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GEOLOGY AND STRUCTURE OF THE MAIN CENTRAL THRUST ZONE OF THE ANNAPURNA RANGE, CENTRAL NEPAL HIMALAYAS.

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ABSTRACT

The present paper describes the geology, structure, tectonic history and petrographical feature of lithologic constituents of the region around(MCT) zone. The report area is lithologically divided into four geologic units; the Midland zone, the MCT zone, the Himalayan gneiss zone and the Tibetan Tethys zone. The MCT zone is distinguished by the lower augen gneiss zone, (MCT–2) and the upper thrust fault (MCT–1).

Three stages of deformations are recognized in the area: the first, the two sets of widespread foldings with EW and NS directions; the second, distinct NS micro foldings and mineral lineations with striation–like forms, which are comparable to the southwards thrusting of MCT; and the third, latest upwards movement of the Higher Himalayas. Mode of occurrence and petrographical feature of augen gneisses suggest close genetical relations with the movements of MCT and/or the activity of younger trurmaline granites.

INTRODUCTION

The Main Central Thrust Zone (MCT zone) is one of the most important tectonic zone of the Himalayas. The Higher Himalayas are topographically bounded to the Lesser Himalayas on the MCT. The Higher Himalayan crystalline basements (the Himalayan gneiss) and their cover of the Tibetan Tethys sediments overthrust the Lesser Himalaya formations (the Midland metasediments). The thrust is gently dipping northwards with east-west direction and runs sub-parallel to the Himalayan Range.

The peculier rock-types (augen gneisses) occur continuously along the MCT zone. Augen gneisses represent an impontant geological and petrological situations on the tectonic developments of the orogenic belts (Kano,1977;1980).

The report describes the regional geology, structure and petrographical features of rocks around Dhaulagiri-Annapurna Himal and discusses the geological situation of the augen gneisses.

OUTLINE OF GEOLOGY

Field observations have been carried out from October. to November 1980 and approximately an area of 100 km W to E and 30 km N to S has been studied on the southern slope of Dhaulagiri-I to Annapurna Himal (Fig. 1). Fig.2 and Fig.3 show the geological map and profile of the area. Geological columns along the main routes are shown in Fig.4.

The geology of the area are lithologically divided into four units in structurally ascending order ; the Midland zone, the MCT zone, the Himalayan gneiss zone and the Tibetan Tethys zone (Fig.5 and Fig.6). Each unit and major thrust lie in a sub-parallel arrangement, despite their different origins.

The structure of the area is generally homoclinal, trending E−W to WNW−ESE and dipping 0°∼30°N. The southern part of the Midland zone is gently folded. The MCT-zone and the Himalayan gneiss zone are monoclinal with 20°∼40° dips (Fig.7).

Thick sequences of the Midland metasediments which are considered to range in the age from Eocambrian to lower Paleozoic (Hashimoto et al., 1973) are subdivided into the Midland zone (lower part) and the MCT zone (upper part) on the basis of lithology. The Himalayan gneiss zone which is presumed to be the Precambrian basement of the Midland metasediments is unconformably overlain by non− or weakly metamorphosed Tibetan Tethys sediments and they overthrust the MCT zone (PL.I-1).

The metamorphic grade increases towards the north and reaches maximum at the amphibolite facies in the Himalayan gneiss zone, and rapidly decreases into the Tibetan Tethys zone.

LITHOLOGY OF THE GEOLOGIC UNITS

Midland zone

Southern-half of the surveyed area is occupied by the Midland metasediments which are composed mainly of alternation of metasandstone and phyllite with minor quartzite, green schist and amphibolite (Fig.6) (PL.I−2). Lithology of the zone is rather monotonous over the area and rocks gradually shift into weakly or non-metamorphosed formations towards the south.

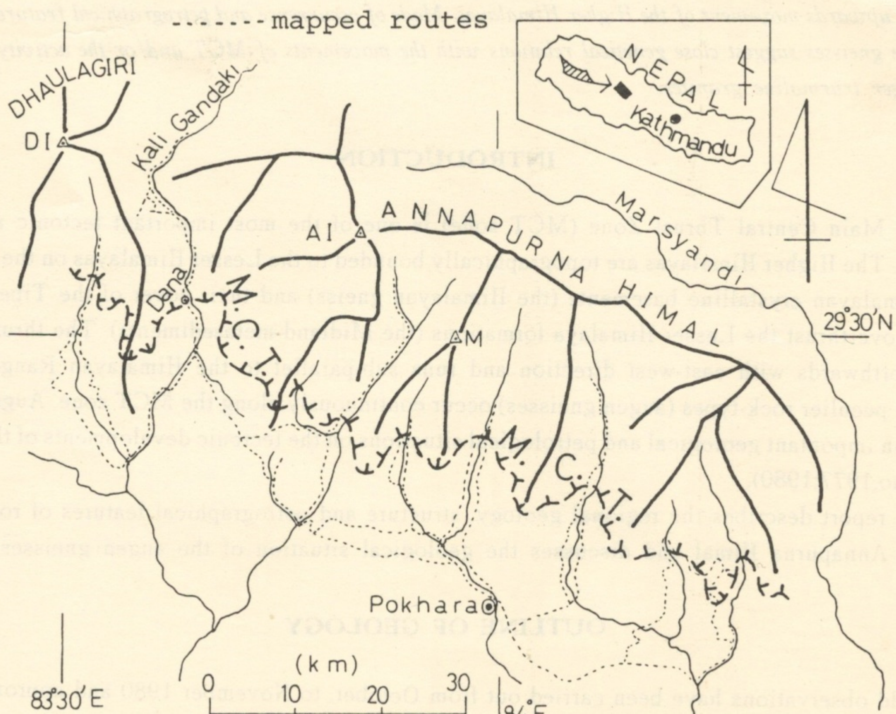

Fig.1 Location and mapped routes.
(DI : Dhaulagiri-I, AI : Annapurna-I, M : Machhapuchhare.)

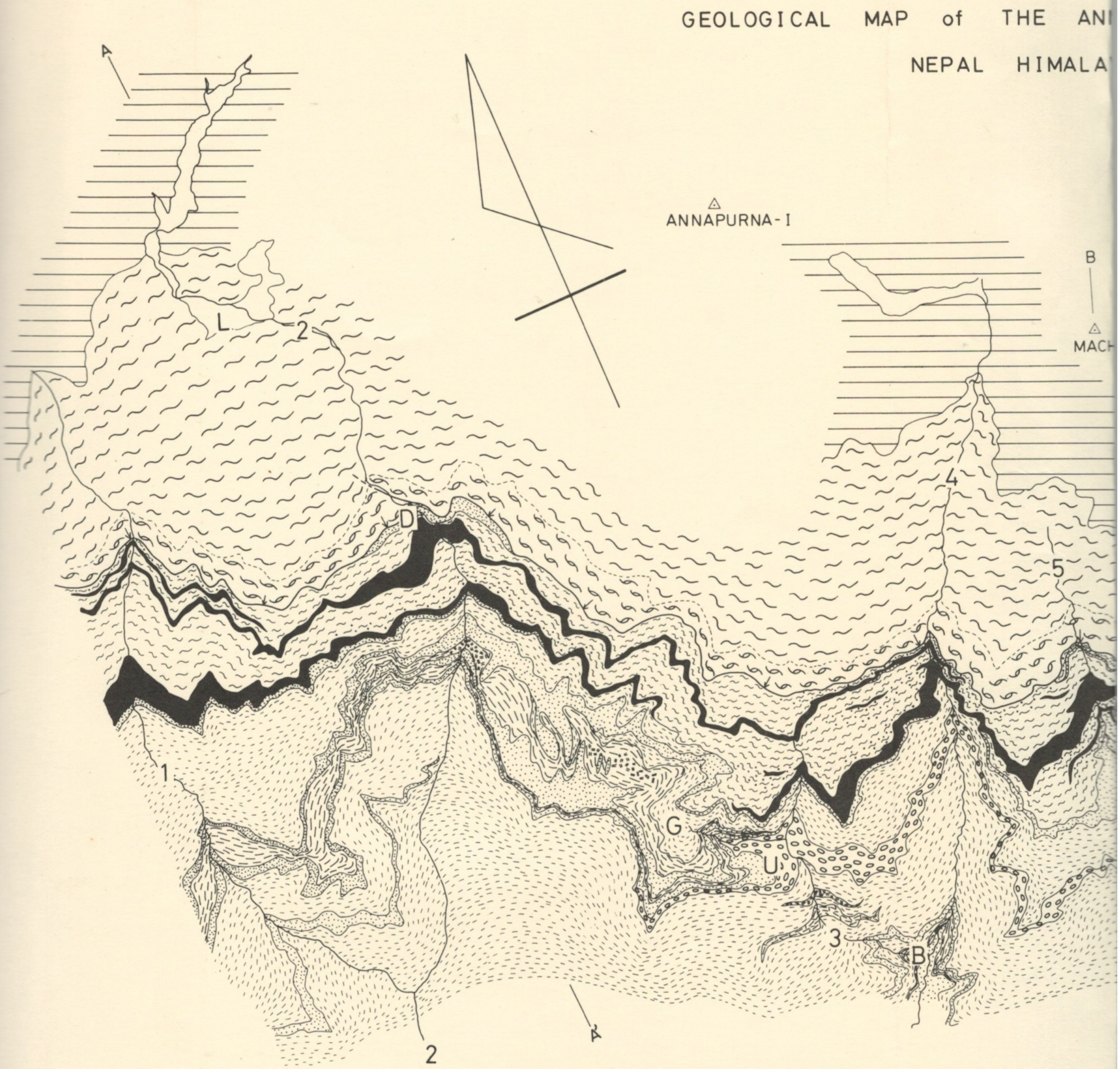

Fig. 2 Geological map around the Annapurna Range.
Location :

1 : Thulo Khola	6 : Seti Khola	B : Birethanti
2 : Kali Gandaki	7 : Madi Khola	D : Dana
3 : Bhurungdi Khola	8 : Rudi Khola	G : Ghorepani
4 : Modi Khola	9 : Midam Khola	L : Lete
5 : Mardi Khola		U : Ulleri

PURNA RANGE,

S.

981. *J. Kano*)

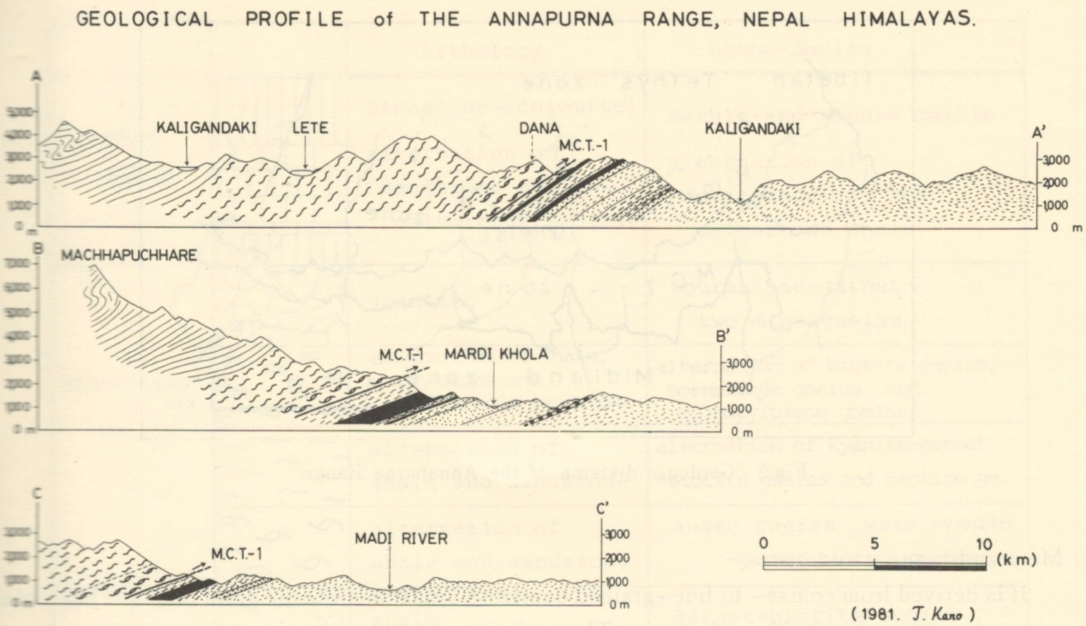

Fig.3. Geological profile of the Annapurna Range, Nepal Himalayas.
(Legend→see Fig.2)

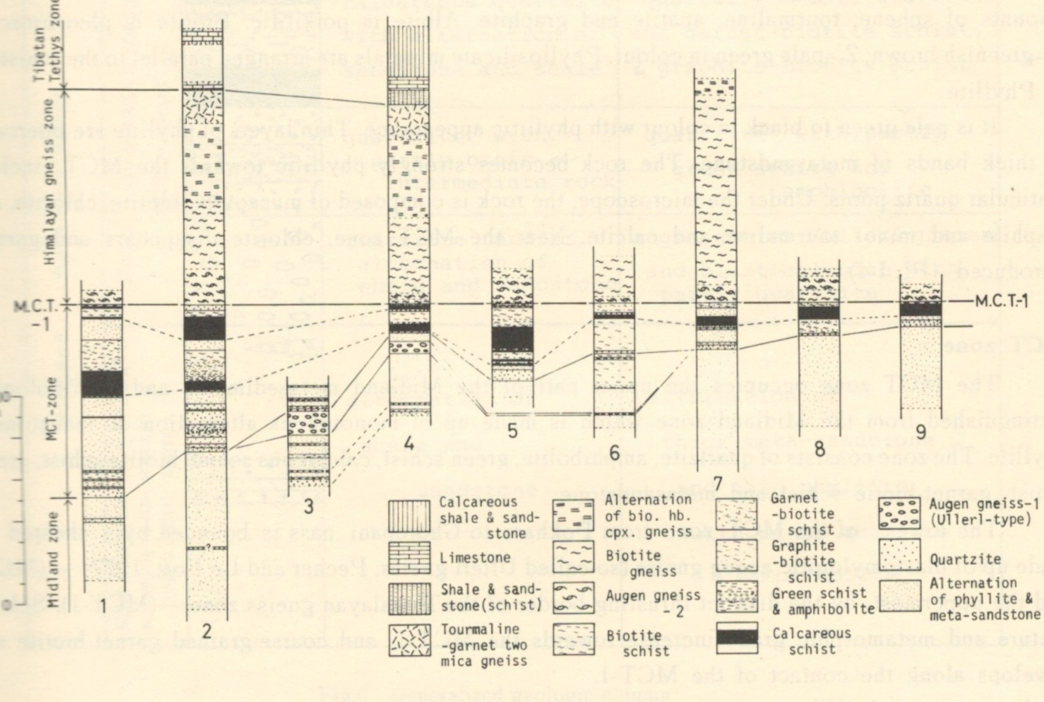

Fig.4 Geologic columns of the surveyed routes.

1 : Thulo Khola
2 : Kali Gandaki
3 : Bhurungdi Khola ~Ghorepani
4 : Modi Khola
5 : Mardi Khola
6 : Seti Khola
7 : Madi Khola
8 : Rudi Khola
9 : Midam Khola ~Rudi Khola

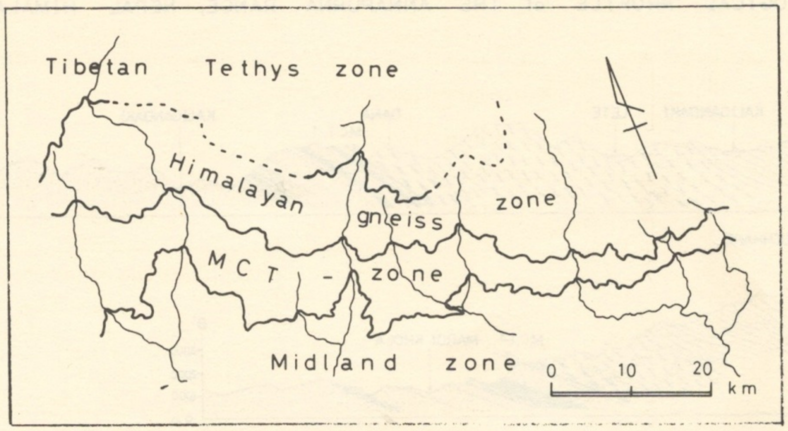

Fig.5 Geologic division of the Annapurna Range.

(1) Metasandstone

It is derived from coarse– to fine–grained quartzose sandstone. Clastic grain of quartz has a bluish grey to milky white tint to the naked eye. The rock appears to be almost non-metamorphosed in the southern part of the area. However, under the microscope, it is completely recrystallized (PL.I–3) and shows lepidoblastic texture. The rock is composed of quartz, albite, chlorite, biotite, muscovite and minor amounts of sphene, tourmaline, apatite and graphite. Albite is poikilitic. Biotite is pleochroic with X'=greenish brown, Z'=pale green in colour. Phyllosilicate minerals are arranged parallel to the schistosity.

(2) Phyllite

It is pale green to black in colour with phyllitic appearance. Thin layers of phyllite are intercalated in thick bands of metasandstone. The rock becomes strongly phyllitic towards the MCT, including lenticular quartz pools. Under the microscope, the rock is composed of muscovite, biotite, chlorite, albite graphite and minor tourmaline and calcite. Near the MCT zone, chlorite disappears and garnet is introduced. (PL.I-4)

MCT zone

The MCT zone occupies the upper part of the Midland metasediments and is lithologically distinguished from the Midland zone which is made up of monotonous alternation of sandstone and phyllite. The zone consists of quartzite, amphibolite, green schist, calcareous schist, biotite schist, graphite schist, garnet-biotie schist and metasandstone.

The lowest of the MCT zone from Pokhara to Ghorepani pass is bounded by a sheared zone made up of blastomylonitic augen gneiss (so-called Ulleri gneiss; Pecher and Le Fort, 1977) — (MCT-2), and the uppermost, by the distinct thrusting border of the Himalayan gneiss zone —(MCT-1). Schistose texture and metamorphic grade increase towards the MCT-1, and coarse-grained garnet-biotite schist develops along the contact of the MCT-1.

(1) Augen gneiss-1 (Ulleri augen gneiss)

The rock is characterized by euhedral to subhedral potash-feldspar and albite porphyroblasts and blastomylonitic appearance(PL.I-5). Feldspar megacrysts are surrounded by fluidal lamination of fine-grained matrix and form augen structure(PL.I-6). The rock is composed of potash-feldspar, albite, quartz, plagioclase, green to greenish brown biotite, muscovite and minor amounts of epidote, garnet, opaque minerals and tourmaline. X-ray powder data of potash-feldspars represent diffuse patterns and Δ

		Lithology	Litho-facies
Tibetan Tethys Sediments		limestone ~ (dolomite?) & alternation of sandstone and calcareous shale	marble and impure marble & alternation of meta-sandstone and calcareous shale
Himalayan Gneiss		granitic	tourmaline-garnet-two mica gneiss
		alternation of shale, sandstone and calcareous sandstone	alternation of biotite gneiss, hornblende gneiss and clinopyroxene gneiss
		alternation of shale and sandstone	alternation of kyanite-garnet-biotite gneiss and biotite gn.
		alternation of shale and sandstone	augen gneiss with kyanite-garnet-biotite gneiss
Midland Meta-sediments	Calc - Quartzite formation (MCT-zone)	shale	garnet-biotite schist
		limestone ~ calcareous quartzite with alternation of sandstone and shale	calcareous schist with quartzite ~ calc-quartzite and garnet-biotite schist, & graphite-biotite schist
		quartzite with partly basic ~ intermediate rock	quartzite with partly green schist and amphibolite
		quartzite and/or alternation of shale and sandstone	augen gneiss (Ullerl gneiss) and blastomylonite with partly quartzite
	Alternation of phyllite & meta-sandstone (Midland zone)	alternation of shale and sandstone	alternation of thick meta-sandstone and thin phyllite with minor quarzite & amphibolite

Fig.6 Generalized geologic column.

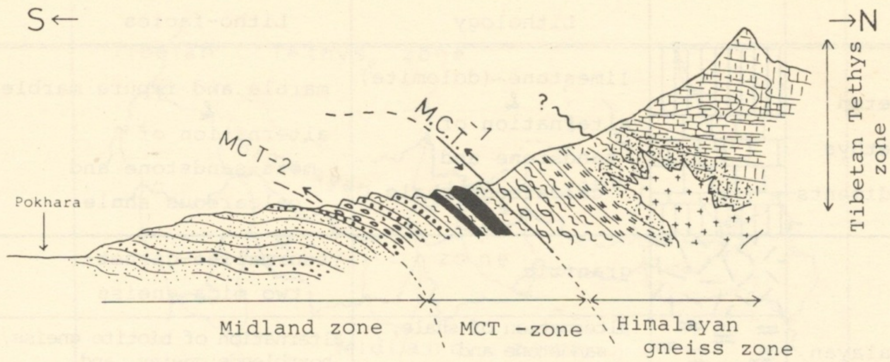

Fig.7 Generalized profile across the MCT zone.

-values* range 0 to 0.96. The layer of augen gneiss intercalates schistose and micaceous quartzites.

The relationship between deformation and recrystallization is complicated. In a certain case, potash-feldspar megacrysts are crushed and replaced by fine-grained matrix, (PL. II-1), on the other case, however, they are complete overgrowths of euhedral porphyroblasts on the matrix. Deformed and non-deformed plagioclses are also observed. Dusty ones are rimmed by clear albitic mantle and the trace of twinning plane is bended on the core-rim boundary suggesting the deformation before recrystallization of albitic plagioclase (PL. II-2). Furthermore, there are two muscovites; the one is fine-grained crystals in matrix and the other is large poikiloblastic and deformed crystals (PL. III-3).

Ulleri gneiss is considered to lie along a shear plane concordant to the surrounding rocks where the strains are concentrated.

(2) Amphibolite and schistose amphibolite

These are fine- to medium-grained and deep green in colour. The rocks are composed of hornblende, plagioclase and minor amounts of biotite, epidote, chlorite, sphene, opaque minerals and with or without quartz. Hornblende is pleochroic with Z'= green to deep green, X'= yellowish green and biotite is also Z' = brown to greenish brown, X'= pale yellow.

(3) Green schist

Green schist or green phyllite in the Midland zone consists of chlorite, muscovite, graphite, quartz, albite and minor apatite, tourmaline, sphene and with or without octahedral crystal of magnetite. Under the microscope, chlorite is pale green in colour and some grains of quartz, are clastic.

Green schist in the MCTzone is composed of chlorite, green biotite, plagioclase, graphite, epidote, calcite and sphene. Chlorite is deep green in colour and biotite is dark green~greenish brown to pale yellowish brown. Grain size and grade of recrystallization of green schists seem to increase towards the MCT-1.

(4) Quartzite and quartzose schist

Quartzite in the Midland zone is white to pale green in colour with massive appearance, consisting mainly of quartz with or without plagioclase and muscovite.

Quartzite in the MCTzone is more or less schistose and intercalates thin micaceous layers (PL. II-4). In the neighbourhood of the MCT−1, the rock shows phyllonitic appearance. It is composed mainly of quartz, muscovite, calcite and with or without minor biotite, plagioclase and opaque minerals. Usually, the

* $\Delta = 12.5\ (d_{131} - d_{1\bar{3}1})$

rock includes considerable calcite and grades into calcareous quartzite, quartzose limestone and limestone.

5) Calcareous schist

It is white in colour and intercalates thin micaceous layers. The rock is composed of calcite, quartz, muscovite, graphite and with or without plagioclase, biotite, apatite and tourmaline. Calcareous schist in the Modi Khola near the MCT-1 has augen structures made up of coarse-grained aggregation of calcite (PL. Ⅱ-5).

6) Biotite schists

Pelitic to psammitic rocks of the Midland formations are converted to biotite schist, biotite-graphite schist and garnet-biotite schist in the MCT-zone, especially near the MCT-1, the rocks are highly recrystallized and foliated. These are composed of quartz, plagioclase, biotite, muscovite, garnet, graphite, apatite, sphene and tourmaline. Graphite biotite schist includes considerable calcite. Large garnet porphyroblasts have snow-ball structure remaining *si*-schistosity (PL. Ⅱ)

Himalayan gneiss zone

The Himalayan gneiss zone is bordered by the narrow thrust fault zone (MCT-1) from the MCT zone. The base of the Himalayan gneiss is phyllonitized and large augen structures are well developed along the MCT-1. The zone is made up of augen gneiss-2 (Himalayan augen gneiss), kyanite-garnet-biotite gneiss, biotite gneiss, alternation of biotite, hornblende and clinopyroxene gneisses (calcareous gneiss) and tourmaline-bearing two-mica gneiss (migmatitic gneiss), in the ascending order from south to north. Northern part of the zone is fairly migmatized by the emplacement of tourmaline granite.

1) Augen gneiss–2 (Himalyan augen gneiss)

The rock is characterized by lenticular quartz-feldspathic aggregation (PL. Ⅲ-1) and phyllonitic appearance. The rock is composed of quartz, plagioclase, biotite, muscovite, kyanite, garnet and minor amounts of opaque minerals, tourmaline, apatite and sphene. Biotite is pleochroic with Z′= greenish brown, X′= pale yellw. Constituent minerals in the Himalayan augen gneiss are very coarse-grained; kyanite reaches up to the maximum 10 cm and garnet, 3～4 cm in diameter. Augen units show irregular pools, veinlets and/or lenticular forms with a maximum size of 30 cm and are made up of very coarse-grained quartz and plagioclase, occasionally including biotite, muscovite, garnet and kyanite without potash-feldspar (PL. Ⅲ-2, Ⅲ-3).

Kyanite and micas are fairly strained. Mineral constituents of the augen gneiss-2 are almost same as the other pelitic gneisses in this zone, except their large grain size.

2) Biotite gneisses

The southern part of the Himalayan gneiss zone is mainly made up of alternation of thin pelitic gneiss and thick psammitic gneiss with quartzose gneiss (PL. Ⅲ-4).

Pelitic gneiss has phyllitic appearance consisting of plagioclase, quartz, biotite muscovite, garnet, ± kyanite and minor opaque minerals, tourmaline and apatite without potash-feldspar. Biotite is pleochroic with brown～greenish brown to pale yellow.

Psammitic gneiss has massive and leucocratic appearance and is composed of plagioclase, quartz, biotite, muscovite and minor garnet, tourmaline and apatite.

Quartzose gneiss is leucocratic and banded rock composed of quartz, potash-feldspar, muscovite, green biotite and plagioclase. The rocks in Modi Khola include considerable amounts of potash-feldspar with microcline structure : the Δ-value $=0.96$.

3) Alternation of biotite, hornblende and clinopyroxene gneisses

The upper part of the Himalayan gneiss zone is made up of frequent alternation of fine-grained biotite-rich layers, hornblende-rich layers and clinopyroxene-rich layers (PL. Ⅲ-5). The thickness of each layer is 1～3 cm and these are very well stratified, rarely intercalating thin beds or lenses of limestone. Part of them is injected by irregular veinlets of coarse-grained clinopyroxene-bearing granitoids.

The rocks are composed of greenish brown biotite, green hornblende, colourless to pale green clinopyroxene (diopsidic), epidote - clinozoicite, quartz, plagioclase, calcite, scapolite, potash-feldspar with microcline structure, sphene and graphite. Hornblende and clinopyroxene are poikiloblastic crystalls and rarely show symplektic intergrowth with quartz. The rocks are invariably calcareous.

(4) Tourmaline-garnet two-mica gneiss

Near the Tibetan Tethys zone, the northern part of the Himalayan gneisses has migmatitic features. The rocks are medium- to coarse-grained, leucocratic and foliated, and partly show massive and granitic appearance. These are composed mainly of potash-feldspar, quartz, plagioclase, biotite, muscovite, tourmaline and garnet. The Δ-valus of potash-feldspars are 0.71～0.95 with subordinate peaks of $\Delta \doteqdot 0$.

(5) Augen gneiss-3 (Himalayan migmatitic augen gneiss)

The part of the tourmaline-garnet two-mica gneiss has augen structures made up of single crystal of potash-feldspar with 2～3 cm in diameter. The constituent minerals are almost same as in the (4). $\Delta = 0.86 \sim 0.95$ with subordinate peaks of $\Delta \doteqdot 0$.

Another kind of augen gneiss is found as big blocks from the branch of the Madi Khola near the MCT-1 (PL.Ⅲ-6). The outcrop is unknown, but the root seems to near the MCT-1. The rock has typical augen form with 1～20 cm in longitudinal axes, and is composed of potash-feldspar, quartz, plagioclase, dark brown biotite, muscovite and minor tourmaline, garnet, opaque minerals and apatite. Augen units are made up of large single crystals of potash-feldspar with tails consisting of fine-grained aggregation of potash-feldspar, quartz and plagioclase. Augens are surrounded by cataclastic matrix. Potash-feldspar has griddy microcline twinnings and Δ-values are 0.38～0.88. (PL.Ⅳ-1).

Tibetan Tethys zone

Tibetan Tethys sediments on the upper stream of the Modi Khola consist mainly of alternation of calcareous shale and sandstone with impure limestone (PL.Ⅳ-2). Near the border of the Himalayan gneiss zone, the rocks are thermally metamorphosed and converted to schistose hornfels. Veinlets injection and dykes of tourmaline-bearing granites are occasionally observed on the boulders or blocks falling down from the surrounding areas.

In the Kali Gandaki area, main constituents are thick muddy limestone (Dhaulagiri limestone) intercalating shale and sandstone. Lower part of them are also metamorphosed to calcareous schist with phologopitic layers, schistose hornfels and hornfels.

It is believed that the Tibetan Tethys sediments unconformably overlay the Himalayan gneisses. The metamorphic grade of the upper part of the Tethys zone is far lower than the Himalayan gneiss zone, however the unconformity is not clear, because of the concealed injection of younger granites near the boundaries.

Furthermore, lithological features of the Himalayan gneisses consisting mainly of alternation of pelitic and psammitic rocks with calcareous materials are similar to those of the Tibetan Tethys sediments and the Midland metasediments.

STRUCTURE

Four tectonic divisions, the Midland zone, the MCT zone, the Himalayan gneiss zone and the Tibetan Tethys zone, correspond to the lithologic units of the previous chapter. The MCT is considered not to be a single thrust but the tectonic zone sandwiched by the several thrusting faults. The MCT zone is

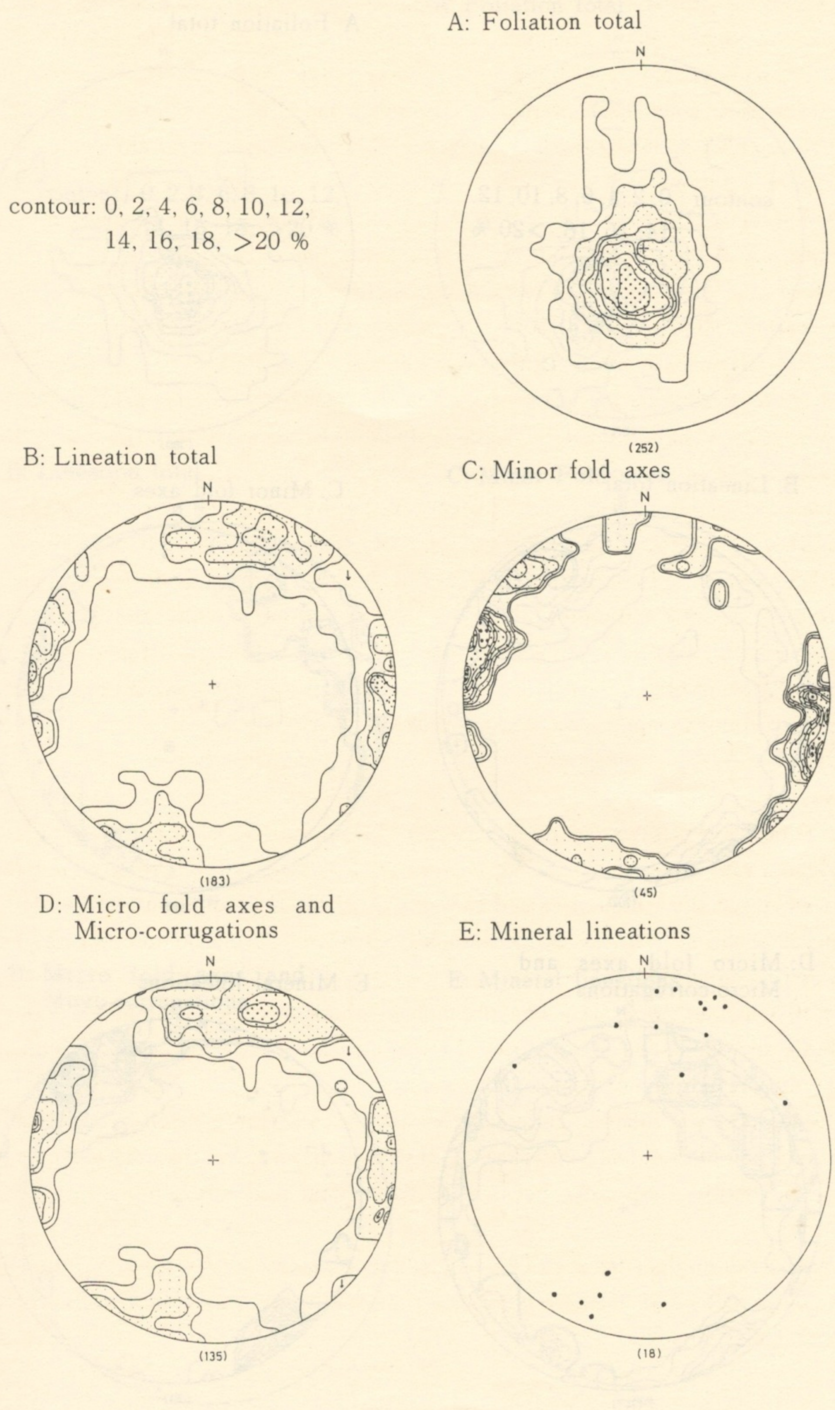

Fig.8 Foliation and lineation diagrams of the Midland zone.

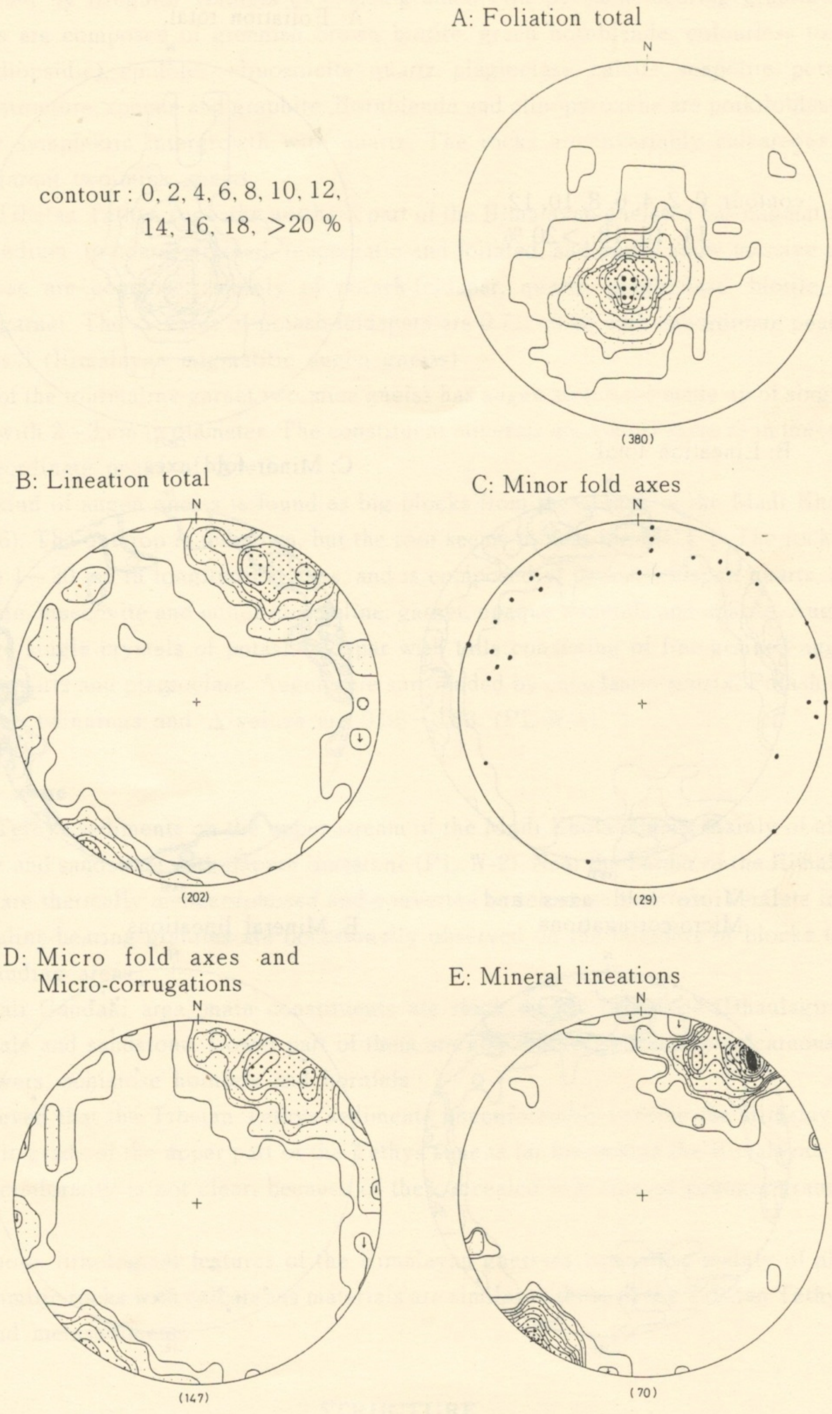

Fig.9 Foliation and lineation diagrams of the MCT zone.

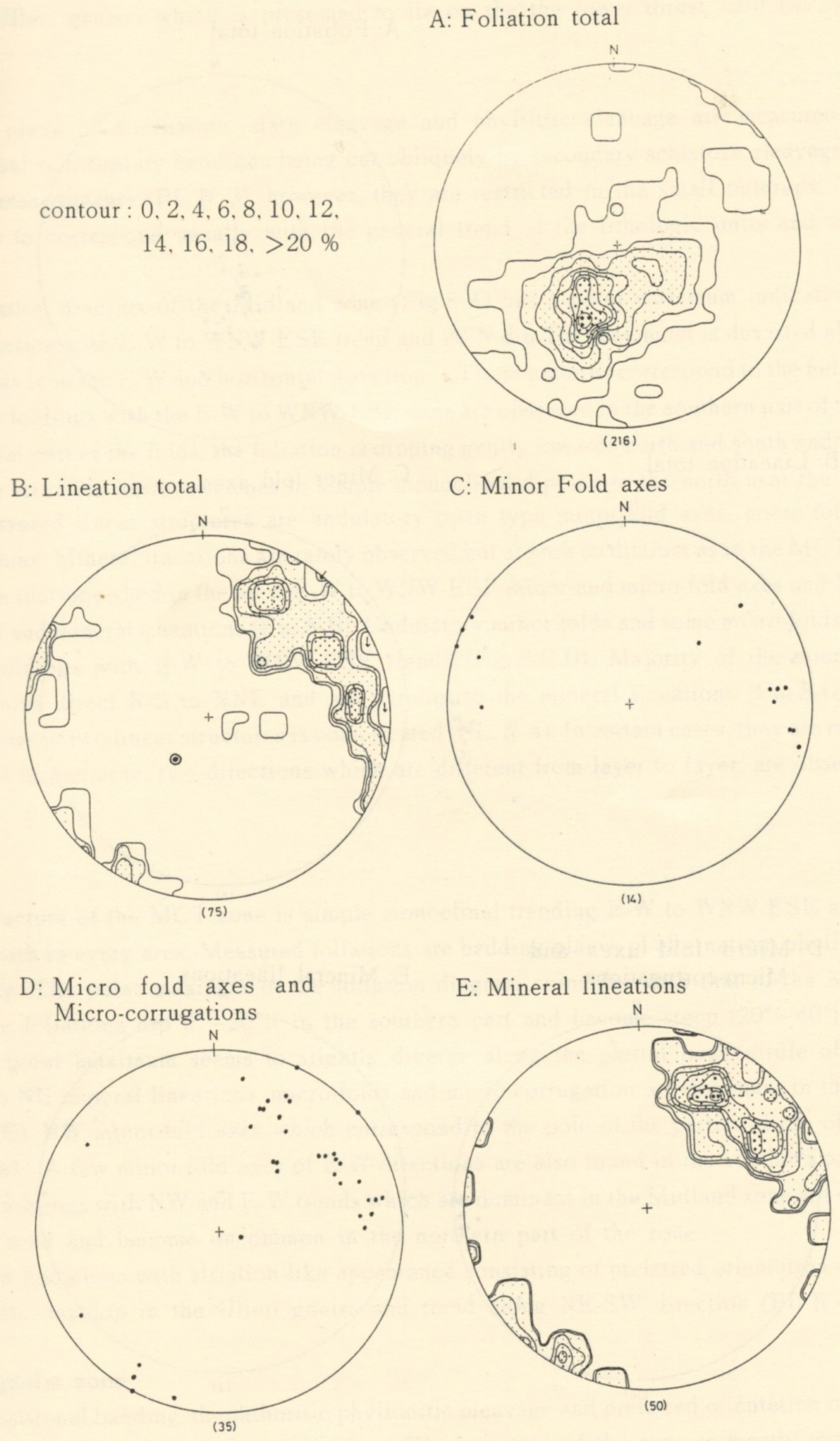

Fig.10 Foliation and lineation diagrams of the Himalayan gneiss zone.

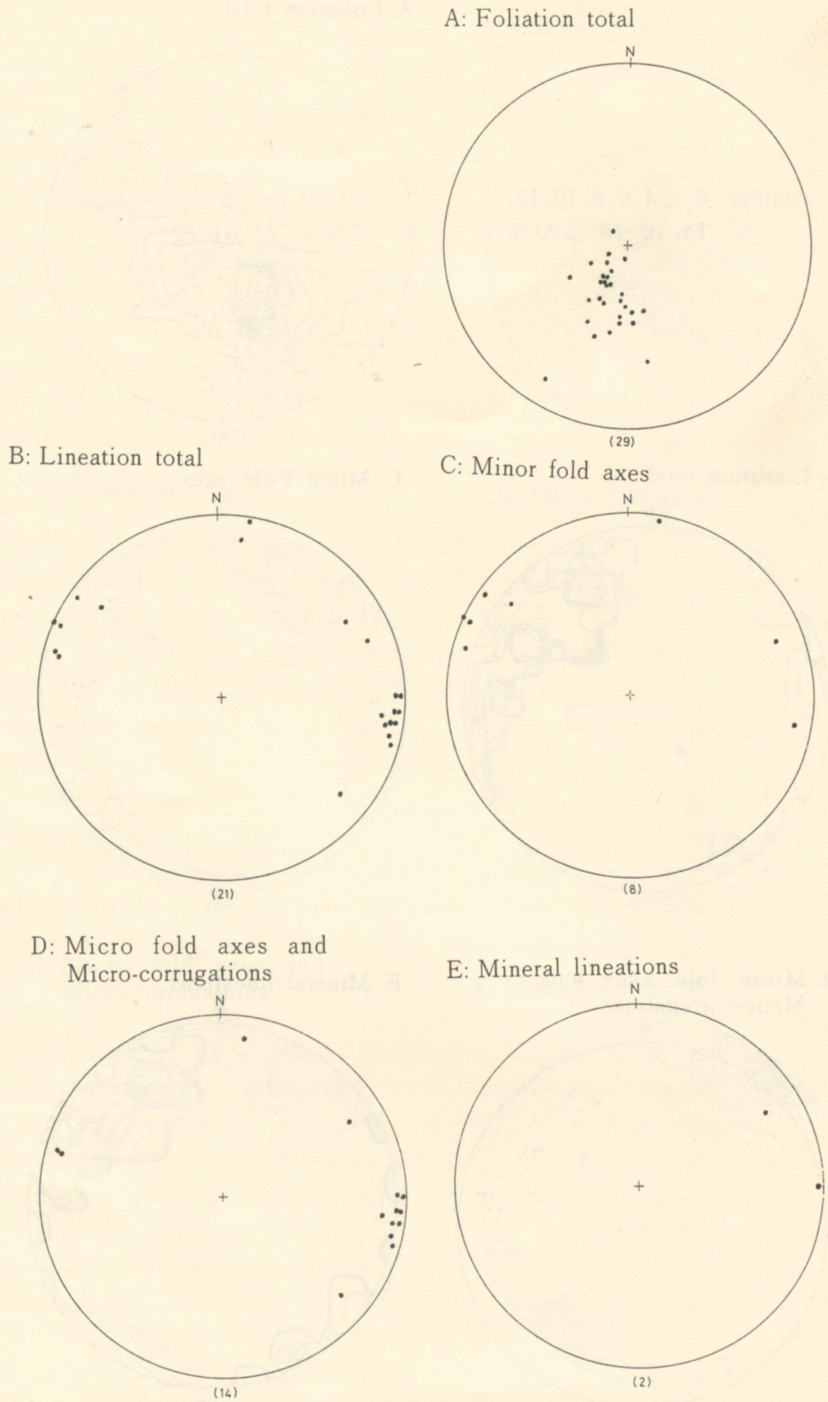

Fig.11 Foliation and lineation diagrams of the Tibetan Tethys zone.

defined by the upper major thrust (MCT-1) limiting the base of the Himalayan gneiss zone and the lower augen gneiss (Ulleri gneiss) which is presumed to lie on the the lower thrust fault (MCT-2).

Midland zone

Bedding plane of alternation, slaty cleavage and phyllittic cleavage are measured as planar structure. Original sedimentary beddings being cut obliquely by secondary schistose cleavage are rarely found in the metasediments (PL.Ⅳ-3), however, they are restricted in the small outcrops. The planar structures seem to correspond usually with the general trend of the lithologic units and sedimentary alternation.

The foliation diagram of the Midland zone (Fig.8-A) has a point maximum indicationg general monoclinal structure with E-W to WNW-ESE trend and 20°N dip.The maximum is deviated alnog a large girdle whose axis is in the E-W and horizontal direction. These patterns correspond to the field evidences that very gentle foldings with the E-W to WNW-ESE axes are observed in the southern part of the Midland zone. At the axial part of the folds, the foliation is dipping gently towards north and south and/or is nearly horizontal. The structure however comes to simple monoclinal dipping to the north near the MCT zone.

The measured linear structures are undulatory open type minor-fold axes, micro-fold axes and micro-corrugations. Mineral lineations are rarely observed but are not so distinct as in the MCT zone. Two major trends are distinguished in the area, E-W to WNW-ESE minor-and micro-fold axes and N-S to NNE micro-fold axes and mineral lineations (Fig.8-B). Undulatory minor-folds and some micro-folds correspond to the major foldings with E-W to WNW-ESE trends (Fig.8-C,D). Majority of the micro-folds and micro-corrugations direct N-S to NNE and are parallel to the mineral lineations (Fig.8-D,E). Mutual relationship between two linear structures is complicated (PL.Ⅳ 4). In certain cases, they are refolded with each other, and furthermore, two directions which are different from layer to layer, are observed in one outcrop.

MCT zone

The structure of the MCT zone is simple monoclinal trending E-W to WNW-ESE and generally dipping 20° north in every area. Measured foliations are bedding planes of alternation, phyllitic cleavage and schistosity. The point maximun in the foliation diagram coincides with that of the Midland zone (Fig.9-A). The foliations dip 0°～20°N in the southern part and become steep (20°～40°) towards the MCT-1. The point maximum seems to slightly diverge along the partial large girdle of NW axis.

NNE to NE mineral lineations, micro-folds and micro-corrugation are dominant in the MCT-zone (Fig.9-B,C,D,E). NW minor-fold axes which correspond to the pole of the partial girdle of Fig.9-A are rarely observed . A few minor-fold axes of E-W directions are also found in the southern part (Fig.9-C). However, the foldings with NW and E-W trends which are dominant in the Midland zone are not important in the MCT zone and become uncommon in the northern part of the zone.

Distinct lineations with striation-like appearance consisting of preferred orientation of biotite and muscovite clots develop in the Ulleri gneiss and trend along NE-SW direction (PL.Ⅳ-5,-6).

Himalayan gneiss zone

Compositional banding, diaphthoritic phyllonitic cleavage and preferred orientation of flaky biotite and muscovite are measured as planar structure. The structure of the zone is mostly monoclinal with WNW-ESE strike and 30°～40° dip to the north. The foliation diagram (Fig.10-A) has a maximum indicating the general trend, however, the maximum is dispersed along the partial large girdle whose axis lies in the NW to WNW direction, and furthermore, it seems to be slightly deviated by the small rotation of

EW axis. Both are corresponding with the fold axes of WNW and EW trends respectively.

Preferred orientation of mafic minerals, minor- and micro-fold axes and striation-like micro-corrugation are measured (Fig.10-B,C,D,E). The mineral lineation, micro-fold axes and micro-corrugation show the trend of NNE to ENE which are predominant in the zone, however, the minor-folds with E-W to WNW directions (Fig.10-C) are not so distinct.

The lineation diagram of the zone (Fig.10-B) has several maxima dispersing along the partial large girdle, whose pole is projected on the Fig.10-B sympbol ⊙. It seems to suggest the superposition of the later upward movement, whose direction is nearly perpendicular to the general foliation. Linear structures in the Seti Khola ~ Madi Khola ~ Rudi Khola region usually trend NE to NNE, and in the Modi Khola ~ Kali Gandaki region ENE to EW directions are dominant. It is estimated that the movement with nearly vertical direction ranges in the wave-length of 30 km or more.

Tibetan Tethys zone

Alternation of bedding plane, slaty cleavage and schistosity are measured as planar structure in the zone. The structure in the Kali Gandaki and Modi Khola regions is almost monoclinal dipping gently northwards or partly horizontal. The pattern of foliation diagram is similar to that of the Midland zone (Fig.11-A, 8-A). Projection of foliation is deviated along the partial girdle of E-W axis which corresponds to the major fold axes with E-W trend.

Though, there is not enough measurements, the lineation diagram of the zone (Fig.11-B) seems to resemble to that of the Himalayan gneiss zone (Fig.10-B), where the superposition of the later vertical movement is suggested.

Large-scale recumbent folds are well seen on the large faces of the higher part of Mts. Tukuche Peak and Machhapuchhare; their style suggests a kind of slump fold (PL.Ⅳ-7).

Tectonic history

Tectonic history of this area will be summarized as follows;

(1) Stage-I

Two sets of folds and lineations are recognized as the Stage-I deformation over the whole area of the Midland zone, the MCT zone, the Himalayan gneiss zone and the Tibetan Tethys zone; the E-W major- and minor-folds (FI-fold) and the N-S micro-folds (FI2-fold). Undulatory open-type minor-folds with E-W axes are co-axial to to the major gentle folds in the area and also to the micro-folds and micro-corrugations (FI=LI).

Micro-folds with N-S to NNE-SSW trends are also frequently observed in the area and are parallel to the micro-corrugations and mineral lineations (FI2=LI2). The FI1-folds and the LI1-lineations seem to become nearly invisible in the MCT zone, whereas the later movements with NS directions are concentrated.

(2) Stage-Ⅱ

Mineral lineations , micro-corrugations and micro-folds with N-S to NNE-SSW trends which are well developed in the MCT zone and the Himalayan gneiss zone are assumed to be the Stage-Ⅱ deformation (LII1=FII1). These linear structures become predominant toward the MCT. Distinct mineral lineations and micro-corrugations with striation-like forms are commonly observed in the MCT zone and in the diaphtholitic Himalayan gneisses near the MCT-1. These phenomena suggest that the Stage-Ⅱ deformation is comparable with the southward movement of the MCT.

The folds and lineations of Stage-Ⅱ are overprinted to the pre-existing N-S folds and lineations of Stage-I and the E-W folds of Stage-I(FI1) seem to be almost erased out by the superposition of Stage-Ⅱ deformation. N-S mineral lineations well developed around the MCT mostly disappear in the Tibetan Tethys zone where the metamorphism and movement become insignificant.

It may be assumed that NW to WNW-ESE folds (FII2) rarely observed in the MCT zone, in the Himalayan gneiss zone and in the Tethys zone are the b-tectonic axis intersecting the movement axis of NNE-SSW direction.

(3) Stage-Ⅲ

Partial girdle pattern of the lineation diagrams of the Himalayan gneiss zone (Fig.10-B) and probably of the Tibetan Tethys zone (Fig.11-B) suggest the superposition of the latest movements of nearly vertical direction. The movement ranges in the wave-length of 30 km or more and it seems to be comparable to the uplifting of the Higer Himalayas in the later history.

GEOLOGICAL SITUATION OF THE AUGEN GENEISSES

Three rock-types of augen gneisses are distinguished in the area; the Himalayan augen gneiss, the Himalayan migmatitic augen gneiss and the Ulleri augen gneiss.

The Himalayan augen gneiss, the base of the Himalayan gneisses, occurs continuously along the MCT-1. The rock is closely associated with kyanite-garnet-biotite gneiss and has phyllonitic appearance. The augens are made up of aggregations of quartz and plagioclase without potash-feldspar. The mineral composition of the Himalayan augen gneiss is quite similar to that of the common Himalayan gneisses with pelitic to psammitic compositions except their large grain size. These facts mostly suggest the recrystallization during the metamorphism and movement of the MCT without notable migration of materials.

The Himalayan migmatitic augen gneiss is associated with tourmaline-bearing two-mica gneiss. The augens are made up of microcline porphyroblast and the mineral composition of rocks is same as of the tourmaline-bearing two-mica gneiss. The augen gneiss found as rolling blocks near the MCT-1 has typical augen structure made up of large microcline porphyroblast and similar mineral compositions. Although, the exact relations are still unknown, origin of these rocks seems to be related to the activities of tourmaline granites near the MCT.

The origin of the Ulleri augen gneiss is rather mysterious.

It occurs along the boundary between the MCT zone and the Midland zone (MCT-2), however, the occurrence is not so completely continuous as the Himalayan augen gneiss. The rock has mylonitic texture with euhedral to augen potash-feldspars and albite. The metamorphic grade of the surrounding rocks is lower than the Himalayan gneiss and no granitic rocks are observed except veinlets of tourmaline-bearing pegmatoids.

Pêcher and Le Fort (1977) claim the volcano-sedimentary origin of the Ulleri gneiss. The gneiss seems to occupy a certain litho-stratigraphic position, however the original volcano-sedimentary rocks can not be found from the same horizon where the augens are not developed. Acidic volcanism is unknown around the Nepal Himalayas; however small amounts of basic rocks, e.g. amophibolite etc are not uncommon. Most of rocks have originated from the normal clastic sediments. The Himalayas are poor in volcanism all through their geotectonic histories. The bulk chemical composition of the metamorphic rocks does not indicate any exact origin but only the result of the metamorphism.

The Ulleri gneiss is composed mainly of potash-feldspar, quartz, plagioclase, muscovite, biotite and minor garnet. Mineral assemblage is similar to that of the surrounding pelitic to psammitic rocks. These lithological similarities are the part of the "volcano-sedimentary origin" theory, such as ① litho-stratigraphic control, ② tectonic and metamorphic characteristics similar to those of the surrounding rocks, ③ intercalation of schists and quartzites equivalent to the surrounding rocks and ④ occurrence of bluish rounded quartz, which rather support the origin from the normal sediments.

In any cases, the origin of the augen gneisses in the Himalayas is closely related to the movements of the MCT, and the formation is considered to be comparable to the Stage-II deformation in the area. Deformations of the minerals and mylonitic appearances of the rocks suggest the recrystallization under the shearing movoment. Certain types of the augen gneisses seem to be genetically related to the activity of the tourmaline granite of the younger age.

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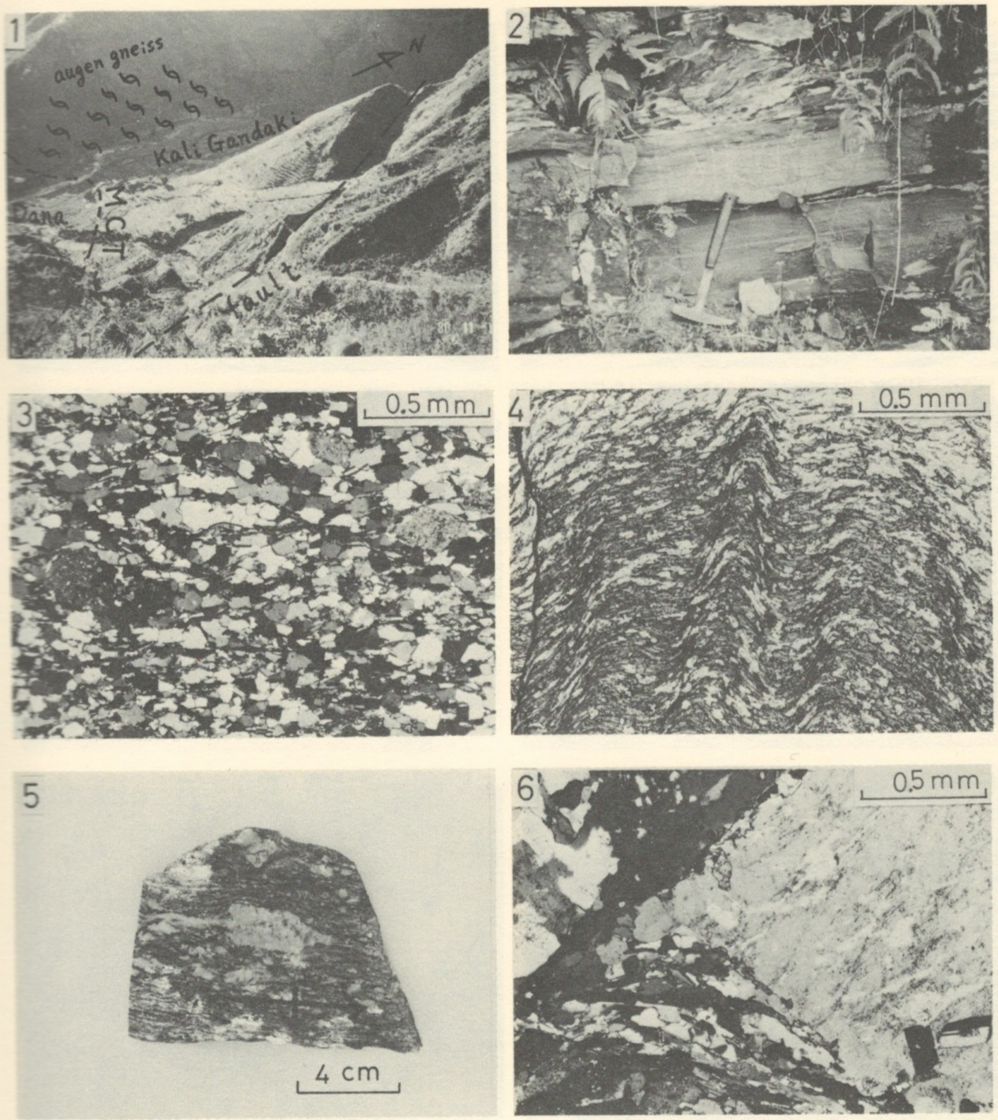

Plate I (PL. I) **1** Topographical view of the MCT-1 near Dana, Kali Gandaki. **2** Alternation of thick meta-sandstone and thin phyllite. Loc. upper stream of the branch of Begnas Tal, near Pokhara (No. 80110501). **3** Photomicrograph of metasandstone. (crossed nicols). Loc. Midland zone, Kali Gandaki (No. 80112903). **4** Photomicrograph of black phyllite with distinct micro-foldings, cut perpendicular to the axes (open nicol). Loc. Midland zone, near the junction of Kali Gandaki and Thulo Khola (No. 80112301). **5** Ulleri-type augen gneiss. Loc. Ghandrung, Modi Khola (No.80120801-5′). **6** Photomicrograph of Ulleri-type augen gneiss. Euhedral potash-feldspar with micro-perthitic texture is surrounded by fine-grained matrix making tail (crossed nicols). Loc. Ditto (No. 80120801-2).

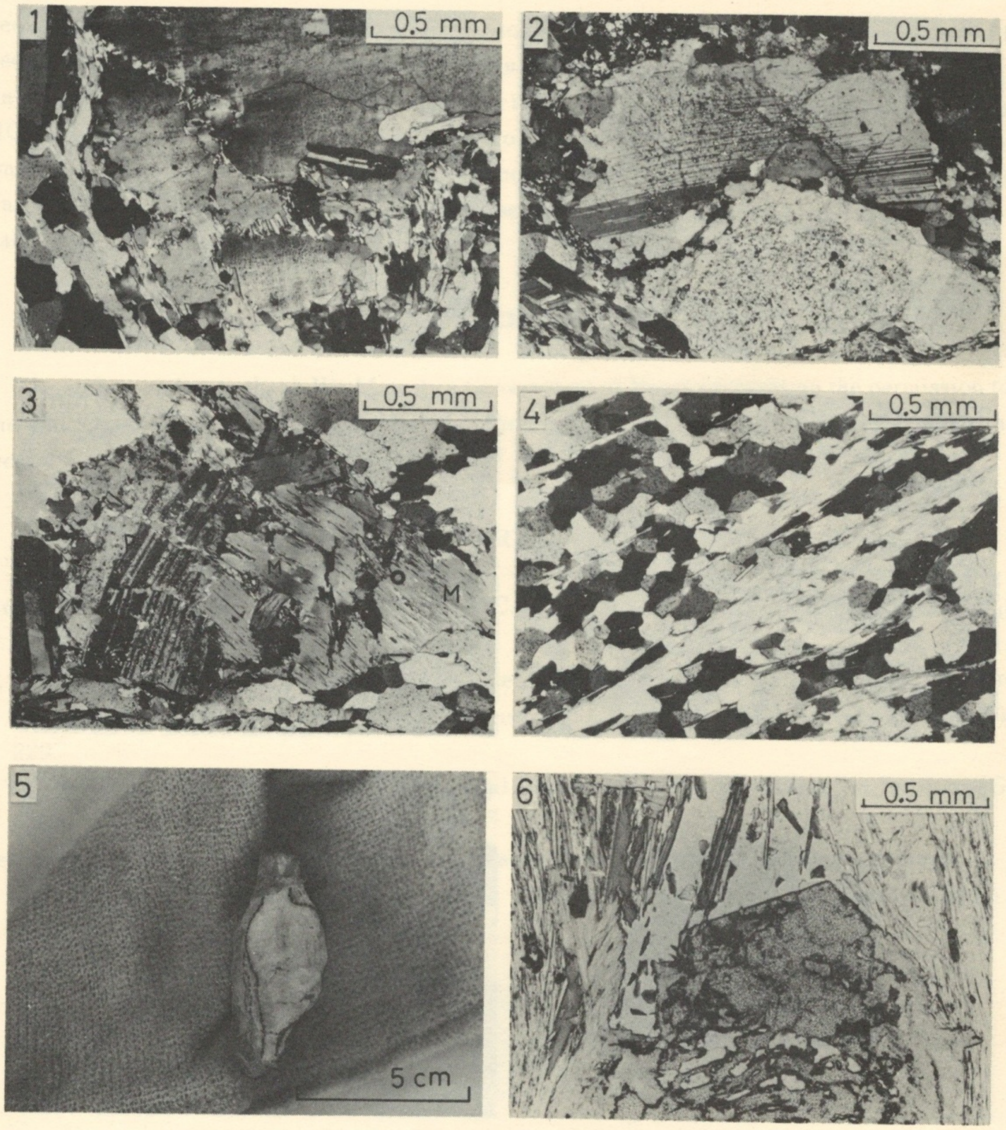

Plate Ⅱ (PL. Ⅱ) **1** Photomicrograph of Ulleri-type augen gneiss. Fractured potash-feldspar (crossed nicols). Loc. Ditto (No. 80120801-1). **2** Ditto. Deformed and zoned plagioclase. Dusty core is rimmed by clear mantle and trace of twinning plane is bended on the core–rim boundary (crossed nicols). Loc. Ulleri (No. 80111005-4). **3** Ditto. Fractured plagioclase (P) and muscovite(M). Cracks are filled by fine-grained quartz, feldspars and undeformed micas (crossed nicols). Loc. Ulleri (No. 80111006). **4** Photomicrograph of phyllitic quartzite intercalated with the Ulleri-type augen gneiss (crossed nicols). Loc. Ulleri (No. 80111105-1). **5** Augen structure in calcareous schist. Augen unit is made up of coarse-grained calcite. Loc. Ghandrung, Modi Khola (No. 80120703T). **6** Photomicrograph of garnet-biotite schist. Euhedral garnet has helicitic structure (open nicol). Loc. Upper stream of Mardi Khola, near the MCT-1 (No. 80121201).

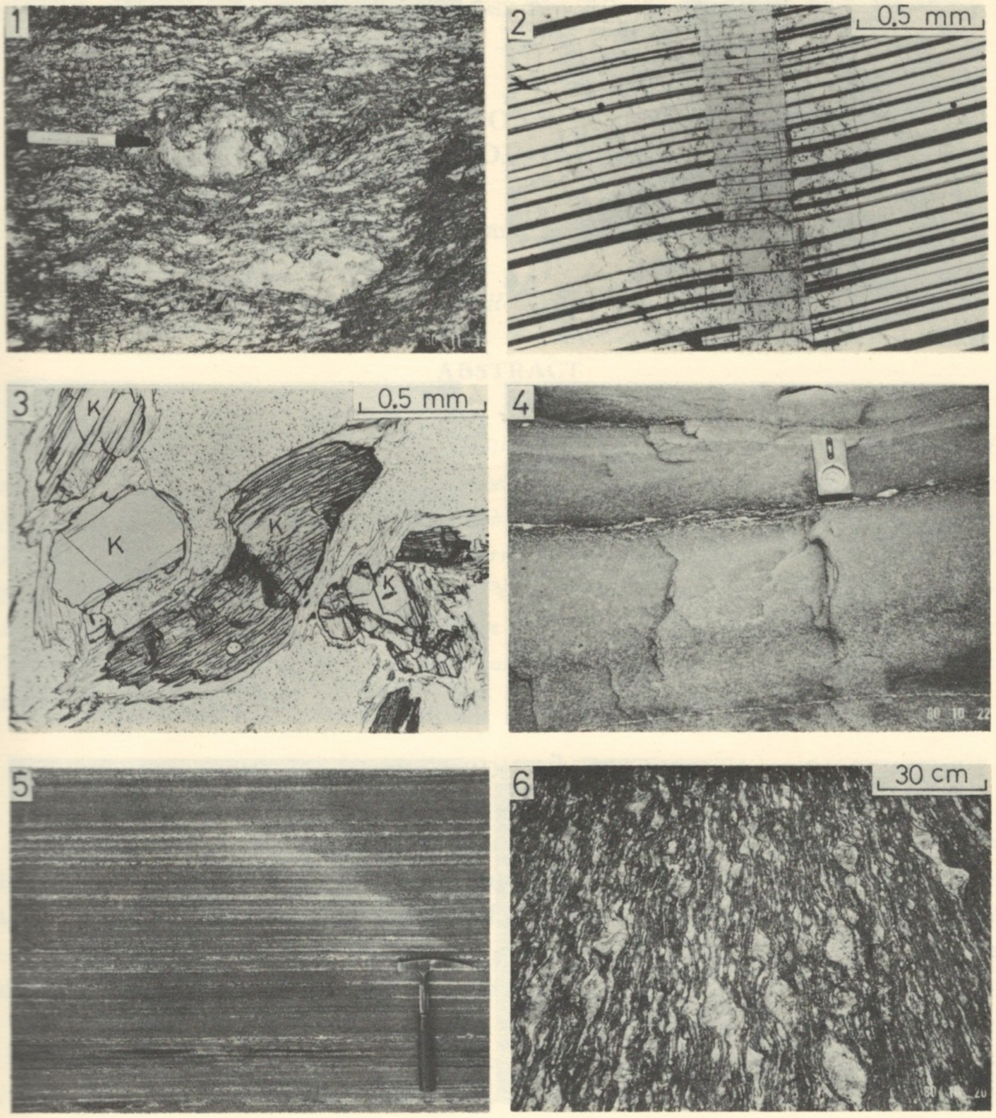

Plate Ⅲ (PL. Ⅲ) 1 Himalayan augen gneiss. Loc. Dana, Kali Gandaki (No. 80111306-1). 2 Photomicrograph of coarse-grained plagioclase in augen unit of the Himalayan augen gneiss (crossed nicols). Loc. Ditto (No. 80111306). 3 Photomicrograph of deformed kyanite(K) in the Himalayan augen gneiss. Kyanite is rimmed by muscovite (open nicol). Loc. Ditto (No. 80111307). 4 Alternation of thick psammitic gneiss and thin pelitic gneiss in the Himalayan gneiss zone. Loc. Upper stream of Madi Khola (No. 801022). 5 Well stratified calcareous Himalayan gneiss made up of thin beds of fine-grained biotite gneiss, hornblende gneiss and clinopyroxene gneiss. Loc. Upper stream of Modi Khola (No. 801204d). 6 Himalayan migmatitic augen gneiss (rolling block). Loc. Taplang, Madi khola, near the MCT-1 (No. 80102009T).

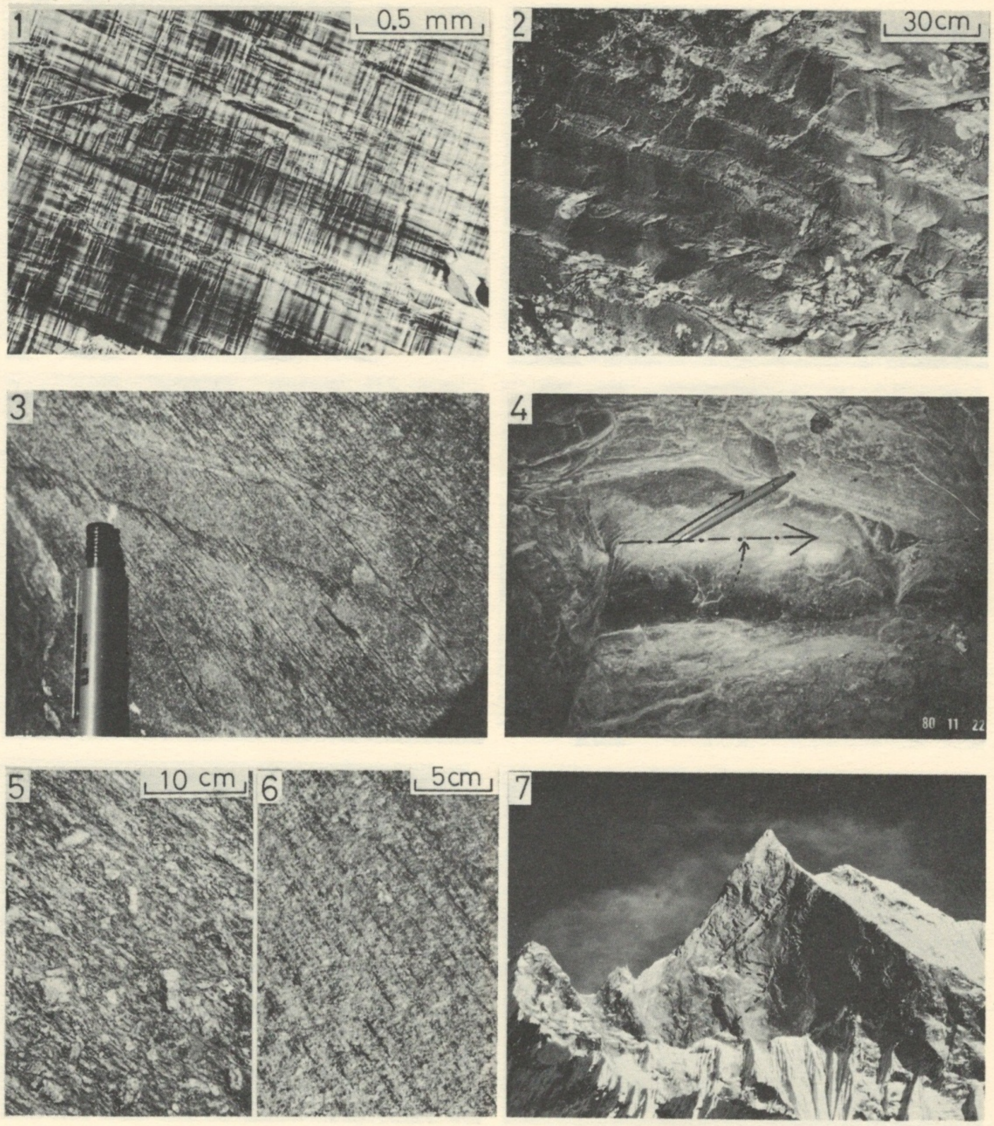

Plate Ⅳ (PL. Ⅳ) **1** Photomicrograph of potash-feldspar showing clear griddy microcline structure in the Himalayan migmatitic augen gneiss (crossed nicols). Loc. Ditto (No. 80102009TA). **2** Alternation of calcareous shale and sandstone in the Tibetan Tethys sediments. Loc. Upper stream of Modi Khola (No. 801205). **3** Schistose cleavage cutting obliquely the bedding plane. Loc. MCT-zone, Thulo Khola (No. 80112701). **4** Oblique relation among E-W undulatory fold axis (—·—·→), ENE micro-fold axis (—→) and N-S micro-fold axis or micro-corrugation (······→). Loc. Junction of Kali Gandaki and Bega Khola, Midland zone (No. 801122). **5** Foliation plane of Ulleri-type augen gneiss. Potash-feldspar megacrysts show rather random orientation to the striation-like lineation. Loc. Ulleri (No. 801111a). **6** Mineral lineation with striation-like form in the Ulleri-type augen gneiss. Loc. Ghandrung, Modi Khola (No. 801208). **7** Large scale recumbent folding with slump-type form (?) in the Tibetan Tethys sediments seen at the north-western face of Mt. Machhapuchhare. (Photographed from the upper stream of Modi Khola)