

SOME OBSERVATIONS ON THE OLDEST FORMATIONS IN THE PROVINCE OF SHANSI.

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WITH SIX PLATES AND 1 TEXT FIGURE

I. INTRODUCTION.

The western and north-eastern parts of Shansi Province are districts of typical development of the oldest Pre-Palaeozoic formations. In western Shansi these formations are well exposed in the territory midway between the Taiyuan plain and the Yellow River and are bordered on almost all sides by the so-called Shansi Formation of late Palaeozoic age. Near the margin the area of oldest rocks is frequently sculptured out in low, gently rooling hills, but the main part consists of partly afforested, sparsely populated and precipitous-cliffed mountain with many high peaks, constituting the Lū Liang Shan range (呂梁山) which runs in a NNE-SSW direction. This territory, therefore, is not only geologically in contrast to, but with its rough contour differs also topographically from the surrounding formations, which appear mostly as gently undulating hills. The area of oldest rocks extends here with a width of more than 50 km from the town of Fen Chow Fu (汾州府) northwards for nearly 240 km.

With regard to north-eastern Shansi a large part of this is occupied by extensive exposures of metamorphosed rocks. They form the holy mountain Wu T'ai Shan (五台山) and the T'ai Ho Ling range (太和嶺) and extend eastwards to the Fu P'ing (阜平) and T'ang Hsien (唐縣) districts in Chihli and towards the north nearly to the town Ta T'ung Fu (大同府). Within this area the oldest formations are typically exposed as a result of uplift and erosion. In western Shansi according to the opinion of C. C. Wang of the Geological Survey¹ the Lū-Liang range is the eroded apex of an anticline "the Lū-Liang anticline". However, the Swedish geologist E. Norin believes the range to be a horst "the Mo Erh Tung (莫兒棟) horst" and his opinion regarding the structure of this part of Shansi² may be summarized as follows.

1. C. C. Wang, Geol. Struct. of Shansi, Bull. Geol. Soc. China, Vol. 4, No 2, 1925.

2. E. Norin, Tzu Chin Shan, Contr. Nystrom Inst. No 1, 1921

Repr. from Bull. Geol. Soc. China; No. 3.

Cutting through the Shansi formation in a direction NNE-SSW, midway between Taiyuanfu (太原) and Huang-Ho (黄河), occurs an Archaean horst, the loftiest point of which is the peak Mo-Erh-Tung, hence the name given to the horst. Field observations in various places indicate that this range has originated by up-warping of a strip of country between the main fault-lines. For instance, the equivalent strata of sedimentary formations appear nearly at the same absolute altitude at both sides of the horst. At several places within the horst the Pre-Cambrian land-surface dips slightly northwards, while the same surface outside the horst slopes towards East or west, which facts may be explained by unequal uplift of the horst-block in comparison to the more stable border-land.

Yet, Norin does not exclude the possibility that the horst has been left standing, while the border-land subsided. The writer is not yet in possession of the necessary evidence to decide this question, as he has not been able to find faults limiting the horst on both sides.

In southern Shansi the oldest rocks have been observed and briefly described by F. von Richthofen (China, Vol. II) and by B. Willis (Research in China, Vol. I) but I have not visited these exposures myself. One occurrence occupying a small area is found east of the town Ho Hsien, (霍縣) where it forms a short precipitous range called Ho Shan (霍山), partly capped by Palaeozoic sediments. Another occurrence is located in the southern-most part of the province forming the base of Feng Huang Shan (鳳凰山), SE of Kiang Hsien (絳縣) town, but extending also over a large area. This territory was visited in 1926 by Père Teilhard de Chardin of the Hoangho Peiho Museum, Tientsin, but his report is not yet at hand.

According to v. Richthofen and B. Willis the oldest formations in Shansi consist of two distinct geological series called from below upwards: the T'ai-shan complex and the Wu t'ai system. In many places the eroded surface of the T'ai-Shan complex is observed to be directly underlying the Palaeozoic formations which may be Cambrian as the case may be.

Where the Wu t'ai system is found, it is represented by a metamorphosed sedimentary (and partly igneous) series of great thickness which v. Richthofen and Willis considered equivalent to the Huronian of Lake Superior in U. S. A. It consists principally of quartzites, marbles, mica and chlorite-schists and para-gneisses often penetrated by granite. The rocks of this series are typically developed in NE Shansi where they make up the main mass of Wu-T'ai-Shan. Here, in 1871, v. Richthofen found green chlorite-

schists and certain other rocks which were difficult to separate stratigraphically from each other.

To the formation as a whole he applied the name "Wu t'ai Schichten". B. Willis retained the term by coining the name "Wu t'ai System" and he enlarged its scope by including other metamorphosed groups (e. g. the Shi-Tsui series) which v. Richthofen had not seen, but which are related in their general characteristics to the "Wu t'ai Schichten". After more detailed study he divided the whole system from the old to the young into Shi-tsui (石嘴), Nan-t'ai (南台) and Hsi-t'ai (西台) series and considered that the south-eastern slope of the main Wu-T'ai range consists of several synclines in which Wu-T'ai strata are preserved. But our recent observations not only show that the structure of this slope is in reality not so complicated, but that the age-relation of Willis' series probably suffers from errors. Near Liu Ting Szū village (劉定寺) which Willis did not visit we found a series of strata which appear to be younger than that of Shang Ho Miao section and older than the Hsi tai series.

Unconformably underlying the Wu-T'ai system the T'ai Shan complex is seen to consist of still more metamorphosed rocks of mostly igneous origin, mainly ancient gneisses and schists, granites and basic intrusives, of these the granites play a most important role. In Northern and western Shansi the proportion of rocks has been roughly established as follows:

Granites.....	65 %
Ancient gneisses and schists.....	25 %
Basic Intrusives.....	6 %
Other Rocks.....	4 %

Western Shansi was first visited by S. L. Tsao, (曹世祿), K. S. Chang (張光嗣) and myself in the beginning of 1924, when we, then students of Shansi National University, undertook a reconnaissance tour in this territory under the direction of Prof. E. T. Nyström (新常富). During this trip the oldest formations were briefly inspected by us. In July of the same year we again undertook a visit to western Shansi with the specific object to survey topographically and geologically the Archaean marble area of Su Chia Wan (蘇家灣) in the W part of Chiao Ch'eng district (交城縣). In the autumn of 1926 we received instruction to explore the Wut'ai formation near Ke Tung Chen (圪洞鎮) in the western part of Fang Shan Hsien (方山縣). Thus the oldest formations of that country became gradually better known to us.

Study of the Pre-Cambrian rocks of northern Shansi was first undertaken by us during 1925. In May 1926 Prof. Nyström of Shansi University,

Prof. P. Quensel of Stockholm University, Sweden, and Prof. G. B. Barbour of Yenching University, Peking, went with us to northern Shansi on an excursion. I wish to take this opportunity to express to these gentlemen my gratitude for their kindness in making this excursion with us and the valuable advice given us during this trip, which had for its object inspection of the beautiful sections of the Archæan available by the recent construction of the motor road through the T'ai Ho Ling range

I am also indebted to Messrs S. L. Tsao and K. S. Chang. Mr. Tsao rendered me much help by discussing with me the mode of occurrence of the oldest formations in the field and by mapping part of the Wu-T'ai area at Hei-Ko-Ta-Ling (黑沱塔嶺). Mr. Chang assisted in the surveying of the geological map of the Su-Chia-Wan (蘇家灣) marble deposit.

II. STRATIGRAPHY

As indicated above, the three divisions of Pre-Cambrian rocks in Shansi-the T'ai Shan, the Wu T'ai and the Sinian (Hu T'o)-show, broadly speaking, greatly different features. The T'ai Shan complex as a rule is marked off by plain dissimilarity in structure and composition from the Wut'ai system, and the Sinian formation is separated from the latter by a striking unconformity. For the three main divisions it is therefore appropriate to maintain the names as above in accordance with the classification of Bailey Willis.

THE T'AISHAN COMPLEX

The T'ashan Complex of which the main exposures have been mentioned above has been studied by me at T'ai Ho Ling Pass (太和嶺), O-Shui Ho river, (峨水河) and at Shi Tsui (石嘴) in northern Shansi and at Su Chia Wan (蘇家灣) and Ke Tung Chen (圪洞鎮) in western Shansi.

Along the T'ai Ho Ling Pass the rocks of the basal complex are very well exposed in the cuttings of the motor-road built a few years ago. The geological interest of this section of the road was first pointed out to me by Prof. E. T. Nyström. For a distance of about 14 km there are numerous cuttings in solid rock from a few m up to 60 m in height, the exposures being so fresh that structural behaviour and relations of members of the complex to each other are probably better exhibited here than in any other place in north China.

In the complex studied here the ancient gneisses, schists and granites are the dominating members, stratified rocks are also rather abundantly present, more subordinate are amphibolites. The complex thus consists of four groups: 1) the ancient gneisses and schists, 2) the granites, 3) the stratified rocks and 4) the basic rocks. They will be described in the same order.

The typical rock in group 1 is a medium-grained hornblende-gneiss of black-and-white colour, somewhat massive in character, composed of hornblende, plagioclase and quartz, with biotite and accessory minerals. The quartz is seen under the microscope to have more or less strong undulating extinction suggesting that the rock, though not of typical gneissoid appearance, has undergone considerable pressure. From this type transitions may be traced on the one hand to a gneiss which contains more biotite than hornblende, and on the other hand to a type where felspar and quartz are the dominating minerals giving the rock a light colour. There are no considerable variations in texture. In many cases in the extremely altered mass segregation-layers of biotite-schist, alternating with those of gneiss, give the rock a banded appearance, the banding sometimes being strongly contorted. The readily attacked biotite seems often to weather out, resulting in shallow depressions on exposed surfaces.

The notable features of the gneiss are that amphibolite-fragments (see further under the fourth group) have been observed imbedded in the gneiss and having irregular form, as if they had been included in a magma at the time of eruption; also that the gneiss is frequently so contaminated by granite-material that it is very difficult to determine whether the resulting rock should be as belonging to the granite or to the gneiss. More or less pygmatic, white pegmatite-veins are not seldom met with; they are only found in the first group and do not cut across the granite, from which it is plain that the latter is the younger rock.

The eruptive character of the gneiss can be distinctly seen in the section just north of T'ai Ho Ling K'ou (太和嶺口) (see Pl. V. fig. 1.) where traces of its primary nature are clearly preserved. During the field-work one is led to assume the following sequence of events: The gneisses have during eruption been subjected to very considerable side-pressure, whereby segregation of the component minerals, felspar and quartz, in thin layers took place and gave the eruptive mass a distinctly banded appearance; then followed complex folding-in part-of the rock which gave rise to a puckered arrangement and intrusion of the white, pygmatic, pegmatite-veins mentioned above. Upon such primary structures subsequent extreme mechanical deformation gave in many parts, the gneiss other structures with the result that the original massive eruptive material has undergone profound alternation and recrystallisation. Thus layers of biotite-schist, segregated from fine biotite-gneiss alternate with each other, producing the marked banded structure. This might easily deceive anyone who first encounters these banded rocks and cause the belief that they represent a sequence of sedimentary rocks in connection with the general gneiss-material. But further

examination reveals that their foliation sometimes distinctly cross-cuts the earlier pygmatic pegmatite layers.

The above described gneiss-formation of T'ai Ho Ling (太和嶺) is probably correlated with that seen near T'ang Hsien, (唐縣), Chihli Province, by Blackwelder* in which the dark mineral is either hornblende or biotite and which also includes numerous lenticular fragments of amphibole-schist in the same manner as the Shansi rock.

Group 2 includes reddish, gneissoid granite, pink aplitic granite and pegmatite. They represent several generations of igneous activity. The older gneissoid granite includes: a) a reddish grey type, b) a red type and c) a grey type.

Type a) mainly contains quartz, orthoclase, microcline and biotite. The texture is usually fine-grained but varies somewhat from place to place. In this rock segregation of mineral components is frequently noticed, thus streaks of quartz alternating with bands of pink felspar give the rock-material a banded appearance though on a small scale. Gneissoid structure is however seldom distinct. The type often lies adjacent to the ancient gneiss.

Type b) may be seen grading insensibly from the reddish grey type, and is a medium-grained rock of red colour containing the following mineral components as seen in hand-specimens: reddish felspar, yellow quartz and brown biotite, the first named being very abundant. This type frequently shows a quite distinct gneissic appearance. There are several varieties of this type, in one place the red granite lacks dark minerals and becomes very aplitic, in other places it becomes rather coarse with white and pink felspar and quartz.

Type c) is a grey, medium-grained granite, very uniform in nature. Though, megascopically, it appears to be massive, it has in fact a distinctly gneissic appearance microscopically, and consists chiefly of light grey quartz, white felspar and dark biotite. The characteristic grey colour is due to lack of pink felspar and increase of dark minerals. The rock though its relations in the field are not quite certain, is probably a variety of the types just described, because it resembles a type in W Shansi which is associated with reddish-grey granite.

The older gneissic granite occurs in large batholithic masses as well as in minor-intrusives. In the latter case it seems that in some places the ancient gneiss before its complete solidification has been injected by masses of granitic material in irregular patches of large or small size. Such injection seems to

* Research in China. Vol. 1, Part 1. P. 101

have taken place when the invaded rock was in a state of movement. In this case the invading rock has been drawn out and subsequently folded, so as to produce bands, irregular lenses, contorted banding and puckered structure (see Pl. v. fig. 2), the intrusion of granite resulting in a net-work in the mass of gneiss. In other cases the gneiss, in a plastic state, while pygmatic folding was still going on, has been invaded by the reddish gray granite (see Pl. v. fig. 1).

Except in a few places where gradation between gneiss and granite may be traced, the former has as a rule been so strongly permeated by granitic juices, that the original features have been entirely effaced and a mixed rock produced which we may designate as "T'ai Ho Ling migmatite".

At a place about 2 li (1 km) N. of T'ai Ho Ling pass a pink, rather coarse, aplitic granite penetrates the ancient banded gneisses along banding planes in numerous irregular lenses and bands, and should therefore be considered younger than those granites just mentioned above. Close to the margin of the granitic intrusives the gneiss is sometimes rather unchanged as shown in PL. VI fig. 2. Sometimes it is not pure but contaminated by resorbed granitic material (see PL. VI fig. 1.). Here it has been noticed that the granite magma gradually entering between more or less minute foliation planes of gneiss and schist formed small lenses and strings traceable between the planes, and then strongly soaked them, so that a real "lit-par-lit" injection is the result.

At the same section younger pegmatite veins are not infrequently met with, which cut across the ancient gneiss as well as the red gneissoid granites and sometimes also the younger aplitic granite.

Group 3. Stratified Rocks. Whereas groups 1. and 2. are assigned to igneous origin the central part of the T'ai Ho Ling section is occupied by a series of metamorphosed rocks, light to dark in colour, which present megascopically a well marked stratified appearance, i.e. they are all in parallel stratigraphical sequence.

The exposures of this sequence which lie in a N-S direction show in the southern portion mainly foliated hornblende-felspar-amphibolites with intercalated layers of black hornblende-amphibolite and dark grey gneisses containing biotite, quartz and felspar which are towards south are associated with gneissic granite in indistinct relationship. In the middle of the sequence are light grey, slaty biotite gneisses composed of white felspar, quartz and biotite, with garnetiferous gneiss and certain other rocks. The northern end includes amphibolite and biotite gneisses alternating with bands of amphibolite. It

appears that the stratified rocks lie in a closed syncline. At the southern end of the sequence the dip towards S is steep whereas towards the north it is more gentle and still in the same direction. Amphibolitic rocks seen in the southern part of the section are again met with in the north.

The bedding or banding of the stratified rocks seems to belong to two stages. The secondary banded arrangement has arisen through the parallel injection of late acid or basic igneous material.

As to the age of the stratified rocks at T'ai Ho Ling (太和嶺) different opinions have been proffered. G.B. Barbour considered them to be oldest Wu T'ai'an or youngest T'aishan sediments lying in a closed syncline. By our research in Wu T'ai Shan and at Ke Tung Chen the basal Wut'ai was found in both cases to consist not of an amphibolite-bearing series as believed by Barbour but of a quartzite-bearing series resting, with more or less distinct unconformity, upon the T'aishan complex.

My observation that the stratiform sequence of T'ai Ho Ling has in some cases been penetrated by well-defined sheets or dykes of granite, which are probably in connection with the old gneissoid granite, inclines me to believe that it includes older sediments of Archæan type pulled up and invaded by ancient gneiss-magma and strongly active gneissoid granite magma. It is not impossible that the above mentioned hornblende-felspar-amphibolite and dark grey biotite-gneiss result from the alteration of ancient calcareous sediments and arkosic quartzite respectively. F. D. Adams has shown that crystalline limestone under the influence of granitic intrusion may change into a typical hornblende-felspar-amphibolite, and B. Willis observed near T'ang Hsien, (唐縣) Chihli, a quartzose Archæan gneiss containing felspar and biotite in the vicinity of white marble, and considered it as an ancient quartzite, in which the grains of mud have by recrystallisation changed into biotite.

Group 4. The Basic Rocks. Amphibolites occur abundantly in the basal complex and appear either as inclusions in the gneissic granite, which may be observed as irregularly lense-shaped or occasionally banded forms or as dykes or masses of irregular shape which cut across gneisses and granites (see PL. VI fig. 2), and sometimes the amphibolites occur as bands and layers in hornblende-felspar-amphibolite or biotite-gneiss of the third group.

The amphibolites are medium-grained, sometimes finegrained rocks always dark and sometimes black in colour. They are frequently granular and massive in character, except those which occur as bands or dykes and which show

a certain degree of schistosity. They are normally composed of hornblende with a little white felspar. The amphibolitic rocks do not only differ from each other in age but also in origin. Many varieties of eruptive emplacement are represented, such as dykes, and irregular masses which cut across granites and gneisses. But when they occur as irregularly shaped lenses, they appear to have been imbedded in the reddish gneiss-granite. In some cases, around the slightly fused, lense-shaped masses, the fluxion-structure of the mixed magma of gneissic granite and ancient gneiss has been clearly observed (see PL. V fig 2). In other places the granite is seen to have intruded along the contact between the amphibolitic lenses and the gneiss, sending occasional veins into the former, but soaking into the latter. These observations apparently suggest that the lenses of amphibolite were relatively rigid masses at the time of intrusion of the gneissic granite. As it has been proved that the gneisses while still in plastic state were penetrated by the granite, it seems that the consolidation of the amphibolite antedates them both. It is believed that the masses of amphibolite represent fragments which were torn from an ancient rock formation and scattered through the invading gneiss as inclusions, being somewhat softened and elongated by the latter so as to assume the present fantastic forms.

Along O Shui Ho (鹹水河). Along this river-bed which was studied at a place 25 km E of Tai-Chow, (代州) the T'aishan complex, bordering upon Wut'ai schists and forming the northern foothills of Wut'aishan, (五台山) is composed almost entirely of the reddish gneiss-granite recognised by v. Richthofen as younger gneiss ("Sang-Kan gneiss"). The gneiss-granite is comparable with the older granite of T'ai-Ho-Ling but much more uniform in character than this.

The prevailing gneiss-granite is a medium-grained and conspicuously gneissic or schistose rock, reddish to red, sometimes grey in colour. It is composed of pink felspar, yellow quartz and dark or black biotite, the latter mineral being sometimes replaced by muscovite but mostly abundantly present. Except a slightly schistose amphibolite intruded as dykes or sheets, on other younger intrusives can be observed in the gneiss-granite. This rock like the gneissic granite of T'ai-Ho-Ling (太和嶺) has probably been intruded in the ancient gneiss though it has not been possible to observe this in the field.

Near Shi Tsui (石嘴). B. Willis describes the T'aishan complex, as observed between Wu T'ai Shan (五台山) and Fu P'ing Hsien, (阜平縣) Chinli, as follows: "The basal complex which is so widespread about Fu P'ing Hsien, Chihli, was followed up the Scha Ho (沙河) and found to form the larger part of the mountains along which stretches the south branch of the Great Wall. The rock is

for the most part a firm biotite-gneiss, frequently reddish in colour, though often grey, and it grades insensibly into grey mica schists. From the intimate association of the schists and gneisses, it is inferred that the two are portions of a single mass of variable composition, in which the effects of metamorphism have been correspondingly unlike. The upper limit of the T'ai-Shan in this section is the unconformity with the Shitsui group of the Wut'ai system."

About 3 km east of Shi Tsui village (石嘴村) we have found a gneiss of the T'aishan complex quite similar to the one seen by Willis at T'ang Hsien (唐縣).¹ The typical fresh, light grey and medium-grained gneiss is composed, chiefly of quartz, hornblende, biotite and feldspar, both orthoclase and plagioclase the former predominant. As in the gneiss of T'ang Hsien a gradation may be traced on the one hand to a less altered, somewhat coarser, grey granite, sometimes containing large sparsely scattered phenocrysts of feldspar and sometimes, under considerable foliation, feldspar individuals of augen form giving the rock a well-marked "Augen" structure. On the other hand the gneiss may grade insensibly into biotite-gneiss and biotite-schist, such gradation produced by the gneiss having been subjected to different degrees of metamorphism.

In this place the relationship of the rock to other ones has not been observed and thus no criterion of age has been afforded. Nor was Willis able to give exact information regarding the age of the T'ang-Hsien gneiss. But the fact just mentioned that the original massive porphyritic granite has been, as the result of powerful compression, so altered and recrystallised as to produce banded mica-gneiss and schists, suggests a deep-seated rock probably equivalent to the T'aiholing gneiss.

Near Su-Chia-Wan (蘇家灣). The principal development of the granitic rocks near this village which is situated in western Shansi about 75 km WNW of the town Chiao Ch'eng Hsien (交城縣) is typical of the composition of the Lü Liang Shan range. Towards west and east of Su Chia Wan for several tens of km nothing is seen except a medium-grained, reddish grey granite, in which the mineral constituents observable in hand-specimens are reddish and grey feldspar, light brown quartz and black biotite, the three being present in about equal quantities. Aplitic or pegmatitic differentiation-products have not seldom been noticed at that place. The granite towards higher levels becomes very coarse-grained. Near the village most of the highest peaks are formed of coarse-grained grey varieties containing sepia-coloured biotite, brown quartz and

1. Research in China. Vol. I, Part I. p. 101.

white felspar, sometimes seen as shining phenocrysts in the rock. At the crest of the ridge west of Su Chia Wan a reddish biotite-granite of coarse grain is likewise observed, which often grades into the local pegmatites.

The granite here is of Archaean age but evidently younger than the T'ai Ho Ling gneissoid granite, because, as described below, it was found to penetrate the ancient gneiss along the foliation planes. This was observed at Ke Tung Chen (圪洞鎮) (see below).

The character of the granite as studied at various exposures near Su Chia Wan indicates a quite homogenous and massive rock, not distinctly gneissoid or foliated. Such structure is only locally developed here and there. The rock is similar to ordinary eruptive masses in the upper portion of the crust. It is penetrated by well-defined lenses and dykes of amphibolite of granular texture as well as compact basalt dykes.

These characteristic phenomena exhibit great contrast to the "stripe-differentiation" or "patch-differentiation" and fused contacts, peculiar to deepseated eruptive masses. The conclusion may thus be arrived at that the intrusion of the granite here took place at comparatively shallow depths under conditions of low regular pressure.

E. Blackwelder* observed at the debouchment of the Wen Shui river (文水河) in the plain (which river runs past Su-Chia-Wan in a ESE direction) that the gravel brought-down by this water-course consists, in addition to Cambro-Ordovician limestone and later sediments, of black-and-white hornblende granite, coarse pink granite, hornblende-porphyry and basaltic rocks. Consequently he considered the occurrence of T'ai-Shan complex in western Shansi to be a fact. The hornblende-granite is probably the one I have just described as a coarse-grained grey granite with sepia-coloured biotite. The basalt may originate from the area near Su Chia Wan or from other exposures in the vicinity.

In one respect there exists a striking contrast between the Su Chia Wan granites and the T'aiholing gneiss-granites. In the latter anamorphism giving rise to fluxion-structure is frequently observed, while in the former katamorphism resulting in disruptive structure is very common in all cases. In the higher peaks, T'ien-Shan (天山) etc., near Su Chia Wan and in the summit of the ridge 15 km west of that village, I have found that the granitic mass has been irregularly divided by extensive joints into huge blocks up to several tens of m in size, which blocks are separated from each other by spaces from 5 cm up

* Research in China Vol. I, Part I, p. 167.

to 60 cm. In other places the rock is somewhat more closely fissured producing smaller blocks.

A few km NE of Su Chia Wan village E. North first found inside the granite area a great mass of coarse white marble the composition of which will be further discussed in the Appendix. It forms an isolated patch and is intruded by veins and dykes of the granite. In other places the marble is observed to exist as smaller inclusions in the granite. These occurrences remind one of so-called inliers in the younger intrusive bodies described by Prof. B. T. Nyström in his "Some Alkaline Rocks of Shansi" * These inliers are fragments of the cambro-Ordovician limestone still partly covering those intrusives. In like manner the Su Chia Wan marbles may be remnants of a once more extensive Archaean limestone.

Near Ke-Tung Chen (圪洞鎮). The basal complex which we found at the western border of the Lü-Liang mountain range differs somewhat in composition from the corresponding formation in the central part of that range. The rocks of the former are ancient gneisses and schists, gneisses and basic dykes, which are all well exposed along a valley not far west of Ke Tung Chen village which is situated 20 km SSW of Fang Shan town (方山縣) in west Shansi. Broadly speaking it bears a certain resemblance to the corresponding formation of the T'ai-Ho-Ling pass. It is in sharply unconformable contact with the basal quartzite of the Wut'ai system also existing here. The contact line may be traced for several tens of km along the western slope of the Lü Liang range.

The ancient gneiss is the prevailing constituent and is a relatively coarse-grained, dark grey rock. As in T'ai Ho Ling the mineral constituents are chiefly white, felspar, black biotite and hornblende and quartz, the biotite often predominates over the hornblende. If, as frequently happens, the gneiss passes into a strongly schistose variety, the rock is practically of the same composition, though streaks of coarse biotite may exist, which probably represent in-situ-differentiation under strong mechanical deformation. The gneiss shows distinct strike of N. 5° W.-S. 5° E. with a steep dip towards west.

The granite most of which is seen to have penetrated the old gneiss along planes of foliation in large or small masses of band-shape does not seem to have suffered much regional metamorphism after the intrusion. There are several varieties of granite, which not only range in colour from reddish grey, through

* E. T. Nyström; Some Alkaline Rocks of Shansi Province, N. China. Contr. Inst. No. 11. Repr. from Geol. Inst. Appsalé XXII 3, 1927.

red to pink, but also vary in structure from fine grained varieties in which the minerals observable in hand-specimens are red or reddish felspar, grey quartz and dark biotite, to coarse-grained kinds containing pink felspar, white quartz and brown biotite. These coarse-grained varieties which are sometimes almost pegmatitic, are probably the last portion to be solidified. Like the type specimen near Su Chia Wan all the granites in the neighbourhood are rather homogenous and massive in character.

Nowhere in this region has lit-par-lit injection or migmatitic conditions been observed. Nor has any soaking of granite magma into the ancient gneiss been observed here. This suggests quick solidification in contrast to the deep-seated features noticed at T'ai Ho Ling.

In the gneiss are found intruded dark basic rocks one of which is an amphibolite. It appears as band-shaped masses following the foliation in a conformable manner. Offering greater resistance to disintegrating forces it stands out from the weathered surface of the gneiss. Its schistosity is very conspicuous. In age it probably lies between the gneiss and the granite just described. There are also diabase-dykes cutting across all the other rocks of the complex and represent consequently the youngest basic intrusion (see PL. VI fig. 3).

In the area in question the foliation of rocks of the T'aishan complex is frequently parallel to the banding of the Wut'ai sediments. But the foliation can not be later than the deposition of the latter, because the relatively massive granite between the foliation planes has not been observed to penetrate the Wut'ai sediments. The granite is thus considered to be of Archaean age or to be more explicit.

THE WUTAI SYSTEM

On the rocks of the T'aishan complex which, as described above, is well exposed in several regions of Shansi province there occurs in a few localities a very characteristic sedimentary series—the Wut'ai System—which is typically developed in this province. But it has mostly been removed by ancient erosion and its stratigraphical position thus been marked by an unconformity of notable magnitude. This may also be said of the system that should succeed upon the Wut'ai, viz. the so-called Sinian sedimentary complex, and thus it often happens that the basal Cambrian "Mant'o" formation of pink sandstone and brown shales is superimposed immediately upon the Archaean, the Wut'ai and Sinian being absent. Near K'an Chuan Chen (甘泉鎮) in northern Shansi C. C. Wang of the Geological Survey has also observed similar conditions. It thus appears highly probable that the deposition of Cambrian sediments was

preceded by a period of so far reaching denudation as to expose in most places the basal complex. The erosion remnants of the Wut'ai System occur as far as I know, only in two regions, one in NE Shansi and one in W. Shansi. The former which is best known as the Holy Mountain of Wu T'ai Shan occupies about 2250 sq. km. The latter is observed at the western flank of the Lū-Liang range as a narrow belt trending N.-S. and forms in part the Hai Ko Ta Ling (黑疙瘩岭) ridge 3 km west of Ke Tung Chen (圪洞镇) (see map. pl. 2).

THE WUT'AI FORMATION OF WU T'AI SHAN.

General Statement. The Wut'aian sequence of Wu T'ai Shan appears to be represented by an ancient, purely sedimentary formation of very great thickness. Like sedimentary deposits of younger age in the geological record it is composed of pelites, calcareous deposits and coarse and fine-grained psammites, though metamorphism often interferes with the recognition of the primary character. They represent a structural development highly comparable with conditions in ordinary stratified rocks. Thus in this ancient sedimentary formation argillaceous and arenaceous sediment are intercalated with beds of carbonates in a manner similar to that obtaining in the Carboniferous of central Shansi, where layers of limestone are interstratified with masses of argillaceous shales and sandstones. But in the former sediments there is a greater variation of thickness from point to point, some members even wedging out.

The Wut'ai sediments are found in many places to have been subjected to regional metamorphism of profound but not uniform character, grading from slight alteration to complete recrystallisation, evidently proceeding from the top downwards. Sometimes the pelite sediments, as in Willis' true Nant'ai series (which will be placed in the uppermost part of the sequence), have passed into the condition of slates which with bands of red crystalline dolomite and siliceous, grey, finely crystalline limestone, make up a parallel sequence directly comparable with the T'outsun (資村) series of the Sinian, but in other cases they occur in the condition of phyllites or schists of great thickness which carry secondary constituent chlorite which gives them a green colour. In many places magnetite-quartzite appears in more or less thick bands interstratified with the green chlorite schists. It consists of thin alternating layers of grey quartzite and black magnetite with some hematite.

At one place a gradation has been traced of dark grey slates into local green phyllites and sometimes even into deeper green schist rich in chlorite mineral. The green chlorite phyllites and schists all lie in the upper portion of the formation and do not include other crystalline schists such as mica-schist.

In the lower portions where slates are infrequent and chlorite schists seem absent, the pelites have passed into mica-schists or mica and chlorite-schists, in some places garnet-mica-schists are also very common. Thus also have the psammitic sediments under conditions of metamorphism of varying degree, been changed into quartzites of different character and coarse and fine gneisses. The gradation may be traced from slightly altered quartzites, of which the fine primary banded structure and original character of grain may still be recognised, into highly altered and recrystallized micaceous rocks of which the original structure has been entirely destroyed. Where large grains of felspar are present in the rocks, forming arkose-quartzites, it is often difficult to distinguish them from granites. In the lower portions of the formation, where a great mass of gneisses exists, which have suffered strong structural alteration followed by frequent change of mineral composition, it is almost impossible to determine the original character but from the megascopic character they may yet be considered to be of undoubted sedimentary origin.

Throughout the formation it is not uncommon that the calico-rocks occur likewise in the quartzites. For instance, in the Shitsui series the magnetite-quartzite called jaspilite by B. Willis is banded by thin layers of grey quartzite and red jasper. The streaks of rock are interstratified with the coarse-grained quartzite. The formation of iron-ore may be explained by dehydration through regional metamorphism. But what we do not believe, is that it is attributable to metamorphism by augen-granite intrusion as considered by Willis, because it has been observed that the magnetite-quartzite lies outside the contact-metamorphic zone of the granite.

The different degree of regional metamorphism is distinctly observable not only in the clastic sediments but also in the calcareous deposits. Throughout the system from the top downwards the metamorphism has affected the limestone in different degree and we may trace a complete transition from ordinary grey limestones to highly crystalline white marbles.

The great basal series of Wut'ai which consists merely of clastic sediments seems to be of continental origin, the deposits having accumulated on the T'aishan crystallines in the form of ordinary coarse or fine psammites, indicating river flood-plain deposition. In the beds of limestone in the Upper Wut'ai marine fossils have not been found, but their general character and appearance indicate marine origin. The frequent occurrence of marine sediments in comparatively thick or very thin beds interstratified with clastic deposits at large or small intervals indicates marine periods alternating with continental deposition. Generally speaking within certain portions of the stratigr-

aphical sequence abundant limestones are found to occur as intercalations in continental deposits, whereas in other sections in the same series only a few bands of limestone have been observed which seem to be a reoccurrence of some of the intercalations observed in the above-mentioned section and a result of the wedging out of the latter.

All these features are in accordance with the idea that the Upper Wut'ai sediments have been deposited in a region close to the sea (or a lake). At the beginning of the Upper Wut'ai epoch the region in question became a near-shore one which was subjected to transgressions of the sea and then sea withdrew. After a long or short lapse of time for accumulation of continental sediments since the emergence of the region, the sea again returned to a point inside or outside the one from which it formerly withdrew. Then invasions and emergences were repeated with the result that the Upper portion of Wut'ai consists of tongue-like masses of limestone intercalated in continental deposits. Out of these limestones a few comparatively thick ones indicate that the sea-invasion sometimes lasted for a long period.

With regard to the relation of the Wut'ai to the T'aishan complex B. Willis did not find an actual contact, but was inclined to believe in probable unconformity between the two because of dissimilarity in their lithological character and the features of metamorphism in the two series. Neither were we able to establish in the course of our recent investigation a quite satisfactory correlation of the two systems at the two points studied: one in the O Shui Ho (鹹水河) valley, one east of Shitsui. (石嘴)

Like the contact described by Willis south of Tai Chou (代州) also in the O Shui Ho there is undoubted occurrence of both Wut'ai and T'aishan. The Wut'ai quartzite-schists and mica-schists dip N. 70-85° towards closely adjacent gneiss, but on account of strong decomposition the actual contact can not be distinguished in the field. According to Willis' observation as above he believes it to be an unconformable contact which has been overturned. Overthrusts may also have taken place.

East of Shi Tsui the banding of the recognised sedimentaries is frequently parallel to the foliation of gneisses and schists, in this case the line of separation is entirely arbitrary. Regarding the hypothetical contact Willis states that: "The lowest recognised sedimentary member of the Wut'ai system is a coarse-grained felspathic quartzite, which is separated from the typical T'aishan gneiss by soft grey mica-schists which either might have been produced by extreme metamorphism of shaly sediments beneath the quartzite or be part of the gneissic complex."

There is still greater difficulty in determining the upper limit of the Wut'ai-system. Speaking for myself nowhere in the Wut'ai area have I found the Wut'ai sediments in contact with the conglomeratic sandstone which is considered by Willis to be the base of the Hut'o (Sinian) system. Only at a place in the vicinity of Hui Lung Liang (回龍梁) village SW of Nan T'ai peak the Wu-T'ai green phyllites are observed to lie adjacent to Toutsun slates, but the contact is here caused by a normal fault.

Stratigraphical Description. According to their lithological characteristics I propose to divide the Wut'ai sediments in five different series. After the names taken from temples, villages and valleys near which typical development of these special series occurs, they will be named from below upwards thus:

1. The Shitsui (石嘴) Series, characterized by felspathic or pure quartzites and gneisses with layers of mica-schists. This series probably rests unconformably on the T'aishan complex.

2. The Paiyūnszū (白雲寺) Series, evidently younger than the Shitsui, composed mainly of marbles, mica-schists, quartzites and greenstones.

3. The Liutingssū (劉定寺) Series, composed of green, phyllites, white and pinkish limestones, dark grey slates and red quartzites probably lying unconformably upon the Paiyūnszū Series.

4. The Sit'ai (西台) Series, composed almost entirely of chlorite-schists and phyllites.

5. The Kuant'angkou (寬唐溝) Series of dark quartzites and thick grey slate containing slightly crystalline limestone bands and quartzite.

This is the youngest member of the Wut'ai formation.

The Shitsui Series* (see PL. III fig. 1) consists of coarse-grained felspathic and fine-grained purer quartzites with interbedded mica-schists, grey coarse and fine-grained alternating with thin layers of mica-schist and sometimes of quartzites and "calico-rocks" associated with grey quartzite all the above being of sedimentary and continental origin. Undoubtedly this is the oldest group of the Wu-T'ai system. This series of rocks has been subjected to mechanical deformation of the most profound character involving changes of form and recrystallisation. A good exposure of this group exists near Shi Tsui village in T'ai Shan Ho (太山河) river-bed and its tributaries. The strata dip here generally towards NW succeeding one another from the fundament of T'ai.

* Mainly after Willis, his Shitsui section also being used.

shan gneiss and conformably superimposed at Ma Ti Kou (馬蹄溝) the western tributary of T'ai Shan Ho, about 18 km NW of Shi Tsui by the Paiyūsū Series (白雲寺). As to the structure of this series Willis has an idea that the strata of the Shitsui group lie in a closed overturned syncline but I can not find this conditions in the field. The total thickness of Shitsui sediments is about 3650 m.

The series begins, east of Shi Tsui village with a pink, coarse-grained arkose-quartzite (HA) which lies upon the dark grey biotite-schist and contains crystals of red orthoclase often several mm in width. Mica is sometimes present. The result of our recent observations is in accordance with the conclusion reached by Willis that the mass of arkose represents a lowest member, for the formation of which the material has been entirely furnished by disintegration-products of the T'aishan mass and does not contain any pebbles of older sedimentary rocks.

The felspathic quartzite grades upwards into a pink quartzite (HMQ) containing mica but not much feldspar. Towards the top thin layers of mica-schist are interbedded, and by gradual transition the rock comes to be largely a mica-schist (HMS) including layers of pink quartzite. These mica-schists are succeeded by brown banded quartzites (HQ) of nearly uniform character, which according to Willis' observation are separated from the mica-gneisses (HMG) by a gap of several hundred feet of unknown character caused by the presence of river-bed. Our recent research has shown that the quartzites are followed directly by the mica-gneisses, as observed at a place north of Shi Tsui.

The great mass of grey, coarse and fine-grained mica-gneiss is well exposed along the T'ai Shan Ho, NW of the Shi Tsui village, and is often seen to grade into mica (muscovite or biotite) schists which probably have been originally layers of argillaceous shales. Thin beds of pinkish quartzites and thick masses of amphibolite occur not infrequently in the exposed series. Although the profound metamorphism has almost effaced their original character, the mica-gneisses have in some places the appearance of arkose quartzite and the stratification is very striking in the field.

The sequence is completed by schists and quartzites. Conformably following the mica-schists is a thick mass of steel-grey coarse-grained quartzite (HMQ) with which the banded "calico-rocks" mentioned above are interstratified. This member grades upwards into a pink, massive, sometimes schistose, micaceous quartzite (HSQ) which here (along T'ai Shan Ho) is observed in contact with the great mass of augen-gneiss (AG).

*The Paiyünszu Series**. Upon the Shitsui series of purely continental origin lies conformably the younger Paiyünszu series of marine deposits grading from off-shore sediments upwards into near-shore ones. Of this series a tolerably complete and in all probability continuous sequence from the basal layer upwards through alternating beds of crystalline schists marbles and quartzites to the thick masses of greenstones and green schists has been found along the canyon Ma Ti Kou (馬蹄溝) mentioned above, and the canyon Pan Lao Yen Kou (斑老岩溝) which flows westwards from the low ridge which forms the divide between these two valleys and drains into a wide valley at Liu Ting Szü village about 10 km south of Nan T'ai peak (南台頂). Both of these canyons Willis probably did not visit. Just north of that ridge a member of the series viz. the marble beds suddenly become very impure indicating the change in sedimentation occurring here, but no available data preclude the idea that the strata are in continuous succession. The dip is rather constant towards NW. The total thickness, under the supposition that no break occurs in the stratigraphical sequence, is roughly estimated to be 2540 m.

A typical exposure of rocks of this series was found near the temple Pai Yün Szu (白雲寺) (called Shang Ho Miao by Willis) in the T'ai-Shan Ho and K'uan T'ang Kou (寬唐溝), its western tributary, from 11 to 15 km NW of Shi Tsui. In this exposure marbles, quartzites and various kinds of schists, all of which have been subjected to profound alteration, occur in alternating bands. This sedimentary complex is separated in the south from the sediments of the Shitsui series by a thick mass of augen-gneiss, a porphyritic altered granite of postwut'aian age. In the north the upper part of the formation is cut off by a normal fault which was encountered 1.2 km N of Pai Yün Szü and runs in a NE-SW direction, being characterized by presence of brecciated jasper and other impure rocks. The upthrow is on the southern side. The thickness of the sedimentary strata from the augen-gneiss to the fault are about 750 m.

Our observations in this region lead us to conclusions differing from the views of Willis**. During his fieldwork along the T'ai-Shan Ho found the Paiyünszu series of strata at the southern side of the fault and another body of strata at the northern side, which latter were called true Nan T'ai by him but which we shall call the K'uant'angkou series (see below). As in the middle of the Paiyünszu series, along T'ai Shan Ho, the thick mass of white marble is followed towards the north by schistose brown quartzites and chloritic-and

* The lower part of this is equivalent to Willis' Shanghomiao series, which he has assigned to the upper of the Nan'tai group.

** Research in China, Vol. I, Part I, pp. 112, 118 and 120.

biotitic schists, which appear to be a recurrence of the strata observed at the southern side of the marble, and on following this body of marbles and garnet-schists into the hills NE of Paiyunszu temple, Willis observed that there a tremolite-marble underlies black quartzite schist with a strike of N.25°E and dip 70°NW, the structure of the marble itself being nearly isoclinal, but on the NE slope the black quartzite is repeated under the marble and with a dip of about 50° towards NW, he was rather inclined to consider these strata as an overturned syncline. He concluded that the fault is an overthrust one and the rocks of the Paiyünszū group are overthrust upon from the north by the strata of the true Nant'ai. With regard to these two bodies of strata he has the opinion that although both groups of rocks are separated from one another by an overthrust fault, which seems to be an important structural feature of considerable displacement and one group consists of rocks not present in the other (the Paiyünszū groups being specially distinguished by the purity of its marbles), the similarities of these two formations nevertheless seem more pronounced than the contrasts and they may be regarded as belonging to one and the same group-the "Nant'ai group". As to the relative ages of the two series his inference is controlled by the supposed overthrust structure. The syncline in the Paiyünszū series is thrust under the true Nant'ai group, thus the synclinal strata appear to be younger, and the rocks are lithologically so similar that no notable age-difference is suggested. Therefor the Paiyünszū series is supposed to contain the upper part of the Nan-T'ai group. Within this group a gradation may be traced upwards from the quartzites (lower member of the true Nant'ai) through impure carbonates (upper members) to purer marbles (Pai Yün Szū). Hence the true Nant'ai may be considered to have relationship with the beds of the basal Shitsui series, although the sedimentary sequence is interrupted by a mass of augengneiss which occurs between them and is specially visible along T'ai Shan Ho. The true Nant'ai series either overlies the Shi-Tsui in conformable succession or is superimposed upon it unconformably.

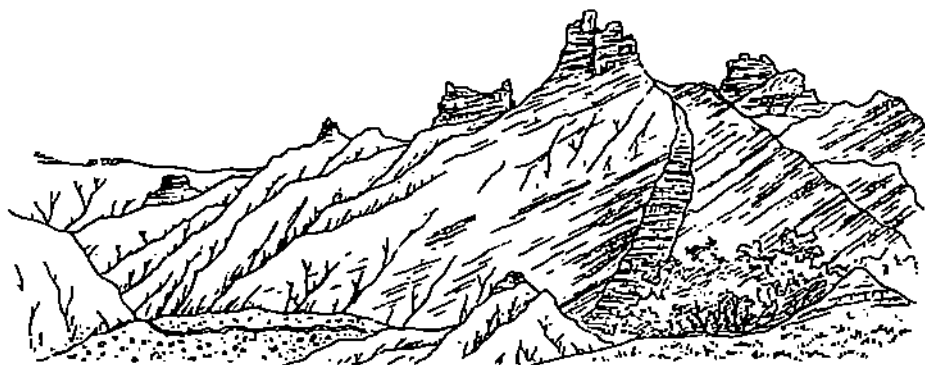
Our present observations, however, indicate that all these inferences made by B. Willis lack evidence sufficient to make them acceptable. The so-called true Nant'ai group contains only very slightly metamorphosed rocks of which all argillaceous sediments still maintain slaty and psyllitic forms and in which no schists are observable throughout, nor have some beds of limestone yet passed into entirely marmorized state, and is therefore distinctly a much younger formation than the sediments of the Paiyünszū series. The relationship of the latter to the Shi-Tsui strata has been satisfactorily determined in

the field by observation of conformable succession between the two in Matikou (馬蹄溝) valley. Within the Paiyünszu series in the T'aishanho region we could not find sufficient evidence to lead us to consider as probable such a complicated structure (overturned syncline) as suggested by Willis, though rocks here are much more profoundly metamorphosed than those in the true Nant'ai series. The degree of metamorphism is not similar in both cases as suggested by Willis.

In describing the different members of the Paiyünszū series I shall use the T'aishanho section shown in Pl. III fig. 2 which seems to contain the lower part of this series. The section is well exposed along the valley of T'ai Shan Ho and has been studied in some detail by us. At about one km SE of Pai Yün Szū bordering upon the body of augen-gneiss, is a thick mass of dark green amphibolite (PHS) which merges upwards into dark green hornblende-and-biotite schist. This is succeeded by the biotite-garnet schist, (PBG S) which when fresh usually has grey colour, but upon exposure changes into a golden yellow rock called by the natives "Huang Chin Shih" (黃金石) (golden stone). In this member occur interbedded thick banks of marble (PM). Next comes a reddish quartzite (PRQ) which is partly micaceous and schistose, its fissibility being somewhat pronounced. The next member is a coarse-grained white brittle marble (PTM) with thin layers of mica-schist. It often contains bunches of large white tremolite crystals. In certain places within the marble a red needle-like mineral has been found which seems to result from alteration of the tremolite and gives the rock a beautiful appearance. The marble is followed by a member consisting of black amphibolites and dark grey mica-schists alternating with coarse-grained white marbles, sometimes greenish in colour. Overlying these are schistose brown quartzite alternating with chlorite-and biotite-schists (PSBQ) and then a mass of finegrained dark-grey biotite-schist which contains large crystals of hornblende forming a beautiful net-work in the rock. Then follows slightly schistose, reddish grey micaceous quartzite (PMQ) which, in the lower portion contains thin strata of biotite-chlorite-schists and upwards grades into banded dark and brown quartzite (PDQ), which is followed by dark grey biotite-schist merging insensibly into green chlorite-biotite-schists with thin brown quartzite (PGBS). We passed from the mass of amphibolite (PHS)—the first of this series—northwards through many such members into more medium-grained, white marble (PPM) which will be described later. Willis suggested that the marble lies in an overturned syncline and is, in Kuan T'ang Kou, followed towards the north by strata which seem to be a recurrence of those at the southern side of the marble. But

from our recent observations it is highly probable that there is a normal sequence from older to younger members here. The following rocks are greenish grey chlorite and biotite schists (PCBS) somewhat hard, banded, reddish brown and grey quartzite sometimes schistose (PRBQ) dark green chlorite-biotite schist (PDGS) which in its lower part contains layers of banded dark and brown quartzite, forming a transition into the underlying body of quartzites, grey biotite-garnet-schist with bands of dark brown quartzite, upwards merging into dark greenish schists (PS) and alternating white and green marbles and chlorite-and sericite-schists. The members following these are here cut off by a fault. In Pao Lao Yen Kou (斑老岩溝) we found an impure red marble in the series, which, according to its stratigraphical position, would be above, below or equivalent to the marble near the faultline in K'uan T'ang Kou (寬唐溝). It is there followed by chlorite schist and then a thick red and white, sometimes grey, crystalline limestone. The limestone is followed by a great mass of metamorphosed greenstone which grades upwards into green schists with quartzites completing the series.

The Liutingszū Series. In the hills around Liu-Ting-Szu village (劉定寺村) the Paiyūnszū group was found to be superimposed by a series of rocks called by us the Liutingszū series and consisting of dark grey slate, pinkish, white or dark finely crystalline limestone, green phyllite or schist and reddish brown quartzite, which members are all comparatively slightly metamorphosed. The foundation of the series is the uppermost division of the Paiyūnszū series, viz. green schists with dark brown quartzite and white marble, and the succession may be conformable or unconformable as the case may be. The strata generally dip westwards and the thickness is about 1400 m.—In a canyon NE of Liu Ting Szu this series was observed to begin with a basal conglomerate (see Pl. III fig. 3) in which the pebbles consist of Pai Yūn Szū white marble, quartzite and green schists. The overlying rock is reddish, white and grey marble (LM) which sometimes contains large crystals of a dark green mineral probably hornblende. This is succeeded by dark grey slate (LSL) with which thin layers of white crystalline limestone are intercalated. The slate, from which slabs up to 1 m by 1½ m may be obtained is often used for building purposes in the villages here about. The following member is a bed of greenstone (LG) which is overlain by very hard reddish and pink quartzite (LQ) in which fissures and cracks are filled by white quartz forming innumerable veins in the form of a net-work. At the base of LQ some grey phyllites with quartzitic intercalations (LP) are found. Succeeding LQ upwards and forming a beautiful hill, Wang Mao Shan (王冒山) (see sketch,)



Sketch—limestone hill, Wang Mao Shan, near Liu Tung Ssu.

occur various kinds of thick crystalline limestones (LGS, LL, LAR and LPL) white, pink, light grey or dark grey in colour, which are often interstratified with thin strata of grey phyllites and reddish quartzites. In the upper part of the complex a few layers of green phyllite appear to enter which, by gradual transition become, at a distance of about one km northeastwards a more important mass containing thin banks of white and grey limestone and brown quartzite. The phyllite is a massive rock which is difficult to cleave, but which upon a stroke of the hammer produces irregular fragments. This thick green phyllite or schist which is apparently a chlorite-rock and unquestionably of sedimentary origin, seems to form the transition into the great mass of chlorite-schist forming the Sit'ai peak of Wu T'ai Shan (the Sit'ai series). In the north it lies adjacent to the K'uant'ingkou quartzite, but is separated from it by a normal fault.

*The Sit'ai Series** — This series is composed almost entirely of green chlorite-schists unassociated with any other rocks and makes up the central mass of Wu T'ai Shan including the western peak (Si T'ai) of these green schists. B. Willis has given an interesting petrographical description as follows: "In themselves the schists exhibit several phases which may be distinguished. In some cases they are massive, not well cleaved, and distinctly argillaceous in composition; chlorite is not visible in this variety although its presence in finely divided condition is inferred from the colour. Elsewhere are slaty schists or phyllites with lustrous green surface covered with chlorite,

* This series was established 20 years ago by Willis who regarded it as the youngest division of the Wut'ai system, overlying the T'ai Shan, Shitsui and Nant'ai groups thus being placed by him at the top of the stratigraphical column. This view is not in accord with the results of our recent investigation. See Willis: Op. Cit. Vol. I, part I, pp. 114, 118-120.

in fact this variety seem to consist almost entirely of that mineral. In other cases the chlorite is mingled with biotite and again with quartz, in a thoroughly schistose mass of green colour. Since they appear to grade directly into the schistose quartzites and possess a mineral constitution which could have readily been derived from the metamorphism of clay-rocks, it seems reasonably certain that they were sediments."

Although the contact between this series and the Liutingszū group can nowhere be observed in the field, yet I am led to suppose that the green phyllites of the latter group form a transition to the Si-T'ai series because of the existing lithological similarity. In the chlorite-schists themselves the stratification could not be distinguished in the field. In the T'aishanho section, they grade southwards into fissile, micaceous grey quartzite, the cleavage surfaces of which are covered with sericite scales and which often merges into grey quartz-sericite schists, sometimes with layers of conglomerate, in which the quartzitic pebbles seem mostly to derive from old Wut'ai strata, and then into schistose grey quartzite which is associated with greenish-grey arkose-schist containing large grains of pink felspar and white quartz. These quartzose rocks, some of which are fissile schists and others banded gneisses of sedimentary origin, all showing trace of severe regional metamorphism, lie southwards adjacent to the slightly altered and probably younger K'uant'angkou series in parallel stratigraphical sequence. The dip is steeply towards north. The conglomeratic quartzite is again met with about $2\frac{1}{2}$ km N of Ch'a P'u village (茶舖村) where it dips very gently towards NW and overlies the chlorite-schist which appears to exhibit the same dip. The repetition of the sequence in reversed order and the convergence of the strata upwards seem to suggest an anticline. The green schists are well exposed in the central part of the range as the result of anticlinal upheaval, which took place at a time probably simultaneous with the formation of the important normal fault which is distinctly seen to cut the Wut'ai strata near the Paiyünszū temple.

The Kuant'angkou Series (Willis' true Nant'ai group). This series is not only younger than the Paiyünszū group as proved above, but also than the Sit'ai formation. The relative ages are inferred by the following argumentation: In the conglomerate at the base of the Kuant'angkou series the pebbles consist only of rocks coming from Sit'ai as well as older formations, even from the T'aishan complex. The strata of Sit'ai are in a state of much mechanical deformation, while in the Kuant'angkou complex the metamorphism has only played an unimportant role. Under these circumstances we may further infer that there exists between the two an unconformity of very

great importance though the contact is not visible in the field. B. Willis has expressed a different view and is inclined to believe that Sit'ai is the youngest member of the Wut'ai system and that the Kuant'angkou series lies unconformably below it. But it seems unlikely that the fundament should be less metamorphosed than the overlying strata.

The Kuant'angkou series consists entirely of moderately altered sediments which are typically exposed in the valley of the same name and in the T'aishan valley and forms the lower part of the southern peak (Nant'ai) of Wu T'ai Shan. The thickness measured by Willis along T'ai Shan Ho, from the conglomerate to the fault-line, is about 600 m.

In describing the stratigraphy of this series I shall commence with the conglomerate which is supposed to constitute the base. The pebbles of this conglomerate—9 to 20 cm in size—consist of whitish grey and red quartzite, seemingly derived from the Paiyūsū and Shitsui series, and sometimes there are fragments of chlorite-schist of the Sit'ai unassociated with pebbles of the two first-named series. The succeeding rock is a banded, dark grey and reddish brown, hard quartzite (see KSQ, PL. III fig. 2) which is sometimes schistose without the original character of the grain being entirely effaced. In the upper part of the quartzite are interbedded thin layers of dark grey slate, which form the transition into the superimposed thick formation of grey slate (KGS), containing banks of grey, siliceous, slightly crystalline limestone and reddish quartzite. The slate is a hard rock which, often characterized by small lenses of sandy substance, becomes very similar to the T'outsun (寶村) slate of the Hut'o (Sinian) system, noticed by us near Huilungiang (回龍梁) village. also along T'ai Shan Ho in the slate we found a few beds of red dolomite which closely resembles those of the T'ou Tsun group observed in the hills E of W T'ai Hsien (五台縣). We are consequently not inclined to believe that the Kuant'angkou series is older than the Sit'ai.—Between the slate and the faultline, as pointed out by Willis, the strata consist of impure ferruginous marble and calcareous arkoses, containing bands of jasper and thin streaks of crystalline hematite.

WUT'AI FORMATION OF HEI KO TA LING

General statement.—In western Shansi the W border-region of the Lū-Liang range was first geologically studied by E. Norin in 1921.* There he found a series of metamorphosed sedimentary rocks lying between the oldest T'ai-

* E. Norin: An algonkian continental sedimentary formation in W. Shansi, China. Contr Nyastr. Inst. No. 6. Rep. from Bull. Geol. Soc. of China: Vol. 3, No. 1. 1928.

Shan complex and the conglomeratic sandstone at the base of the Ho-T'o (Si-nian) formation and forming the low Hei-Ko-Ta-Ling ridge (黑疙塔嶺). He referred the newly found system to the Wut'ai formation, and recently we have studied it in some detail at the ridge in question.

The series is composed from below upwards of clastic sediments, beds of volcanic material (?) and marine series with which are associated effusive or intrusive sheets of diabase also sometimes occurring as vertical dykes. All these rocks do not show very strong metamorphism.

The upper marine series consists of crystalline limestones and mica-schists which appear to be equivalent to the Paityūnszū series of Wu T'ai Shan (see above) and probably belong to middle Wut'ai, though here younger strata cannot be observed. The old clastic sediments, mainly quartzite and slate, seem undoubtedly to be lower Wut'ai: purely continental deposits accumulated on the strongly eroded surface of the T'aishan complex. These rocks however are found to be younger than the Shitsui of Wu T'ai Shan because the former include quartzite-pebbles which still belong to Wut'aian age, whereas the latter as pointed out above contains only material deriving from the T'aishan complex. The strata of the Heikotaling formation are very steeply dipping towards west, but the sequence is quite regular.

In this region the relation between the Wut'ai sediments and the T'aishan complex has been distinctly observed. That the two are unconformably related appears evident not only from the much more intense metamorphism of the basal complex and its general igneous origin, but also from the presence of an obviously prolonged erosion-interval between the two formations. From the overlying Hut'o system the Wut'ai is also separated by a very pronounced unconformity represented in the region in question, as pointed out by Norin, by an old land-surface, he gives the following description.

"South of the Tsi Shang village (蔡上村) the old land surface composed of post-Wut'aian granite is strongly weathered and the sands thus formed show downward transition into granite disintegrated by insolation.—At the northern end of Han Kao Shan (漢高山) the foundation consists of Wut'aian muscovite-garnet schists and veined gneisses. The surface is strongly weathered and transformed into a soft reddish-brown micaceous rock. The weathering products have been removed and replaced by micaceous reddish brown and coarse-grained sandstone with conglomerate-layers."

Stratigraphical Description (see accompanying geol. map Pl. II and profile, Pl. IV fig. 2). The thickness of the lower quartzite-complex reaches the

considerable figure of 850 m. This complex is composed mainly of pinkish grey, deep brownish grey and reddish brown quartzites, usually very hard, sometimes, slightly schistose in which the primary grains observable in hand-specimens range from fine to medium size and generally consists of red felspar, grey quartz and other darkish material. The quartzite sometimes exhibits alternating reddish-brown and dark grey bands, the origin of the former being probably mud and of the latter sandy material. The banded structure is rather well marked. Ripple marks are often observed at the higher levels. In the lowest portions of the group the pinkish quartzite is locally associated with arkoses in which pegmatitic quartz and pink felspars are both abundantly present. Such apparently represents deposits derived directly from the T'aishan complex by erosion. Sometimes near the base conglomerates are met with, the pebbles of which consist only of dark grey, grey or reddish quartzites distinctly water-worn and well rounded. They have without doubt come from the oldest Wu-t'ai sediments, though the conglomeratic rocks lie directly upon the rocks of the basal complex. The size of the pebbles as far as observations have been done, seldom exceed 20 cm.

In the upper part of the series the micaceous dark grey slates are a dominant element, they are associated with some bands of quartzite. The slates were originally horizons of very sandy shale and the bedding planes and cleavage surfaces are sprinkled with minute mica-scales either deposits simultaneously with the clay-material or produced by metamorphism of the mud-substance, which has been spread over the cleavage-planes.

In the uppermost part of the slate-formation, i.e. in close vicinity to the superimposed greenstones, two diabase sheets are observable. The notable feature of the upper one of these is the general porosity of substance evidently produced during the time of eruption and amygdaloid structure is also common. The northern extension seems to wedge out. This suggests that the diabase lava in the form of an effusive sheet covered the slate-beds and was after consolidation covered by the formation now to be described.

The overlying member is a thick mass of greenstone (900 m) which is sometimes found to include banks of reddish quartzite. The greenstone is a dark green amphibolite of fine grain, composed chiefly of abundant hornblende and chlorite, with other minerals. The rock probably represents a bed of volcanic material interbedded with sediments, the formation subsequently being metamorphosed. Still higher is a fine, whitish grey, crystalline limestone (about 350 m) which is succeeded by crystalline schists (about 650 m). The schists, dipping W 45°, unconformably underlie the basal conglomeratic

sandstone of Han Kao Shan (漢高山) and is partly developed as coarse-grained muscovite-garnet-schist and partly as veined garnet-gneisses. The schist was not seen directly in contact with the crystalline limestone because of intervening covering of loess, but at a place beyond our area of investigation Norin found in the muscovite-schists intercalations of white marble which undoubtedly form a transition into the lower thick crystalline limestone. The alternation of banks of schist and marble suggests unquestionably a sedimentary origin, the schist being originally argillaceous shale.

III. SUMMARY

In the T'aishan complex the ancient gneisses observed in NE and also in W Shansi, all seem to be eruptive types, in which either hornblende is the dominant ferro-magnesian constituent associated with somewhat abundant quartz, plagioclase and a little orthoclase, or biotite is the prevailing dark mineral occurring together with plagioclase, orthoclase and quartz nearly equally present. The rocks have been generally, banded, crumpled, plicated and dislocated, only some of them escaping such powerful disturbance. We could not avoid the idea that portions thereof belong to a still more ancient formation as under the enormous mechanical compression they have frequently altered and re-crystallized as banded biotite schists.

I have received the information from G. B. Barbour that the gneisses resemble highly the typical T'aishan gneiss of Shantung, which Blackwelder* described as follows: "The rock is usually a banded grey gneiss composed of quartz, orthoclase and biotite, sometimes with hornblende more abundantly present than the biotite. The rock is probably an ancient granite which was intruded into dark greenish or black schists containing quartz and hornblende." These older schists are not seen in Shansi. We may now come to the conclusion that the gneisses referred to are the oldest crystalline rock in Shansi and that the basal complex of that province partially belong to the *typical T'aishan*. The younger granites, belonging to the same generations of igneous activity and showing sometimes massive character, sometimes distinctly gneissic appearance, constitute the larger portion of the complex as now exposed at the surface. We may speak of them as young T'aishan. They are specially developed in western Shansi.

In NE and W Shansi the T'aishan complex is without doubt unconformably succeeded by the Wut'ai system which according to V. Richthofen and Willis is equivalent to the Huronian at Lake Superior, U. S. A. The

* Research in China: Vol. I. Part I. p. 19.

lower part of the Wut'ai is represented both in NE and W Shansi by purely continental deposits consisting mainly of psammites and pelites, accumulated on the eroded surface of the basal complex. The upper part is composed of a series comprising alternating marine and continental sediments, which have been metamorphosed into marbles, quartzites and schists. It is thus inferred that during late Wut'ai the regions in questions have been now and then subjected to marine transgressions.

The typical development of the Shansi Wut'sian rocks have been mostly studied in the type-locality, Wu T'ai Shan, in the north-eastern part of the province. The succession is shown below in descending order:

The Kuan'anghou Series (Willis' true Nant'ai group)

Conglomerates, quartzites, phyllites, siliceous marbles and jasper.

Thickness about 600 m.

Erosion interval.

The Sit'ai Series.

Chlorite-schists and quartzites, which constitute the main Wut'ai range. Thickness 2 m.

The Liutingszū Series.

Conglomerates, green phyllites or schists, dark grey slates, crystalline limestones and quartzites. Thickness nearly 1400 m.

Erosion interval.

The Paityünszū Series.

White marbles, biotite-and chlorite-schists, quartzites and green stones. Thickness about 2540 m.

The Shitsui Series.

Arkoses, micaceous quartzites, gneisses and mica-schists. Thickness about 3650 m.

These continental sediments unconformably overlie the T'aishan complex.

IV APPENDIX: SOME SHANSI MARBLES

From the above description it is evident that a great amount of marble enters into the oldest formations of Shansi. Some of these marbles exhibit a highly crystalline structure and form in many cases a material useful for various purposes. Others, as a result of comparatively slight metamorphism of the original limestone, are not to lightly crystalline.

Two regions where the marble is specially well developed will be considered below:

1) *Su Chia Wan*, (蘇家灣) in Chiao Ch'eng District (交城縣), about 100 km WSW of Tai Yuan Fu (太原府). The marble occurs in the mountains immediately NE of Su Chia Wan village and attains an altitude of about 700 m above the village. It occupies a roughly circular area of approximately 22.5 sq. km (see geol. map. Pl. I) and is at least 300 m thick. Between the area and the Taiyuan plain no adequate communications exist. There is a mule-path from village Yü K'ou (峪口) 12.5 km SW of Chiao-Ch'eng town up the K'ai Shan river-bed (開柵河) (also called the Wen Yu Ho (文峪河) to the marble-area and the distance along this path is about 63 km, but this road can only be used by pack-animals and it takes them a little more than one day to cover the distance. It might be possible however to make use of wooden rafts which could carry considerable weight in the summer when the river-bed carries more water.

The country-rock NE of Su Chia Wan (see above) is a medium-grained, reddish-grey granite probably of Archaean age, which is traversed by various kinds of basic dykes. The marble deposit in question is found disturbed and invaded by the granite, so it would be reasonable to attribute the marble to the T'aishan epoch. One is inclined to think that the marble formerly occupied a more extensive area and that it is an erosion remnant now remaining isolated in the granite region. In the surroundings a few minor bodies of the same marble are found scattered as "inliers" in the granite. The granite invading the main mass of marble occurs as dykes and veins both in centrally located and marginal portions of the deposit. The contact between marble and granite has nowhere been distinctly observed on account of covering of debris overgrown with trees and bushes. Having been subjected to regional as well as contact-metamorphism the marble exhibits a very completely crystalline texture and affords an almost unlimited supply of valuable ornamental stone. The difficulties of transportation mentioned above have hitherto precluded systematic working of the deposit and only very little quarrying has been done. There are two main varieties of marble at Su Chia Wan, namely:

Serpentine Marble. This marble, eminently adapted for purposes of interior decoration and for making table-tops etc., is found at the base of the deposit and sometimes in the contact zone, especially in Yeh Sha Kou (野沙溝) valley and at the NW corner of the area. It is fine to medium-grained and takes a high polish, the surface often exhibiting brilliant crystal faces. It has mostly a greenish colour, due to presence of serpentine as determined under the mi-

croscope. Sometime there are irregular bands or streaks of green and white which give the rock a beautiful appearance, especially when polished. This variety which is much appreciated by the local people has been quarried to a certain extent for making monuments etc. which are often seen in the temples in the neighbourhood.

Pure White Marble. In the area in question there is a practically unlimited supply of pure white marble. It has a fine to coarse crystalline texture sometimes the grain is quite large. The stone also affords a very suitable material for building and ornamental purposes. Large blocks of immaculate whiteness can be obtained and various parts of the deposit, but the quarrying is as yet very inconsiderable.

A specimen of the white marble taken at a place 2.5 km NW of Ho Chang Chuang (合成莊) was examined and its specific gravity found to be 2.85. This high density would make one suspect that this is not ordinary calcite marble. An analysis was therefor undertaken by courtesy of Mr. E. Norström of the Government Steel Works, Taiyuanfu, who found the following composition:

SiO ₂	0.53%
Fe ₂ O ₃ & Al ₂ O ₃	1.36
CaCO ₃	58.00
MgCO ₃	42.00
<hr/>	
Total	101.89%

The S.G. of pure dolomite is 2.85 (cf. above) and the composition (CaMg₂CO₃): CaCO₃—54.35% and MgCO₃—45.65%. Hence the Su Chia Wan white marble is rather closely approaching the composition of pure dolomite. This confirms the well-known observation that ancient carbonate rocks in China have generally a high tenure of magnesium.

2. *Wu T'ai Shan.*—In the Wu T'ai Shan region the marble of Wu-t'ai age is very well developed in the hills round the Pei Yün Szū (白雲寺) temple, which are formed by the marble series. The sequence is best exposed in the section along T'ai Shan Ho (台山河) (Pl. III fig. 2) which has already been described above and is made up of alternating marbles, quartzites and various kinds of schists, steeply dipping towards NW. The marble varies in texture from coarsely crystalline through medium-grained and fine-grained to compact, and the colour is also different: from pure white and greyish white to greyish and reddish pink. The reddish marble is sometimes very beautiful with alternating bands of white or grey and pink. Though the aggregate thickness of the marble strata would be considerable (a few hundred m) the supply of stone

Explanation of Plate III.

PLATE III

Fig. 1. Geological Section of Shitsui Series, observed near Shi Tsui on T'ai Shan Ho and its eastern tributary (mainly after Willis)

TG fine-grained biotite gneiss. HA pink arkose quartzite. HMQ micaceous quartzite with layers of biotite schist. HMS dark biotite schist. HQ massive brown quartzite. HMG alternation of grey mica-schist and gneiss. HAQ schistose arkose quartzite. HAM amphibolite. HMSG mica-schist and gneiss with amphibolite. HGQ hard magnetite quartzite. HSQ moderately schistose pink quartzite with seams of mica-schist. AG augen-gneiss.

Fig. 2. Section along T'ai Shan Ho and Kuan T'ang Kou, showing the lower portion of Paiyunszu series and sediments of Kuant'angkou series AG augen-gneiss of post Wutai age. PHS hornblende-schists. PBGS biotite-schist containing crystals of garnet. PM coarse-grained, greyish white marble. PRQ schistose reddish micaceous quartzite. PTM tremolite-marble. PA amphibolite. PGM greenish marble. PMS dark grey biotite-schist with coarse white marble. PSBQ Schistose brown quartzite with thin layers of chlorite-and biotite-schists. PBHS dark biotite-and hornblende-schists. PMQ schistose reddish grey, micaceous quartzite containing layers of biotite-and chlorite-schists. PDQ banded brown quartzite. PGBS grey biotite-schists. PPM pure white marble. PCBS chlorite-and biotite-schists. PRBQ reddish brown quartzite, occasionally schistose. PDGS dark green chlorite-biotite-schist. PS biotite-garnet and chlorite-biotite schists. PCGM coarse-grained greenish marble. PCS chlorite-and sericite-schists. PWM white marble. KGS grey slate interstratified with siliceous grey marble and reddish brown quartzites. KBQ banded reddish brown and grey quartzites with thin layers of purplish grey slate. BDS dark grey slate containing bands of reddish quartzite. KSQ hard reddish brown and grey banded quartzite, less schistose, with layers of reddish quartzite.

Fig. 3. Section of lower Liutingssu series observed in the canyon NE of Liu Ting Ssu valley.

PUG Paiyunssu greenstone. PUS chlorite-schist. PUQ quartzite with green schists. PUM white marble. LC coarse conglomerate. LM reddish and white marble. LSL dark grey slate with thin layers of limestone. LG greenstone, generally massive. LP grey phyllite with layers of reddish quartzite. LGS grey slate containing thin beds of whitish grey limestone. LL dark limestone. LAR alternate light gray phyllite, pink quartzite with finely crystalline grey and pinkish siliceous limestone. LPL white and pink crystalline limestone.

Explanation of Plate IV.

PLATE IV

- Fig. 1. Generalized section from a point 6 Li S. E. of Shi Tsui to a point 5 Li N of Tsa Pu, showing the Wut'ai strata of the S. E. slope of the main Wut'ai range
- Fig. 2. Section extending from Ke Tung Ho to Han Kao Shan across Hai Ko Ta Ling.

Explanation of Plate V.

PLATE V

- Fig. 1. Section of the T'aishan complex, 2 li N of Tai Ho Ling Kou showing that the gneiss in a plastic state had been invaded by the reddish granite during the ptygmatic folding.
- Fig. 2. Section of the T'aishan complex, 3 li N of T'ai Ho Ling Kou showing that the gneiss had been injected by irregular masses of granitic material before its complete solidification. In this case the invading rock was drawn out and subsequently folded, so as to produce irregular lenses, controlled banding and pucked structure. The masses of amphibolite (oldest), imbedded in the reddish gneiss-granite had been also elongated.



Fig. 1.



Fig. 2.

Explanation of Plate VI.

PLATE VI

Fig. 1. Section of the T'aishan Complex 2 li NE of T'ai Ho Ling Ting, showing ancient banded grey gneiss penetrated by aplitic granite and amphibolite and the latter two cut across by a dyke.

Fig. 2. Detail of the T'aishan Complex showing the ancient crumbled grey gneiss intruded by pink granite, and the two cut across by a mass of amphibolite. Locality: 3 li N of T'ai Ho Ling Ting.

Fig. 3. A. Ancient grey biotite-gneiss.
B. Reddish grey fine-grained granite.
C. Amphibolite.
D. Diabase dyke.
Immediately W. of Ke Tung Chen.



Fig. 1

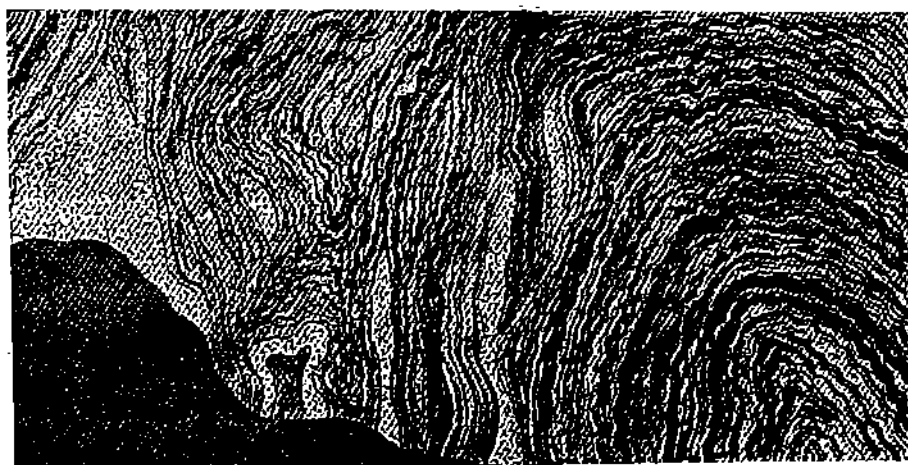


Fig. 2

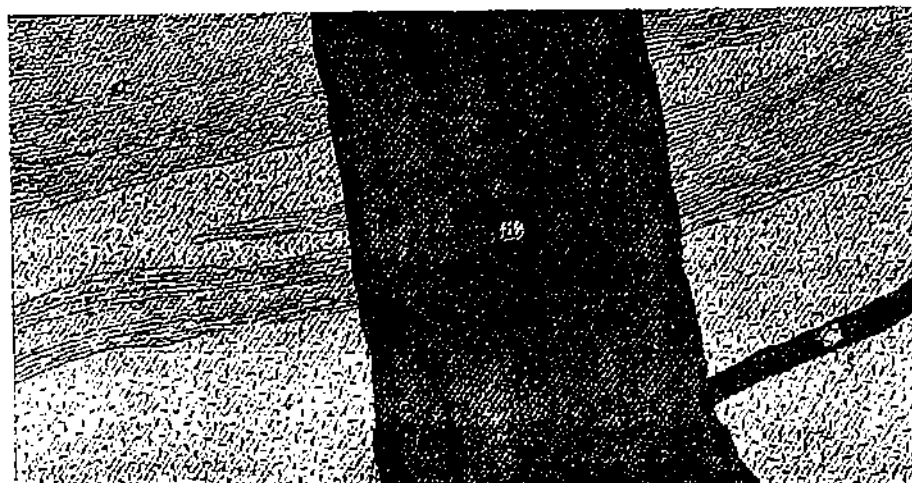


Fig. 3