SOME NOTES ON THE GEOLOGY AND PETROGRAPHY OF THE SOUTHERN APPROACH TO MT. MANASLU IN THE NEPAL HIMALAYA

By

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Mt. Manasulu (8125 m) is situated in the northern part of the central province of Nepal. The first ascent of this mountain was made by the Japanese Himalayan Expedition on the 9th of June 1956. The writer was given an opportunity to investigate the geology during the journey from Katmandu to the mountain in 1955 as one of the member of the reconaissance expedition.

The writer wishes to express his sincere gratitude to the Japanese Alpine Club, to Mr. Y. MAKI, the leader of the expedition and to Prof. J. SUZUKI who was always ready to assist by sharing his experience and knowledge. The writer is much indebted to Dr. M. HUNAHASHI for very valuable suggestions and criticism; also to Dr. V. P. SOHNDI and the members of the Geological Survey of India, who kindly supplied unpublished information upon the Nepal-Himalayan geology.

The route to the mountain

The reconaissance expedition followed the route from Katmandu, the capital city of Nepal, at first westwards to Arughat Bazaar via Nawakot and then turned northwards along the course of the Buri Gandaki*, one of the main branches of the river Gandak, to the Nepalo-tibetan border. During the traversing of this route, a continuous section across the Great Himalayan Range could be observed. The distance from Katmandu to the mountain is about 180 km.

The whole land of Nepal was surveyed by Dr. T. HAGEN who published his account of the survey in 1951, '54 and '55. Most of his works concerned with the tectonic problems of the range. In 1954, Dr. MUKTINANTH of the Geological Survey of India made a traverse survey along the Trisuli Gandaki, in the adjoining area just west of the Buri

* Gandaki in nepalese, means river.

Gandaki. To the results of that survey the writer is much obligated. According to T. HAGEN, tectonically, the Nepal Himalaya is divided into the following six units: Tibetan zone, Katmandu nappe, Hiunchuli zone,

A view of Mt. Manaslu from the Dudh Khola side.
The skyline on the left up to the "plateau" as far as the ridge which falling down to the foreground, the strata of calcareous schist are exposed. The snow covered buttless in the center to the right side, is composed of granite.

Piuthan nappe, Nawakot nappe and the zone of Pokhara.

The basement complex comprises the zone of Pokhara, upon which the Piuthan and Katmandu nappes are overturned and are thrusted in the order of succession from the base. In the southern part of central

Nepal the Katmandu nappe has been overthrusted about 60 to 70 km from north to south to form a "half klippe" in the Sheopuri range. Based on HAGEN's papers the route followed by the writer's expedition started from the Katmandu nappe then traversing the Nawakot nappe in the middle of the course, lastly returned again to the "root" zone of the Katmandu nappe.

Geological units

Along the route surveyed, the following geological units are distinguished from south to north.

1) Sheopuri granitic gneiss
2) Nawakot phyllitic group
3) Lower metamorphic group
4) Higher metamorphic group
5) Migmatite and augen-gneiss
6) Tibetan group
7) Granite

Sheopuri granitic gneiss

Sheopuri granitic gneiss occurs in the hilly belt of the Sheopuri range which extends from Mt. Sheopuri on the west to the village of Kakani and Mt. Manipur on the east to compose the northern boundary of the Nepal valley. The rocks representative of the top and the southern side of hills, are chiefly coarse-grained granitic gneiss and garnet mica gneiss which strike north-west direction and dip towards the north in the Nepal valley side or dip southwards on the top of the hills.

Granitic gneiss is formed by a metasomatic development of potash feldspar "augen" on some layers or zones in mica gneiss.

The rocks forming the northern slope of the hills, are remarkably crushed and sheared, being directly bordered by the Nawakot phyllitic group. The most abundant rocks making up the hillsides, are crushed gneiss, phyllitic mica schist and chlorite schist as one proceeds to the north. They often preserve original coarser grained gneissic texture. A subordinate amount of amphibolite has been detected near Thansing village.

The whole strike extends east-west or north-west and dips steeply towards the south or dips to the north.

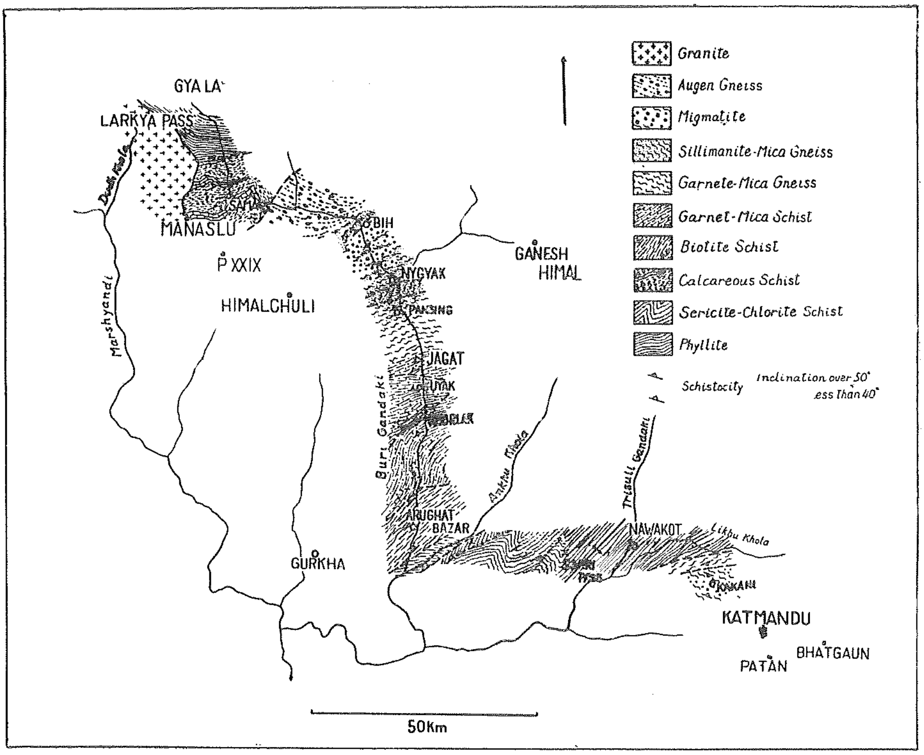


Fig. 1. Geological traverse map along the expedition route.

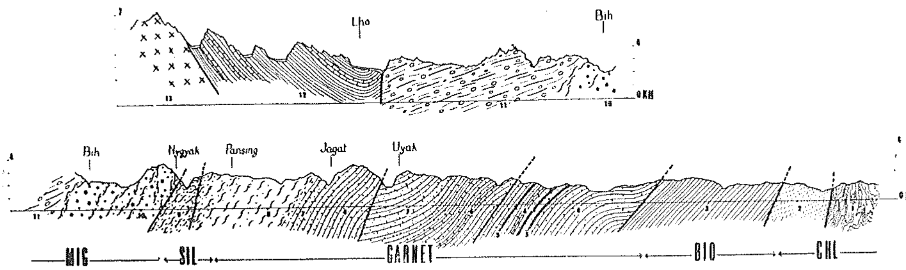


Fig. 2. Section across the central Nepal Himalaya along the Pass of Samri to Larkya Pass.
CHL: Chlorite zone BIO: biotite zone GARNET: garnet zone
SIL: sillimanite zone MIG: zone of migmatite

Nawakot phyllitic group

The Nawakot phyllitic group is exposed in an area north of the Sheopuri range. Lithologically, the group is divided into two parts; well cleaved black phyllite formation and less cleaved sandstone formation. Black phyllite which constitutes the upper part of the group, develops along the course of the Likhu Khola* and runs generally N 60° E direction with gentle dipping parallel with the strike of the range. The rock adjoining the Sheopuri gneiss is intensly sheared to yield well cleaved chlorite phyllite. The lower part of this group comprises less cleaved thick sandstone which occurs in the area west of the Trisuli Gandaki and the area along the Samri Khola. There was found no fossil evidence during the present survey.

This group is, according to T. HAGEN, a member of the Nawakot nappe and makes a "half window" in the valley of the Likhu Khola.

Lower Metamorphic group

The rocks of the lower metamorphic group are characterized by

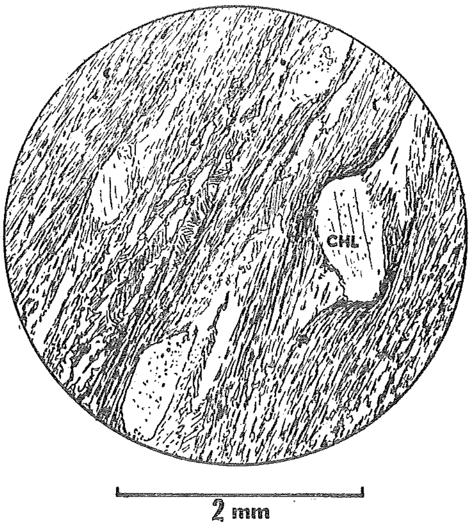


Fig. 3. Chloritoid chlorite schist near Tharp village CHL: chloritoid

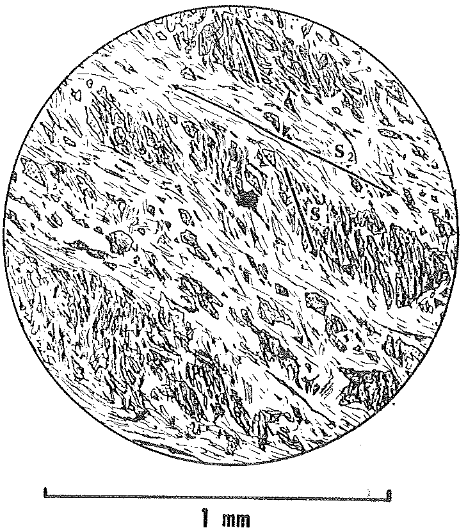


Fig. 4. Sketch showing intersection of the schistocity. S_1: earlier formed s-plane, characteristic mineral association being chlorite and albite. S_2: later-formed s-plane, being characterized by an alignment of sericite flakes.

* Khola means small river.

their low grade of metamorphism. The group includes chloritoid chlorite sericite schist, sericite quartz schist and biotite schist (Fig. 3).

Chloritoid chlorite sericite schist has been observed in the vicinity of Katonje hill, west of the Samri Bhanjhang.* It is grey green fissile

TABLE 1. The Chemical composition of chloritoid chlorite sericite schist

SiO_2	59.46%	CaO	.42
TiO_2	.44	Na_2O	1.10
Al_2O_3	21.54	K_2O	3.80
Fe_2O_3	2.85	H_2O (+)	3.72
FeO	3.57	H_2O (−)	.26
MgO	2.57	Total	99.73

Analyst: S. HASHIMOTO

in appearence. The rock has been influenced by strong penetrative movements, has a miniature folding and shows two sets of s-planes which intersect each other at a large angle (Fig. 4). S-planes, earlier formed, are characterized by the mineral assemblage of chloritoid, chlorite and minor amounts of sericite, albite and quartz. Chloritoid, now mostly altered to chlorite, attains 1 mm in size. The other set of s-planes is observed as a parallel arrangement of minute crystal flakes composed exclusively of sericite. Apparently such s-plane had two metamorphic episodes, the first being typified as chloritoid metamorphism and the second sericite metamorphism of lower grade. It is interesting to note that a transition in the direction of the movement in the schist is reflected in the degree of concentration of some of the elements in a metamorphism.

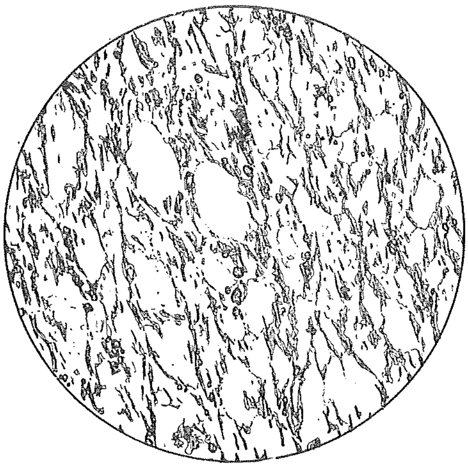
The original rock is thought to be the upper member of the Nawakot phyllitic group. The rock observed along the side of the river Ankhu Khola, is weakly metamorphosed sandstone. It is fine to medium-grained sericite quartz schist. Quartz has somewhat large grain size and in some places shows evidence of the original cataclastic habits. Plagioclase occurs as small granoblastic grains. Among micas, sericite is characteristic in the rock of the southern area, while biotite occurs in varying amounts in the northern part of this area.

Original sedimentary structure is, in some localities, well preserved. Bedding is disturbed but general strike direction tends to deviate from north to 50° east or east-west as one comes nearer to the Buri Gandaki river. Structurally, the sericite quartz schist shows anticlinal position

* Bhanjhang means pass.

and is correlated to the lower sandstone member of the Nawakot group.

In the lower course of the Buri Gandaki, rocks have changed abruptly into a well metamorphosed biotite schist which strikes N 30°E direction and dips 50° uniformly to NW. In this schist, original sedimentary structure is entirely obliterated. Biotite has light yellowish brown tinge which is different from the tinge belonging to the much metamorphosed schist. Minute granules of garnet are also scattered throughout (Fig. 5). The rocks are relatively rich in quartz and may be derivatives of



2 mm

Fig. 5. Biotite schist 1 km south of Arughat Bazaar. The rock contains quartz and fine flaky biotite. Minute granules of garnet are also detected.

1 mm

Fig. 6. Garnet mica schist 1.5 km south of Jagat. Gar : porphyroblast of garnet Mu : muscovite Bi : biotite

the metamorphic equivalents of the sandstones. The degree of metamorphism observed in this schist, is almost uniform and the northern boundary of the lower metamorphic group is placed on garnet isograd which has marked distinction on account of the appearance of garnet (almandine) porphyroblasts.

Higher metamorphic group

Northwards from the garnet isograd, which is situated about 5 km north of Arughat Bazaar, the rocks of the higher metamorphic group occur. The isograd boundary is marked by a tourmalin mineralization of rocks, which may indicate the presence of a tectonic line between the biotite and garnet zones.

The higher metamorphic group consists mainly of garnet mica schist, muscovite quartz schist intercalated with thin layers of amphibolite, calcareous schist and limestone and of garnet mica gneiss and sillimanite garnet mica gneiss. The grade of metamorphism increases towards the north and near Jagat village a series of schists gradually changes into coarser-grained, foliated gneissic rocks.

Garnet mica schist occurring just north of the garnet isograd is still relatively low metamorphic, consisting small garnets and being fine-grained. The rock has a well-developed schistocity. Garnet crystals are usually, free from pigments and measure 0.5 to 0.3 mm in diameter. Quartz and plagioclase form mosaic aggregates of about 0.2 to 0.1 mm. Biotite brown to greenish brown in tinge, makes minute flaky crystals. The crystals of muscovite are somewhat larger than those of biotite and usually exceed them in amount. In some places, hornfelsic rocks appear as thin lenses or layers. Garnet and muscovite are quite scarcely found in these layers. Intercalation of this kind is considered to be of sedimentary origin derived from arenaceous bands developed in argillaceous rocks.

Garnet mica schist north of the Khorlak Khola, shows an advance in metamorphism. It is medium-grained (0.4 to 0.3 mm) and is characterized by large poikiloblastic garnet (Fig. 6). In some places "whirls" of andalusite porphyroblasts have been observed. Biotite is reddish brown, sillimanite is sporadically found in quartz.

A large band of mylonite developed near the Khorlak Khola is responsible for a boundary which divides garnet mica schist into the less metamorphosed schist and much advanced one. Amphibolite, limestone, calcareous schist and quartz schist have accompanied with the schist.

Amphibolite occurs as a comparatively thin layers, and is characterized by a large amphibole content which may surpass 90% in volume. The amphiboles are observed as long acicular crystals which aggregate into prominent bands and enclose granules of epidote and sphene. The pleochroism of the amphiboles is pale bluish green (Z) to very pale greenish yellow (X). $c \wedge Z = 10$ to $21°$. Amount of plagioclase is small and the rock contains considerable magnetite granules. Layers of limestone are observed together with the calcareous schist near the conflux of the Khorlak Khola. The limestone is constituted almost entirely of calcite and a subordinate amount of fine flaky phlogopite. Muscovite quartz schist is exposed for some distance below the Khorlak

Khola. The rock is formed exclusively of quartz and muscovite while a subordinate amount of sillimanite is also detected. Rocks more siliceous and massive are found near the village of Uyak.

Garnet mica gneiss has been observed in the northern part of the group. Above Doman village, coarse-grained, gneissic bands are embedded in the schist. The garnet appears as a poikiloblast and is full of pigments. The diameter is 1 to 4 mm. The proportion of biotite to muscovite varies from rocks to rock. The biotite has pleochroism of red brown to chocolate brown (Z) to yellow brown (X). The muscovite appears in a form replacing biotite crystals. Parallel intergrowth of two micas is not rare. Plagioclase has a composition of An 20 and is free from zoning. Twins are rarely found. The quartz occupies 90% in volume of the felsic minerals and shows weak wavy extinction. Silimanite and orthite make accessory compositions. Sillimanite appears as very fine needles which have been found in the boundary between quartz grains or enclosed in biotite.

The rocks, developing in the northern vicinity of Jagat village are somewhat coarser-grained. Veining of the quartz felspathic materials is so common that the rock is called banded gneiss. The darker bands of the gneiss are composed of garnet, quartz, plagioclase (An 30), biotite and muscovite. Sillimanite is also detected in quartz or biotite crystal and is often replaced by muscovite. The marginal parts of the dark bands have pronounced schistocity and the biotite is considerably chloritized or replaced by distinct crystals of muscovite. Light bands are coarser grained; the size of plagioclase grains attains up to 6 mm, quartz 2 mm and garnet 2 to 4 mm. A minor amount of sillimanite needles is of common occurrence in quartz or in biotite.

Near Nygyak village, the most intensive introduction of quartz has taken place in company with marked concentration of sillimanite. A moderate amounts of perthite and microcline have been detected in

TABLE 2. The chemical composition of sillimanite muscovite gneiss collected from Nygyak village

SiO_2	68.69%	CaO	1.90
TiO_2	.71	Na_2O	1.95
Al_2O_3	14.80	K_2O	4.64
Fe_2O_3	1.00	H_2O (+)	.52
FeO	3.47	H_2O (−)	.12
MgO	1.88	Total	99.68

Analyst: S. HASHIMOTO

the form of schlieren. Plagioclase is replaced principally by quartz and potashfelspar. In these rocks, sillimanite shows two distinct stages in its formation. The earlier one is evidenced by the needle like crystals intergrown within biotite. The later one is represented by the bundles

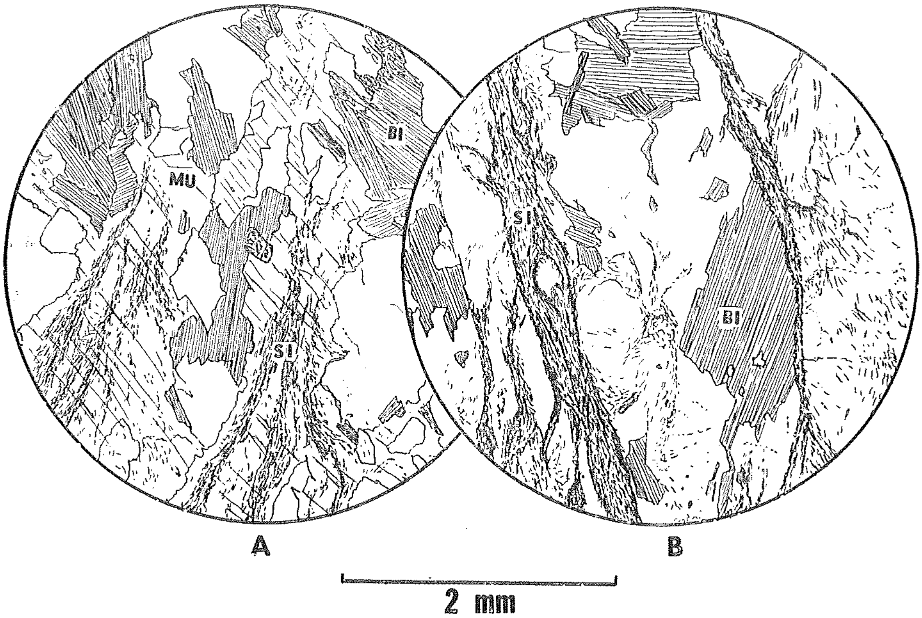


Fig. 7. Sillimanite mica gneiss near the village of Nygyak.
A : large crystal of muscovite (MU) encloses minute needles of sillimanite (SI). BI : Biotite.
B : Segregative aggregation of sillimanite needles in the gneiss.

of needle crystals which usually have a direction intersecting obliquely with the alignment of the biotite. Muscovite is also divided into two types. The one includes distinct flaky crystals which transverse the cleavage direction of biotite. The other develops as a large irregular crystal enclosing sillimanite needles (Fig. 7).

Migmatite and augen-gneiss

Transition from the gneiss to the migmatite has taken place in the neighbourhood of Nygyak village. The veins or lenses of leucocratic minerals, which had once been characteristics of the sillimanite gneiss, tend here to concentrate in bands of porphyroblasts of quartz, plagioclase and potashfeldspar. The muscovite is less distinct; its place had taken by potashfeldspar. The boundary of the infiltrated material, being characterized by a concentration of sillimanite aggregates, becomes less clear. The sillimanite crystals are distinctly corroded but their shapes tend to become somewhat stout prismatic. The gneiss remnants embedded in the massive migmatite, greatly change their orientation from place to place.

Still further north, introduction of the quartz feldspathic materials is so evident that the rock has been converted into granitic rock or augen-gneiss.

Typical migmatic granite of this region has been exposed near the village of Bih. Granitic rock of Bih is a medium to coarse-grained rock. It is exposed in an area a few kilometers wide parallel with the strike

TABLE 3. The chemical composition of granitic gneiss

SiO_2	68.97%	CaO	3.99
TiO_2	.44	Na_2O	2.58
Al_2O_3	15.50	K_2O	2.54
Fe_2O_3	1.03	H_2O (+)	.34
FeO	2.47	H_2O (−)	.14
MgO	2.60	Total	100.60

Analyst: S. HASHIMOTO

of the gneiss. A sleight orientation of dark minerals and porphyloblasts could sometimes be observed in the most granitic part. Under the microscope, the rock is seen to be composed of porphyroblastic microcline and quartz, blastic grains of plagioclase and biotite.

Microcline forms large porphyroblasts of 2 cm and encloses fine crystals of plagioclase (An 25), quartz and biotite. Enclosed plagioclase shows myrmeckitic structure. Near the microcline crystals, coarse-grained quartz and plagioclase are well developed. The biotite is somewhat directed. Together with the blastic crystals of quartz and plagioclase, it reveals gneissic structure. Almost no muscovite is found. The sillimanite is small amount even in the gneissic part.

The augen-gneiss, exposed in the area between the village of Bih and Namru, is chracterized by large porphyroblasts of microcline. Porphyroblasts may attain a diameter up to 20 cm. Sometimes, instead of a development of porphyroblastic microcline, coarse grained granitic parts have been formed, around which mantles of microcline have been observed. The augen-gneiss has a well developed foliation which extends its strike N 60° W and dips towards the northeast at an inclination of 50 to 60°. An introduction of potassic substances being formed as microcline crystals, has taken place into the disturbed parts in the granitic gneiss where the foliations change their disposition abruptly.

Tibetan formation. Calcareous schist group

Above Namru village, the bottom of the valley is almost entirely covered by the morainic deposits of vast thickness.

Near the villages of Lho and Sama, there were some exposures showing black, fine and fissile rocks. Limestone forms layers or lenses alternating with schist in the neighbourhood of Sama and on the eastern slope of Mt. Manaslu.

The rocks of this group are almost entirely calcareous in composition. These are biotite quartz calcite schist and limestone or marble. Small amounts of sillimanite muscovite gneiss have been found embedded in the form of "schlieren".

The whole area is strongly folded and faulted. According to the survey of T. HAGEN, the rocks of the calcareous schist group are thought to belong to the Tibetan sedimentary series, having been deposited in in marginal geosyncline during the Silurian to Cretaceous Eras.

Biotite quartz calcite schist is of frequent occurrence; it is coloured brownish grey and is fine grained. Biotite is pale light brown in tinge and forms fine flaky crystals. The rock contains a large amount of calcite which shows somewhat coarser grained than the other minerals. A band consisting almost entirely of calcite with subordinate amounts of muscovite and quartz, and colored pale yellowish is detected.

Granitic intrusion occurs in this schist group especially on the northwestern side of Mt. Manaslu. A widespread development of diopside biotite calcite hornfels has been formed by the contact metamorphic effects of the granitic intrusion.

Larkya formation

In the vicinity further north, a black phyllitic formation alternating in some places with beds of limestone has been observed. A steep fault exists along the southern boundary of this formation between it and the calcareous schist series near Larkya Bazaar. Phyllitic formation is constituted chiefly of well cleaved, fine grey staurolite garnet biotite schist or biotite schist and is also intruded by granitic rock near Larkya Pass where the phyllitic schists and limestone have been subjected to contact metamorphism.

Hornfelses of various grade are observed along the road to the pass. A contact surface of the granite and the schist is clearly observed to have a concordant relation. There are sill-like offsets of the granite body. The contact rocks sometimes contain "schlierens" formed by tourmalin aggregates.

Granite

A large body of granite is exposed in the area extending from the south western part of Mt. Manaslu to the northwards to Mt. Cho Dhana (Cheo Himal) and Mt. Himlung Himal just north of the pass of Larkya. The rock is a leucocratic, medium-grained tourmalin granite and is apparently magmatic, intruding into the calcareous schist group and phyllitic schist group with a sharp contact. Surrounding schists of granite are, in some localities, dipping away from the granite body and have been subjected to strong contact metamorphism. The most of high ridges including the summits of Mt. Manaslu and Mt. Cho Dhana,

Fig. 8. Tourmalin granite
PL : plagioclase, OR : orthoclase,
Q : quartz, MU : muscovite, T : tourmalin

stand on the very contact surface between the granite and sediments. Near the contact there branch off many aphophyses from the main mass, some are discordant while others appear concordance. The granite shows, as a whole, no trace of deformation. It is composed of hypautomorphic plagioclase (An 25 to 20), granular or lenticular quartz and xenomorphic orthoclase. Microcline which is a characteristics of the migmatic granite, is quite absent. Among mafics, tourmalin and muscovite are of common occurrence. Biotite is found in sleight quantity (Fig. 8.).

Remarks on the metamorphism of the region

Making an exception of the Sheopuri granitic gneiss and the rocks of the Tibetan group, all the rocks are so distributed as to reveal a progressive metamorphism, increasing in its intensity towards the north; in the zone of the culmination of the metamorphism the migmatic rocks occur.

The lowest in grade in the progressive metamorphism is the zone of chlorite, followed by biotite, garnet and sillimanite zones respectively.

The chlorite zone includes Nawakot phyllitic group and chloritoid chlorite sericite schist, sericite quartz schist. In this zone, a formation of chloritoid schist is of special interest. The chloritoid porphyroblasts, as a rule, formed in close connection with the formation of a single set of schistocity. The mineral formation, as is well known, occurs only under such a condition as those ferrous components are concentrated with a concomitant expulsion of lime. On the other hand, the schistocity which intersects the earlier-formed s-plane, is characterized by the sericite formation. A change in the direction of movement means alteration in component as well.

Garnet-bearing biotite schist in the vicinity of Arughat Bazaar corresponds to the rock of the biotite zone. Garnet granules enclosed, have nothing to do with a porphyroblast; pale yellow greenish tinge in the biotite proves its grade to be that of biotite chlorite subfacies in the greenschist facies.

The rocks of the garnet zone are represented by garnet mica schist, amphibolite, calcareous schist, garnet mica gneiss from which main part of the higher metamorphic group have been constructed. The garnet mica schist is divided into two units by the sheared zone developed near the conflux of Khorlak Khola and Buri Gandaki.

The less metamorphosed garnet mica schist is characterized by the mineral association of garnet and greenish brown biotite: the associated amphbolite is epidote amphibolite. The rock may belong to the chlorite almandine subfacies in epidote amphibolite facies. The garnet mica schist developing to the north of Khorlak Khola, distinguishes itself by the development of large poikiloblastic garnet and red-brown biotite. The porphyroblast of andalusite has also been observed. The rocks have been metamorphosed in much higher temperature; the amphibolite facies.

Gradational transition is shown in the contact between the gneiss and the schist. An initiative of metasomatic action indicated by the replacive introduction of feldspar and quartz, is observed parallel with the schistocity.

Although sillimanite is of common occurence, the amount is so small as to typify the metamorphism of the gneiss as being granulite facies.

The sillimanite zone is represented by the sillimanite mica gneiss near the village of Nygyak. The frequent and a marked occurrence of sillimanite is very interesting. Sillimanite, characteristics of this gneiss, is somewhat different from that observed before.

Replacive introduction of quartz-feldspathic materials in company with the segregative concentration of sillimanite shows that the sillimanite has interrelation to the migmatite formation and that it has been formed by the excess aluminous component squeezed out from the migmatitic domain. Thus, the sillimanite zone may be considered as a frontal zone of the migmatite.

A formation of sillimanite in pelitic gneiss is, in some cases attributathe to high temperature-pressure condition of granulitic metamorphism. However, the case will be quite different in the migmatite front where a substance moved shows inhomogeneous motion as to bring a specific concentration of a certain element in an aggregate of porphyroblasts during or after the course of deformative metamorphism.

The formation of sillimanite in the Nygyak gneiss is responsible for such substancial condition prevailed in the metamorphism as facielly to that of high amphibolite facies.

An addition of potassium is principally difined as the perthite formation or the muscovitization of the sillimanite formed before. Processes involved are quite complicated and seem to contain a number of episodes in which it is obvious that silicon-aluminum introduction is the prior event, then followed the addition of potassium.

While, an introduction of potassic substance in the domain of migmatite is displayed by the replacive formation of the microcline crystals. A rather simple and a stabilized mineral formation as these, is thought to be due to homogeneized process in the granitic migmatite in amphibolite facies.

The general arrangement of the metamorphic zones, as stated before, will establish a continuous structural and metamorphic unit in the axis of the range. The writer is doubtful of the interpretation of the Himalayan structure as consisting of pile up "nappe sheets" which have been driven almost horizontally from north towards south.

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