Journal of Nepal Geological Society, vol.2, Special Issue, 1982, 5−29

GEOLOGY AND STRUCTURE OF THE POKHARA-PIUTHAN AREA, CENTRAL NEPAL

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ABSTRACT

The geological mapping of the present area revealed that the area is a transitional area between central and western Nepal. The Kali Gandaki – Bari Gad fault which runs obliquely to the general Himalayan trend separates the present area lithostrato-tectonically into the northeast and soutewest units. Both units are in contrast each other in many respects. The northeast unit comprises the Tibetan Tethys,Himalayan gneiss, Main Central Thrust, Baglung and Bihadi zones. The last two are composed of the Midland meta-sediment Group of Riphean to Eocambrian age and autochthonous in character. The Himalayan gneisses are thrust over the Midland meta-sediments by the Main Central Thrust zone forming a klippe in the southwest unit. On the other hand the southwest unit consists mainly of slightly metamorphosed sediments probably of Paleozoic age which are folded and faulted as compared to those of the northeast unit. The metamorphic grade of the latter is obviously higher than the former.

The present area, particularly the Kali Gandaki - Bari Gad fault is of exteme significance in considering the tectonic flame of the Nepal Himalayas.

INTRODUCTION

The Nepal Himalayas are both topographically and geologically divided mainly into five strips in parallel to the main Himalayan trend: from south to north the Siwalik zone, the Mahabharat zone, the Midland zone, the Himalayan gneiss zone (Higher Himalayas) and the Tibetan Tethys zone. The Mahabharat and Midland zones are sometimes named the Lower Himalayas or the Lesser Himalayas in the lump.

Among them the Mahabharat Lekh * which as well as the Siwalik Range is a vangard range of the Himalayas, is distinct in eastern and central Nepal but not so in western Nepal. In addition as visualized from a summit level map around Nepal (Hashimoto *et al.*, 1972, Fig. 2) a straight arrangement of the Higher Himalayas, comprising Sagarmatha (Jolmo Lungma), Ganesh Himal **, Manaslu Himal, Annapurna Himal and Dhaulagiri Himal in eastern and central Nepal, plunges down to the west of the Dhaulagiri Himal although its remnant is appreciable farther westward as the Chakhure Lekh south of Jumla. And northeast of Jumla another alignment of high mountains begins again from Kanjiroba Himal to Nanda Devi in Kumaun through Saipal and Api in western Nepal. Hashimoto *et al.*, (1973) classified topographically it into the Kumaun Himalayas. Western Nepal is geologically featured by the prevalence of crystalline

* "Lekh" means a range in Nepali.

** "Himal" means a range covered with snow and ice in Nepali.

klippes (Ando *et al.* in Hashimoto *et al.*, 1973; Arita et al., 1982), while no crystalline klippe without the Arkha crystalline klippe is found in the present area and its eastern adjacent area in central Nepal. Hence, the present area is situated in the transitional zone between eastern to central Nepal and western Nepal.

The present authors carried out the geological mapping in central Nepal between the Modi Khola * in the east and the Lungri Khola in the west from November in 1979 to January in 1980 as a geological work of the Project "Studies on the Crustal Movement in the Nepal Himalayas" led by Prof. K. Kizaki (Fig 1). The stratigraphy and structure of the area will be presented in this paper.

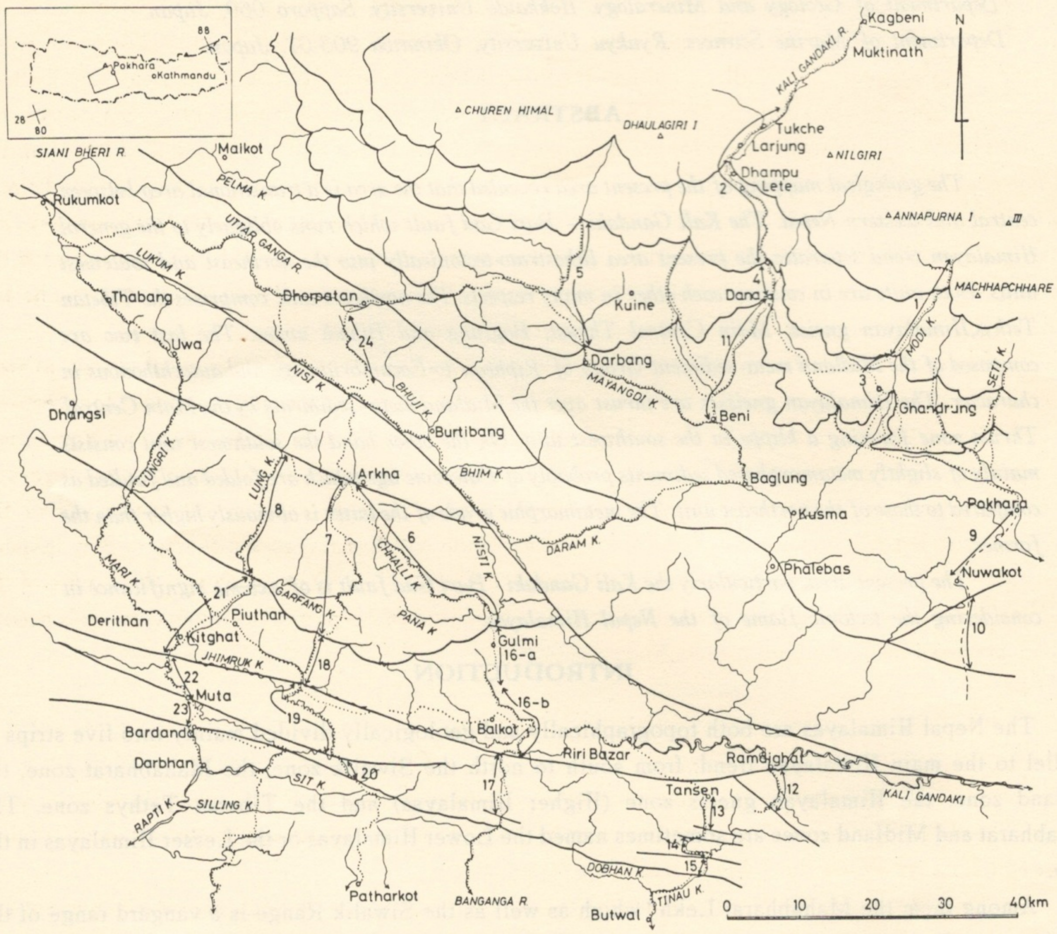

Fig.1 Location, mapped routes and localities of lithostratigraphic columnar sections in Figs. 4, 5 and 6. Dotted lines and thick lines represent mapped routes and boundaries of lithostrato-tectonic zones, respectively. Routes mapped by Kano (1980) are also included. The route numbers of the map correspond to column numbers in Figs. 4, 5 and 6.

PREVIOUS WORKS

In spite of various geological investigations published recently (Gansser,1964 ; Hagen, 1969; Fuchs and Frank,1970 ; Bordet *et al.*,1971; Hashimoto *et al.*, 1973), the Nepal Himalayas, especially its Lower

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* "Khola" means a river in Nepali.

Himalayas, are geologically still little understood.

The earliest comprehensive reference to the present area is from Hagen (1969) who has presumed a number of large scale nappe structures in the present area as well as other parts of the Nepal Himalayas. According to him the parautochthonous Pokhara window together with the Piuthan zone in the area, both being the lowest tectonic units found in Nepal, are overlain by the Nawakot nappes which are further covered by the Kathmandu nappes. As clearly stated by Gansser (1964), however, Hagen's structural subdivision on the basis of nappe unit is difficult to follow and his stratigraphical interpretations are questionable.

Sako *et al.* (1968; in Hashimoto *et al.*, 1973) carried out a geological survey in the same area as the present study in 1965. They are of the opinion that the present area is geologically divided into four major zones (the Tethys Himalayan, Midland meta-sediment, Mahabharat and Siwalik zones) and the Midland meta-sediment zone is exclusively occupied by the Midland meta-sediment Group which is composed of the lower arenaceous, middle argillo-arenaceous and upper calc-argillaceous Subgroups and is of Precambrian age. They stressed the tectonic significance of the Dhorpatan zone which is, according to them,an important tectonic zone separating the Lower Himalayas of central Nepal into two: the Buri Gandaki-Kali Gandaki area in the east and the Kali Gandaki-Bheri Khola area in the west. In addition they regarded the Arkha crystalline schist zone, which had been considered to be a nappe by Hagen (1969) and Fuchs and Frank (1970), as to be an autochthonous synclinorium having a deep root.

Fuchs and Frank (1970) published the results of their regional geological investigations in west Nepal including the present area with excellent geological maps. In their paper they proposed four tectonic units apart from the Tibetan zone and Siwaliks: the Tansing Unit, the Rukum Nappe, the Chail Nappes and the Crystalline Nappes. Taking the identities of Nepal and the NW-Himalayas in the rock sequences as well as the main structural units into account, they correlated the unfossiliferous formations in the Nepalese Lower Himalayas with those of Paleozoic age in the NW-Himalayas. Furthermore they insisted on that there can be no doubt about the equivalence of the Krols of the Outer zone and the Shalis of the Inner zone of the Lower Himalayas. The Shalis can be correlative with a part of the upper calc-argillaceous Midland meta-sediment Subgroup mentioned above.

GENERAL GEOLOGY

The general structural trend of the present area is almost parallel to the main Himalayan trend striking N70-80°W. Thirteen lithostrato-tectonic zones, delineated by thrusts and faults, are recognized in the present area as shown in Table 1 and Fig. 2.

The Siwaliks in the southernmost part, trending west-northwest to west, are thrust over by the sediments of the Tansen and Bardanda zones on the north. The Tansen and Bardanda zones are lithologically the equivalence and consist of the younger sediments, while the Derithan and Piuthan zones are composed of Paleozoic sediments. Accordingly the Muta fault is more significant tectonically than the Jhimruk fault although its eastern extension is unknown. The Arkha crystalline zone is an allochthonous component in the Midlands derived from Main Central Thrust zone to the north and is thrust over the Piuthan zone. The zone is sharply demarcated by the Bihadi zone and its northwestern extension (Dhorpatan zone) on the north, the trends of which are clearly oblique to the main structural trend of the present area. The Bihadi zone is called the Kekmi-Bandipur zone on the east (Hashimoto *et al.*, 1973). The southern boundaries of the Dhorpatan and Bihadi zones are distinctly marked by the Bari Gad fault which continues far eastwards along the Kali Gandaki (Hashimoto *et al.*, 1973). In contrast to this the northern boundary of these zones is relatively vague due to the lack of our own data although the northwestern

Table 1 Correlation of topographic and geologic divisions of central Nepal between the Modi Khola and the Lungri Khola.

Topographic unit		Geologic unit	Boundary
Higher Himalayas		Tibetan Tethys Zone	
			No tectonic contact
		Himalayan Gneiss Zone	
			Main Central Thrust II
Lower (or Lesser) Himalayans	Midlands	Main Central Thrust Zone (Rukum Zone)	
			Main Central Thrust I
		Baglung Zone (Dhorpatan Zone)	
			Phalebas Thrust
		Bihadi Zone	
			Kali Gandaki-Bari Gad Fault
		Arkha Crystalline Zone	
			Gulmi Thrust
		Piuthan Zone	
			Jhimruk Fault
	Mahabharat Lekh	Derithan Zone	
			Muta Fault
		Tansen Zone	
		Bardanda Zone	
			Main Boundary Fault
Outer Himalayas		Siwalik Zone	

Fig.2 Geologic division of central Nepal between the Modi Khola and Lungri Khola.

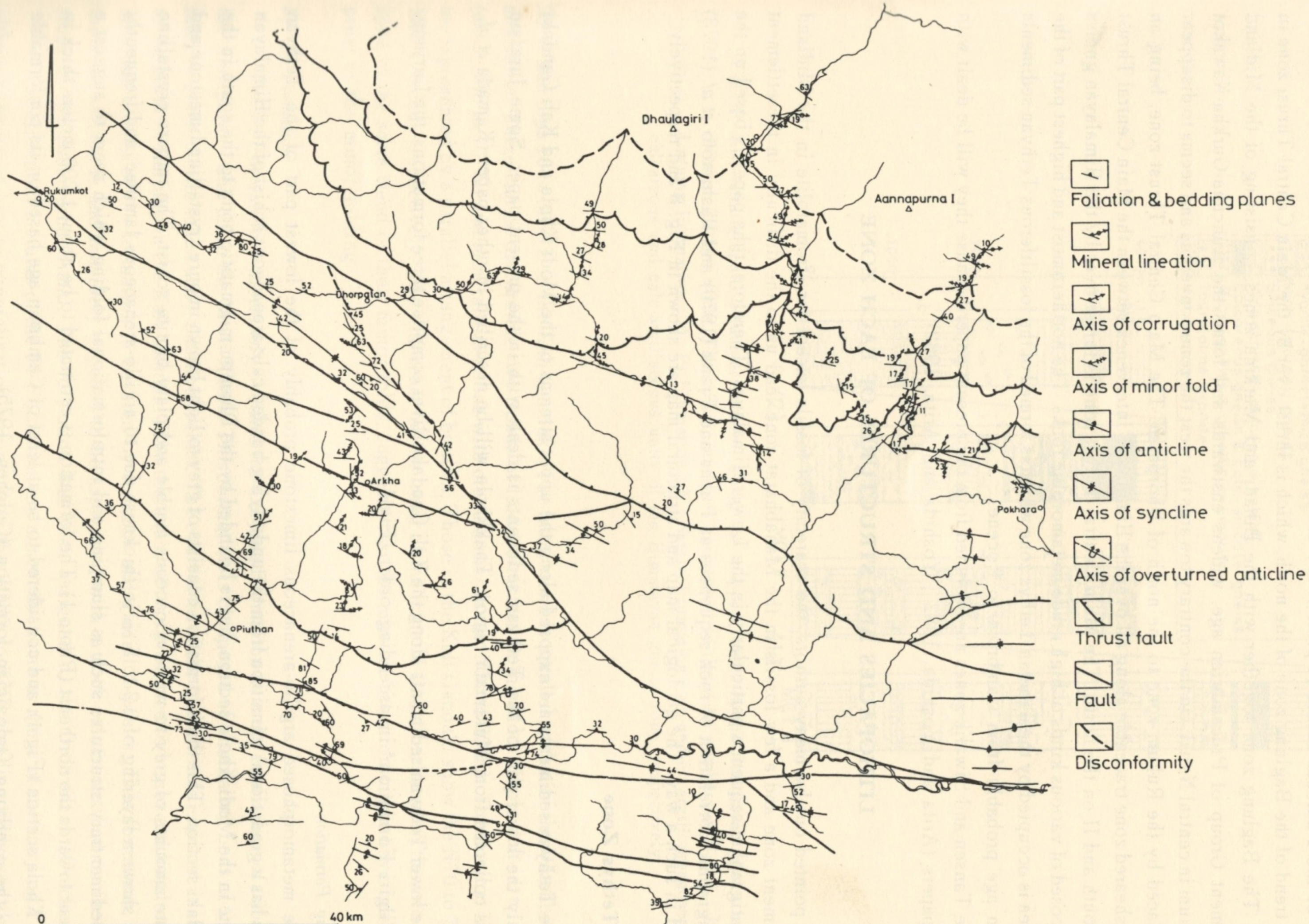

Fig.3 Structural map of central Nepal between the Modi Khola and the Lungri Khola.

extension of the Phalebas thrust (Upreti *et al.*, 1981) is likely to mark it. The thrust cuts across the structural trend of the Baglung zone of the north, which is thrust over by the Main Central Thrust zone in the north. The Baglung zone together with the Bihadi and Markina zones, consisting of the Midland meta-sediment Group of Precambrian age, widens eastwards and forms the Kunchha-Gurkha-Nawakot anticlinorium in central Nepal. On the contrary towards the west the zone converges and seems to disappear to be replaced by the Rukum zone to the north of Dhorpatan. The Main Central Thrust zone, being an intensive sheared zone traceable along all over the Himalayas, intervenes between the Main Central Thrust I on the south and II on the north. The Main Central Thrust zone is thrust over by the Himalayan gneiss zone composed of various kinds of high grade metamorphic rocks. The northernmost and highest part of the present area is occupied by the Tibetan Tethys zone which is formed of the fossiliferous Tethyan sediments ranging in age probably from Cambrian to Eocene.

The Tansen and Siwalik zones are excluded from the present paper because they will be dealt with in other papers (Arita and Yoshida, 1982 ; Yoshida and Arita, 1982).

LITHOFACIES AND STRUCTURES OF EACH ZONE

As pointed out by many authors, the scarecity of fossils except for stromatolite in the Midland meta-sediment zone and a few fossils in the Mahabharat zone lead us to the difficulty in thesettlement of the stratigraphic sequence particulariy in the Lower Himalayas. Therefore, thhs paper is based nn the lithostraiigraphic correlation of rock sequences as Fuchs and Frank (1970) and Hashimoto *et al.* (1973) have tried in such a way. The geological map and structural map are shown in Fig. 8 and respectively.

Tibetan Tethys Zone

The Tethyan sediments are exposed along the upper streams of the Modi Khola and Kali Gandaki River. Only the lower part of the Tethyan sediments is dealt with in the present paper. Some Jurassic ammonites collected from Muktinath region, Thakkhola will be described in other paper (Kamada *et al.*, 1982).

The lower Tethyan sediments along the Kali Gandaki River comprise three formations: the Larjung, Pi and Nilgiri Formation* in ascending order (Fig.4).

a) *Larjung Formation*

The metamorphosed argillo-arenaceous limestone probably of the lowest part of the Tethyan sediments has a gradational transition from the underlying banded calc-arenaceous schist of the Himalayan gneiss zone in the Modi Khola section, but is bounded by the Dhampu migmatitic body to the south in the Kali Gandaki section. This thick formation consists of grey to light brown impure crystalline limestone and subordinate amounts of grey to white micaceous marble and platy biotite schist. The impure crystalline limestone shows a layering of 0.2 to 5 cm in thickness due to argillo-arenaceous laminae, and frequently exhibits sedimentrary structures such as slumping and intraformational folding which seem to suggest a paleocurrent towards the northeast (Photo 1). The formation is estimated to be about 1,200 meters thick in the Modi Khola section (Fig.4), and considered to be at least of Cambrian age based on its conformable contact to the overlying Ordovician formation (Colchen, 1975).

The formation strikes N65 to 85°W and dips 20 to 35°NE in the Modi Khola while strikes N25 to

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* Formation names adopted here are after Bordet *et al.*(1972)

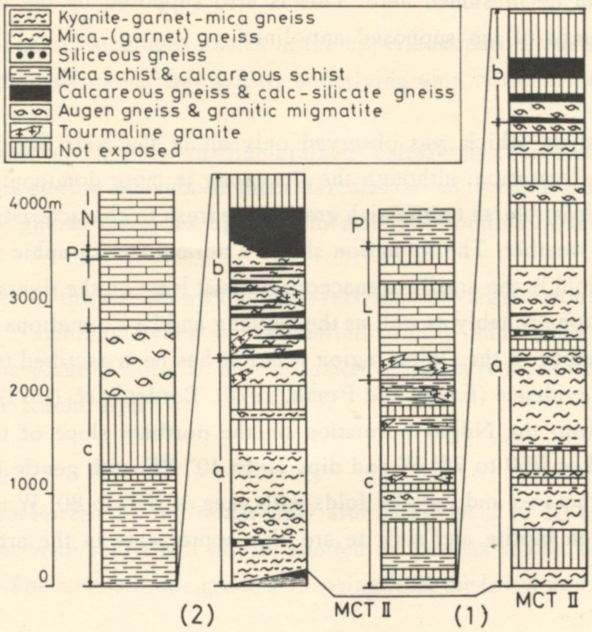

Fig. 4 Lithostratigraphic columnar sections along the mapped routes in the Himalayan gneiss and Tibetan Tethys zones. The column numbers correspond to the route numbers in Fig. 1. L : Larjung Formation ; P : Pi Formation ; N : Nilgiri Formation ; a,b and c : argilloarenaceous, calcareous and calc-argillaceous units of the Himalayan gneiss zone, respectively

35°W and dips 10 to 30°NE in the Kali Gandaki. The latter trend is parallel to that of the Dhampu granitic migmatite. There can be discernible two trends of linear structure in the Modi Khola,that is, minor folds (axes: N65 to 75°W) and mineral lineations with crenulations (axes: N30 to 35°E). The mineral lineations are represented by a parallel arrangement of biotites. Those in the Kali Gandaki show the N70 to 75°W and N60°E trends respectively. The difference in the trend of the mineral lineation between the two areas, in spite of the same trend of their minor folds, suggests that the mineral lineation might have been formed prior to the minor folding.

b) Pi Formation

The Pi Formation conformably overlies the Larjung Formation near the confluence of tributaries to the Annapurna I and III in the Modi Khola. This formation is composed of alternating beds of 2 to 15 cm thick of green biotite schist and calcareous schist. The equivalent of the formation is exposed at an outcrop to the north of Larjung in the Kali Gandaki. The thickness of it is presumed to be several hundreds meters although almost of the formation is covered by terrance and glacial deposits. This formation, however, thickens eastwards and is widely exposed to be associated with a thick calcareous bed on the southern slope of the Annapurna Himal. The formation has been assigned to the Ordovician (Colchen, 1975).

The structural features of the Pi Formation are almost the same as those of the Larjung Formation although the green biotite mineralization accompanies the WNW to ENE trending fold axes also. There can be observed interesting phenomena in the formation of the Modi Khola: downstream from the Machhapuchhare Base Camp axial-plane cleavages of the formation dips northwards more gently than its bedding cleavages (Photo 2), so that this suggests the bed to be an overturned limb. Therefore, an anticline overturned southwards can be presumed here. This is also supposed by the normal drag folds in the overturned and normal limbs of the supposed anticline.

c) Nilgiri Formation

The Nilgiri Formation, which was observed only along the Kali Gandaki by us, is similar in lithology to the Larjung Formation, although the limestone is more dominant than in the latter. This formation ranges in color from bluish to greenish grey where fresh to characteristic reddish brown to brick red where exposed to the weather. The formation shows a normal stratigraphic sequence judging from a cross-bedding and a drag fold in the argillo-arenaceous parts at least on the riverside of the Kali Gandaki.

The Nilgiri Formation probably as well as the Larjung and Pi Formations is likely to be correlated with the Dhaulagiri Limestone in the Dolpo region where it has been ascribed to Cambro (?)-Ordovician age on the basis of fossil evidence (Fuchs and Frank, 1970). Bordet *et al.* (1971) also obtained the Lower Ordovician brachiopods from the Nilgiri Formation on the northern slope of the Annapurna Himal.

This formation strikes N50 to 75° W and dips 10 to 40° NE with gentle fold. The limestone bed shows often boudinage structures and parallel folds with axes of N75 to 80° W trend. The N15 to 30° E trending lineations of green biotite and sericite are also appreciable in the argillo-arenaceous layers.

Himalayan Gneiss Zone

The Himalayan gneiss zone is traceable along the southern flank of the whole Himalayas at the base of the Higher Himalayas. This zone, composed of various kinds of metamorphic rocks, has been diversely named in various areas in the Himalayas: Kathmandu Nappes (Hagen, 1969), Upper Crystalline Nappe (Fuchs and Frank, 1970), Tibetan Slab (Bordet *et al.*, 1971) and Himalayan gneiss zone (Hashimoto *et al.*, 1973) even in the present area. The zone reaches up to 8,000 *m* in thickness in the Modi Khola section and 7,000 *m* in the Kali Gandaki section (Fig.4), and is lithologically divided into three units from the base upwards: the argillo-arenaceous, calcareous and calc-argillaceous.

a) Argillo-arenaceous Unit

This unit consists mainly of kyanite-garnet-mica and garnet-mica gneisses, which show conspicuous banding structure composed of coarse-grained micaceous pelitic layers of 0.5 to 3*cm* thick and fine to medium-grained massive psammitic layers of 2 to 10cm thick (Photo 3). Kyanite, of up to 3*cm* in length, is related with the former layers. Sillimanite is rarely present as acicular aggregates in the Modi Khola section. Potash feldspar is rare. Folded migmatitic gneiss and augen gneiss occur in places especially in the Modi Khola section. The leucocratic mobilizate layers contain characteristically kyanite and tourmaline (Photo 4). Potash feldspar in the augen gneiss reaches occasionally up to 10*cm* in size and includes kyanite, garnet and tourmaline. A few intercalations of siliceous gneiss and/or calcareous gneiss is found in the unit.

The gneisses near the Main Central Thrust II are intensively sheared. Garnet is elongated into lenticular shape and, together with biotite, is altered to chlorite. So it is difficult in the field to distinguish them from the phyllitic schist in the Main Central Thrust zone.

The Himalayan gneisses trend in the N45 to 70°W direction and dip 25 to 60°NE along the Modi Khola, and N50 to 85°W and 30 to 75°NE along the Kali Gandaki. Two different linear structures exist in the gneisses: a mineral lineation accompanied by a micro-fold of N30 to 70°E trend and a micro-folding axis with a small scale undulation of N65 to 80°W. The former appears to be bent by the latter.

b) Calcareous Unit

The first occurrence of calcareous gneiss in the uppermost part of the above-mentioned unit forms the boundary between the calcareous unit and its underlying unit, notwithstanding a transitional change between them.

The unit is made up largely of fine-grained calcareous hornblende schist, coarse-grained calc-silicate gneiss, mica marble and subordinate intercalations of fine-grained argillaceous to arenaceous gneiss. The calcareous gneiss increases upwards in amount. Boudins of the crystalline limestone are frequently found.

Structural features of the unit as well as the overlying calc-argillaceous unit resemble those of the above-mentioned unit. Numerous dykes of tourmaline granite and aplite intrude concordantly and obliquely to the bedding plane (Photo 5). The intrusion of dykes reaches up to the Larjung Formation especially in the Modi Khola area.

c) Calc-argillaceous Unit

The unit is characterized by the remarkable alternation of 2 to 10 cm thick, which consists of fine-grained biotite-muscovite schist and biotite spotted calcareous schist. Mica marble is sporadically intercalated in the unit. The metamorphic grade decreasing from the lower unit upwards, seems to decrease rapidly in this unit.

The unit can be correlative with the Samla Pass schist of western Nepal (Arita *et al.*,1982).

Tourmaline-mica granitic migmatite rests on the unit near Dhampu in the Kali Gandaki area (Dhampu granitic migmatite). The granitic migmatite cosists of leucocratic gneissose granite and tourmaline-garnet-mica augen gneiss (Photo 6). The latter is similar to that of the upper part in the argillo-arenaceous unit of the Modi Khola area. The granitic migmatite demarcates the upper limit of the Himalayan gneiss zone of the Kali Gandaki area. The relationship between them, however, is uncertain , although they are concordant structurally each other. This type of migmatitic rock can not be found on the top of the calc-arenaceous unit in the Modi Khola area.

Main Central Thrust Zone

The Main Central Thrust zone, together with the overlying Himalayan gneiss zone, is traceable along the whole Himalayas but conspicuously variable in thickness. The zone has been called the Scale Zone ("Zone des Ecailles")(Bordet *et al.*, 1972) and the Lower Crystalline Nappe (Fuchs and Frank, 1970). The existence of an intensely sheared zone has been recognized by the above authors, but the range of the zone varies from author to author . The present authors define it as a zone between the Main Central Thrust I on the south and the Main Central Thrust II on the north. The latter thrust is clear everywhere, whereas the former is not always distinct particularly where no blastomylonitic augen gneiss lies at the base of the Main Central Thrust zone (e.g. Mayangdi Khola section).

Roughly speaking , the zone in the present area can be subdivided lithologically into five units: from the base upwards lower argillaceous, lower calc-siliceous, upper argillaceous, upper calc-siliceous and uppermost argillaceous units (Columns 3,4 and 5 in Fig, 5). The lower argillaceous unit is exposed in the Mayangdi Khola and Kali Gandaki sections and formed of wavy green phyllite with or without biotite, biotite bearing black phyllite and rare intercalations of greenish quartzite. The unit in the Mayangdi Khola section contains a few beds of quartzite with amphibolite and calcareous schist. The lower calc-siliceous unit consists of calcareous schist and quartzite which is occasionally accompanied by lenses of amphibolite , and both two grade into each other. In the Modi Khola section the peculiar augen gneiss (Ulleri augen gneiss of Le Fort, 1975) is found to be associated with quartzite south of Ghandrung. The blastomylonitic augen gneiss seems to grade into quartzite with intercalations of wavy phyllitic schist (Phto 7). The augen gneiss increases its thickness towards the west and reaches a thickness of over 1,000*m* near Ulleri (Photo 8). The upper argillaceous unit is composed of biotite-graphite phyllite, wavy green phyllite, biotite-chlorite phyllitic schist with or without garnet, and subordinate amounts of quartzite and/or calcareous schist. The phyllitic schist is characterized by the wavy micaceous layers with irregular folded lenticular quartz aggregate (photo 9). The upper calc-siliceous unit is made up of quartzite and limestone. The uppermost argillaceous unit consists of wavy biotite-chlorite phyllitic schist with rare intercalation of calcareous schist. The unit is well exposed in the Mayangdi Khola section. The zone thins eastwards: over 7,000*m* in the Mayangdi Khola section , about 3,000 m in the Kali Gandak section and about 2,000 m in the Modi Khola section. However, the shearing character as a whole and the repetitive occurrence of lithofacies strongly suggest the repetition of the beds owing to an imbricate structure.

The schists of the zone strike commonly the N40 to 75°W and dip 10 to 35°NE. The trends in the Kali Gandaki and Modi Khola areas vary up to N80°E. Nevertheless the distinct mineral lineations in these three areas trend similarly N5 to 35°E. It is notable that the lineations are rather constant in the direction and shifts more northwards as compared with those of the Himalayan gneisses. The minor fold and crenulation of the trend of N65 to 80°W are found to bend the former lineations.

Arkha Crystalline Schist Zone

The zone is supposed to be a klippe derived from the Main Central Thrust zone to the north. However, the zone,differing from the latter, consists largely of pelitic rocks such as garnet-biotite schist.

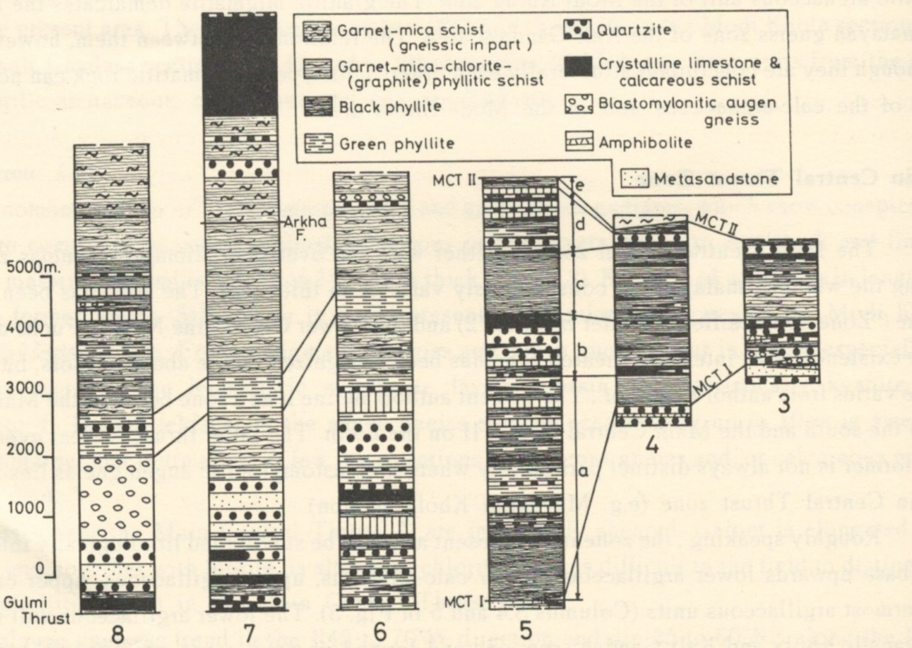

Fig.5 Lithostratigraphic columnar sections along the mapped routes in the Main Central Thrust and Arkha crystalline zone. The column numbers correspond to the route numbers in Fig. 1.MCTI : Main Central Thrust Ⅱ ; MCT Ⅱ : Main Central Thrust Ⅱ ; a, b, c, d and e : lower argillaceous, lower calc-siliceous, upper argillaceous, upper calc-siliceous and uppermost argillaceous units, respectively.

biotite phyllitic schist and graphite phyllitic schist except for quartzite and limestone at the bottom (Columns 6,7 and 8 in Fig.5). The total thickness exceeds 9,000*m*. The blastomylonitic augen gneiss of the Ulleri-type is found along the Lung Khola and 3*km* south of Arkha. In the Lung Khola the transitions of the augen gneiss to quartzite can be observed as follows; banded quartzite with muscovite-rich seams grades into biotite-muscovite siliceous schist; coincidently quartz veinlet becomes rich in parallel with the bedding plane; as biotite and muscovite become more rich, wavy structure begins to occur and wrap quartz aggregates in lenticular shape; then augen of potash feldspar 0.5 to 1*cm* long begins to appear sporadically. These transitions are just the same as those observed in quartzite south of Ghandrung. Sheared garnet-mica gneiss similar to that found at the base of the Himalayan gneiss zone also occurs near Arkha village. The lower part of the zone is made up of white to pale brown muscovite quartzite, platy grey limestone, biotite schist and silver to green phyllite.These rocks are likely to be lower in metamorphic grade than those upwards from the augen gneiss, but apparently higher than those of the Piuthan zone.

The structural features of the zone are almost the same as those of its root zone: the Main Central Thrust zone, except for the southward dipping in the northern part of the north Arkha Crystalline zone.

The Arkha Crystalline zone is tectonically subdivided into the north and south zones by the Arkha fault.

Baglung Zone

The Baglung zone, along with the Bihadi zone and the Markina and the Kekmi-Bandipur zones in the easternmost part of the present area, is underlain by the Midland meta-sediment Group.

The zone seems as a whole to form a WNW trending anticlinorium which is the western extension of the Kunchha- Gurkha anticlinorium. Biotite bearing black phyllites with quartz veins occur at the core of the anticlinorium along the Kali Gandaki (Column 11 in Fig. 6), and are conformably overlain by gritty quartz sandstones. The gritty sandstone, developed extensively near Pokhara (Column 9 in Fig 6), is composed of monotonous alternating beds of quartz sandstone of 10 to 40*cm* thick and green phyllite 1 to 5*cm* thick (Photo 10). Quartz grains in the sandstone are characterized by greasy purplish to bluish color and ovoidal shape attaining often 0.5*cm* in size. The sandstone is likely to be in normal stratigraphic sequence based on the slightly graded bedding. South of Tatopani the gritty sandstones grade into the overlying white and pale green to pale brown muscovite quartzite accompanied with a few layers of schistose and massive amphibolites with an inherited igneous texture. The quartzite shows ripple marks in many places. The quartzite together with associated amphibolite is widely exposed in the southern part of the zone (Upreti *et al*., 1980). These rocks are correlated with the Lower to Middle Midland meta-sediment Subgroup.

The axis of the Kunchha-Gurkha anticlinorium passes north of Pokhara. But its northern flank is reduced by overthrusting of the Main Central Thust zone especially in higher altitude. Along the Kali Gandaki some gentle mappable folding are developed parallel to the trend of the anticlinorium.

Bihadi Zone

In the Markina and Kekmi-Bandipur zones stromatolite limestone and phyllites of the Upper Midland meta-sediment Subgroup are found to be folded gently (Column 10 in Fig.6). The stromatolite limestone widely distributed near Bihadi (Upreti *et al*., 1980) can be regarded as to be its northwestern continuation (Bihadi zone).

Further northwest in the Dhorpatan zone the possible younger sediments mentioned later are

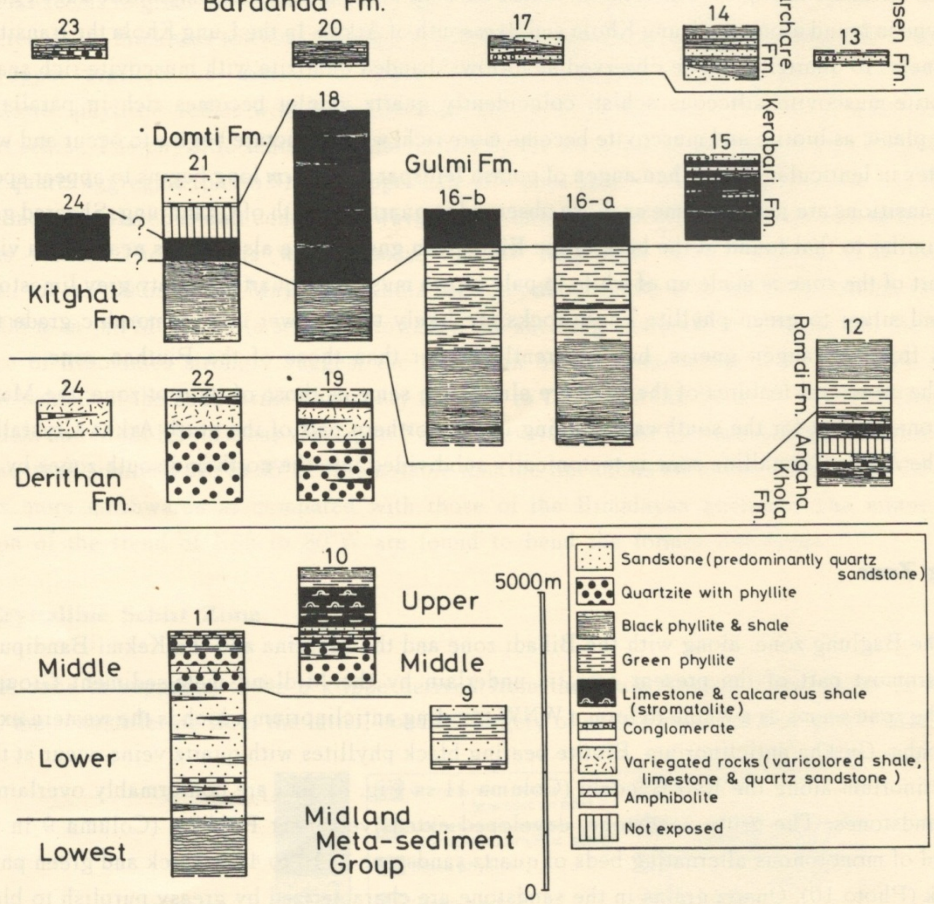

Fig.6 Lithostratigraphic columnar sections along the mapped routes in the Bihadi, Dhorpatan, Derithan, Bardanda and Tansen zones. The column numbers correspond to the route numbers in Fig. 1. Columns 9 and 10, and 12 to 15 are from Hashimoto *et al.* (1973) and Arita and Yoshida(1982), respectively.

overlain by a thick limestone bed. According to Fuchs and Frank (1970) the stromatolite structure is present in the limestone bed. The detailed relationship between the zone and the Dhorpatan zone is unknown, although a fault is estimated to exist along the Bhuji Khola based on the photographical survey by 1:50,000 scale airphotographs (Nakata,1982).

Piuthan Zone

The Piuthan zone is occupied by the Kitghat, Gulmi and Domti Formations of the Piuthan Group (Columns 16, 18 and 21 in Fig. 6). The Kitghat Formations is composed of monotonous regularly alternating beds of grey fine-grained sandstone of 2 to 10*cm* thick and black slaty shale of 1 to 3*cm* thick, and is turbiditic in character. A graded bedding and a cross-bedding are commonly found to represent the general normal stratigraphic polarity with local reverse polarity in the vicinity of Kitghat. The formation thickens eastwards and diverges into the lower carbonaceous black phyllite to shale with fine-grained sandstone and the upper green phyllite. The pelitic formation corresponds to the Simla Slates of Fuchs and Frank (1970). The pelite passes gradually into the overlying calcareous Gulmi Formation.

The Gulmi Formation consists of platy grey limestone characterized by the banding structure of 1 to 15*cm* in thickness, and subordinate amounts of intercalations of dark grey calcareous shale and green to pale brick-red shale. Siliceous layers are rarely interbedded in the limestone. The formation rearches to 3,000*m* in thickness in the Samne Khola (Column 18 in Fig.6) provided the possible repetition of the formation is disregarded. The formation contains no stromatolitic structure and closely resembles lithologically the Kerabari Formation in the Tansen zone (Column 15 in Fig.6).

On the Gulmi Formation the Domti Formation rests. The formation is formed of laminated quartzose sandstone to quartzite, black shale and subordinate amounts of green phyllite.

The sediments of the Piuthan zone strike nearly parallel to the general Himalayan trend of WNW, and dip as a whole NNE although some pairs of rather steep anticline and syncline with minor folds are present in the vicinity of Piuthan. In contrast to this the Kitghat Formation along the Bagha Khola shows homoclinal structure dipping north steeply. It is interesting to note that the formation in the upper stream of the Bagha Khola shows a normal graded bedding while that in the lower stream shows an inverted one. Furthermore the inverted graded bedding is found in the platy grey limestone south of Balkot. Assuming that these inverted graded bedding are not local phenomena, a large scale anticline overturned southwards has to be supposed to exist. The micro-corrugation trending parallel to the macro fold is well developed in pelites of the zone. The NE trending mineral lineation is never found in the zone.

Derithan Zone and Dhorpatan Zone

The Derithan zone is composed only of the Derithan Formation of the Piuthan Group. The Derithan Formation is featured by its diverse lithologies: pinkish, brownish, greenish to white quartzite to quartzose sandstone, variegated shale with green, brick-red and black color, pinkish, brownish to white limestone, and green to black phyllite (Columns 19 and 22 in Fig. 6). Among them quartzitic rocks are predominant although calcareous rocks seem to be rich in the upper horizon. The quartzitic rocks have a platy structure of 2 to 40*cm* in thickness, and show sedimentary structures such as cross-bedding, ripple mark and sun crack in many places. These structures indicate a normal stratigraphic polarity with a few local reverse polarities and a direction of the paleocurrent towards SSW. The limestone is interbedded with variegated calcareous shale and black shale, and often grades into siliceous layer. The shale often alternates with fine-grained sandstone, representing graded bedding. Stromatolite-like structure is found in a limestone layer within the ripple marked quartzite north of Derithan.

In the Tansen zone a thick series (over 1,000*m*), called the Angaha Khola Formation and composed of grey to pinkish limestone and greenish, purplish red to black shale , is distributed (Arita and Yoshida, 1982). In addition along the Bhuji Khola in the Dhorpatan zone there occur thick alternating beds of variegated shales and varicolored limestones which grade into cherty layers to make a banding structure of 1 to 15*cm* thick (Column 24 in Fig. 6). The alternation is followed downwards by varicolored quartzite to quartzose sandstone interbedded with variegated shale. They are characterized by a remarkable facies change and various sedimentary structures such as cross-bedding, intraformational folding and intraformational conglomerate. These characteristic rocks of these zones are correlative with those of the Nagthats of Fuchs and Frank (1970). The variegated rocks in the Dhorpatan zone are overlain by the thick limestone bed (Column 24 in Fig.6) which shows stromatolite structure in places (Fuchs and Frank, 1970).The relation between them, however, is uncertain.

The Derithan zone is a folded zone striking N30 to 80°W.The quartzite-rich alternating beds represent major folds with amplitude of several tens to several hundreds of meters and the alternating incompetent beds are strongly folded in order of outcrop to handspecimen. The variegated rocks of the Dhorpatan zone strike N40 to 75°W and dip northeast homoclinally south of Dhorpatan, but are folded into a pair of anticline and syncline northwest of Dhorpatan. The platy grey limestone resting on the variegated rocks makes up a syncline on the Surtibang Lekh. No mineral lineation in the NE trend is found at all in these zones.

Bardanda Zone

The zone is composed of only the Bardanda Formation which consists largely of greenish to pinkish quartzose sandstone to quartzite, green to brick-red shale, fine-grained quartzose sandstone and subordinate amounts of black slaty shale (Columns 20 and 23 in Fig. 6). These lithologies are similar to those of the Derithan zone just on the north. Further, the boundary fault between them (Muta fault) is estimated only by the sheared green to black shales of the Bardanda zone which contact to the brick-red quartzite with variegated shale of the Derithan zone. Therefore, it is possible that these rocks of both zones are the same. Nevertheless, the present authors are inclined to distinguish Bardanda zone from the Derithan zone, because the former zone is folded more intensively than the latter zone, and the shales of the former zone represent a characteristic splintery weathering which is never observed in the shales of the former zone. The similar lithology of splintery chracter is found in the Charchare and Tansen Formations of the Tansen zone (Columns 14 and 13 in Fig. 6). The varicolored rocks of the zone correspond to the Dagshais and Tals of Fuchs and Frank (1970).

A series of greywacke sandstone, medium-to coarse-grained sandstone containing pebbles to cobbles of varicolored limestone, white to pinkish quartzite and sandstone,brick-red shale and grey splintery shale is exposed between the Bardanda and Tansen zones (Column 17 in Fig. 6). The series is correlated to the Tals of Fuchs and Frank (1970).

The Bardamda zone is an intensely folded zone trending N60°W to N70°E and shows folds in various amplitude. The drag folds suggest a thrusting condition from north to south.

DISCUSSION ON SOME STRATIGRAPHICAL TOPICS

The stratigraphy of the present area except for the Tibetan Tethys zone can be compiled as shown in Fig.7. Some topics as to the stratigraphy of the present area will be discussed in this chapter.

Age of the Midland Meta-sediment Group

Hashimoto *et al.* (1973) divided the Midland meta-sediment Group into four Subgroups on lithological basis (Argillaceous Lowermost, arenaceous Lower, siliceous Middle and calcareous Upper Subgroups), and concluded that the Group is of Precambrian age from the following reasons:

a) The Upper Subgroup seems to be unconformably overlain by the Kathmandu Group of early to middle Paleozoic age.
b) No NNE trending mineral lineation, which is dominant in the Midland metasediments, is observed in the early to middle Paleozoic sediments of the Kathmandu basin.
c) Stromatolite limestones being characteristic of the Precambrian age in various regions of Eurasia are widely developed in the Upper Subgroup.

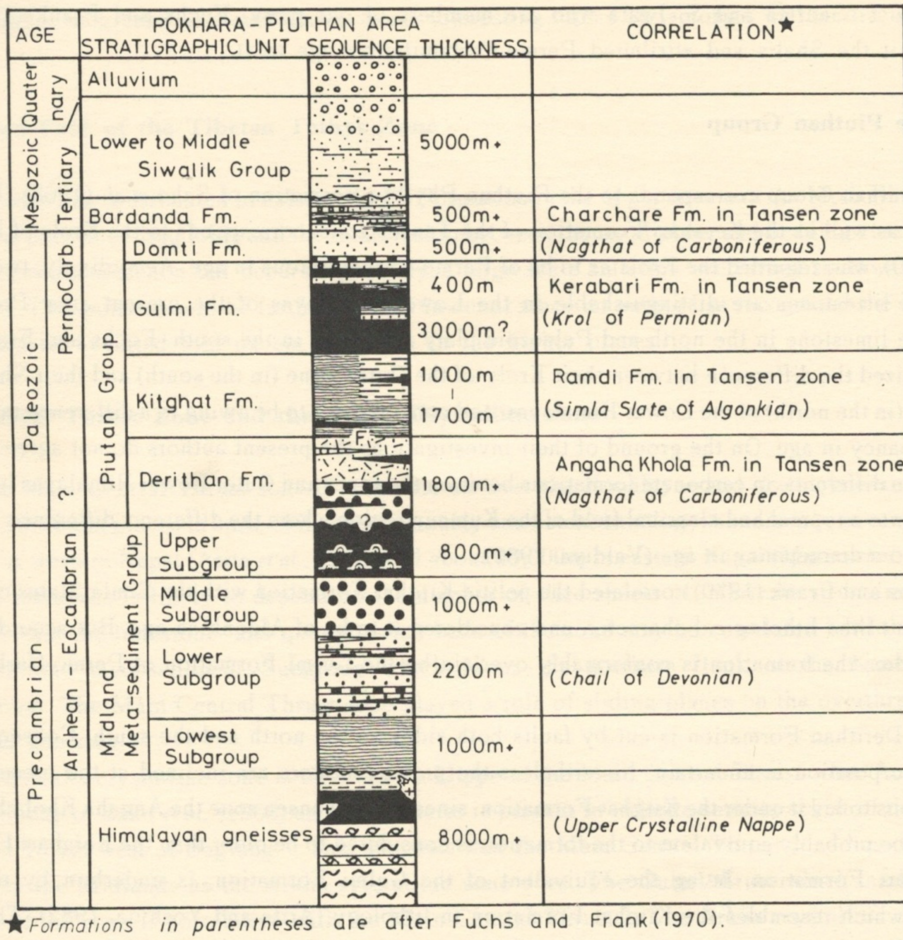

Fig.7 Generalized stratigraphic columnar section of central Nepal between the Modi Khola and the Lungri Khola except for the Tibetan Tethys and Main Central Thrust zones. Legends are same as Figs. 4 and 6.

Among the above-mentioned reasons, however, a) and b) have opened to doubt because the Kathmandu nappe theory (Hagen, 1969) was revived (Brunel, 1975; Maruo *et al.*, 1979).

On the other hand according to Valdiya (1980) the Damtha and its overlying Tejam Groups of the Kumaun region western adjacent of Nepal have been assigned to the Lower and Middle Riphean ages, respectively. K-Ar dating of whole rock on the basic rocks in the Damtha Group gave ages between 410± 10 and 1,19035±m.y.(Sinha, 1977).It is evident from a lithologic similarity that these Groups may be correlated with the Lower to Middle and Upper Midland meta-sediment Subgroup of central Nepal, respectively. In addition Krummenacher (1966) reported K-Ar ages of 872 m.y. for detrital muscovite of sandstone in the Kunchha series between Baglung and Beni and 819±80 m.y. for uralite of basic rock in the Kunchha series at Tatopani. It is beyond question that the basic rock corresponds to amphibolite intruded into quartzite of the Middle Subgroup. These ages, however, are expected to be younger than true ages due to rejuvenation resulting from the metamorphism in Tertiary age. Hence it can be asserted that the Midland meta-sediment Group is Lower to Upper Riphean in age.

The Midland meta-sediment Group of the present area amounts in thickness to more than 5.000m. The stromatolite limestone of the Upper Subgroup was cofirmed to occur in the midstream of the Kali

Gandaki by T. Sharma and S. Iwata who are members of our party. Fuchs and Frank (1970) have designated it the Shalis and attributed Permo-Carboniferous age to it.

Age of the Piuthan Group

The Piuthan Group corresponds to the Piuthan Phyllite Formation of Sako *et al.* (1968). The Gulmi Formation, as well as the Kerabari Formation of the Tansen zone, corresponds to the Krols of Fuchs and Frank (1970), who regarded the Krols as to be of Permo-Carboniferous in age. Accordingly, two different horizons of limestones are distinguishable in the Lower Himalayas of the present area: Precambrian stromatolite limestone in the north and Paleozoic platy limestone in the south. Fuchs and Frank (1970) also recognized the difference between their Krols of the Outer Zone (in the south) and their Shalis of the Inner Zone (in the north) of the Lower Himalayas, and considered it to be owing to a difference in facies not to a discrepancy in age. On the ground of their investigations the present authors do not agree with their view. Such a difference in carbonate formations between the Inner and Outer Lower Himalayas is traceable westwards into a typical and classical field of the Kumaun region where the differenc difference has been attributed to a discrepancy in age (Valdiya, 1980).

Fuchs and Frank (1970) correlated the pelitic Kitghat Formation with the Simla Slates of Kumaun on the basis of the lithological character, and considered it to be of Algonkian age. But according to the present studies the formation is conformably overlain by the Gulmi Formation of Permo-Carboniferous age.

The Derithan Formation is cut by faults both sides on the north and the south. Consequently its stratigraphic position is uncertain. Nevertheless the present authors are inclined at the present step of investigations to lay it under the Kitghat Formation, since in the Tansen zone the Angaha Khola Formation which may be probably equivalent to the formation is considered to be older than the Kerabari Formation. The Kerabari Formation, being the equivalent of the Gulmi Formation, is underlain by the Ramdi Formation which resembles the Kitghat Formation in lithology (Arita and Yoshida, 1982). The present authors have no data concerning the relationship between the Derithan Formation and the Upper Midland meta-sediment Subgroup, so they tentatively put the Derithan Formation into Paleozoic age in spite of an occurrence of stromatolite-like structure in a limestone bed of the Derithan Formation.

Lower Limit of the Tethyan Sediments

As mentioned already the oldest formation determined by fossil evidence is of Lower Ordovician age (Nilgiri Formation). The Nilgiri Formation is conformably underlain by the Pi Formation and then Larjung Formation which is followed by the calc-argillaceous unit of the Himalayan gneisses without a distinct tectonic contact in the upper stream of the Modi Khola. If this is the case, the calc-argillaceous unit is naturally assigned to Precambrian in age. In other words, this unit can be correlative with the calcareous Upper Midland meta-sediment Subgroup in age although the metamorphic grade is quite different between them. This leads to a probability that the Tethyan sediments might have began to deposit during the late Precambrian. This is an impotant point in considering the geologic development of the Himalayas, so the further studies are required.

DISCUSSION ON STRUCTURAL FEATURES

The present area is a transitional zone between central and western Nepal from the view points of tectonics and stratigraphy as stated above. Some interesting topics on tectonics will be discussed in this chapter.

Overturned Fold of the Tibetan Tethys Zone

An anticline is estimated to exist in the Pi Formation in the upper stream of the Modi Khola from the distribution pattern of drag folds and the relationship between the axial-plane and bedding cleavage. If this is not a local phenomenon but occurs regionally, a large scale anticline overturned southwards must be considered. This point should be further studied in detail since no author has recognized the existence of such a gigantic inverted fold except for those in the higher places.

Main Central Thrust Zone and the Arkha Crystalline zone

The Main Central Thrust zone is traceable all over the Himalayas and its thickness is extremely variable in different places in spite of its conspicuously consistent lithology: hundreds to several thousands of meters in western Nepal (Arita *et al.*, 1982) and about 10,000*m* in eastern Nepal (Maruo *et al.*, 1979). The variety of thickness is likely to depend on the number of slice sheets of imbricate structure. There is a possibility that the limestone- and quartzite-rich beds of the zone may be correlated with the Middle to Upper Midland meta-sediment Subgroup which forms the northern flank of the Kunchha-Gurkha anticlinorium. The Main Central Thrust zone played a role of sliding planes on the overthrusting of the Himalayan gneisses.

The Arkha crystalline zone is obviously a klippe of the Main Central Thrust zone. According to a geological map of Sako *et al.* (1968) an augen gneiss is present in chlorite-sericite schist of their Baglung Formation 15 km west of Baglung. This suggests that the Main Central Thrust zone has once covered extensively the Midlands as the Arkha crystalline zone does. The Gulmi thrust which marks the lower boundary of the zone is correlative with the Main Central Thrust I. The Arkha crystalline zone extends farther northwests into western Nepal where it is named the Jajarkot crystalline zone (Arita, 1978; Arita *et al.*, 1982).

Autochthonous Baglung Zone and its Northwestern Extension

The Baglung zone corresponds to the Nawakot nappes (Hagen, 1969), Chail Nappes (Fuchs and Frank, 1970), and Pokhara Block and Baglung schuppen zone (Sako *et al.* in Hashimoto *et al.*, 1973). The present authors have no mapping data in the Baglung schuppen zone. However, at least the Kunchha-Gurkha-Nawakot anticlinorium appears to continue into the present area. The axis of the anticlinorium passes on the north of Pokhara and between Tatopani and Beni. There is no evidence for an allochthonous character of the zone as well as the Markina and Kekmi-Bandipur zones. The autochthonous Baglung zone narrows northwest probably owing to the southward overthrusting of the Main Central Thrust zone, and north of Dhorpatan is replaced by the Rukum zone of Fuchs and Frank (1970). According to them the zone is composed of the Tansen Unit, Rukum Nappe and Chail Nappes in ascending order. Thus, of particular importance is the Rukum zone in considering whether the Midland metasediment zone (that is, the Baglung zone or Chail Nappes) is autochthonous or allochthonous in character.

Parautochthonous character of the Piuthan Zone

In the lower stream of the Bagha Khola the Kitghat Formation shows the inverted graded bedding at two judgeable points, and the Gulmi Formation also indicates the inverted grade bedding at only judgeable point. If these inverted graded beddings are not local, a large scale anticline inclined southward has to be supposed to exist. But the reverse stratigraphic polarity is not found in the Piuthan area. In this context it is noteworthy that the Angaha Khola and Ramdi Formations in the Tansen zone which are considered to be the equivalents to the lower part of the Piuthan Group represent a reverse stratigraphic polarity (Arita and Yoshida,1982). Such a gigantic overturned fold has not found in the Midlands of central and eastern Nepal.

Tectonic Significance of the Kali Gandaki-Bari Gad Fault.

As clearly shown in Fig. 8, the Dhorpatan zone can be regarded as the boundary zone which runs obliquely to the general Himalayan trend and divides the present area into the northeast and southwest units which correspond to the Buri Gandaki-Kali Gandaki and Kali Gandaki-Bheri Khola areas of Sako *et al.* (in Hashimoto *et al.*, 1973), respectively. These units stand in contrast each other in various respect: open and gently folded autochthonous Precambrian sediments in the northeast unit and comparatively intensely folded parautochthonous to allochthonous younger sediments in the southwest unit. They are distinguishable as to the metamorphic grade too; the former being higher than the latter. The Dhorpatan zone is stratigraphically and structurally rather similar to the northeast unit especially in its southeastern part, so the Kali Gandaki fault and its northwestern extension (Bari Gad fault) have much more importance than the Phalebas thrust in tectonic significance. In other words the Kali Gandaki-Bari Gad fault is a boundary fault between central and western Nepal in geological sense.

Southern Marginal Folded Zone

The Derithan, Bardanda and Tansen zones are characterized by intense folding. Such folded zones in the southern margin of the Lower Himalayas is observable in many places. These zones correspond topographically to the Mahabharat zone.

METAMORPHISM

Only a part of rock specimens collected in the present area has been so far examined under microscope and some garnets from the Himalayan gneiss, Main Central Thrust and Arkha crystalline zones have been determined their chemical composition by EPMA analysis. So the outlines of metamorphism mainly of the above three zones will be stated in this chapter. Partial EPMA analyses of garnets, biotites, muscovites, plagioclases and potash feldspars are shown in Table 2.

Himalayan Gneiss and Tibetan Tethys Zones

The mineral assemblages of the lower part (argillo- arenaceous unit) of the Himalayan gneiss zone are as follows:

Kyanite-garnet-biotite-muscovite ± fibrolite ± paragonite
Garnet-biotite-muscovite
Biotite-muscovite

Quartz and plagioclase (albite to oligoclase) are always present. Potash feldspar is rare. Kyanite is found much in lower to middle part of the argillo-arenaceous unit and appears to be classified into two

Table 2 Partial EPMA analyses of minerals from the Himalayan gneiss, Main Central Thrust and Arkha crystalline zones. HA80112004: kyanite-garnet= mica gneiss of the Himalayan gneiss zone, about 1*km* north of Dana; HA81011803: garnet-epidote= mica phyllitic schist of the Arkha crystalline zone, in the upper stream of the Chhalli Khola; HA80111006: garnet-mica mylonitic augen gneiss of the Main Central Thrust zone, at Ulleri; HA80112106: garnet tourmaline-mica granitic migmatite of the Himalayan gneiss zone, about 500*m* south of Dhampu; HA77148: garnet-tourmaline= mica granite, about 30*km* ENE of Jumla in western Nepal.

	HA80112004				HA81011803		HA80111006		HA80112106		HA77148	
	Garnet				Garnet		Garnet		Garnet		Garnet	
	core	rim	core	rim	core	rim	core	rim	core	rim	core	rim
FeO*	30.46	29.98	29.48	29.23	25.52	31.02	15.84	18.82	27.58	27.64	31.71	31.16
MnO	1.64	2.22	3.18	1.50	7.39	2.23	8.47	7.06	10.78	11.90	8.08	8.25
MgO	6.61	5.28	6.51	7.37	1.20	1.80	0.09	0.09	0.80	0.69	0.43	0.41
CaO	1.04	0.84	1.20	1.08	7.07	6.26	15.98	14.71	1.44	1.56	1.15	0.93
	Biotite				Biotite		Biotite		Biotite		Biotite	
FeO*	12.91				18.70		28.38		26.25		no	
MgO	13.84				9.85		2.71		4.57			
	Muscovite				Muscovite		Muscovite		Muscovite		Muscovite	
FeO*	2.00				3.18		2.99		3.13		2.99	
MgO	0.90				1.33		0.77		1.09		0.77	
Na_2O	1.24				0.46		0.41		0.31		0.34	
	Plagioclse				Plagioclase		Plagioclase		Plagioclase		Plagioclase	
CaO	1.44				0.57		1.02		1.91		2.19	
Na_2O	9.38				8.89		9.69		9.96		9.96	
K_2O	0.06				0.02		0.13		0.25		0.15	
	K.feldspar				K.feldspar		K.feldspar		K.feldspar		K.feldspar	
Na_2O	no				no		n.d.		0.80		1.04	
K_2O							n.d.		14.79		14.40	

FeO* means total iron as FeO.

types: one occurring in parallel to the foliation in biotite-rich layer and another occurring in the leucocratic mobilizate of the migmatitic gneiss or being included with garnet and tourmaline in potash feldspar augen of the migmatitic augen gneiss.Garnet of the kyanite-garnet gneiss in the Kali Gandaki have two types of compositional zoning (Table 2). Since only the reverse zoning pattern (Mg-rich core and Mn and Ca-rich rim) is observed in the Himalayan gneisses in the Modi khola (Arita, in prep.), this point is to be further studied in detail. The mineral assemblages described above ascribe the lower part of the Himalayan gneiss zone to the kyanite zone of the amphibolite facies. The gneisses at the base of the Himalayan gneiss zone have wavy micaceous layers with irregular, locally folded lenses and veinlets of quartz. This exhibits effects of strong post-recrystallizational deformation which resulted in chloritization of biotite and garnet.

The mineral assemblages of the upper part (calcareous and calc-argillaceous units) of the Himalayan gneiss zone are as follows:

Calcite-biotite-muscovite-quartz-plagioclase ± microcline,
Calcite-scapolite-biotite-muscovite-quartz-plagioclase-microcline
Calcite-epidote-hornblende-garnet-biotite-quartz-plagioclase- microcline ± diopside
Hornblende-garnet-biotite-quartz-plagioclase

The gneisses of the upper part are of the amphibolite facies. But the metamorphic grade apparently decreases upwards especially in the calc-argillaceous unit represented by a biotite-muscoite assemblage of the intercalating pelitic schist and by a decrease in grain size. The metamorphism has affected at least up to the Nilgiri Formation which altered to biotite spotted marble and alternating sericite phyllite.

The interesting Dhampu granitic migmatite contains muscovite, tourmaline, quartz, plagioclase (oligoclase), potash feldspar and rare garnet. Its occurrence and a similarity to garnet-bearing tourmaline granite of western Nepal in chemical composition of minerals (Table 2) suggest a close relationship to the *tourmaline granite in origin*.

Recent radiometric studies on the Himalayan gneisses (Kai, 1981; Bhanot *et al.*, 1977; etc.) have confirmed that the Himalayan gneisses underwent a few episodes of regional metamorphism during Precambrian to early Paleozoic age. It is, however,confirmed that these rocks were again subjected to intense metamorphism during Tertiary age.

Main Central Thrust and Arkha Crystalline Zones

The mineral assemblages of the Main Central Thrust zone are as follows:

Garnet-biotite-muscovite-chlorite ± graphite
Muscovite ± biotite
Biotite-muscovite-chlorite ± calcite
Chlorite-sericite
Epidote-chlorite-biotie ± actinolite
Calcite-muscovite ± potash feldspar

Quartz and plagioclase are always present. Therefore, the rocks of the zone have been metamorphosed into the albite-epidote-almandine subfacies of the greenschist facies. The garnets show a distinct rotated texture which has a core rich in MnO and CaO and a rim rich in MgO and FeO as far as examined so far.

The peculiar mylonitic augen gneiss in the zone contains biotite,muscovite, quartz, albite and/or microcline, and rare garnet and chlorite. As pointed out by Pecher and Le Fort (1977), Na_2O/K_2O ratio of bulk composition of the augen gneiss varies very considerably. The further geological and petrological studies are required to investigate the origin of the Ulleri augen gneiss.

The Arkha crystalline zone is nearly the same as the Main Central Thrust zone in metamorphic grade and the garnet-chlorite-mica phyllitic schist is most predominant. The phyllitic schist in the zone, however, contains gneissic layers. These rocks especially in the north Arkha zone can be easily mistaken in the field for the mylonitic banded mica gneiss at the base of the Himalayan gneiss zone. There is a possibility that part of that gneissic schist of the Arkha zone may belong to the Himalayan gneisses,as shown in the geological map of Fuchs and Frank (1970).

Baglung Zone

Characteristic mineral assemblages of the zone are as follows:

Biotite-muscovite-chlorite
Muscovite-chlorite ± chloritoid
Biotite-muscovite-microcline
Biotite-chlorite-epidote

Quartz and plagioclase are always present. The above mineral assemblages attribute the zone to the biotite zone of the greenschist facies. But the southern part of the zone may be of chlorite zone since the biotite is not found there. The biotite isograd is expected to pass near Pokhara. The metamorphic grade of the zone certainly increases northwards (i.e. stratigraphically upwards), into the garnet zone in the Main Central Thrust zone. Such an inverted metamorphism, which is observed along the whole Himalayas, is considerd to be due to the thrust movement of the Main Central Thrust zone (Arita, in prep.).

Other Zones in the Midlands

The rocks in the Dhorpatan, Bihadi, Piuthan and Tansen zones preserve their inherited original sedimentary structure to a certain extent, and show somewhat lower grade of metamorphism as compared to those north of the Phalebas thrust.

The NE trending mineral lineation is not found at all in the southwest unit including the Piuthan zone which is situated in front of the Gulmi thrust (i.e. Main Central Thrust I). In contrast to this the mineral lineation is considerably prevailing in the Baglung zone which is a frontal zone of the Main Central Thrust I. This fact is noteworthy regarding age of the mineralization or character of the Gulmi thrust.

CONCLUSIONS

Central Nepal between the Modi Khola and Lungri Khola is primarily divided lithostrato-tectonically into the northeast and southwest units by the Dhorpatan-Bihadi zone which runs obliquely to the general Himalayan trend.

The northeast unit is subdivided into four zones: from north to south the Tibetan Tethys, Himalayan gneiss, Main Central Thrust and Baglung zones. The Himalayan gneiss zone, composed mainly of lower kyanite-garnet gneiss and upper calcareous gneiss, decreases the metamorphic grade upwards (i.e. northwards), and grades into the overlying Tibetan Tethyan sediments. The transitional zone between them is represented by the calc-argillaceous schist of the uppermost part of Himalayan gneisses in the Modi Khola, whereas a granitic migmatitic body intrudes between the transitional zone and the Tibetan Tethyan sediments. The Tibetan Tethyan sediments consist of the Larjung, Pi and Nilgiri Formations of the Lower Paleozoic in ascending order.

The Main Central Thrust zone, being an intensely sheared zone and remarkably varying in thickness, has played a role as sliding planes to the southward overthrusting Himalayan gneisses. A klippe of the Main Central Thrust zone is found on the south of the Kali Gandaki-Bari Gad fault (Arkha crystalline zone) which continues into the Jajarkot Crystalline zone in western Nepal.

The Baglung zone as well as the Bihadi is made up of the Midland meta-sediment Group of Riphean to Eocambrian age and autochthonous in character. The stratigraphic and structural position, however, of the northwestern extensions of these zone (Rukum and Dhorpatan zones) is open to question.

The southwest unit comprises the Arkha crystalline, Piuthan, Derithan and Tansen zones of parautochthonous in character. These zones are characterized by intense folding and faulting as compared to those in the northeast unit, and are composed of the Piuthan Group except for the Arkha crystalline zone and a part of the Tansen zone. The Piuthan Group consists of the Derithan, Kitghat, Gulmi and Domti Formations from the base upwards, and is considered to be Paleozoic in age, although no fossil has been found.

The Bardanda zone composed of the younger sediments is a folded zone which is bounded to the Siwalik zone on the south by the Main Boundary Fault. The Siwaliks are excluded from the present paper.

The metamorphism of the Himalayan gneiss, Main Central Thrust and Baglung zones correspond to the amphibolite, upper greenschist and lower greenschist facies, respectively. The Midland metasediments in the Baglung zone show the increasing metamorphic grade northwards (i.e. stratigraphically upwards). Such a reverse metamorphism may be attributed to the southward overthrusting of the Main Central Thrust and Himalayan gneiss zones

The northeast and southwest units are in contrast each other in various respects, for example stratigraphy, tectonics and metamorphism. The separating Dhorpatan-Bihadi zone preferably belongs to the northeast unit in the above respects. In conclusion the present area is both geologically and topographically a transitional area between central and western Nepal, and the Kali Gandaki-Bari Gad fault is of particular importance in considering the tectonic flame of the Nepal Himalayas.

ACKNOWLEGEMENTS

We are indebted to Mr. K. Shiraishi (National Institute of Polar Research) for his kind assistance with EPMA analysis and Dr. T. Kano (Yamaguchi University), who is a member of our party, for providing the route map along the Ranughat Khola. We are also thankful to Miss. C. Sato and Mr. N. Yoda for help in preparing the manuscript and laboratory work. Mrs. K. Arita kindly typed the manuscript.

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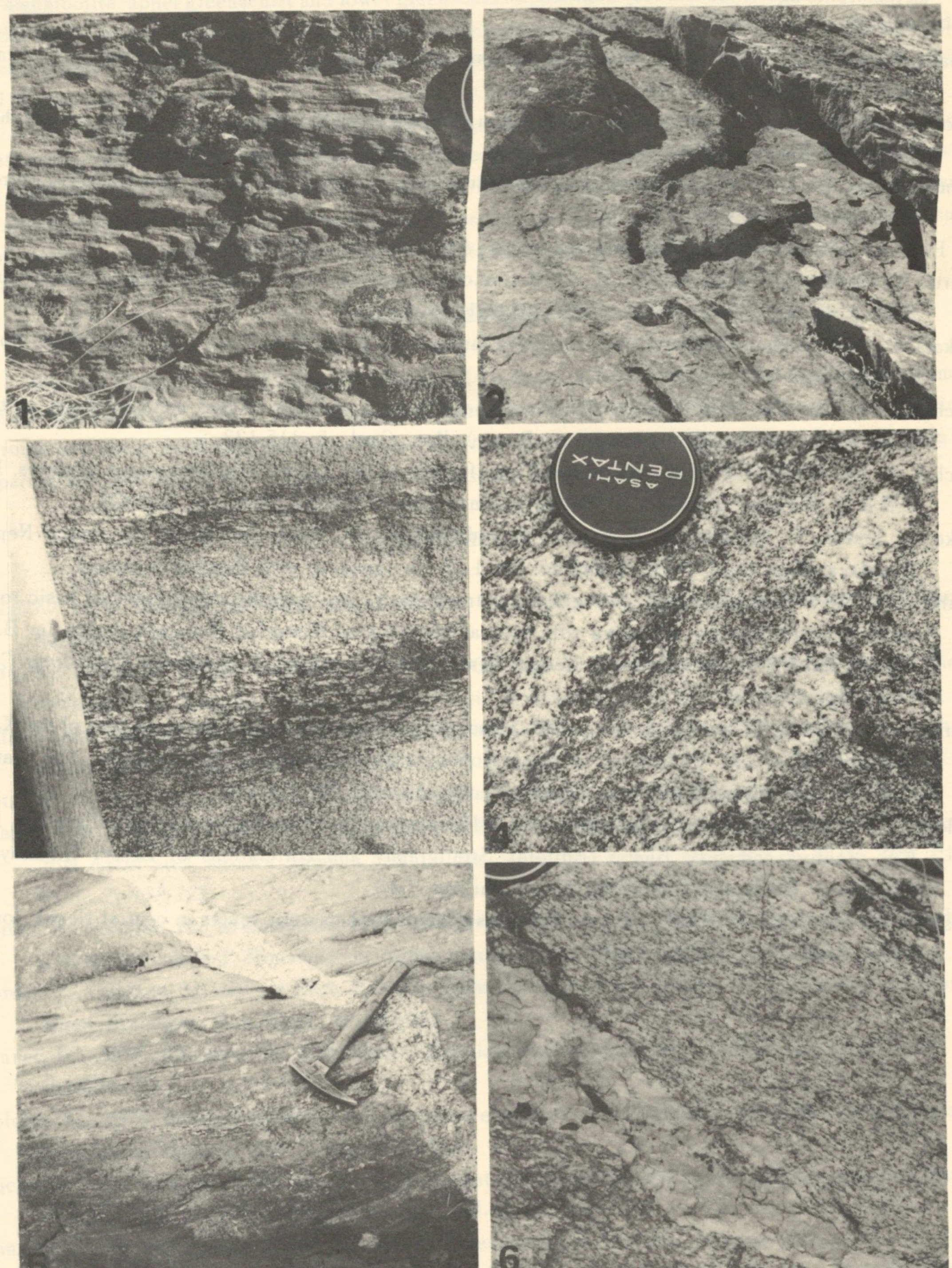


Plate I. 1. Slump fold in Larjung Formation. 2. Axial-plane cleavages in Pi Formation. 3. Banding structure of the Himalayan gneiss. 4. Leucocratic mobilizate in the Himalayan gneiss. 5. Intrusion of tourmaline granitedyke in the Himalayan gneiss. 6. Leucogranite and tourmaline-garnet-mica augen gneiss in the Himalayan gneiss zone.

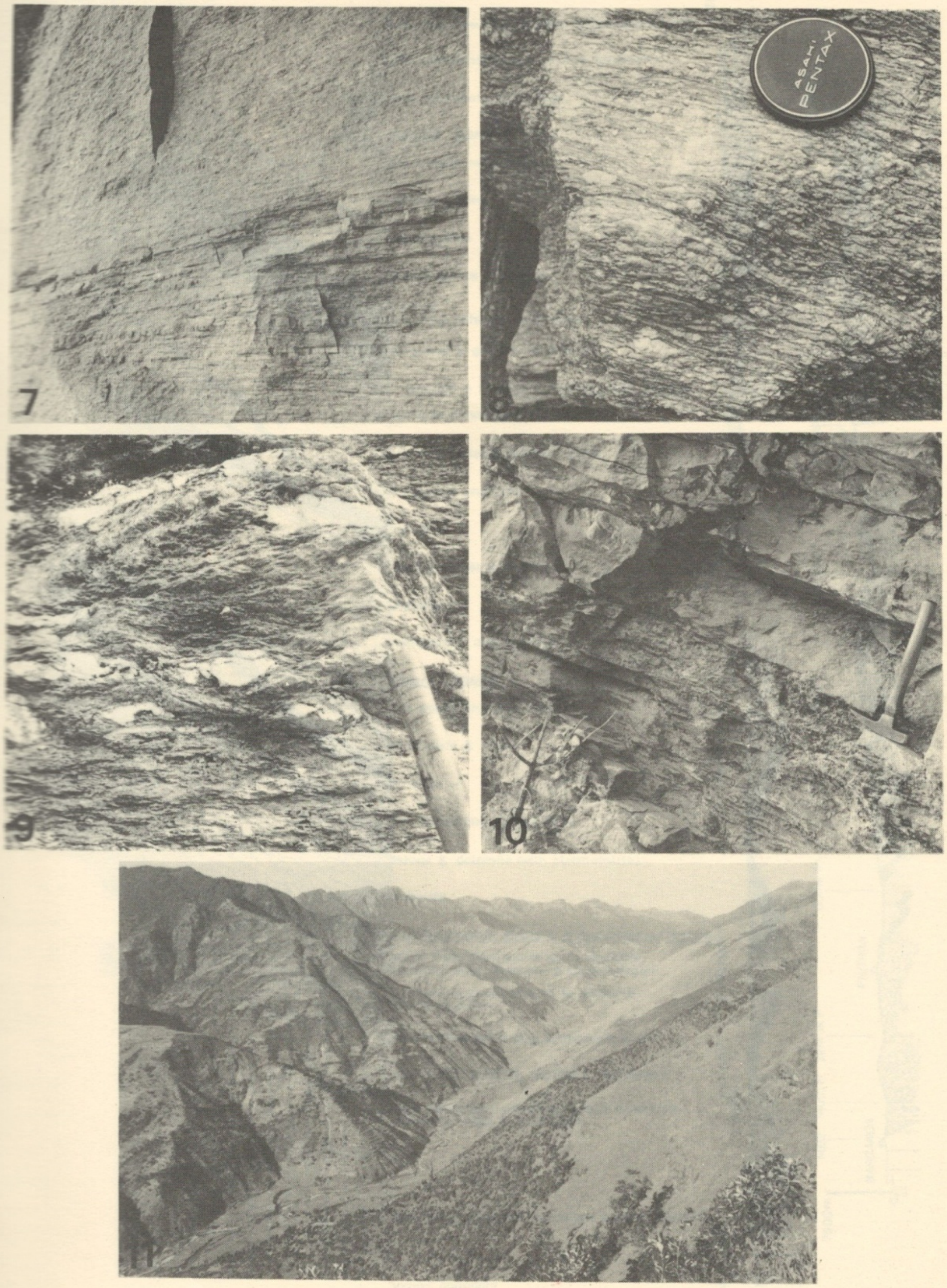


Plate Ⅱ. 7. Augen gneiss grades into quartzite near Ulleri. 8. Ulleri augen gneiss. 9. Phyllitic mica schist with lenticular quartz aggregates in the MCT zone. 10. Alternating beds of quartz sandstone and green phyllite in the Baglung zone. 11. The upstream of the Kali Gandaki near the crossing of the MCT at Dana.

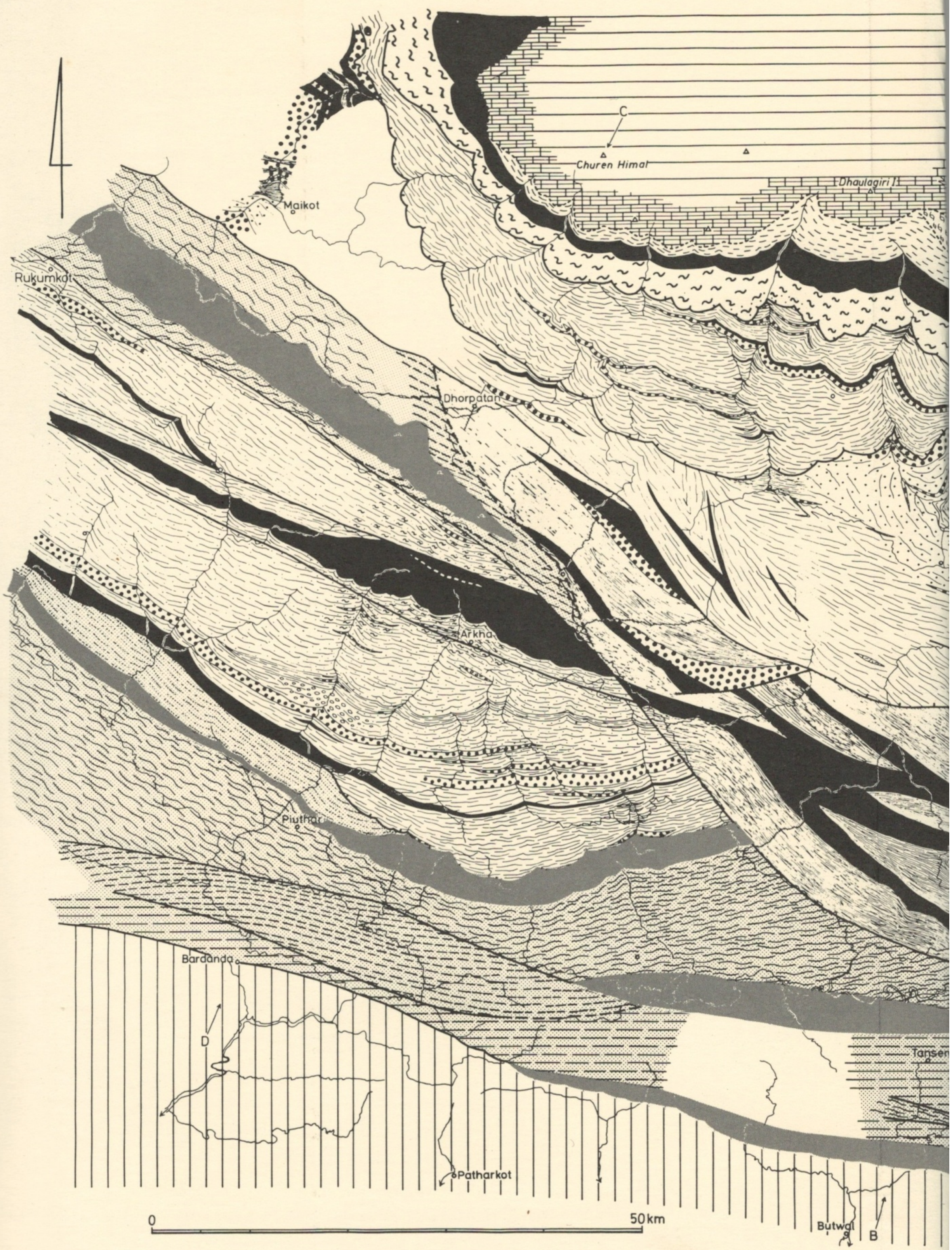
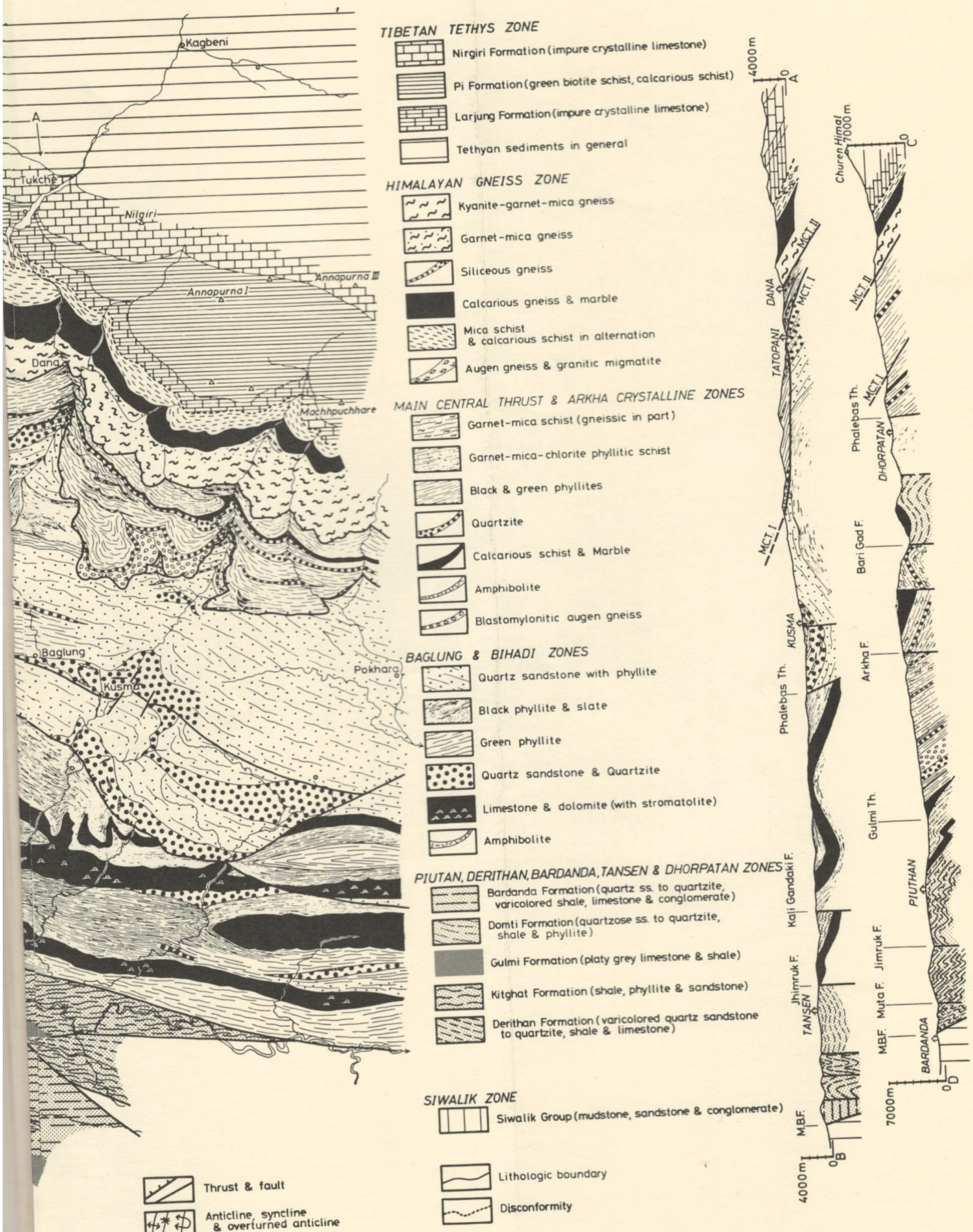


Fig.8 Geological map and cross-sections of central Nepal between the Modi Khola and the Lungri Khola, Compiled from



ako *et al.* (1968), Fuchs and Frank (1970), Hashimoto *et al.* (1973), Pêcher (1975), Kano (1982) and Present data.