its slope occurs some weathered and partly decomposed quartz-diorite. From the upper portion of its slope to the ridge, a considerable outcrop of garnetiferous iron ore lode, sometimes stained with a little malachite, stands out in relief. It is this outcrop which renders the Tungkuan-shan known as a source of

[1] op. cit. p. 210.

copper ores in the past, but is now well-known as a source of iron ores instead. Further east is the Hsiao-Tungkuan-shan where the same features are found, except at one place where a small body of iron ore projects out in the midst of the quartz-diorite as a tiny prominence. At the little pass, Koto-wang, lying between the Pi-shan and the Tungkuan-shan, there appears a good section of the well jointed quartz-diorite. Passing Koto-wang and going eastward, two small hills, the Pine Hill and the Tiny Lion Hill come into view. They are both made up entirely of the earthy, concretionary, and sometimes loose and porous, deeply weathered iron ores. Further eastward on the slope of Changshanto, another outcrop of such weathered iron ore is seen. The southern portion of Changshanto is composed of the Chihsia, Swine and other Limestones; the lower part of the limestone series is mostly metamorphosed into coarse crystalline marble. Running parallel to the ridge of Changshanto and separated therefrom by the Hsianghsuichung Valley, there is another low ridge, named Tien-o-pautan (Plate II A), where clear evidence of contact metamorphism due to the quartz-diorite intrusion is to be found. On its northern and eastern foothills exposures of quartz-diorite show porphyritic texture in places; on the western slope, large boulders of weathered iron ores are scattered about. Between the quartz-diorite and the iron ores lies a narrow zone of contact silicates. The southern portion of this ridge is composed of the Chihsia Limestone, the Lungtan Coal Series and the Chinglung Limestone in normal succession. The low ridges to the south and east of Tien-o-pautan reveals mainly undulatory folds of the Chinglung Limestone. Near the head of the Tsienhsui-lao Valley, some Chinglung Limestone is metamorphosed into a finely fibrous and more or less porous rock, chiefly composed of tremolite. The main Tungkuan-shan which occupies the greater part of the area here considered is composed of the massive Quartzite.

## STRATIGRAPHY.

The sedimentary formations in the area under consideration are more or less contact-metamorphosed. Their correlation is chiefly based on the lithological characters. The ascending sequence of the stratified rocks are briefly as follows:—

*a.* The Massive Quartzite. It is generally white in colour when fresh, somewhat thick-bedded, and corresponds to the so-called Wutung Quartzite of Changhsin, Chekiang. Age: probably lowest Carboniferous; minimum thickness: 400-450 m.

*b.* Recrystallized Limestones. These limestone series, mostly contact metamorphosed into marble, can be lithologically correlated with the Chuanshan Limestone[1] for its topmost part, and with the Huanglung Limestone[1] for the remaining portion. Thickness: 30 m.

*c.* Swine Limestone.[2] It usually assumes a dark blue colour, presents a light grey or bluish tint on the weathered surface, and gives a typical fetid odour when struck by the hammer. It contains no chert nodules. Groups of foraminifera occur in the rock mass, but mostly indeterminable due to intense metamorphism into coarse calcite. In a certain layer of the middle portion of this Limestone, gastropods are especially abundant. The latter usually are embedded in the lenticular and more calcareous parts of the Limestone. Thickness: 30-40 m.

*d.* Chihsia Limestone. This is a dark blue limestone containing cherty nodules or intercalating with cherty bands or lenses arranging in layers parallel to the bedding plane. Sometimes the top and the basal parts of this Limestone are intercalated with lydite layers. Thickness: 120 m. Both the Swine and the Chihsia Limestones are regarded as of middle Permian age.

*e.* Lungtan Coal Series. Its upper part consists of massive shale and slate of grey colour. The lower part contains mainly coarse sandstone. At the Pi-shan the shaly beds are metamorphosed into dark hornfels and slates. No coal seam is found near the Tungkuan-shan. Several *li* east of the district mapped, specimens of *Lyttonia, Spirifer,* and *Productus* were collected from a cherty stratum on a small dump at Chipei-Chung where coal mining had been attempted. These fossils may belong to the very basal part of the Coal Series or may even range down to the Upper Lydite. The age of the Lungtan Coal Series is considered to be upper Permian. Thickness not ascertained.

*f.* Chinglung Limestone. This limestone largely consists of a light grey thin-bedded limestone. The basal part often alternates with thin layers of shale. On approaching the underlying Coal Series, the alternating beds become thinner. Age: probably Triassic; thickness: over 100 m.

*g.* Red Clay. Although in the area mapped no red clay is to be seen, it is distributed in the adjoining areas, *e.g.* Yangshanchi (Plate II B) and

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[1] Lee, J. S., Note on Chihsia Limestone and Its Associated Formations, Bull. Geol. Soc. of China, Vol. IX, pp. 37-44.
Lee, J. S., Chen, S., and Chu, S., Huanglung Limestone and Its Fauna, Mem. Nat'l. Res. Inst. Geol., No. IX, pp. 85-172.

[2] Lee, J. S., Bull. Geol. Soc. of China, Vol. X, p. 281.

around Chipei-Chung, forming low terraces about ten to twenty metres above the Yangtze flood plain.

## STRUCTURE.

The limited area here considered forms the eastern limb of a large presumed anticline with its axis running approximately north by east and south by west. Its western limb is not seen. The massive quartzite crops out on the west constituting the peaks of the Yangshan and the Tungkuan-shan. Going east, there appear in succession discontinuous outcrops of the Huanglung, Chuanshan, Swine and Chihsia Limestones, the Lungtan Coal Series and the Chinglung Limestone, the last mentioned being again folded into small anticlines and synclines.

The main Tungkuan-shan structurally constitutes a semi-circular dome. The massive Quartzite near the top of the Tungkuan-shan assumes very gentle dips and at places lies nearly horizontal. Toward the northern, eastern and southern edges of the hill, the Quartzite together with the overlying formations gradually dips in accordance with the respective slopes. On the west, the Tungkuan-shan dome is cut open by a fault which separates the same from the Pao-shan and follows the valley southward to Suishiling and further. Hence the massive Quartzite at the Pao-shan and the Yang-shan dips northward or northwestward at fairly steep angles, whereas the same at the Tungkuan-shan is nearly horizontal or dips gently toward the northerly, easterly or southerly directions. Such difference in dip-angles between the strata of the Yang-shan and the Pao-shan and those of the Tungkuan-shan also accounts for the topographical discordance between them; the former all having pointed peaks and steep slopes while the latter assuming a nearly smooth and rounded hilltop. These structural and topographical features can well be observed at any place on the road from Suishiling to Tienmenkou when looking at these quartzite ranges.

The foothills to the northeast of the Tungkuan-shan reveal an anticlinal structure pitching northeastward. The Pishan forms one limb of the anticline while Changshanto and Tien-o-pautan constitute the other. These two limbs should join together at the further northeastern corner beyond the area mapped, where the last trace of the solid strata is buried under the flood plain of the Yangtze. At the Pishan limb, there are exposed the Chihsia Limestone and the Lungtan Coal Series. The former is traversed by fractures at places, sometimes dipping northwest at a steep

angle, but generally dipping southwest at an angle of 40 to 50 degrees. It is thrown into fault contact with the Lungtan Coal Series which latter dips N. 10° W. at an angle of 40°. The other limb stretching from Changshanto to Tien-o-pautan is divided into two portions by the fault running along the Hsianghsuichung Valley. The portion at Changshanto is composed of the Huanglung, Chuanshan, Swine and Chihsia Limestones, all dipping southeast. The other portion at Tien-o-pautan is represented by the Chihsia Limestone, Lungtan Coal Series and Chinglung Limestone, these being also dipping southeast. The main quartzite range of the Tungkuan-shan forms the axial portion of the small pitching anticline.

The fault, running through the valley of Hsianghsuichung and separating Changshanto from Tien-o-pautan, trends southeast on the north, but swings round to follow the valley upstream, and then turns southwestward on the southern end. It is the effect of this fault that causes the missing of the several formations lying between the Chinglung Limestone and the massive quartzite at Tsaohsulin and Shertsen; it is also due to the same cause that the Chihsia Limestone at Tien-o-pautan is displaced a little to the north-northwest when compared with its corresponding position at Chanshanto. Other minor faults are those running between the Chihsia Limestone and the Lungtan Coal Series at the Pishan and that along the valley to the west of the Tiny Lion Hill where a fault block of the Swine Limestone, dipping N. 63° W. at an angle of 50°, perches on the edge of the quartz-diorite outcrop.

Chronologically these faults can be divided into two sets. The first set of faults are those which were caused by the quartz-diorite intrusion. These are the minor faults as manifested by the fault blocks at the Tiny Lion Hill and the faults running accross the Lungtan Coal Series and the Chihsia Limestone at the Pishan. They were probably developed during the intrusion of the quartz-diorite. The second set, which is of quite common occurrence in South Anhui, is of larger magnitude and later age. The large fault running accross the Hsianghsuichung belongs to this set. These faults were brought about at a date later than the period of mineralization, for along the fault line generally no trace of the activities of the iron-ore bearing solution can be detected. On the contrary, the iron-ore deposits were more or less affected by such faults.

Faults which bring the Chinglung Limestone in direct contact with the massive Quartzite are frequently met in South Anhui. In the vicinity of the Shuitung Colliery in Hsuenchen, the writers found a large circular fault of the same nature which affected not only the Chinglung Limestone

but also the Red Clay beds, the latter have been considered to be of the latest Tertiary Age. Thus faulting must have played a rôle in the recent tectonic history of South Anhui.

## THE QUARTZ-DIORITE INTRUSION.

The quartz-diorite forms a zone running nearly west—east from the Pao-shan to Tien-o-pautan and further. Going west from the Pao-shan, its presence is marred by erosion, but in places the residual clay shows characteristics of a decomposed quartz-diorite. In the eastern part of the area surveyed, the quartz-diorite runs across Niehkulin and further. Near Hsianghsuichung its presence is again marred by erosion or covered under alluvium. Judging from its mode of occurrence, the quartz-diorite may be in the form of a sill or a small stock wedging in mostly between the base of the Huanglung Limestone and the top of the massive Quartzite, though in places it even comes up near the Chihsia or as far as the Chinglung Limestones. It is sheeted and well jointed, thus easily plucked out by agency of erosion. Like granite, it presents rounded and smooth surfaces when weathered, and shows spheroidal exfoliation. The main portion of the quartz-diorite is usually of light grey to white in colour, medium-grained and granular in texture, although the marginal parts may assume a darker and finer phase. The phenocrysts which can be detected megascopically are quartz, plagioclase and hornblende, none of them showing good crystal boundaries. But at the marginal portions the texture is decidedly porphyritic with phenocrysts of hornblende as black, long and slender prisms, and plagioclase as short stubby ones. At Tien-o-pautan where the quartz-diorite comes into contact with the Chihsia Limestone, a contact metamorphic zone of about one metre in width is exposed. Megascopically this zone reveals a roughly banded structure with white fibrous wollastonite bands, each about ten to twenty centimetres in width, alternating with light green fine-granular and compact bands of two or six centimetres in width. The latter are more resistant to erosion and weathering, and consequently stand out in relief. Thus, the contact metamorphosed part, when exposed, still resembles the normal Chihsia Limestone in appearance with the compact bands standing out as if they were the lydite layers. Other contact metamorphic effects which can be detected megascopically are the transformation of parts of the Lungtan Coal Series into slates and hornfels; parts of the Chinglung Limestone into tremolite; Huanglung Limestone into marble or coarse

crystalline calcite and the massive Quartzite somewnat foliated. In addition, large bodies of magnetite and andradite with subordinate amount of hematite are usually deposited at the marginal parts of the quartz-diorite.

## PETROGRAPHY OF THE QUARTZ-DIORITE.

In all the specimens examined, quartz constitutes more than 5% of the component minerals. Andesine[1] is the chief feldspar and orthoclase plays a minor part. Both hornblende and augite occur, but their respective abundance varies in places, sometimes only one of them is present. In the marginal parts of the intrusion, augite is distinctly more often represented than hornblende, and usually it is titaniferous. For the most part the quartz-diorite is holocrystalline, rather coarse, granular, somewhat ophitic in places with andesine varying from idiomorphic to hypidiomorphic and hornblende hypidiomorphic to allotrimorphic crystals. Interstitial quartz occurs between hornblende and andesine. Andesine, generally fresh but now and then kaolinized along its border and cleavages with marked zonal growth (Plate III A), and albitic and pericline twinning. Hornblende is somewhat interfered by andesine growth, and sometimes forms the core of the zonal andesine. The greenish hypidiomorphic augite appears in the marginal portions of the quartz-diorite intrusion as at Hsiao-Tungkuan-shan and Tien-o-pautan. It is usually closely associated with wedge-shaped titanite, and is distinguished from ordinary augite by its higher refringence and birefringence and faint pleochroism. Such abnormal optical characters may be due to the effect of contact metamorphism. The accessory minerals are as usual wedge-shaped titanite, apatite, ilmenite, magnetite, zircon, pyrite, etc. They are evenly distributed in the rock-mass. The iron oxides, magnetite and hematite, seem to be especially abundant in the quartz-diorite of the Pishan. This fact is also revealed through chemical analysis of the same rock (Table I). In places the feldspars, especially orthoclase, are more or less sericitized. The quartz-diorite at Neihkulin shows, in addition to quartz and hornblende, a small amount of biotite which often intergrows with hornblende.

The quartz-diorite near the contact metamorphic zone where the intrusive gradually grades into the contact silicates as at Tien-o-pautan, shows a holocrystalline, medium-grained and granitoid structure, with quartz

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[1] Some essential optical properties of this mineral are: biaxial, positive, indices of refraction higher than Canada balsam; extinction angles (a) in section $\perp$ a, $x' \wedge 010 = 13^\circ$ (margin), $19^\circ$—$28^\circ$ (core); (b) in zone $\perp$ 010, $x' \wedge 010 = 20^\circ$

in places especially abundant, and the greenish augite more prominent than hornblende. Calcite veinlets and replacements of the feldspars along cleavages, zonal planes, or twinning planes are quite common (Plate III B) Fractures of augite may also be filled with calcite veinlets, while quartz is generally free from such replacement. Kaolinization becomes more prominent in the contact part where the typical contact silicates are found. Near the contact zone the quartz-diorite shows some characteristics different from the normal rock: it seems to be more titaniferous, and contain more quartz in places. Among the dark constituents augite supersedes hornblende and biotite, and the greenish augite often grades into ferriferous diopside.

There is another specific feature of the quartz-diorite shown near the contact zone at Tien-o-pautan, where it presents a porphyritic texture and assumes a structure similar to that of a dolerite. Most of the andesine phenocrysts show idiomorphic outlines while the greenish augite phenocrysts are hypidiomorphic and quartz is as larger irregular grains. Certain zonal andesine phenocrysts have their central cores greatly altered to calcite while the peripheral portions are not affected. Besides, biotite is sometimes found either as long irregular grains, or as small prismatic grains included in hornblende. In certain parts of the rock the groundmass is composed of mainly fine granular quartz and subordinate amount of orthoclase, but in general it is essentially of fine-grained kaolinized orthoclase intergrown with a minor amount of quartz, approaching a crypto-crystalline or micrographic structure. Calcite and kaolin disseminations are frequent in the groundmass. In the peripheral part of this quartz-diorite porphyrite, irregularly bounded phenocrysts of quartz are quite abundant, while feldspars are greatly kaolinized, and gradually decrease in amount in proportion to quartz as the contact zone is approached. Here again augite begins to grade into diopside or is metamorphosed into clinozoisite with very weak birefringence. The very fringe of the quartz-diorite is usually marked by the presence of a veneer of peculiar mineral aggregate, about 1mm. thick, which is composed chiefly of quartz, diopside, some kaolinized andesine, and a micro-granitic groundmass of quartz and feldspars. This is followed by a thin layer of carbonate about 2 mm. in width, where the fine-grained calcite dominates. Intermingling with the carbonates are some wollastonite, diopside, clinozoisite, and fine granular quartz. Next to the carbonate layer is the zone of contact silicates which are composed of the intergrowths of wollastonite and diopside with interstitial calcite and incipient garnet (highly

refringent and isotropic material). Thus the gradation of the contact effect from quartz-diorite to limestone can be roughly stated in the following order:

1. Quartz diorite
2. Quartz diorite porphyrite
3. Reaction border (sometimes unobservable)
4. Contact silicates and iron ores
5. Normal limestone.

Representative specimens of the quartz-diorite or porphyrite in the Tungkuan-shan district were analyzed. Their compositions are given in Table I with their respective symbols and names shown according to the

TABLE I.

CHEMICAL COMPOSITIONS OF THE QUARTZ-DIORITE IN THE TUNGKUAN-SHAN DISTRICT.

| Locality | Southern Slope of Pi-shan | Eastern Slope of Hsiao-Tung-kuan-shan | Niehkulin-Chung | Northern Slope of Tien-o-pautan |
|---|---|---|---|---|
| $SiO_2$ | 64.18 | 64.44 | 62.74 | 61.72 |
| $Al_2O_3$ | 17.13 | 16.87 | 16.40 | 16.81 |
| $Fe_2O_3$ | 2.63 | Tr. | 1.80 | 0.90 |
| FeO | 2.53 | 2.44 | 3.00 | 4.74 |
| MgO | 1.60 | 1.63 | 2.08 | 1.90 |
| CaO | 4.80 | 6.90 | 5.14 | 5.12 |
| $Na_2O$ | 3.71 | 4.07 | 3.80 | 3.50 |
| $K_2O$ | 3.20 | 2.88 | 3.10 | 3.20 |
| $H_2O-$ | 0.36 | 0.35 | 0.37 | 0.34 |
| $H_2O+$ | 0.20 | 0.17 | 0.41 | 0.66 |
| $TiO_2$ | 0.56 | 0.58 | 0.70 | 0.70 |
| $P_2O_5$ | 0.22 | 0.30 | 0.30 | 0.28 |
| Total | 100.82 | 100.63 | 100.84 | 99.85 |
| Sp.g. | 2.75 | 2.68 | 2.71 | 2.72 |
| Nomenclature | Quartz Hornblende Diorite | Quartz Augite Diorite | Quartz Hornblende Diorite | Quartz Diorite Porphyrite |
| C.I.P.W. Classification — Symbol | I(II).4.3.(3)4 | I". 4. "3. "4 | (I)II.4". "3.(3)4 | "II.4".3.3(4) |
| C.I.P.W. Classification — Name | Yellowstonose | Yellowstonose | Tonalose | Harzose |

C.I.P.W. system of classification. It is found that the intrusive lies in the range of the sub-rangs of Yellowstonose, Tonalose and Harzose where majority of the rock-analyses recorded[1] are those of the quartz-diorite, granodiorite and quartz-monzonite.

TABLE II.

RECALCULATION OF THE CHEMICAL COMPOSITIONS OF THE VARIOUS QUARTZ-DIORITES ACCORDING TO NIGGLI'S METHOD.

| Locality | Southern Slope of Pi-shan | Eastern Slope of Hsiao-Tung-kuan-shan | Niehkulin-Chung | Northern Slope of Tien-o-pautan |
|---|---|---|---|---|
| *si* | 235 | 233 | 226 | 218 |
| *al* | 37 | 36 | 34.8 | 35 |
| *fm* | 23.4 | 16.2 | 25.1 | 26.6 |
| *c* | 18.9 | 26.8 | 19.8 | 19.3 |
| *alk* | 20.7 | 21 | 20.3 | 19.1 |
| *k* | 0.36 | 0.32 | 0.35 | 0.38 |
| *mg* | 0.37 | 0.54 | 0.45 | 0.38 |
| *ti* | .02 | .02 | .02 | .02 |
| *p* | 00: | .004 | .004 | .004 |
| section | 5 | 7 | 5 | 5 |
| Free Quartz | 52.3 | 49 | 44.8 | 42 |

With the same rock analyses, using Niggli's method of colculation[2] of the different constituents, the obtained proportions of *si, al, fm,* etc., are stated in Table II. This calculation enables us to compare our diorite with what Niggli considers to be typical representatives of the corresponding rock species. It is noted that the relation between *c* and *fm* is near that of granodiorite, that is to say, the rock as a whole is low in ferromagnesian minerals, a fact also revealed in the petrographical study of its thin sections. The other constituents suggest the composition of an intermediate member between granodiorite and quartz-diorite, although its mineral constituents as a whole show a stronger tendency toward the latter.

[1] Washington; H. S., Chemical Analyses of Igneous Rocks, U.S.G.S., P. P. 99, pp. 253-267; pp. 359-403.

[2] Niggli, P., Gesteins-und Mineralprovinzen, Band I, pp. 51-196.

Another fact which may be noticed in Table II, is the marked difference in the content of free quartz among the different specimens especially in the porphyrite. The original magma appears, therefore, to have undergone a degree of differentiation which has caused the concentration of basic elements toward the marginal parts of the rock-body. Thus we might expect to find a real granitic rock in the main body of the intrusion.

## EFFECTS OF CONTACT METAMORPHISM OF THE QUARTZ-DIORITE ON THE DIFFERENT SEDIMENTARY FORMATIONS.

The effects of contact metamorphism have been briefly described in the early part of the present paper, but they are those which can be readily detected megascopically. When the specimens from the various sedimentary formations are carefully examined, nearly every one of them more or less suffered from contact metamorphism. Such wide-spread influence pre-supposes the presence of a large mass of intrusion. Probably only the roofs of the deep-seated mass are now being exposed. If prospective work is done in the future there is a possibility of finding the intrusive to enlarge in extent as going downward. In case this be true, the outlook for more iron-ore along the yet unrevealed contact would be very favourable. This point will be referred to later when we come to discuss the ore-reserve of this district. In the following a detailed account will be given of the effects of contact metamorphism.

The massive quartzite at the contact zone which megascopically appears white in colour, very compact in texture and somewhat schistose in structure is composed of quartz grains about .01 mm. in diameter with muscovite and sericite developed interstitially. In a certain zone minute grains of vesuvianite of .005 mm. in diameter (high refringence, negative elongation, parallel extinction, weak birefringence and seemingly uniaxial negative) are abundantly disseminated among the quartz grains. Rutile and zircon are also represented as a few minute prisms or grains. Magnetite grains are sparingly present. Limonite and kaolinite are found as fine-grained disseminations. Thus the contact metamorphic effect on the massive quartzite is manifested by the somewhat schistose structure, the formation of the interstitial sericite, and of the minute grains of vesuvianite in certain zones. Quartz is generally not affected except at the vesuvianite zone where it is more or less interfered by the growth of the metacrysts of the former.

As mentioned before, the contact metamorphic zone at Tien-o-pautan presents the appearance of the Chihsia Limestone with its lydite layers (Figs. 1 & 2). But in fact the composition of the original rock is entirely changed. The part which is supposed to represent the former calcareous

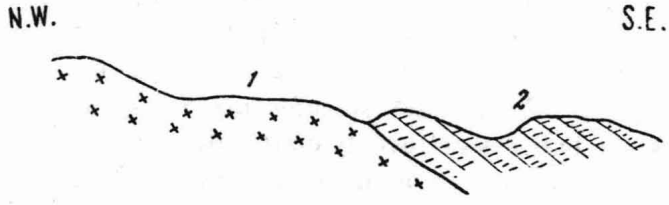


Fig 1. An ideal section across the Contact Metamorphic Zone of Tien-o-pautan to show the relation between the pure contact silicates with the garnetiferous magnetite. Here the quartz diorite is not exposed to view.
1. Garnetiferous magnetite: chiefly andradite and magnetite, the latter increases in abundance while the former is relatively decreasing as going further away from the pure contact silicates (2).
2. Pure contact silicates: composing of wider wollastonite bands of 10-20 cm. in width alternating with the narrow diopside or salite bands of 2-6 cm. in width. Coarse crystalline calcite also intergrows with these contact silicates. Megascopically the outward appearance of this zone still simulates that of the typical Chihsia Limestone with its lydite layers.

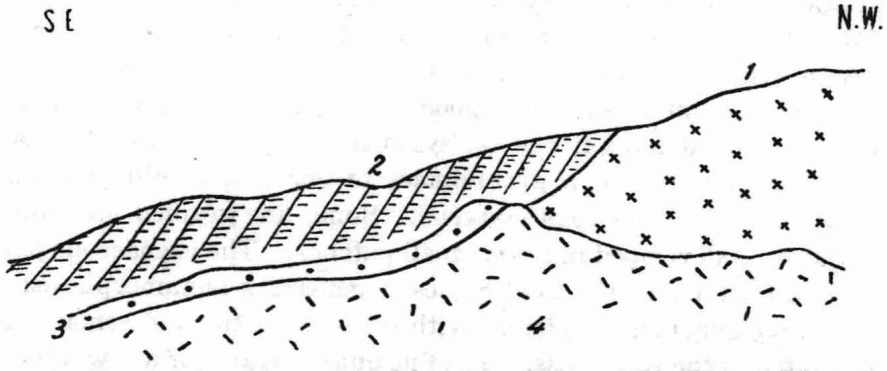


Fig. 2. Another ideal section across the contact Metamorphic Zone at Tien-o-pautan to show the relation with one another of the pure contact silicates, the garnet belt, the garnetiferous magnetite, and the quartz diorite porphyrite.
1 and 2. Same as in Fig. 1.
3. Garnet Belt: chiefly composed of grossularite with some diopside and wollastonite developed in it.
4. Quartz Diorite Porphyrite.

portions is now made up of the white to very light green fibrous wollastonite (Plate IV A), while the former lydian members are now transformed into a green to dark green and fine granular diopside or salite. Sometimes the fine granular part of the metamorphosed zone consists of an intergrowth of green salite and reddish grossularite (Plate IV B). These two minerals are so interwoven that no crystal outline of grossularite can be traced, and salite usually forms clusters of small stubby prismatic crystals.

Such incipient grossularite together with salite clusters shows a somewhat granulated structure. Calcite and dolomite grains are also found included in grossularite. Some sections of wollastonite show the fibrous outline but are entirely replaced by the very fine grained calcite. Such replacement which is often seen along the cleavages of wollastonite has very little effect on the granular diopside and salite. The latter two minerals may also grade into each other depending on their iron content. Calcite veinlets, traversing the contact silicates are fairly abundant. Quartz grains of irregular outlines are evenly distributed among the contact rock. The zone of contact silicates gradually grades into coarse crystalline calcite, and then the normal limestone.

The light coloured shaly portion of the Lungtan Coal Series is *in toto* metamorphosed into fine-grained muscovite and sericite with some kaolin disseminations. Occasionally the muscovite grains are coated with limonite. Some definite orientation of the comparatively coarser muscovite grains among the fine grained sercite is also noticeable. The former usually follows the bedding plane of the original unmetamorphosed rock. The dark-coloured shaly portions, which megascopically resemble hornfels or slates, have undergone similar changes of intense sericitization. Here no coarse grains of muscovite are revealed, but crystals of chiastolite in prisms 1.0—1.5 mm. long with good cleavages (110) and carbonaceous inclusions along dominant crystal symmetrical planes (Plate V, A), are developed abundantly in a groundmass of sericite, kaolin, and fine disseminations of carbonaceous material. Some fine-grained and somewhat drusy quartz is developed in a few small patches. The arenaceous portions, at Niehkulin-chung of the Coal Series is generally metamorphosed into a light coloured quartzose sandstone with some magnetite and hematite grains disseminated in the rock mass. The fine quartz grains of a few hundredths of a millimeter in diameter are more or less cemented together by a limonitic material.

Near the head of the Valley of Tsienhsui-lao some Chinglung Limestone is found metamorphosed into a porous and finely fibrous mass of tremolite (Plate V, B) of grayish light green colour which has suffered some alteration since formation. It is nearly colourless in thin section intermingled with a fine, nearly opaque, material along the original bedding planes of the Chinglung Limestone. Thus its chemical composition still remains to be that of a normal tremolite, while its optical properties deviate somewhat from the unaltered material. Megascopically the metamorphosed part still resembles the Chinglung Limestone when not closely scrutinized.