Report on the Geological Survey of Nepal

by Toni Hagen

Fieldwork carried out under appointment
of the United Nations Programme of Technical Assistance

Volume 2:

GEOLOGY OF THE THAKKHOLA
including adjacent areas

Attached plates in separate cover

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Mémoires de la Société Helvétique des Sciences Naturelles

Band / Vol. LXXXVI/2

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Preface by the author

Following the first volume of the Report on the Geological Survey of Nepal, which was dealing with the geological features of the entire country in a brief comprehensive way, this second volume gives the detailed geology of the Thakkhola area in northern Nepal (fig. 1). The choice of this remote area, which is at present of minor importance regarding economic geology was made due to the fact that the Thakkhola takes a key position for the understanding of the whole geology of Nepal and even beyond the country for the understanding of the structure and evolution of the Himalayas in general. It might be mentioned here, that volume 3, covering the western third of Nepal is under preparation at present, and it is intended to cover the rest of the country in two further volumes.

The first short trip to the Thakkhola was made in spring 1952. Rich findings of fossils in the sediment zone north of the main range of the Himalayas made the importance of the Thakkhola from geological standpoint of view, clear. In the course of a long expedition in 1954 to the remote, hitherto completely unknown areas of the Dolpo and Mugu, the Thakkhola was again visited. However this campaign turned out disastrous, which severe dysenterie, malnutrition and Beri-Beri sickness, and a monsoon which was by the local people considered to be the most severe they were able to recall. Finally I had tried again in autumn 1957, this time successfully.

The Manang valley, neighbouring the Thakkhola in the east, was investigated in 1952, 1953, 1954 and 1957, the main work being done in 1954 (see fig. 2).

Preparation of this volume was made possible through the Bureau of Technical Operations of the United Nations (BTAO) which enabled me to work on the manuscripts and geological maps and profiles from October 1962 through to the end of January 1963. However, completion of the work took considerable more time in 1963 and 1964, during my United Nations Technical Assistance assignment to Bolivia. In fact I spent all my free time on this volume.

Printing of the volume and the costly multicoloured maps and cross sections is financed through the Denkschriften-Kommission of the Schweizerische Naturforschende Gesellschaft (Swiss National Academy for Natural Sciences).

I want to express my sincere thanks to both the mentioned organizations. Of the BTAO of the United Nations I should like to mention Mr. Chi-Yuen Wu (Deputy Director of the BTAO) and Mr. Ricardo Luna (Chief, Section for Asia and the Far East BTAO).

Considerable difficulties arose for printing, reading of proofs, etc., due to the transport and communication problems between Switzerland and my various duty stations and missions to which the proofs had to be sent back and forth: La Paz, New York, Khartoum, Addis Ababa, Niamey. Due to the excellent cooperation from the printer, Fretz Bros. Ltd., we eventually succeeded in this difficult task. It was very fortunate that during 1967 and 1968, due to my various missions to Africa, I was able to visit Switzerland several times and discuss all the problems with the printers personally. In this connection I should like to express my gratitude to Mr. Myer Cohen, Assistant Administrator and Director, Bureau of Operations and Programming, United Nations Development Programme, who enabled me twice to stay a few days in Switzerland for that purpose.

Regarding the financing I owe most thanks to the Denkschriften-Kommission of the Schweizerische Naturforschende Gesellschaft, and especially to its President, Prof. Dr. Max Geiger-Huber.

Prof. Dr. L. Vonderschmitt was kind enough to read my manuscript on behalf of the Denkschriften-Kommission.

His valuable suggestions were most appreciated and I should like to express my sincere thanks to him.

Finally I owe great thanks to Prof. Dr. H. Gutersohn, who, in his capacity as President of the Swiss Federal Coordination Commission for development aid has taken much efforts to bring this publication to a good end.

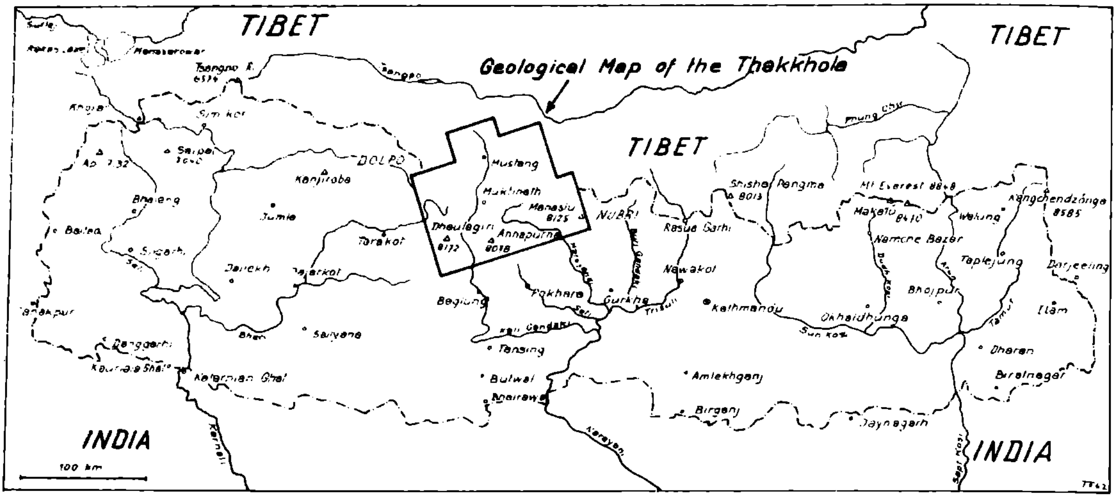


Fig. 1. Index Map of Nepal
showing the area of the geological map of the Thakkhola

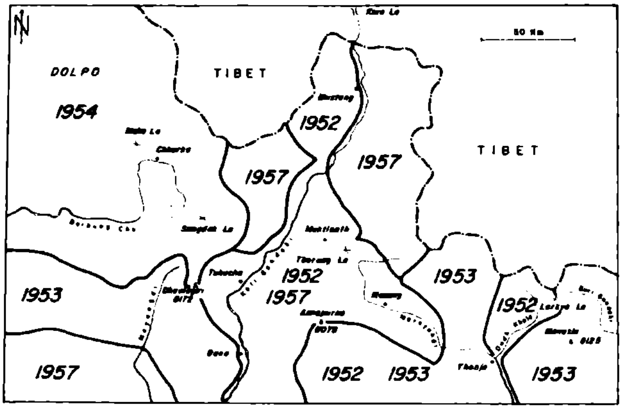


Fig. 2. Index Map of the Thakkhola and the Adjacent Areas
showing the years and the respective cover of fieldwork by the author.

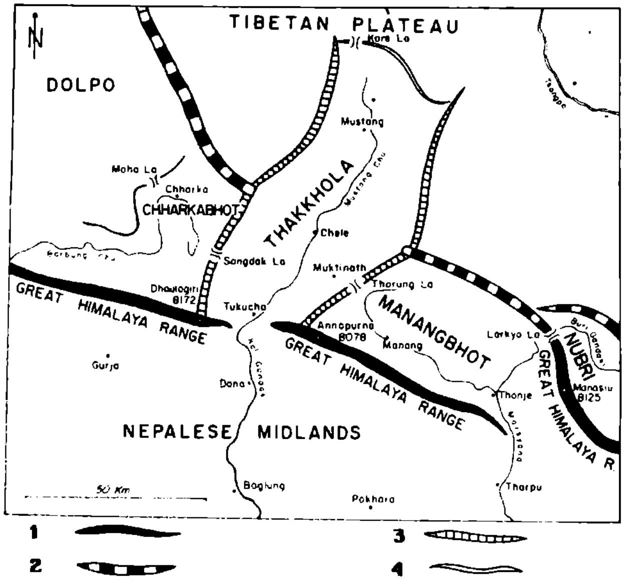


Fig. 3. Physiographic Sketch Map of the Thakkhola

1 Great Himalayan Range
2 Tibetan Marginal Range
3 Horst ranges along the Thakkhola Graben
4 watershed Tsangpo—Ganges

I Geography of the Thakkhola and the Adjacent Areas

1. Physiography

1.1 General

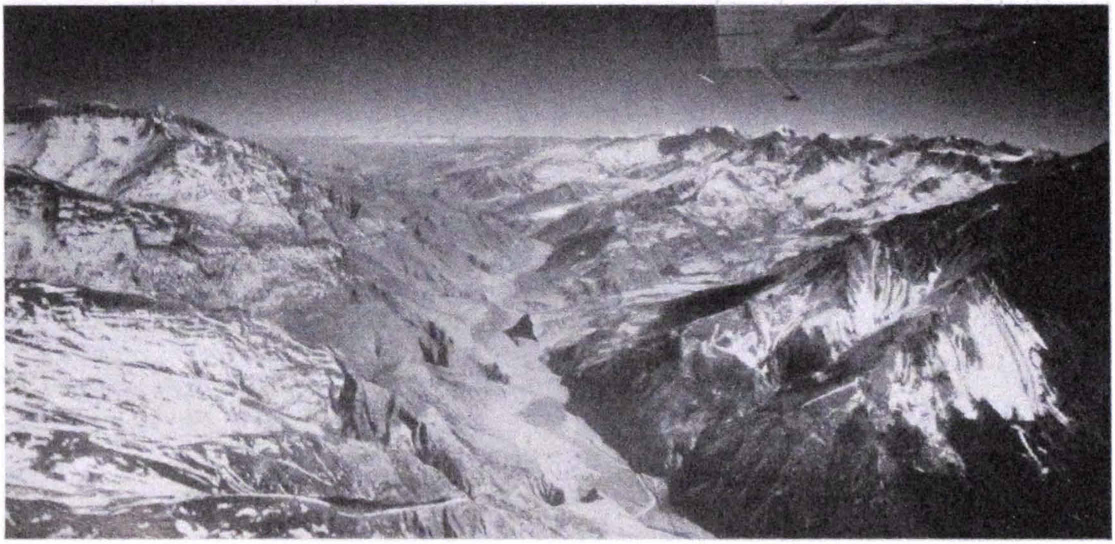
This volume is dealing with the Geology of the Thakkhola area and adjacent regions, namely the Manangbhot in the east and the Chharkabhot in the west (see fig. 3).

These three major valleys form natural compartments which are situated north of the main range of the Himalayas. In earlier publications (see especially volume I), dealing with the Geography and Geology of the whole of Nepal, this type of valleys has been called the *Inner Himalayas*, because they are surrounded on all sides by high snowcovered mountain ranges with altitudes up to 6300 m. In the south, the valleys of the Inner Himalayas are bordered by the main range of the Himalayas, or the *Great Himalayas*, as it is also called. In the north, their natural limit is formed by the *Tibetan Marginal Range* with altitudes at some places up to 7000 m. In the area dealt with hereafter, the Manangbhot lies behind the Annapurna range (8078 m), while the Chharkabhot has the Dhaulagiri range (8172 m) as its natural southern barrier.

Phot. 1. View of the Thakkhola from the South
(aerial photo)

The whole valley is formed by a Graben structure. The major fault at the western side (left side in the picture) can be recognized at the eastern flank of the Dangartse. The major eastern transverse fault system strikes along the foot of the mountain range of the Thorungtse–Deriatse. The down movement was much stronger in the western fault system (Dangarjong fault) than in the eastern fault system. On the other hand, the Mesozoic and Tertiary fillings of the Graben show a strong dip towards the west (left in the picture).—The soft-shaped low mountain range in the far background is the watershed between the Kali Gandaki–Ganges system and the Tsangpo–Brahmaputra.

Dangartse Mustang Thorungtse Deriatse Thini Nup La



Phot. 2. View of the Southern Part of the Thakkhola from the North
(aerial photo)

The white plain in the foreground is the alluvial plain of Tukucha. Its bedrocks form a basin originated both by tectonics and ice age glacial erosion. The southern limit of the basin and thus of the alluvial plain is at Lete formed by the topmost granitic formation of the Kathmandu nappes (see plate III, profile 3). Behind this crystalline barrier, the Kali Gandaki river drops from 2400 m at Lete on a horizontal distance of only 12,5 km to 1200 m at Dana in the bottom of the gorge.

The Thakkhola, lying between has both the Dhaulagiri and Annapurna range as southern limit. (See fig. 3.)

The Tibetan Marginal Range represents (from geological standpoint of view) the southern edge of the *Tibetan Plateau.* In the area in question the said edge does not run parallel to the Great Himalaya, but under an angle, getting away from the main range towards northwest. In the case of the

Phot. 3. View of the Kali Gandaki Gorge from the South
(aerial photo)

Note the ancient land surface at an altitude of about 4000–4500 m at the foot of the high mountain ranges and the convex shape of the valleys below that altitude

Manangbhot, the Tibetan Marginal Range continues via the Larkya pass (5212 m) into the Manaslu Range (8125 m), which belongs to the Great Himalaya. In spite of the angle between the Great Himalaya Range and the Tibetan Marginal Range, the valleys and mountain chains in both the Chharkabhot and the Manangbhot run parallel to the strike of the geological structure. As shown in fig. 3, the Thakkhola and the surrounding mountain range (Sangdak Himal and Mustang Himal in the west, Muktinath Himal and Damodar Himal in the east) take a different position: They run south-north, that is transverse to the general geological strike.

The Great Himalaya is intersected by the narrow gorge of the Kali Gandaki river, while the Tibetan Marginal Range is entirely interrupted through the Thakkhola transverse valley on a distance of about 55 km.

Thus, from the points of interruption of the Tibetan Marginal Range on either sides of the Thakkhola valley the mountain ranges run north, right into the Tibetan Plateau. This is quite an exception in the whole of the Himalayas.

While the Kali Gandaki river draining the Thakkhola, cuts through the Great Himalaya between Annapurna and Dhaulagiri, the drainage pattern of the Chharkabhot and the Manangbhot show a surprising symmetry with regard to the Thakkhola axis: The Barbung river turns towards west behind the Dhaulagiri range and breaks through the main range at the western end of the said mountains. The Marsyandi, draining the Manangbhot, turns towards east just north of the Annapurna range and breaks through the main range at the eastern termination of the Annapurna range. (See fig. 3.)

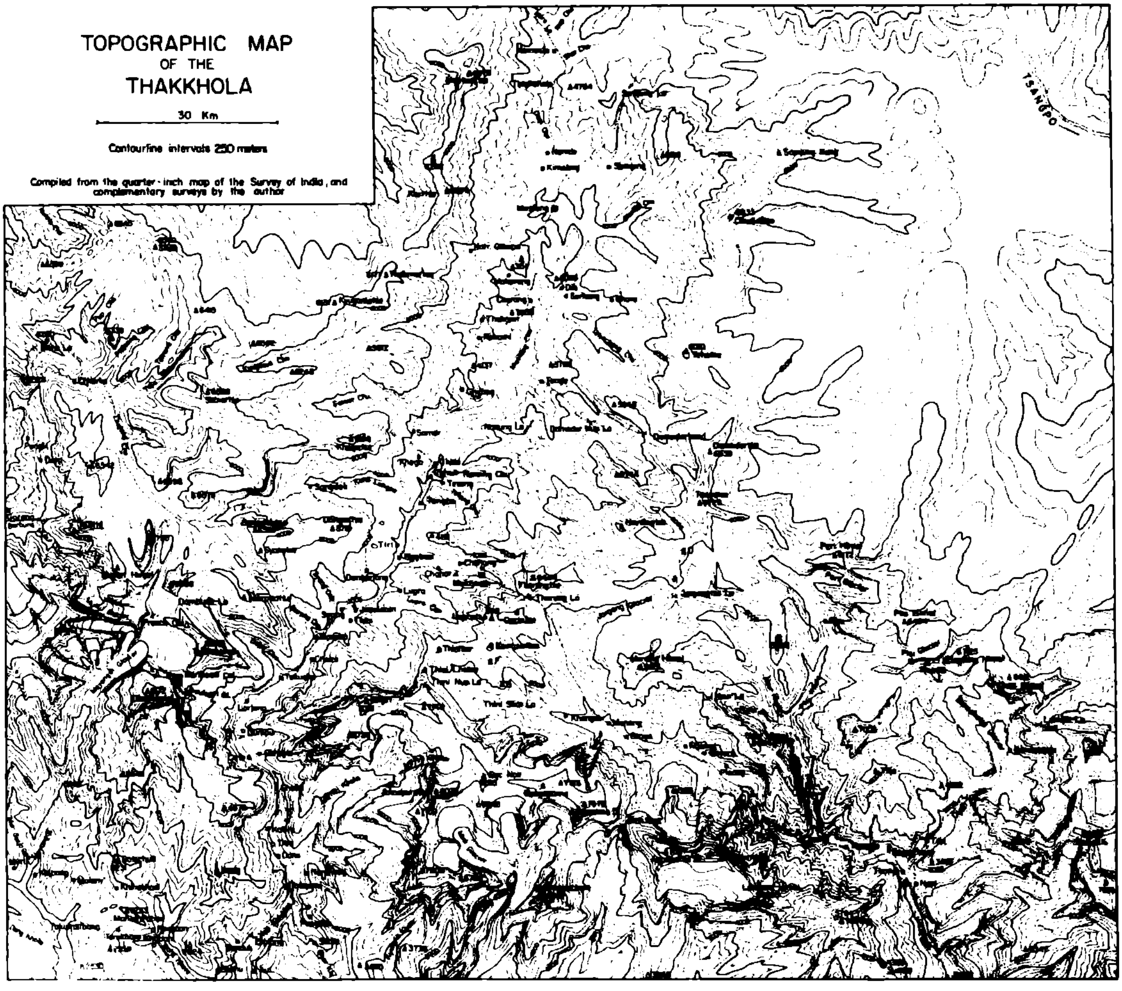


Fig. 4. Topographic Map of the Thakkhola

A generalized topographic cross section through our area dealt with shows three distinctly different levels: The Nepalese Midlands have altitudes between 400 m and 2000 m. The valleys of the Inner Himalaya are between 3000 and 3700, while the Tibetan Plateau, north of the Tibetan Marginal Range has an average altitude of 4000 m and more. However, the Thakkhola valley lies, in a given section east–west, several hundred meters lower than the neighbouring valleys of the Chharkabhot and the Manangbhot. (See profiles I–VIII, plate IV.)

From geological standpoint of view the mentioned four areas cover three distinct zones: the mainly crystalline roots of the great nappes, which build the main range of the Himalayas and their southern flanks; the complicated sediment zone of the Tibetan marginal synclinorium (southern part of Thakkhola, Manang and Chharka) and the simple structured sediments of the Tibetan Plateau (northern part of Thakkhola beyond Chele, see map fig. 3). In this report detailed geological description will be given on the Main Himalaya Range and the areas north of it. However, the geological map and the cross sections include also the southern flank of the Annapurna and the Dhaulagiri range as well as the Chharka area in order to render a better comprehensive understanding of the whole region and especially of the evolution of the Himalayas of that area.

Geological fieldmapping was based on the Quarter-inch map of the Survey of India (1:250000). Mountain climbers, used to the modern large scale photogrammetric maps of the Alps, have repeatedly complained about the inaccuracy of the Quarter-inch map of Nepal. However in my view those complaints are not justified. The work done by the Survey of India in 1926/27 has to be considered as a masterpiece of triangulation and survey work, regarding the most difficult conditions which were met within the Nepal Himalayas, lacking all the modern facilities, like any kind of transport, modern communications, aerial survey and computers.

There are very few areas, all of them on and beyond the main range of the Himalayas, which show inaccurate mapping or gaps. In the enclosed topographic map, those gaps and errors have been corrected mostly as a result of own fieldwork. Those areas and the respective corrections are dealt within the regional geological descriptions here after.

The Quarter-inch map of the Survey of India has been drawn in the obsolete English scale in feet and miles. India is right now changing to the metric system. However it will last some time until new maps in the metric system will be edited by the Survey of India. Besides, the whole territory of Nepal has been declared as "restricted area" from map standpoint, due to the political struggles in that area. Thus, the reader will have to rely for many years to come on the present editions of maps in the English system.

Nepal herself has no Survey Department, which is in the position of carrying out any survey work of this kind. The Nepal Government still sticks to the old English system. However they will have to change in the future, if they are not willing to run the risk of being bypassed in modern topographic surveys. (Also China has adopted the metric system.)

All the data in this publication are given in the metric system. In order to help the reader, an index map is given with all the data in both the English and in the metric system. (Fig. 9.) A major difficulty was found in the lack of names of mountains, valleys, passes and other localities. Where names are given in the Quarter-inch map of the Survey of India, they proved correct within the area where the Nepalese language is spoken. However, the region north of the main range of the Himalayas is populated by assimilated Tibetan people, speaking the Tibetan language. In addition there are zones especially in the Thakkhola, where the tribe of the Thakkhali is living. There, both the Nepalese and the Tibetan languages are in use. The tremendous trade through the Thakkhola route brought different tribes and people together, and with the well known ability of the Nepalese people to pick up other languages very fast, most of the people in the whole of the Thakkhola and the adjacent areas are bilingual. Thus it must not surprise us that also the names of the localities show a bewildering complexity, depending from the standpoint of view of the Survey or who covered the area. Several mountains have got two names, depending on whether one asks a Tibetan living on one side or a Nepali living on the opposite side of it. As a result of this complexity, many names are crippled and the original sense difficult to recognize. For example «Mohala Bhanjyang» of the Quarter-inch Map (10 km northwest of Chharka) is a faulty mixture of Tibetan and Nepali language. The correct name would be "Moha La". "La" means pass in Tibetan language, thus "Moha La" means "Moha pass". "Bhanjyang" is the Nepali and Hindi word for pass. Apparently, when the Indian surveyor asked local people (Tibetans in that area) for the name of the important pass he got as reply "Moha La" which he promptly understood as "Mohala" to which he added the word Bhanjyang in his own language, thus resulting "Mohala Bhanjyang".

Unfortunately, only very few language experts have carried out investigations in the area. David L. Snellgrove, well known Tibetologist of the University of London, has made some trips in this part of Nepal. His findings have been adapted in this volume. As usual in survey work, I have tried hard, to use the names of the local language spoken in the area, and I have adopted only those foreign names introduced by mountaineers, which are already in common use in publications (for example "Roc Noir" of the French Annapurna Conquerers).

1.2 Thakkhola

Thakkhola is the name of the largest Nepalese valley lying entirely north of the main range of the Himalayas (see fig. 1), at 84° east and 29° north. Its main direction is north–south, that means it is a transverse valley. Its southern border is well defined by the Annapurna and Dhaulagiri range, both reaching 8000 m altitude.

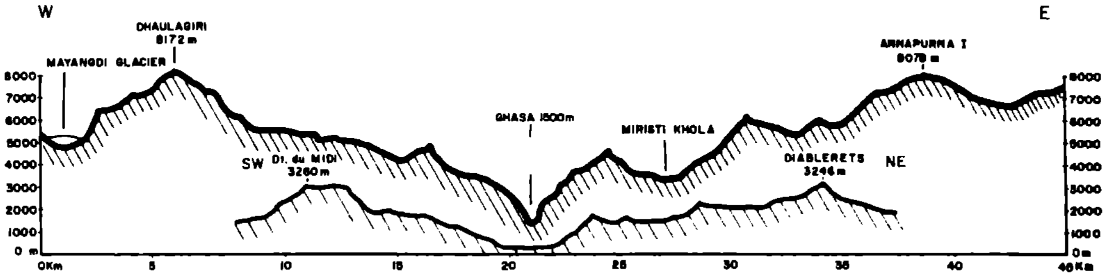


Fig. 5. Cross Section through the Kali Gandaki Gorge
(between Dhaulagiri and Annapurna)
With a comparative section through the Rhone valley (Swiss Alps) between Dents-du-Midi and the Diablerets, in the same scale.

The northern end of the Thakkhola is formed by the relatively low (4400 m) main watershed between the Ganges river system of India and the Tsangpo river in Tibet. From Dumpu at the northern foot of the Main Himalaya Range the Thakkhola extends for about 78 km to the Mustang Himal, which forms the said watershed. The width varies between 15 km in the south (near Tukucha) and a maximum of 55 km in the central part (near Chele). In the northern part, near Mustang the width decreases again to about 38 km.

The name Thakkhola is derived from the Nepalese words: Thak = red; Khola = river. Thus Thakkhola means the valley of the red river, or brief, the "red valley". Indeed, in the cañon-like intersection in the huge Tertiary and Quaternary formations and also on the dry and deserted higher plateaus the red colours are far prevailing. The mountain ranges on either flanks (east and west) of the Thakkhola, reach between 6000 and 6500 m altitude. They show a surprisingly even level, which we may call "Gipfelflur" (phot. 46). There is a sharp drop from the main range in the south (Dhaulagiri 8172 m, Annapurna 8078 m) to the "Gipfelflur" of the northern mountain ranges (see plate VII fig. 2 and 3, and photos 1, 41, 46 and 70).

The Kali Gandaki (Kali = Hindu Goddess; Gandaki = river in Sanscrit) drains the Thakkhola valley. However, this big river maintains this name only from the entrance into the Ganges plain up to Chele, in the central part of the Thakkhola. The upper course (north of the village) is called Mustang Chu (Mustang = districts capital in the north; Chu = river in Tibetan language).

The gradient of the Mustang-Kali river shows the various steps and flat basins, which are characteristic for all the transverse rivers of the Nepal Himalayas: a steep gradient from the place of origin on the main watershed; a flat portion north of the main range and a tremendous drop within the gorge of the main range (fig. 6). From its origin on the Kore La (La = pass in Tibetan language) it drops within 25 km from 4400 m to 3600 m near Mustang. From Mustang the gradient is flattening; it drops only 500 m as far as Chele (3000 m). From Chele to Dumpu (2600 m) it flows in an alluvial plain which has on 35 km horizontal distance a drop of only 400 m. At Dumpu the Kali Gandaki enters the crystalline of the Main Himalaya Range and drops on a distance of only 12.5 km down to 1200 m at Dana, rushing down in what may be called the deepest gorge in the world (phot. 3 and 4). Dhaulagiri (8172 m) and Annapurna (8078 m) on either sides are separated by only 30 km horizontal distance. If we take the Nilgiri peaks of the Annapurna group (7000 m) the horizontal distance reduces to mere 22 km (fig. 5 and photo 3). Unique for a drainage pattern in a major mountain range, but ordinary for the Himalayas the Mustang-Kali river originates on a comparatively low mountain range and cuts through a much higher mountain range after 80 km river course.

The Thakkhola is well known to the Nepalese people of the central Midlands, since the most important trade route from Nepal to Tibet follows this valley. Indeed, the only 4400 m high pass (Kore La) represents the only pass between the Nepalese lowlands and the Tibetan highland which is practically accessable the whole year round.

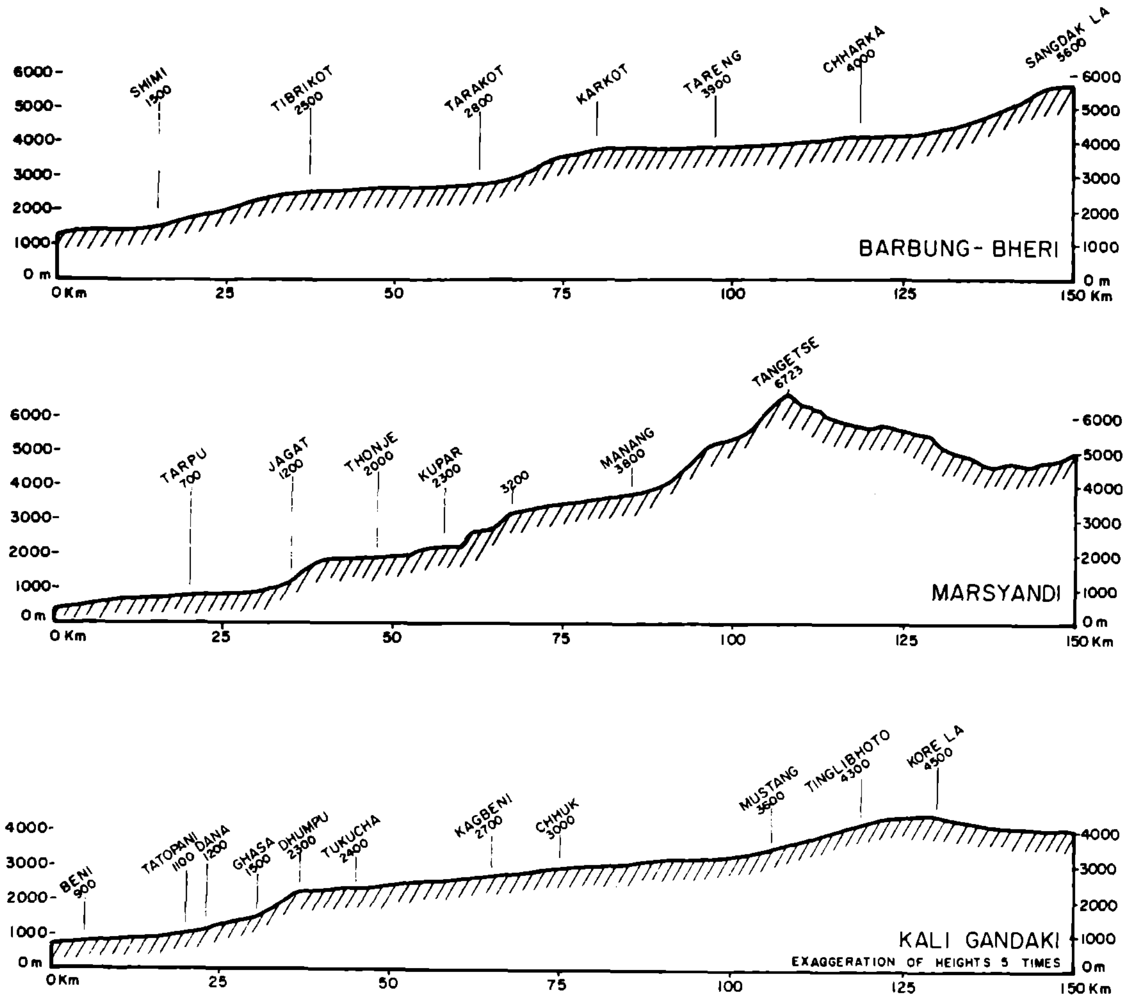


Fig. 6. Longitudinal Profiles of the Barbung River, the Kali Gandaki River and the Marsyandi River
(heights five times exaggerated)

All the 3 profiles show the characteristic step in the gorges of the main range of the Himalayas, i. e. Tarakot–Karkot; Jagat; and Ghasa–Dumpu. – Also the flat basins above those steps are well-illustrated.

Phot. 4. The Kali Gandaki Gorge
The ancient trail is cut into the gneisses above Ghasa. It was a safe route even during the monsoon, until in 1954, when a rock slide destroyed part of it. It has never been repaired since then. Consequently the river has to be crossed twice on the detour on two hazardous makeshift bridge devices. During exceptional heavy rains the gorge is totally inaccessable.

However, the Thakkhola valley consists of two physiographically and also otherwise distinct parts, the respective boundary lying at Chele. The Nepalese people call the whole valley, from the Main Himalaya Range right up to the main watershed Thakkhola, though this name should in a strict sense be applied only to the southern part, where the Nepalese word "Khola" is used, and where the tribe of the Thakkhalis is living. In this publication, as common in Nepal, the name "Thakkhola" is applied to the whole valley, right up to Mustang.

1.3 Manang

Different from the Thakkhola valley, the Manang valley is alined with the geological strike, and thus a longitudinal valley extending from northwest to southeast. It forms a natural compartment, with the Annapurna range as southern barrier, the Muktinath and Damodar Himal bordering in the northwest, the Peri and Himlung Himal lying in the north and northeast and the Manaslu range in the east. Lowest gap in the Muktinath Himal is the Thorung La (5300 m), while in the northeast the Larkya La (5212 m) leads to Nubri, the neighboured main valley of the Buri Gandaki. The Marsyandi river drains the Manang valley and breaks through towards south in the tremendous transverse gorge between the Annapurna range and the Manaslu range.

By geological and especially structural reasons, the Manang valley is divided into several natural compartments. The wide basin in the upper course is dense populated, with the big town Manang as center. Between Pisang (3000 m) and Chame (2600 m), the river enters the crystalline roots of the nappes, in which he has cut the first V-shaped deep gorge. From Chame to Thonje (1900 m) the gradient is relatively flat, with a step just below Thangja. Between Thonje (1900 m) and Mipra (1100 m) the Marsyandi thunders through the deep gorge cut through the main range to reach the Nepalese Midlands at Tharpu. (See fig. 6 and photo 18 and 23.)

The Marsyandi river has two important tributaries, namely the Naur Chu, draining the Peri Himal and the Naur Himal, and the Dudh Kosi (Dudh = milk; Kosi = river, in Nepalese language) draining the much glaciated mountain groups of the Manaslu range, the Cheo Himal, and the Himlung Himal.

1.4 Chharka

The Chharka area is situated to the west of the Thakkhola. It comprises the upper course of the Barbung Khola, which has several tributaries as origin. Those are joining near the small village of Chharka. In contrast to the Thakkhola and to the Manang area, Chharka is very thin populated. The upper part of the valley (above Chharka) would provide sufficient space for mountain pastures and settlements, however, it is to high, since Chharka village itself is already 4000 m. In addition, there is no important trade route through this valley. The access from the south through the Barbung valley is difficult and dangerous.

The best connection is with the Thakkhola over the 5500 m high Sangdak La. But also this route is feasible only from May to November. However, there are good trails towards northwest into the Dolpo area, the most remote corner of Nepal, and from there on into Tibet. (See fig. 1 and 3.)

The Barbung Khola enters the first gorge 3 km below Chharka village, flowing in southern direction (see fig. 6). From Tareng it changes towards western direction, following the northern foot of the mighty Dhaulagiri range. This portion is symmetric to the course of the Marsyandi valley and also from geological standpoint it corresponds to the Manang basin. The break through the Himalaya at the western end of the Dhaulagiri range is as much a spectacular gorge as the Marsyandi gorge between Annapurna and Manaslu range (see fig. 1). From here towards the south the river is called Bheri. However, this area is beyond the subject of this volume.

The Chharka area has been included in the enclosed geological map. However, detailed description will be given in volume 3, dealing with western Nepal, which includes the Dolpo area.

2. Climate

The main range of the Himalayas is known as one of the most distinct climate barriers in the world. It separates two entirely different climatic zones: the monsoonal subtropical zone of India and Nepal in the south and the arid highland of Tibet in the north.

The Nepalese Midlands enjoy the monsoonal rains between June and October, while the rest of the year is more or less dry. However, there are the so-called "western disturbancies" in winter, which bring occasionally rain in the Midlands and snow at the southern flank of the Himalayas down to approx. 2,900 m in central Nepal. In addition the southern flank of the Himalayas show extensive deviations from the strict monsoonal climate. Local influences, like the strong insolation in combination with convectional and ordinary updrafts at the mountain barrier, caused by the prevailing southerly winds (southwesterly in dry season; southeasterly during monsoon) bring the southern flank of the Himalayas much more rainfall than the plains further south in India. Regular thunderstorms every

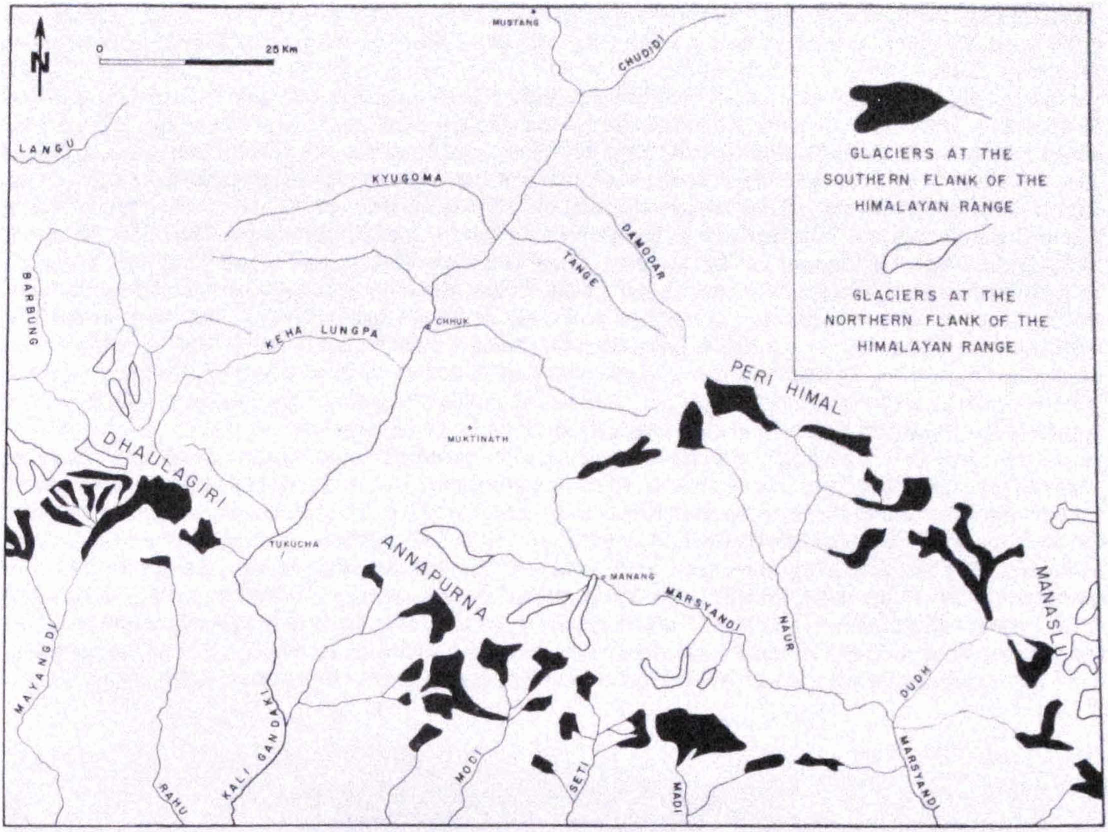


Fig. 7. Sketch Map of the Drainage Pattern and the Glaciation
The main glaciers are situated at the southern flank of the mountain ranges.

afternoon start at the southern flank of Annapurna and Dhaulagiri already in April. This is reflected in the extreme dense tropical evergreen jungles in those areas, and also in the rich rice production.

The climate of the areas north of the main range is entirely different. True, the monsoon shows its effects far into the Tibetan Plateau; however not in form of heavy rains, but only in an occasionally increased cloud cover with fine spray rain.

Local conditions play an important role in the Thakkhola valley. Due to distinct convectional drafts the Thakkhola valley is a so-called dry valley. Strong insolation causes updrafts on the flanks of the valley, while downdrafts prevail above the center. As usual, downdrafts are extremely dry and consequently, the bottom of the valley practically does not get any rainfall at all. This fact is clearly reflected in the vegetation (see fig. 8). The valley itself (3000 m) is desert, while mountain pastures and light forests are found only on the flanks at altitudes around 4000 m. However, the forests decrease from south to north. Apparently surprising, the snow limit lies at the northern flank of the Annapurna range higher than at the southern flank (5000 m compared with 4600 m).

At the southern flanks of the main range, single peaks of a little more than 5000 m are glaciated, while north of the Great Himalaya peaks of 6000 m are during summer completely free of snow.

When I made my trip in October 1957 I was not able to cross the 4500 m high Namun La at the eastern end of the Annapurna range (see fig. 4) due to a snow cover of more than 1 meter. I was concerned about the feasibility of my further programme, since I planned to cross the Thorung La (5300 m) 50 km further to the northwest, in order to get from the Manang valley into the Thakkhola (see fig. 3 and 4).

However, I was most surprised, when moving further north and steadily climbing from Manang towards the Thorung pass, that the snow limit gradually raised with me from 4000 m at Manang to 5000 m on Thorung La, and at the same time also the snow cover above the snow limit became more and more thin.

It is evident, that precipitation has greater influence on glaciation of the Himalayas than the temperature. Also the exposure to sunshine appears to affect the glaciation more than the real air temperature. The area north of the main range gets much more exposure to sunshine than the southern flank, though the air temperature is much lower. A look at the map of the drainage pattern and glaciation (fig. 7) shows that all the big glaciers are situated on the southern flank of the main range. In zones, where the main range is interrupted by deep transverse valleys we find the big glaciers at the southern flank of the Tibetan Marginal Range. In those areas, like between Larkya La and Tangetse, the monsoonal winds are not stopped by the barrier of the Great Himalayan Range but get a free entrance through the Marsyandi valley and the valleys of the Dudh Khola and the Naur Chu. They drop their water content when drifting up to the further north situated Tibetan Marginal Range, where we consequently find the big Bimtakothi glaciers, the Phu glacier and the Peri glacier (fig. 7). These are just general remarks on the general glaciation related to the climatic barrier of the Himalayas. Details with regard to both the present and the ancient glaciation will be given later on.

A trip from the Thakkhola down through the Kali Gandaki gorge brings the greatest possible contrasts in any respect and in any season. During summer monsoon, the northern limit of the monsoonal clouds form a tremendous barrier above the Himalayas (phot. 5). They seem to move northwards, but they really remain more or less at the same place, with their northern front between Dumpu and Tukucha. They turn like a big roller and remind one very much of the "Föhnmauer" of the Alps. Except the center of the valley itself, the air which has traversed the main range of 8000 m altitude, drops into the northern valleys and is therefore locally dry like other downdrafts. When walking from the north towards Tukucha, one enjoys the fine weather of the Tibetan highlands. However a storm-like southerly wind can render crossing the narrow bridges sometimes dangerous.

Phot. 5. The Cloud Barrier Forming the Northern Front of the Monsoon above Tukucha and on the Annapurna range, seen from the north

The climate is dry: barley grows in the fields with irrigation only. At Tukucha either flanks of the valleys show increasing coniferous forests. At Larjung, one enters the cloud barrier, which, for the time being, greets the traveler with a fine spray of rain. It is getting darker, when moving towards the south. At Lete, one enters the real monsoon with heavy rains. Moist mountain forests with rhododendron, ferns and bamboo, over and over covered by fungus and lichen indicate the humid climate. For the three months of the monsoon the valley is veiled by thick clouds and fogs. The southerly wind has ceased in the gorge itself. During exceptional heavy monsoon rains, the walk down the Kali Gandaki gorge to Dana can be dangerous. Rockfalls, landslides, washed off bridges threat the people; a tremendous noise of all the thundering water fills the whole valley and sometimes for days and weeks the whole valley is not accessable. Then down towards Dana, there is again a surprising change, when one finds temperatures up to 40 centigrades, rich ricefields and banana trees. And these entirely different areas are separated only by a one day's walk!

In winter, the change of climate is not less impressive. At Lete, there is snow and ice, the ground and the waterfalls on the steep mountain flanks frozen, while only after a few hours walk down the gorge one can pick delicious oranges from the trees.

Of course, the two completely different types of climate on either sides of the main range have a great influence on the erosion of the mountains. The southern flanks of the Dhaulagiri and Annapurna range are exposed to extreme erosion forces. All the weathered material is washed down and deposed in the valleys of the Midlands and further south in the Ganges plain. Tremendous steep, even perpendicular slopes, intersected by deep gorges drop down from the snowcovered mountains of 7000 m and 8000 m altitude down to the steaming hot subtropical valleys. The Annapurna range for example builds up from the valley of Pokhara (800 m) to 8000 m on a horizontal distance of only 30 km, and without any intermediate mountain ranges, but just in one single flank. The drop of the Dhaulagiri range down into the Mayangdi and Gurja valleys is not less impressive. Undoubtedly, these areas represent the world's greatest differences of altitudes compared with the short horizontal distances.

3. The Natural Vegetation

Fig. 8 gives a map on the natural vegetation of the area concerned. There are three main factors which affect the natural vegetation. At the southern flank of the main range, the influence of the altitude is dominant. The boundary between different types of vegetation corresponds approximately to contour lines. Thus we find up to 2000 m tropical evergreen forests; between 2000 m and 3000 m tropical wet evergreen mountain forests; between 3200 and 3900 m temperate wet mountain forests of rhododendron and conifers; up to 4000 m rainy subalpine forests and up to 5000 m wet alpine scrub and meadows.

Different from this division according to altitudes we find in the Manang valley and in the Thakkhola a different pattern of natural vegetation. The northern flank of the Annapurna in the Manang valley shows the most beautiful temperate mountain forests, with tremendous conifer trees between 3000 and 4100 m. This zone, though belonging to the Inner Himalayas, gets humidity from clouds entering the Marsyandi valley from the south. Often, a solid cloud cover can be seen at this altitude sweeping along the northern flank of Annapurna, while the opposite side of the valley, at Pisang and Manang, enjoys full sunshine. Consequently, the mentioned temperate mountain forests can be found only at the southern flank of the valley while the northern flank is bare of forests, but covered by dry scrubs and the land is used for cultivation of potatoes.

In the Thakkhola, especially in the northern part, a similar feature can be observed. Frequently a cloud cover between 3600 m and 4400 m is entering from south through the Kali Gandaki gorge and hanging around on either flanks of the Thakkhola, while the bottom of the valley, caused by convectional downdrafts, enjoys full sunshine. Consequently the bottom of the valley is a pure desert, while on the flanks at altitudes around 4100 m we find thin forests, scrubs and extensive mountain pastures (for example on the Damodar La west).

The boundary between this arid light subalpine forest and the temperate mountain forest is extremely sharp on the eastern flank of the valley. The latter reaches as far as Lupra (see fig. 8).

In the Barbung valley we find a similar pattern. The bottom of the valley (west and beyond our map) is a desert, while the southern flank (towards the Dhaulagiri range) shows beautiful temperate mountain forests.

The extensive mountain pastures on either flanks of the Thakkhola, in the Barbung and Dolpo are well known to the Tibetan salt traders. There they find excellent grazing grounds for their herds of yaks, sheep and goats. However it has to be mentioned here, that the belt of arid light subalpine forests and mountain pastures is not only caused by the special type of climate, but also by horizons of increased humidity due to unpermeable morainic deposits from ancient tributary ice age glaciers, under which many springs occur.

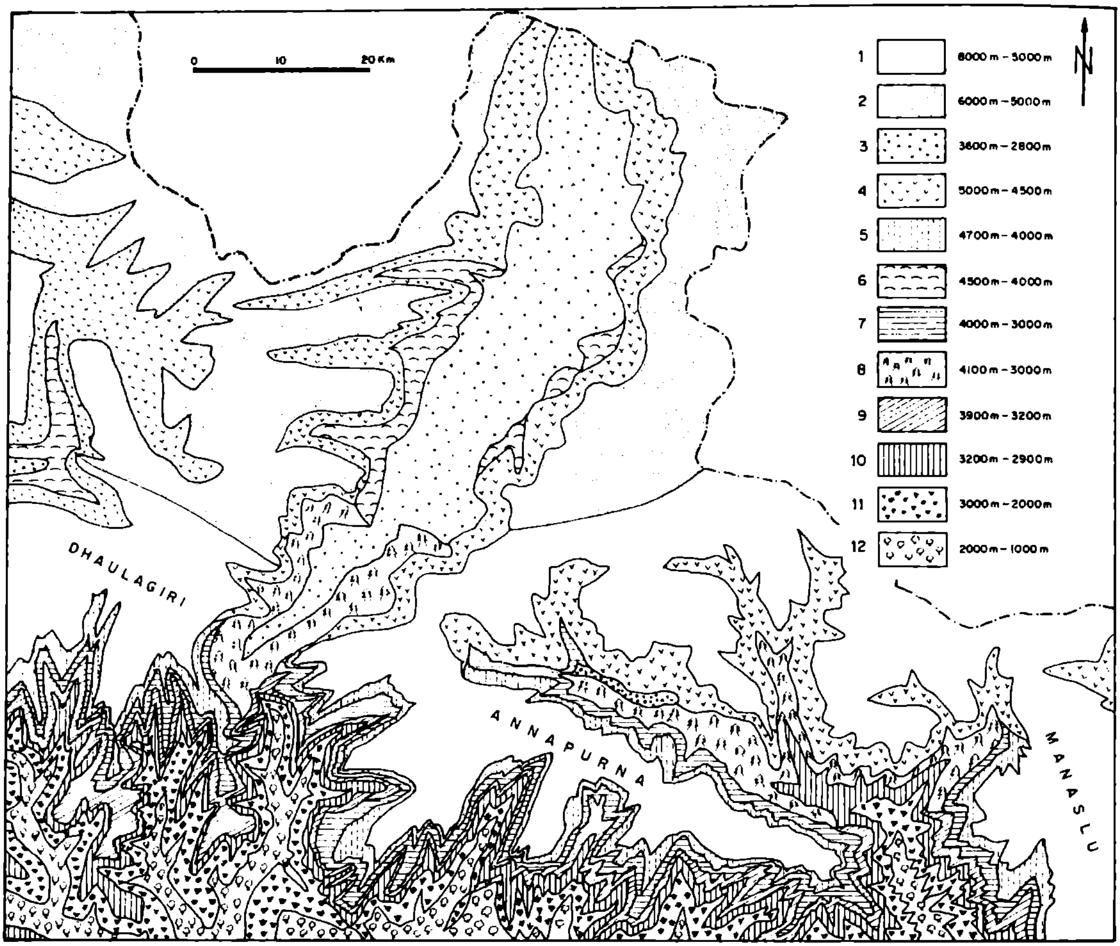


Fig. 8. Map of the Natural Vegetation

1 (8000 m–5000 m) Arctic desert, including glaciated areas
2 (6000 m–5000 m) Arid mountain desert to the north of the Himalayas, included minor glaciated areas
3 (3600 m–2800 m) Dry desert valleys of the Inner Himalayas
4 (5000 m–4500 m) Dry alpine scrub and pastures (fir, juniper)
5 (4700 m–4000 m) Wet alpine scrub, pastures (rhododendron and juniper)
6 (4500 m–4000 m) Arid light subalpine forest (fir, juniper)
7 (4000 m–3500 m) Rainy subalpine forest (birch, rhododendron, juniper)
8 (4100 m–3000 m) Temperate mountain forest, conifers, (Inner Himalaya)
9 (3900 m–3200 m) Temperate wet forest of rhododendron and conifers
10 (3200 m–2900 m) Temperate wet forest of oaks and conifers (with bamboo and fern)
11 (3000 m–2000 m) Tropical wet evergreen mountain forest (oak, bamboo)
12 (2000 m–1000 m) Tropical evergreen forest of medium altitude (pine or fir, chestnut, walnut, oak, Pipal = Ficus religiosa

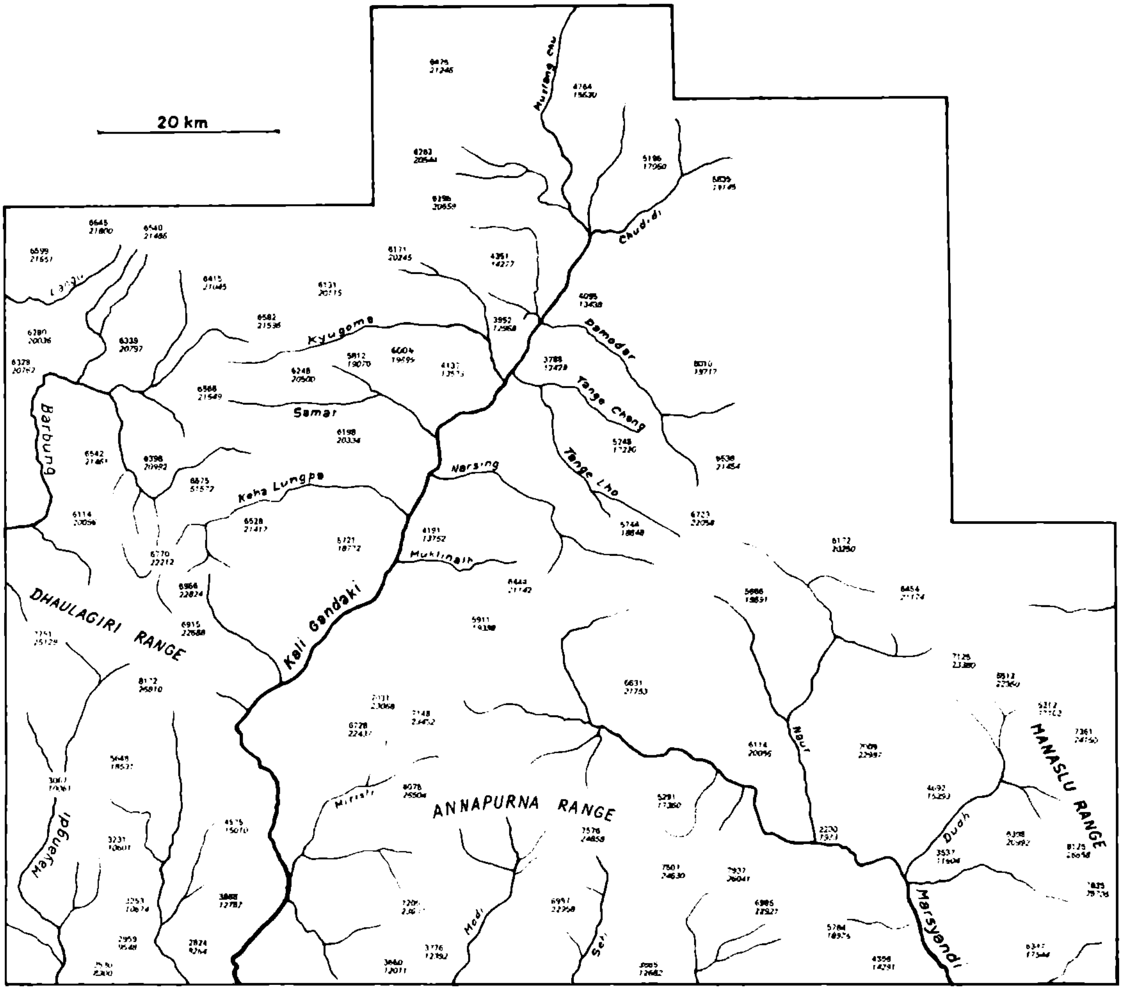
The figures on altitudes are of course only average values. Deviations due to local specific climates occur frequently.

II Geological Observations in the Catchment Area of the Marsyandi

The reconnaissance survey carried out by the author in Nepal is based on geological descriptions of the itineraries followed. The character of this survey, not to speak of the inaccessibility of wide areas, made it impossible, to cover the whole area, as it is used to do with normal geological survey work. Only few areas, which appeared to be key areas were studied in details, and got repeated visits. Of course, many gaps are left by such a survey. Thus the description of the geological itineraries is the backbone of this work.

In this volume, a detailed description will be given on the areas north of the main range of the Himalayas. For the area south of the main range, just the geological description of some of the approaches will follow.

Fig. 9. Index Map Feet — Meters



1. Geological Itinerary at the Southern and Eastern Flank of the Annapurna Range

We start our expedition in the plain of Pokhara, where the Pokhara zone, tectonically the lowest zone of the Nepal Himalayas occurs in a tectonic window.

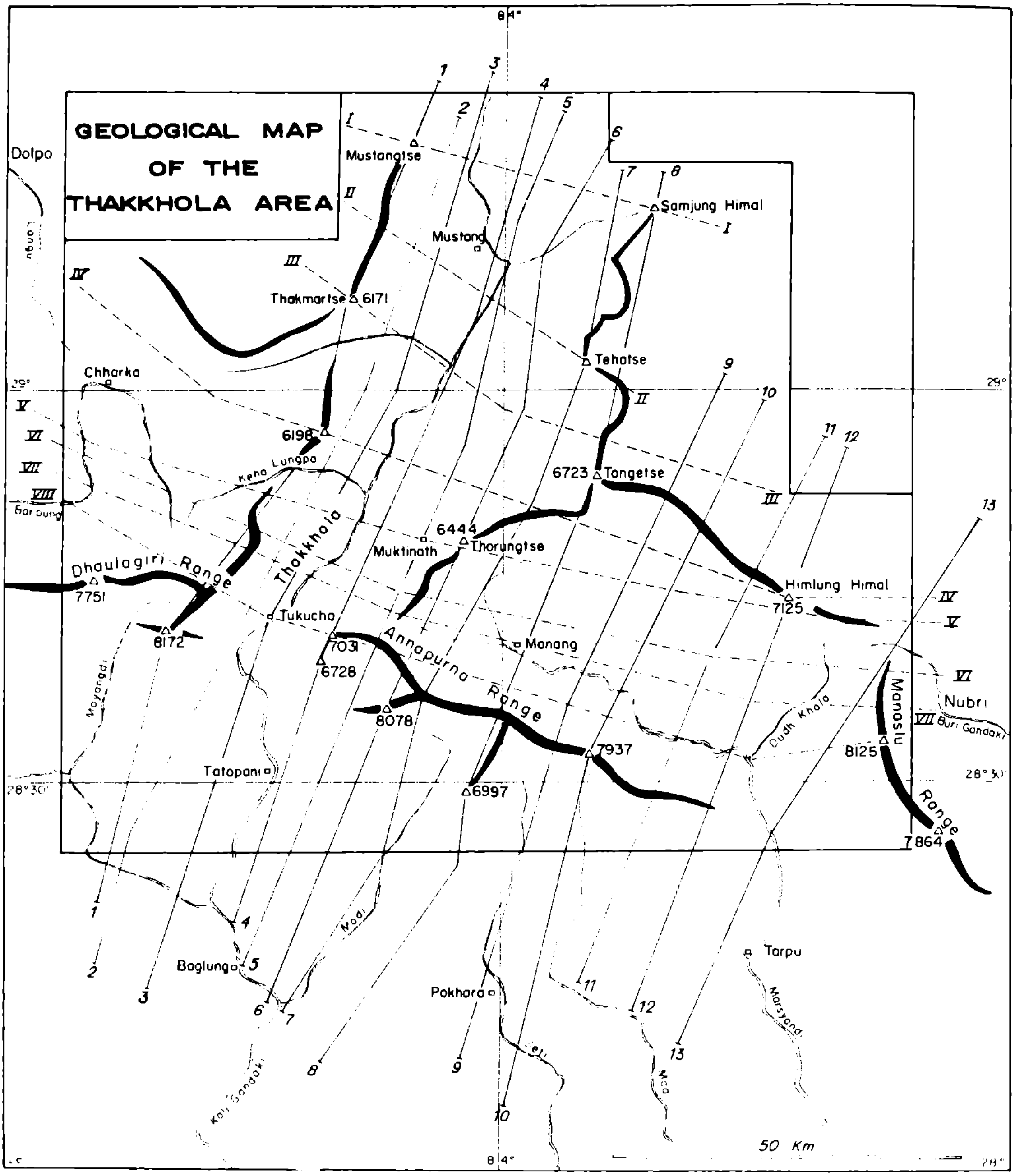


Fig. 10. Index Map of the Transverse and Longitudinal Profiles
(given in plates III and IV)

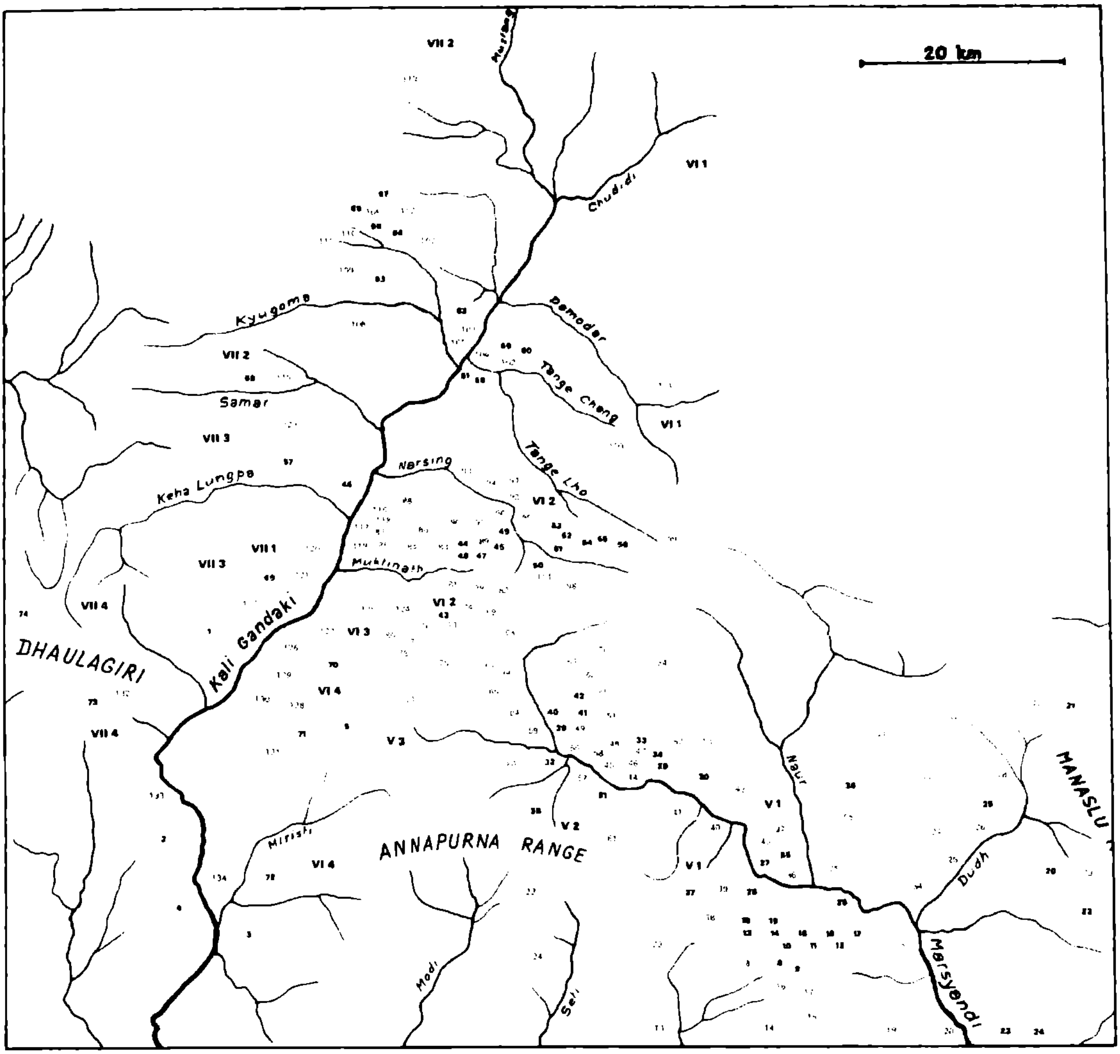


Fig. 11. Index Map for the Figures and Photographs in the Texts
Thin numbers denote figures in the texts, while bold numbers indicate photographs.
The combined Roman-Arabic numbers mark the geological panoramic views of plates V–VII.

The author considers it as parautochthonous formations of uncertain age, possibly ranging from Devonian to Permian, with sericite schists, shales and coarse-grained boulderbeds and conglomerates. The Pokhara zone forms an anticline with the axial strike in the normal westnorthwest–eastsoutheast direction. We meet the axis on our route in the small topographic saddle of Khanwali, 6 km northeast of Pokhara. The axis follows from here in eastsoutheast direction into the river course of the Madi Khola between Thulosonwara and Chisankhu. (Quarter-inch map.)

It is uncertain on this route where exactly we cross the boundary from the Pokhara zone into the overthrust Nawakot nappes. The formations are not much different (see fig. 12), but the basic overthrust must be somewhere between Khanwali and Atigar. A much tectonized zone is found in the middle of the distance between Khanwali and Atigar, in which dolomite slices are found interbedded

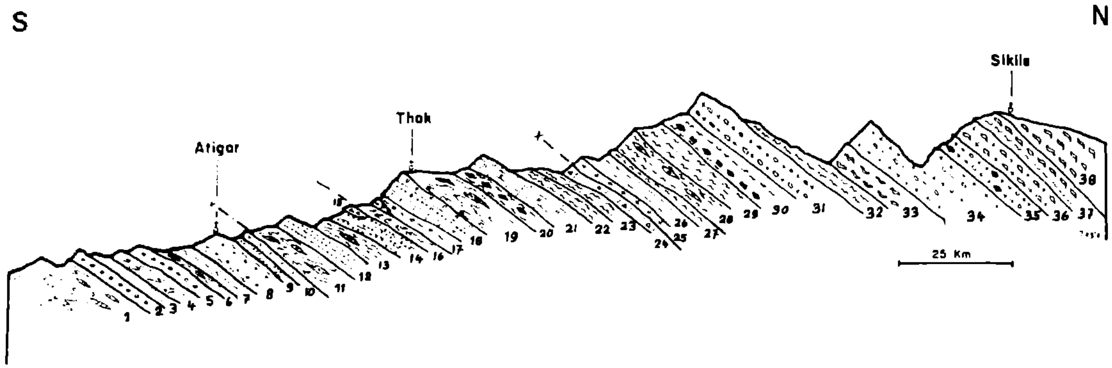


Fig. 12 Profile Sketch Pokhara—Siklis

1 Nawakot slates with quartz veins in the anticline axis; the quartz veins originated possibly in connection with pegmatites;
2 conglomerate, quartzite boulders in phyllites, diameter of the components 1,5 cm;
3 sandstone;
4 tectonized zone, with white weathered quartzites, "Tüpfelschiefer" (spotted shales), schistose slates with biotite and amphibol porphyroblasts; the latter up to 4 mm long and parallel positioned;
5 conglomerates and sandstones;
6 series of alternating quartzites, "Tüpfelschiefer" and quartz veins;
7 chlorite sandstone, soft, with much sericite;
8 large series of slates, sericite-phyllites, and sandstones, with interbedded fine-grained and course-grained conglomerates. Ripple marks on sandstones;
9 white dense platy quartzite, well-bedded, at the top reddish and greenish laminated;
10 dolomite slices;
11 thrustplane, series of slates and phyllites thrust under angel-unconformity over the quartzites and dolomites. Turmaline pegmatites, tectonized and torn into breccia-like formations. Garnet-phyllites in neighbourhood of the pegmatites (see also phot. 7)
12 coarse-grained biotite-sandstone;
13 sericite-phyllites with pegmatite layers and lenses;
14 well-bedded clear-coloured quartzite;
15 series of breccias, components of dolomite and coarse-grained laminated calcareous sandstone in limestone; also components of calcareous "granite" (of the type occuring at the top of Kathmandu nappes 5 and 4 at Namun);
16 sericite-phyllites, tectonized, with microfolds;
17 conglomerates in sericite-phyllites;
18 series of 400 m of Rauhwacke, dolomite, quartzitic dolomite, laminated calcareous sandstones and calcareous conglomerates;
19 black shales with quartz veins, microfolds, apparently thrust upon the series of 18 above;
20 clear-coloured sericite-garnet-phyllite with "Tüpfelschiefer" (spotted shales);
21 limestone, coarse-grained; marble, dolomite;
22 sericite-schist;
23 sandstone with mica (muscowite with biotite);
24 laminated limestone, calcareous breccias;
25 granitic intrusiva;
26 black shales;
27 sericite-phyllites;
28 biotite-gneiss, with layers of granitic intrusivas;
29 biotite-muscowite sandstone;
30 garnet-kyanite schist, diameter of the garnets up to 2 cm;
length of the kyanite crystals 15 cm;
31 porphyric granite-gneiss;
32 coarse-grained biotite-muscowite mica-schist;
33 well-bedded fine-grained biotite-gneiss, with a few intrusive layers;
34 laminated porphyric granite-gneiss;
35 granite-porphyr with garnets up to 1 cm;
36 granite-gneiss;
37 mica-schist, with layers of laminated and porphyric migmatites;
38 biotite-gneiss series of Siklis;

with calcareous slates, conglomerates and sandstones (phot. 6). On the dolomite north of Atigar follows another thrusplane, on which the overlying series are much tectonized and thrust under angle unconformity. Those series also contain turmaline pegmatites and quartz veins, which by tectonics are contorted and torn into what we may call a "pegmatite breccia" and "quartz breccia" wherein the pegmatite and quartz components are bedded in garnet schists and garnet phyllites. (11 in fig. 12, see also phot. 7.)

Between Thak and Taprang the formations change completely and we find various gneisses with granitic intrusives and mica-schists. This has to be considered to be the overthrust of the Kathmandu nappes (fig. 12, up from No. 25).

The whole series up to Siklis (2400 m) the highest village at the southern flank of the Annapurna (settled by Gurungs), has to be considered to be one tectonic unit in spite of the great thickness of approx. 2.5 km. The northern dipping, flat slope north of Siklis consists of garnet mica-schists and muscovite-schists, causing the soft soil suitable for the cultivation of rice.

On the top of this mica-schist series we find laminated coarse-grained limestone and marble (fig. 12).

The overlying series, consisting of fine-grained biotite gneiss, porphyric granite with garnets and porphyric granite-gneiss, are heavily folded and thrust. Undoubtedly the whole series have to be considered to belong to the Kathmandu nappe 2, overthrust upon the limestone on the top of the crystalline Siklis series (see fig. 13).

Our further route from Siklis to Rambrong (12278 ft, 3742 m) leads towards the east and consequently in the direction of the geological strike. The whole western ridge, right down to the Madi river consists of the formations of Siklis, the steep southern flank being built of the granite-gneiss, while the flat northerly dipping flank consists of the fine-grained biotite-gneiss and mica-schists.

Phot. 6. Torn and Folded Dolomite Lenses in Calcareous Sandstone

Clefts in the dolomite are filled with idiomorph quartz crystals (top of Nawakot nappe no. 1, south of Atigar). Such tectonized zones are common along thurstplanes.

Phot. 7. "Quartz Breccia"
formed out of quartz veins and quartz layers due to tectonization.

The cross section from Rambrong to Namun Bhanjyang shows the various crystalline formations of the Kathmandu nappes (fig. 14). When approaching the Namun Bhanjyang, we found the map greatly misleading: What in the map is given as Namun Bhanjyang (18976 ft, 5784 m) is not a pass but rather a glaciated peak. There are two mountain ridges which extend from the Lamjung Himal (22921 ft, 6985 m) towards the east (phot. 8). Between the two ridges there is a great glacier (Namun glacier) feeding the river flowing towards the east into the Marsyandi halfway between Naje and Jagat (fig. 7). The pass itself, which leads from the southern flank of the Namun Himal to Thangja is situated more to the east. That means there are two passes crossing the two mountain ranges mentioned above.

The geological details of the itinerary from Rambrong to Namun Himal are given in fig. 14.

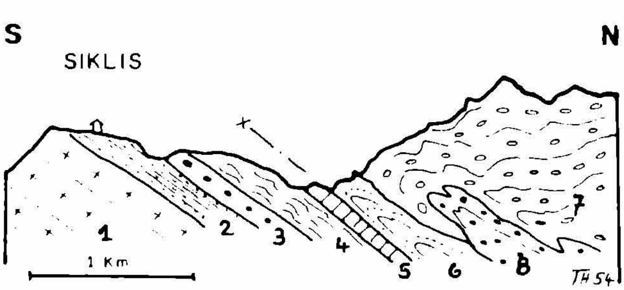


Fig. 13. Profile Sketch North of Siklis

1 granite-gneiss
2 fine-grained biotite-gneiss, with few migmatitic layers
3 garnet mica-schist
4 muscowite-schist
5 laminated limestone and marble, calcareous sandstone
6 fine-grained biotite-gneiss, with few intrusions
7 granite-gneiss, porphyric
8 granite with garnets, porphyric

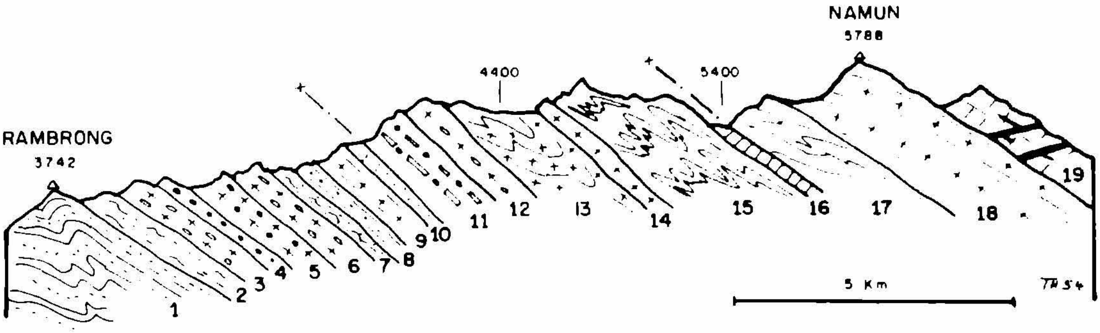


Fig. 14. Geological Profile Sketch Rambrong-Namun (5788 m)

1 sandstone, interbedded with migmatites
2 micaceous sandstone
3 porphyric muscowite-granite, interbedded with migmatites
4 garnet-granite
5 fine-grained biotite-gneiss
6 porphyric granite-gneiss
7 fine-grained micaceous sandstone
8 fine-grained biotite-gneiss
9 granite-gneiss
10 micaceous sandstone and gneiss
11 granite with garnet and kyanite (the latter well-idiomorph with crystal length up to 10 cm)
12 porphyric and migmatitic granite
13 well-bedded gneiss, with migmatite layers
14 granite (muscowite-biotite)
15 large series of migmatites; the latter showing thicknesses between 2 cm and several meters. Various types of dykes cross each other
16 slices of calcareous sandstone
17 gneisses with migmatites, layers of porphyric granite (several meters thick), frequently under angle to the bedding of the mother rock
18 similar as 17 above, however the percentage of gneiss and granite approx. fifty-fifty.
19 Calcsilicate rocks with various pegmatites.

There is a clear unconformity between (15) and (17) in the dip as well as -especially- in the strike. The lower series show a strike in southeast direction, while the overlying (or rather overthrust) series strike east-west. Also both series show a great number of folds and microfolds.

Phot. 8. The Southern Flank of Lamjung Himal (6985 m)
(compare also fig. 18, which gives the geological information)

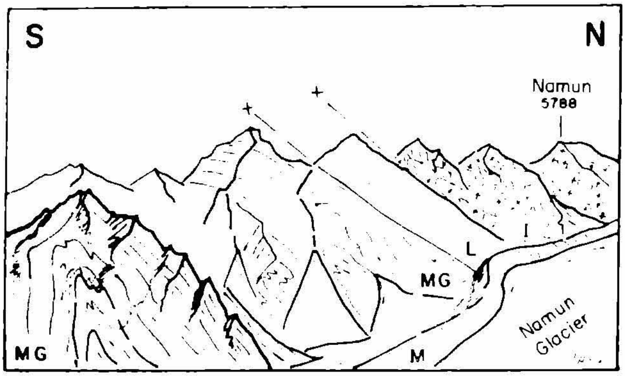


Fig. 15. The Namun Range Seen from the Northeast

I	Intrusive zone of Namun with various mixed gneisses, including calcsilicate gneisses and pegmatite layers and dykes
L	silicious limestone
MG	mixed gneisses, migmatites
M	lateral morain of the Namun glacier

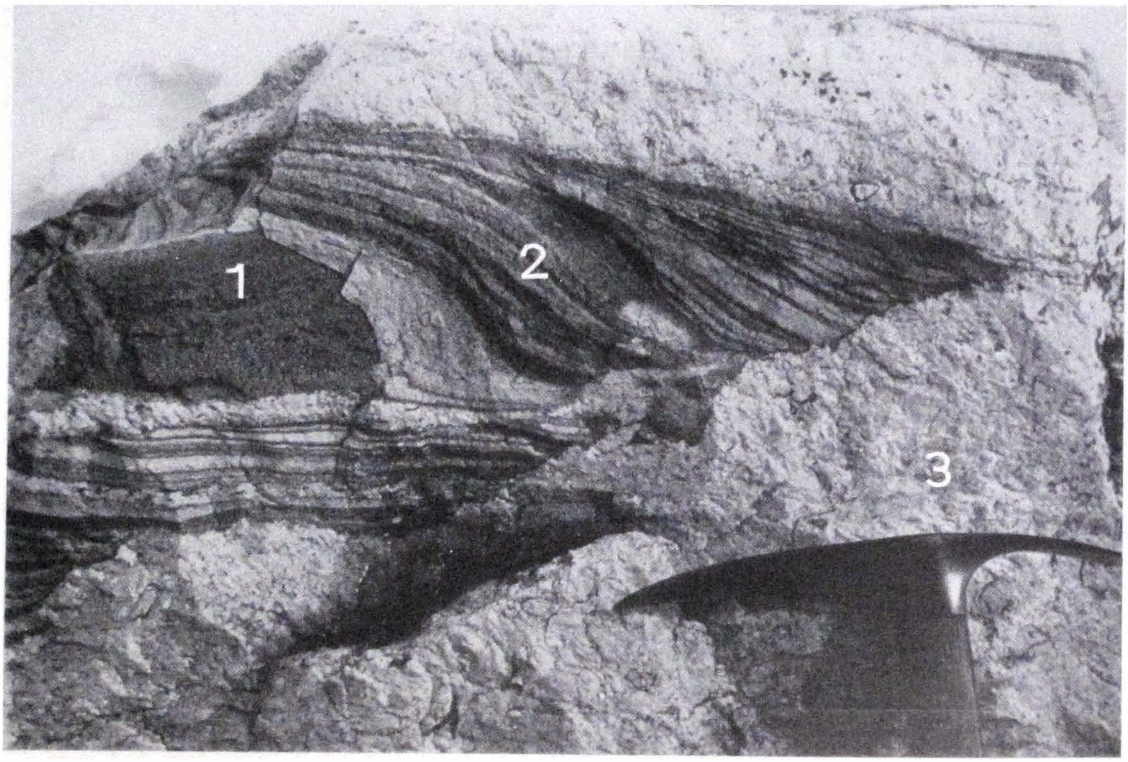
The limestone series belong to the top of Kathmandu nappe 3. The Namun series are overthrust and thereby heavily folded. (Compare also phot. 10.)

All through the whole section tectonics play an important role. Four Kathmandu nappes are involved in the area, and besides, there is an anticline striking through in east–west direction 4 km north of Singdi (see also plate III, profile 12).

The Namun peak (5784 m) is a distinct geological boundary (see fig. 15).

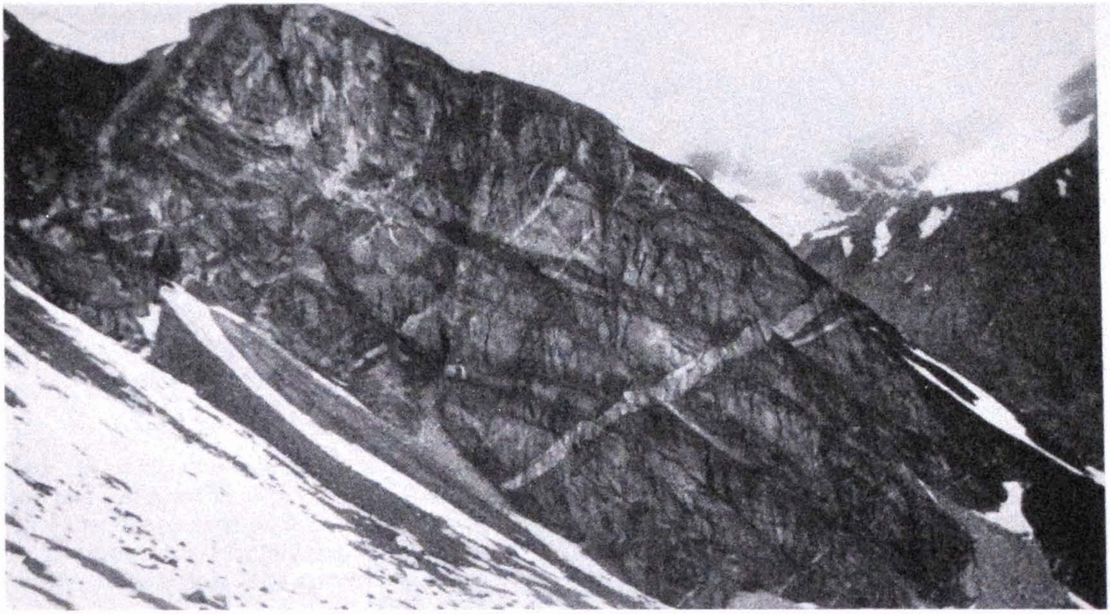
North of it the crystalline series decrease, while more and more calcareous formations take place. Various features of granitic, aplitic and pegmatitic intrusions are well exposed in the valley of the Namun glacier (north and east of Namun (see phot. 9—13 and fig. 16 and 17).

As everywhere in the transitional zone between the Kathmandu nappes and the sediment zone of the Tibetan marginal synclinorium, the dykes cross the beds at an angle directed towards the north. Also two phases of dykes can be recognized (phot. 15).



Phot. 9. Inclusion of Gneiss in Pegmatite
(northeastern flank of Namun range)

1 fine-grained biotite gneiss
2 laminated migmatitic gneiss
3 tourmaline pegmatite



Phot. 10. Oblique Pegmatite Dykes Crossing Granite and Gneisses
(northeastern ridge of Namun, view from the east)

Gneisses (lower part) are interbedded with granite layers. The upper part consists of nearly plain granite. The angle under which the dykes cross are very characteristic for the marginal zone between the Kathmandu nappes and the sediments of the Tibetan marginal synclinorium.

Phot. 11. Two Phases of Intrusions (southern border of Namun glacier)

1 migmatitic gneiss, intensively microfolded
2 aplite
3 second phase, coarse-grained turmaline pegmatite (within 2)

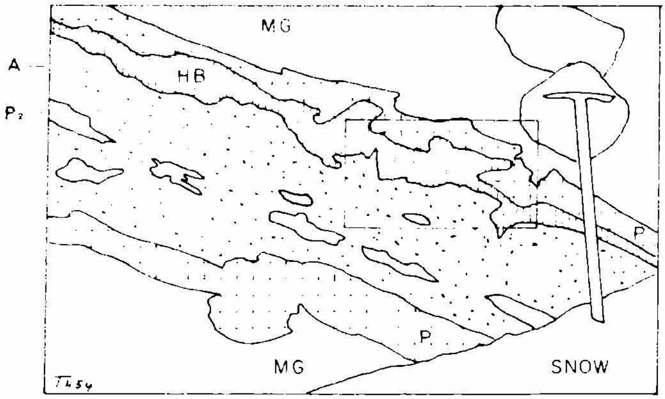


Fig. 16. Aplite and Pegmatite with Marginal Hornblende Crystallisation
(northeast of Namun)

Compare also phot. no. 11, which shows the same aplite (the ice-axe may serve as scale).

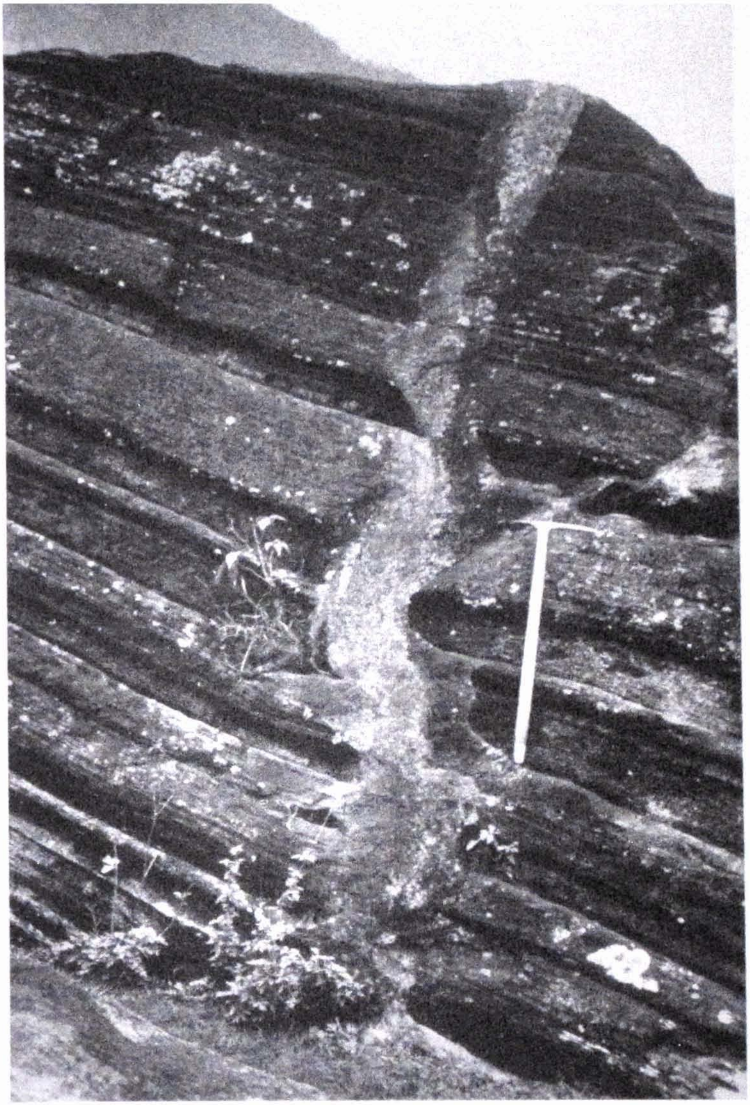
P	pegmatite
A	aplite
P2	second phase pegmatite within the aplite
MG	migmatite
HB	hornblende

The rectangle marks the close-up of the photograph no. 12 and the following fig. 17.

The further route from Namun towards north and down into the Marsyandi valley to the sharp bend of the Marsyandi between Thangja and Bagarchhap follows the dip of the formations and does therefore not show any interesting features. The mountain range north of the Namun glacier, which is glaciated on both flanks (phot. 14) consists of gently northwestern dipping calcsilicate rocks of the Bagarchhap-Thonje series. The western component of the dip is caused by a strong axial pitching

Phot. 12. Close up of the Hornblende Crystals
(same area as the rectangle in fig. 16)

The hornblende crystals are well idiomorph, with length up to 10 cm and 4 cm diameter. Their main axis is directed transverse to the pegmatite. (Compare also figs. 16 and 17 which give the explanation to this photograph.)



Phot. 13. Pegmatite Dyke

filling a fracture in thickly-bedded calcareous sandstone. The dyke partly extends also into the bed-joints of the sandstone.

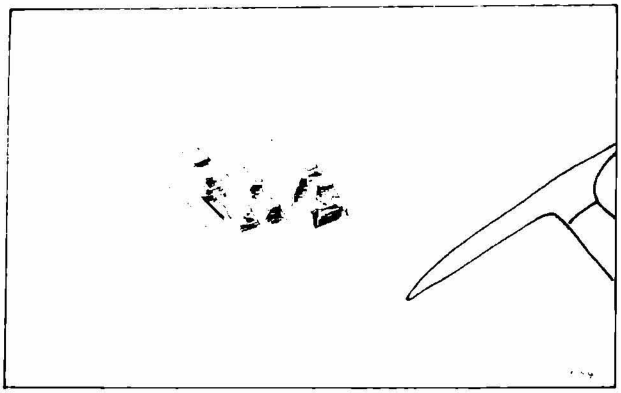


Fig. 17.

Hornblende crystals in the marginal zone of the aplite. (This fig. is a close-up of the rectangle in fig. 16; compare also phot. 12, which shows the same hornblende crystals.)

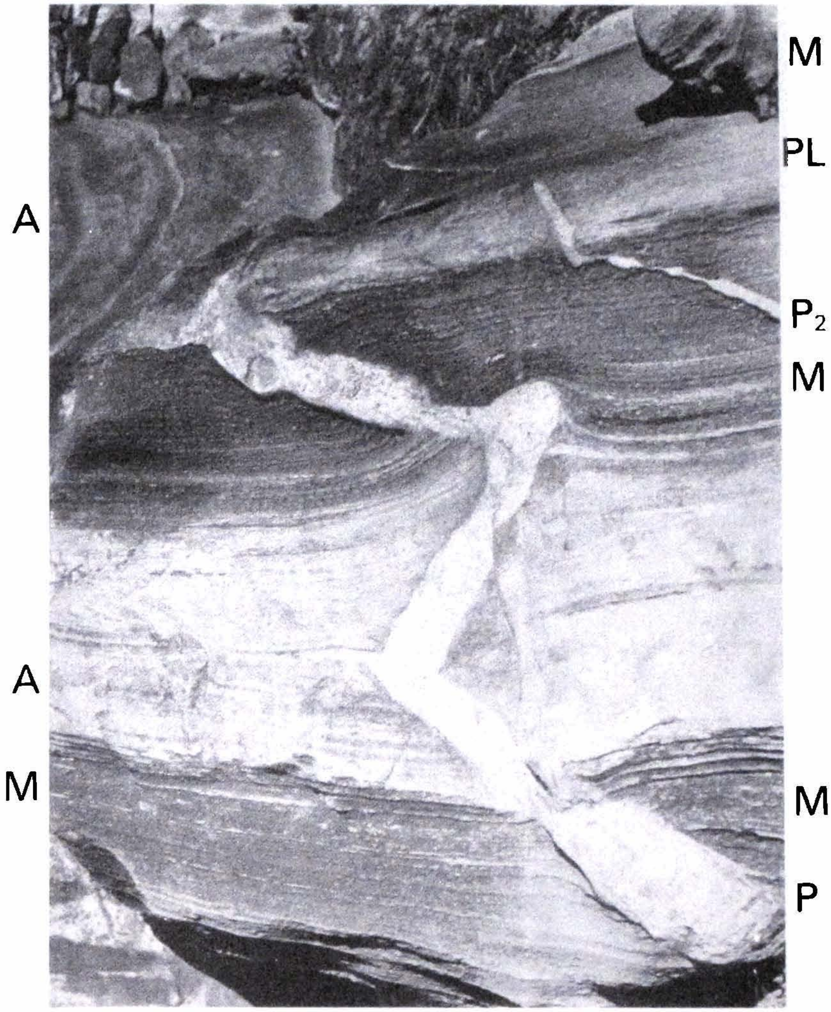
The hornblende crystals are well-idiomorph with lengths up to 10 cm and diameters of 4 cm. Their main axis is directed transverse to the aplite and pegmatite.

towards west, which corresponds to the western plunging of the Manang synclinorium, as we shall see later on. The western pitching is accompanied by a number of steeply western dipping transverse faults, which occur in the whole range from Lamjung Himal (6985 m) to the Marsyandi gorge in the east (fig. 18; phot. 8, southern flank of the Lamjung Himal, and phot. 14).

Phot. 14. The Mountain Range North of the Namun Glacier
(seen from southeast)

Calcsilicate rocks with granitic and pegmatitic layers.
The beds dip north. The dip towards south (left side) is apparent only, caused by the axial rise of the Manang synclinorium. Note the folds and thrustfolds in the central portion of the photograph, indicating the Himalayan Schuppen zone.

The range is intersected by transverse faults, morphologically expressed by deep cuts, now filled by hanging glaciers. These transverse faults are also an expression of the western pitching of the Manang synclinorium.



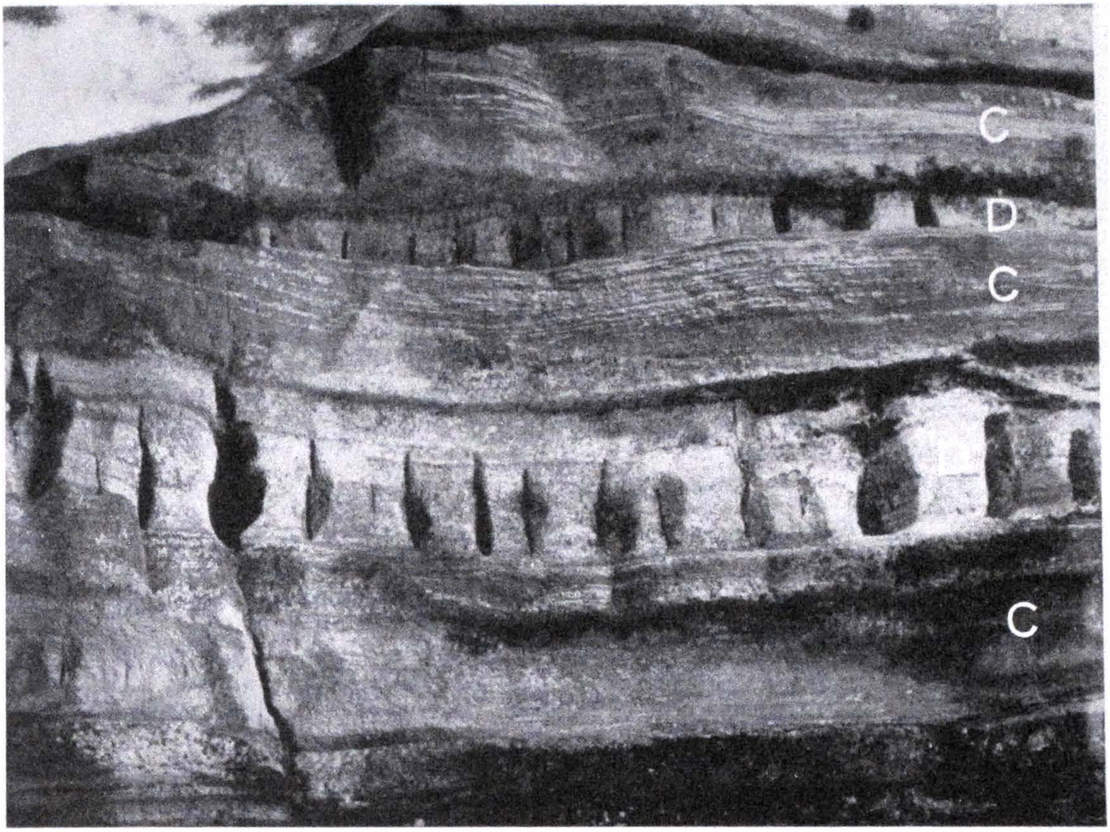
Phot. 15. Turmaline Pegmatite in Calcsilicate Migmatite
(Namun glacier, 4500 m)

P turmaline pegmatite dyke
PL turmaline-pegmatite layer (in connection with the dyke P)
M laminated silicious marble, slightly migmatized
A aplite layer, containing small pegmatite lenses (PL)

The folding of the mother rocks along the pegmatite indicates slight movement and sliding within the formations during intrusion of the pegmatite or, rather, the pegmatite intrusion followed previous zones of latent weakness, like fractures, faults and local micro-thrustplanes.
In the right hand upper corner, a secondary pegmatite crosses the main pegmatite (P2)

Phot. 16. Migmatized and Folded Calcsilicate Gneisses
(Namun glacier, 4000 m)

White masses are pegmatites (*P*)



Phot. 17. Dolomite Layers in Migmatized Calcsilicate Rocks
(Namun glacier)
C calcsilicate rocks
D dolomite
It appears that migmatization preferred the calcsilicate rocks

Instead of moving towards north following the dips, we turn now back to south and climb down the ridge towards the southeast via Sundar (4356 m) to Tarpu Ghat. On this route we cross the cristalline series of the lower Kathmandu nappes, which are in this area showing a flat anticline and syncline structure (see profile I, plate III). Above Puranagaon (Purana = old; Gaon = village) where the mountain ridge between the Marsyandi and the Kudi Khola drops suddenly from 3000 m down to 900 m we meet the overthrust of the Kathmandu nappes. At Tarpu occur mighty limestones and marbles which belong to the top of the Nawakot nappes (fig. 19 and phot. 23).

From Tarpu Ghat, we move again towards the Himalayas and follow the Marsyandi river. We enter now one of the most tremendous gorges of the Himalayas, the transverse valley of the Marsyandi river where it breaks through the main range between the Annapurna range and the Manaslu range (see phot. 18, 23 and 24).

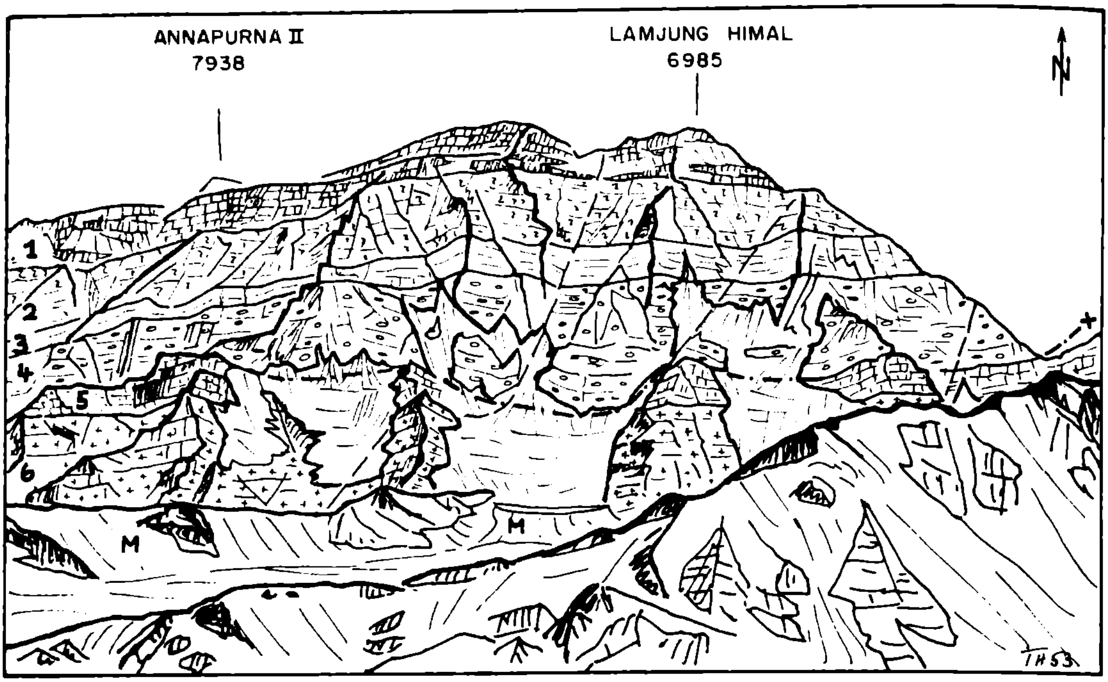


Fig. 18. The Southern Flank of the Lamjung Himal (6985 m)

1 Silurian-Ordovician limestone
2 calcsilicate rocks with intrusions
3 mainly paragneisses
4 mixed gneisses and migmatites
X overthrust of the Kathmandu nappe 5
5 limestone, partly marmorized, with intrusions
6 granite-gneiss
M morains

Due to distortion, looking steeply upwards the Silurian limestone appears to be less thick than it really is. Our standpoint is about 4500 m.

We take our geological profile again near Chhiju (fig. 20) where we met a limestone series with intrusive layers, overlying the lowest (most southern) series of granite-gneiss (series of Tagring). At Jagat, we enter the first step in the gorge. Clivage is tremendous, making the formations appear to dip south.

In the narrow gorge, where the trail crosses over the suspension bridge (phot. 18), we are amidst the crystalline series with granites and gneisses and various intrusions. Near the suspension bridge, the strike is exceptionally turned towards the north–south, parallel to the river course. This seems to be caused by a transverse structure along the gorge. After the suspension bridge we climb the steep step in the valley. The western tributary (Namun Khola) joins the Marsyandi in a thunderous waterfall, with tremendous kolks washed out of the coarse-grained granite (1700 m). The upper part of the gorge, the last 5 km before Thonje shows a flat bottom with however vertical rockwalls on either sides. The trail follows hair-raising suspension devices on these perpendicular rocks. It is easy to guess that this difficult portion of the trail is not manageable for pack animals. Traders with pack animals use to come down from the north (Manang and Bimtakothi) just as far as Thonje. Further down the valley, all the trade has to be performed on porters back.

Towards Thonje (1980 m) the dip is decreasing, and the formations contain more and more calcareous components (fig. 21).

Also two thrustplanes can be recognized and the whole series overlying the calcareous formations show a tremendous tectonization with intensive microfolds.

But before continueing our geological itinerary towards the north, we consider the geology of the southern and the eastern flank of the Annapurna range.

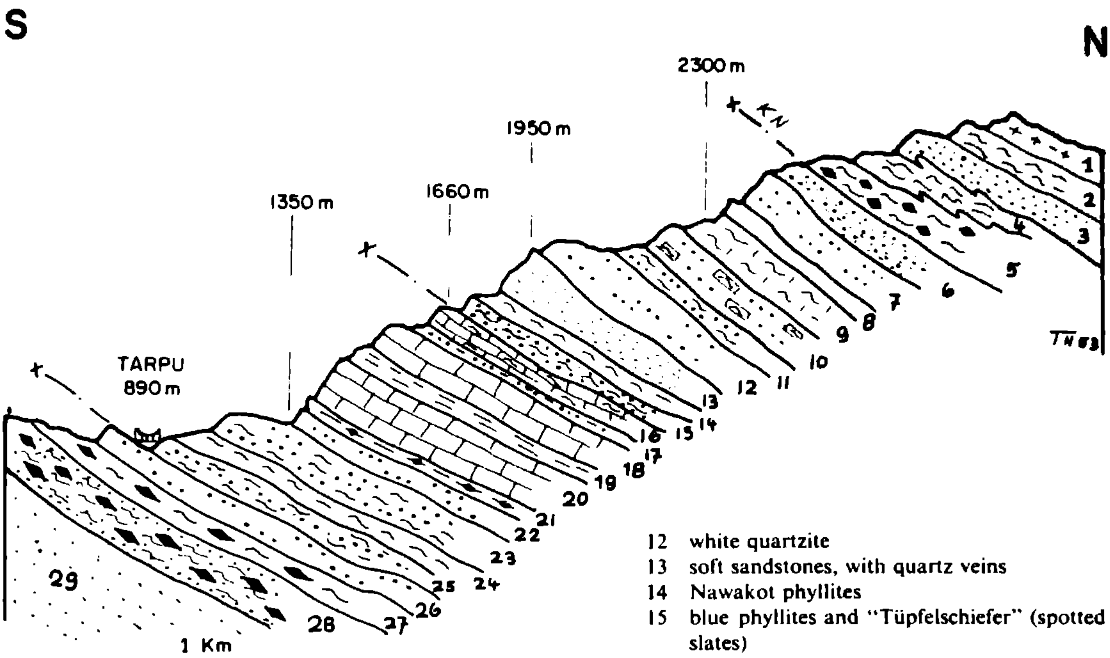
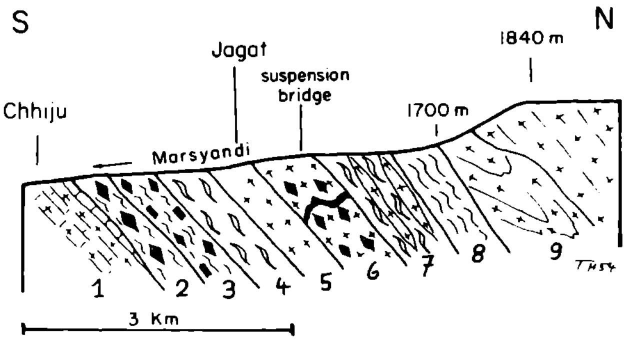


Fig. 19. Detail Profile North of Tarpu Ghat

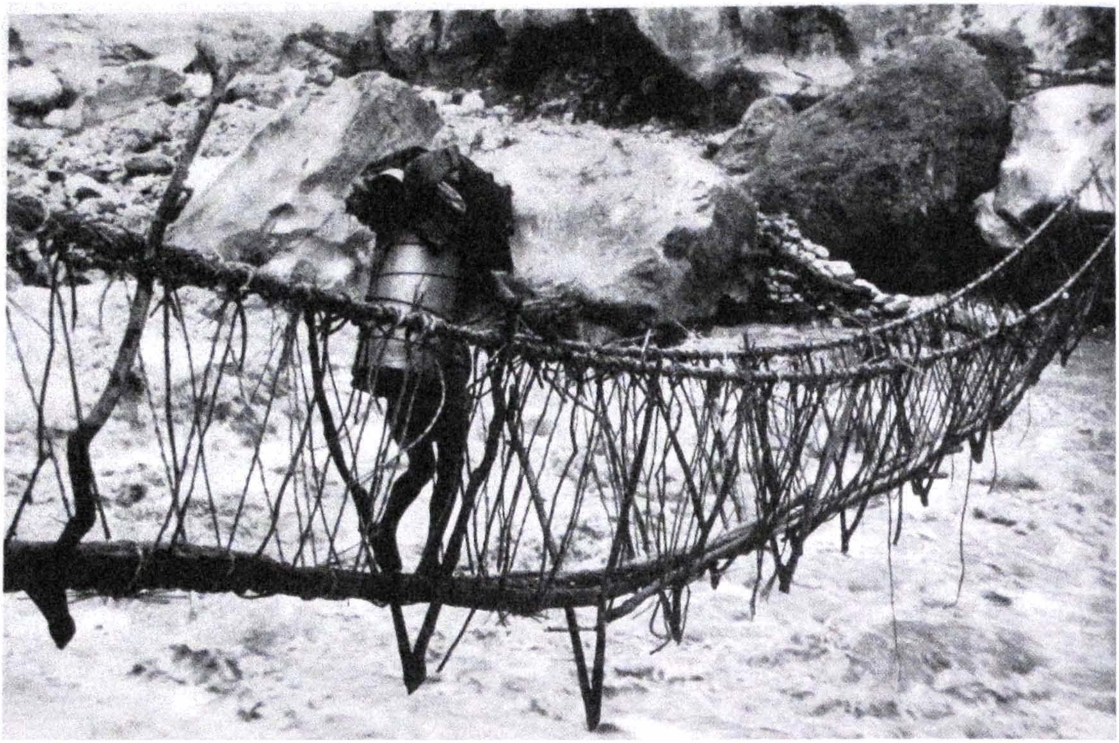
1 granite-gneiss series of Tagring
2 muscowite mica-schist, with pegmatites
3 sandstone, (Kokani sandstone) with migmatites interbedded with pegmatitic layers and dykes
4 muscowite mica-schists
5 garnet mica-schists, coarse-grained
6 red quartz-sandstone
7 white quartzite with thrustmarks
8 white quartzite with slices of coarse-grained marble
9 calcareous mica-schist
10 marble, coarse-grained, fluidal texture
11 sericite-quartzite schist
12 white quartzite
13 soft sandstones, with quartz veins
14 Nawakot phyllites
15 blue phyllites and "Tüpfelschiefer" (spotted slates)
16 laminated limestone, calcareous mica-schist, marble; (fluidal texture; microfolds, subaquatic sliding)
17 graphitic quartzite slates
18 blue limestone
19 black slates, graphitic
20 limestone
21 hematite, interbedded in quartzite and phyllites
22 quartzite
23 coarse-grained sandstone, partly slightly metamorphosed towards gneiss
24 dark phyllites
25 sericite-sandstone
26 dense white and reddish quartzites
27 garnet-phyllites
28 sericite-sandstone with garnets
29 sandstone

Fig. 20. Profile Sketch in the Marsyandi Gorge



1 limestone, with intrusive layers
2 garnet-mica-schist, phyllites
3 garnet-kyanite mica-schist
4 fine-grained biotite-gneiss, interbedded with migmatites
5 biotite-granite (near Jagat)
6 granite with garnets, porphyric, with pegmatites
7 fine-grained biotite-gneiss with intrusive layers
8 biotite-muscowite mica-schist
9 dominantly granite-gneiss

This series form the barrier in the Marsyandi gorge, above which the alluvial plain reaches for 4 km towards north. The strike of the barrier series (9) is excessively turned toward southsoutheast.



Phot. 18. The Suspension-Bridge in the Marsyandi Gorge

This hazardous device has since been replaced by a solid steel-rope suspension-bridge, built by the Swiss Technical Assistance Programme.

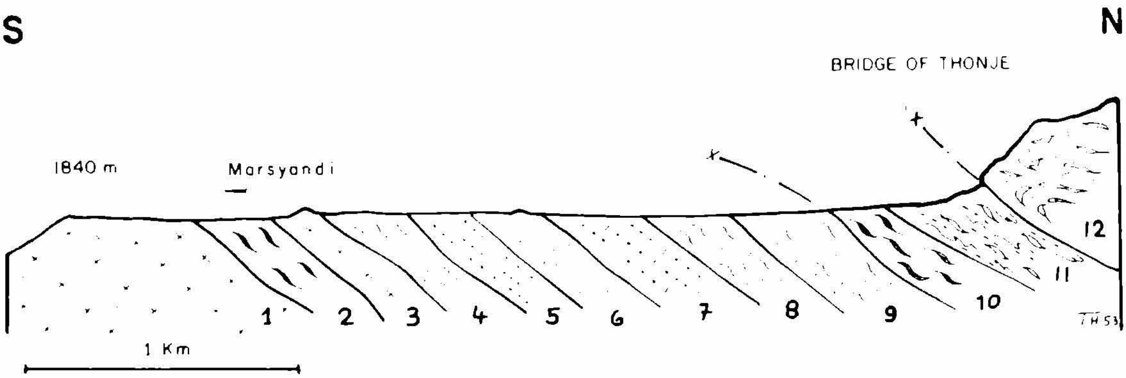


Fig. 21. Detail Profile of the Marsyandi Gorge below Thonje

1 granite and gneiss, with pegmatites
2 laminated gneisses, migmatites, pegmatitic layers
3 coarse-grained granite
4 sericite-sandstone with migmatites
5 quartz-sandstone and coarse-grained quartzite
6 thickly-bedded calcareous quartz-sandstone
7 calcareous quartzite, coarse-grained, with sericite
8 laminated calcareous mica-schist with layers of marble and quartzite
9 calcareous schist (800 m)
10 coarse-grained biotite-gneiss, laminated and platy
11 fine-grained biotite-gneisses with migmatites, with intensive folding and microfolds
12 migmatites with well-idiomorph orthoclase crystals (3 cm diameter)

2. Geology of the Southern Flank of the Annapurna Range

The Annapurna range is not only one of the most beautiful mountain ranges of the Himalayas but undoubtedly from the geological standpoint far the most interesting one. First of all, not like the mountains of the Everest group or Kangchendzönga or K 2 group, the Annapurna is built not only of crystalline rocks, but at its northern flank also of the sediments of the Tibetan marginal synclinorium with their great varieties of rocks and tectonics. But the most interesting mountain would be useless with regard to scientific research, if it were not accessable, both from technical or political standpoint. The Annapurna is relatively easily accessable, main trade routes passes round Annapurna and big villages are situated on all sides, and, important in politically delicate areas, also from this standpoint of view accessable from all sides, since it lies far away from any border.

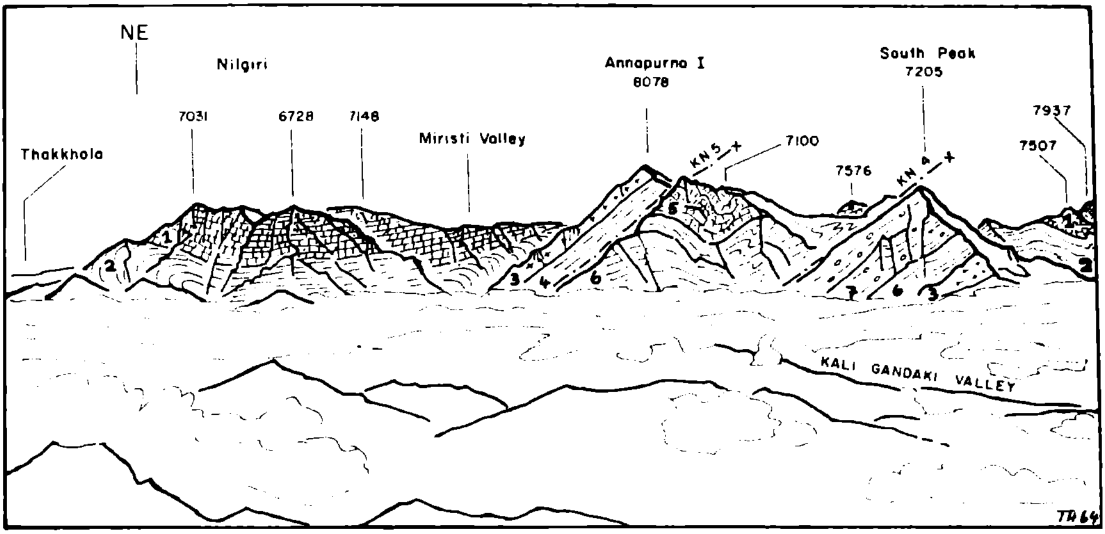


Fig. 22. The Annapurna Range Seen from Southwest
(according to an aerial photograph by the author)

The southwestern flank (from Annapurna I towards the right side) shows the northern dipping crystalline roots of the Kathmandu nappes. The Nilgiri range consists of the very thick sedimentary formations on the top of the Kathmandu nappe 5, with the folds of the marginal Schuppen zone (reverse folds at the northern flank of peak 7031 m). Compare also phot. 70 and 71.

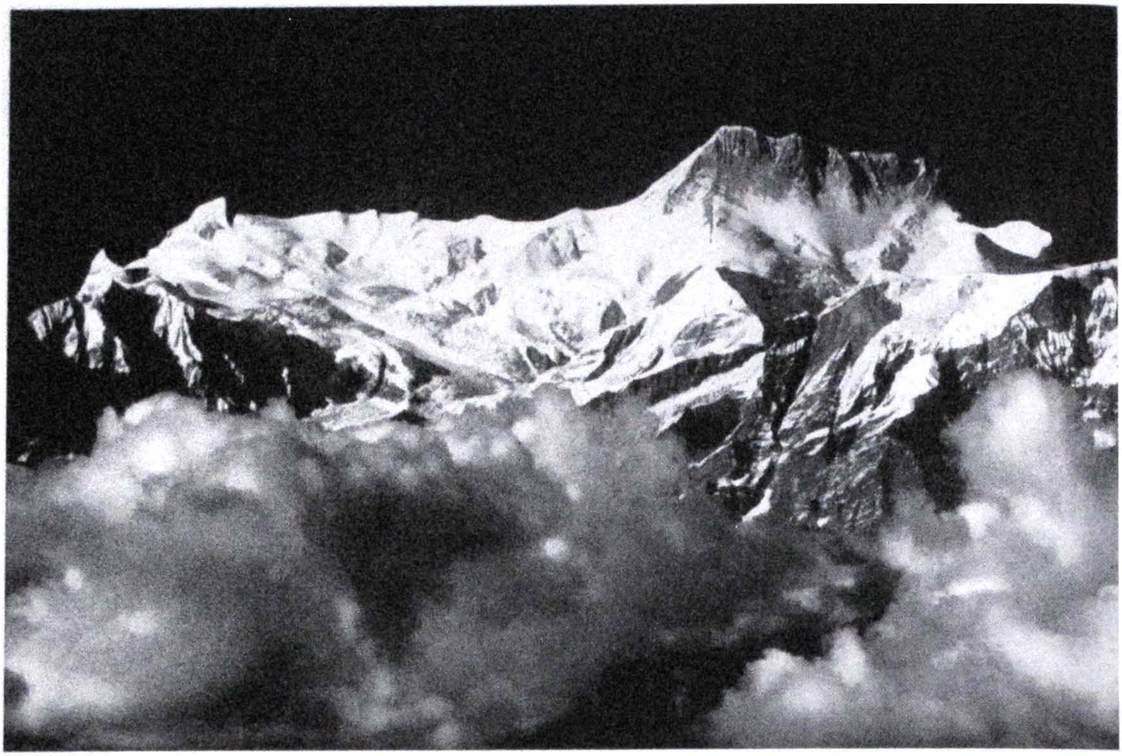
1 Devonian limestone
2 Silurian-Ordovician
3 granite-gneiss (in Annapurna I interbedded with paragneisses and limestones)
4 paragneisses
5 calcsilicate rocks
6 paragneisses
7 migmatites

There is also no other mountain range in the Himalayas which is so diversified with regard to topography, the variety of peaks and vegetation, because, nowhere else the peaks of 8000 m are so close to tropical lowlands.

The southern flank of the Annapurna range consists mostly of the northerly dipping crystalline formations of the roots of the Kathmandu nappes. However, at altitudes below approx. 2500 m also the underlying Nawakot nappes participate in mountain building (see map and profiles plates II and III).

Not like most any other ranges in the Himalayas, the Annapurna does not consist of one crest only, but has also outlyers with a considerable extention in transverse (north–south) direction. This is especially the case in the western part, where the Nilgiri has two summits connected by a south–north ridge; or the main summit (Annapurna I) which sends a ridge towards the south peak (7205 m). Also the bold summit of the Machhapuchare (6997 m) is situated by about 7.5 km south of Annapurna III of the main range. (See map plate II, or profiles 6 and 8 plate III.)

The boundary between the crystalline of the topmost Kathmandu nappe (5) and the overlying sediment formations does not follow the main crest of the Annapurna range. All three of the Nilgiri



Phot. 19. Annapurna II (7937 m) and Annapurna IV (7597 m)
(seen from south, aerial photo)

The lower part consists of various gneisses and calcsilicate rocks. The upper part is built of the sediments which are folded in a reverse sense. The right half of the picture shows the western dip of the well-bedded formations due to the axial rise of the Manang synclinorium towards east. Compare fig. 23, which shows the same mountain from the southwest (left in the photograph).

peaks are situated in the sediment zone, while the Annapurna summit I is built of the topmost crystalline formations (various gneisses with migmatites and granitic and pegmatitic layers). From the Annapurna I towards the east-southeast the highest summits of the main range are all built by the sediment formations. Only Machhapuchare consists of crystalline (see plate II). Typically for the topmost Kathmandu nappes, also the crystalline is involved in the tectonics. This can be well seen in the Machhapuchare (fig. 24) and in the ridge between the Annapurna I and the south peak (fig. 22; also profile 6 in plate III). It seems as if at this place there would have been more space between the topmost Kathmandu nappes for playing in tectonics: a transitional zone between the uniformly northern dipping roots of the Katmandu nappes and the Tibetan marginal synclinorium with its variety of foldings both in normal and reverse sense. This transitional zone has been called the *Himalayan Marginal Schuppenzone* (see vol. I of this publications series) and has been described especially in the Everest area. (See fig. 22, the Annapurna range seen from the southwest.) 1 km south of the peak 7100 m a sediment formation (the top of Kathmandu nappe No. 4) has been folded in underneath the thrust-plane of Kathmandu nappe 5.

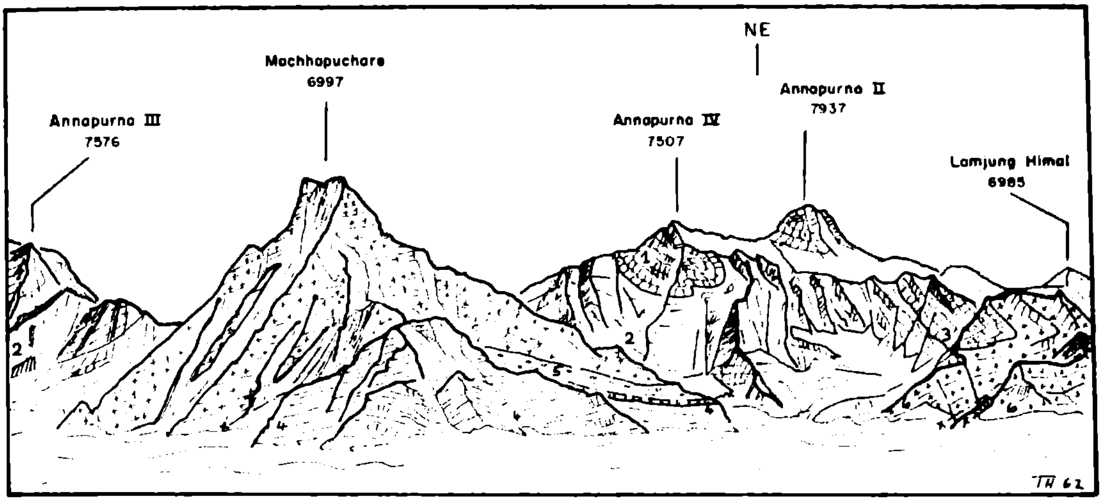
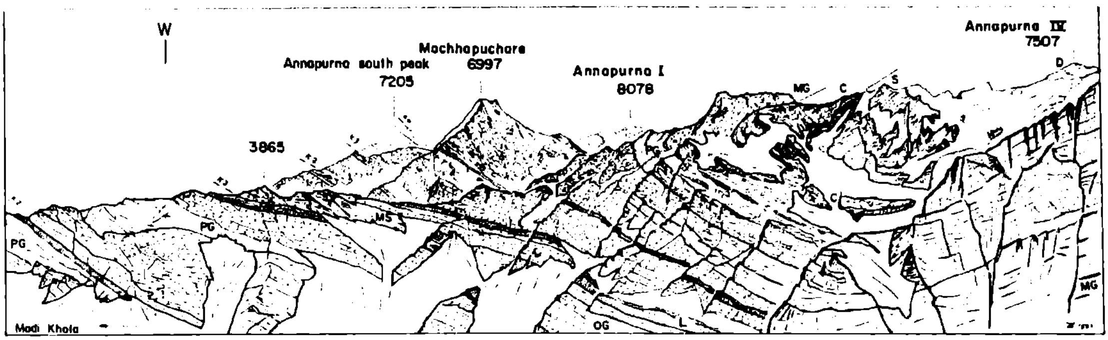


Fig. 23. The Annapurna Range Seen from the South
(according to an aerial photograph by the author, compare also phot. 19)

The Machhapuchare consists of the folded, but generally northern dipping granite-gneisses of the Kathmandu nappe 4 (folding in this picture is not visible due to the view onto the outcrops, see fig. 24). The western flank of Annapurna IV gives a good cross section through the reverse folded sediment cover of the Kathmandu nappe 5. The gneisses have also been involved in the folding.

1 Devonian
2 Silurian-Ordovician-Cambrian
3 calcsilicate rocks
4 paragneisses
5 mixed gneisses and migmatites
6 granite-gneisses
7 quartzite and limestone



TIBETAN ZONE

D Devonian
S Silurian-Cambrian
C Calcsilicate rocks

KATHMANDU NAPPES

L Limestones and quartzites
PG Slates and fine grained biotite gneiss
MG Mixed gneisses
OG Mainly orthogneisses
MS Micaschists

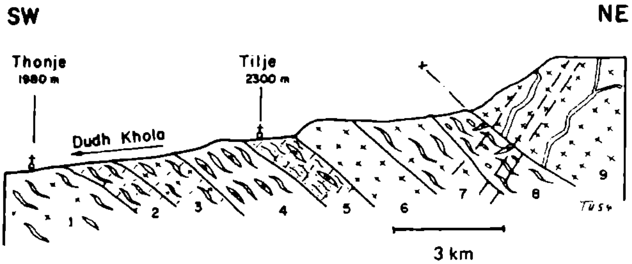
Fig. 24. The Annapurna Range Seen from Southeast
(from the ridge between Rambrong and Namun)

3. Geological Itinerary in the Dudh Valley

The Dudh Khola is the main eastern tributary of the Marsyandi. It drains the western flank of the Manaslu range, and the southern flank of the heavily glaciated mountain range consisting of the Phu Himal (6454 m), the Himlung Himal (7125 m) and the Cheo Himal (6812 m). The big glaciers at the eastern flank of the nameless peak 7009 m send their water also into the Dudh Khola. Thus, the Dudh Khola receives its waters mainly from glaciers, and this explains its name: Dudh = milk, Khola = river.

As seen in previous chapters, an important trade route leads through the Dudh valley, crossing over the Larkya La (5212 m) into Nubri, the big transverse valley of the Buri Gandaki neighboured to the east. The whole route over the glaciated Larkya La right down to Thonje is manageable for pack animals.

Fig. 25. Profile Sketch Thonje-Dudh Khola



1 migmatites with well-idiomorph orthoklas crystals up to 3 cm diameter
2 calcsilicate-gneisses
3 calcsilicate-gneisses and migmatites
4 gneisses with granitic layers and pegmatites
5 calcareous biotite-sericite sandstone, with granitic and pegmatitic layers
6 granite
7 migmatite
8 fine-grained biotite-gneiss with augen-gneisses
9 granite and pegmatites, crumbled to grit

These latter series are overlying by a thrustplaneover formations of (8). However, the upper complex has in the last phase been gliding reverse towards the northeast. This is indicated by pegmatites which are transposed through this thrustplane. This zone also shows a strong clivage which dips towards the southwest. The dip of the formation is strongly turned toward the north, indicating the anticlinal structure in the Dudh valley.

When starting our journey at Thonje through the narrow valley of the Dudh Khola one would not expect to be so close to the boldest mountains of the Himalayas, for one cannot see any snow-covered mountains until halfway up to Bimtakothi.

The formations of Thonje consisting of mainly fine-grained biotite-paragneisses interbedded with migmatitic zones with large felspars (fig. 25) reach about 1 km further up from Thonje. There seems to be a minor anticlinal structure in the valley: At the eastern flank the strike is directed towards east, while on the western flank the strike shows towards the north.

At Thonje itself, the beds are nearly horizontal. The zone 1 km above Thonje shows tectonization in form of folds and thrusts. Clivage is dipping south, at places misleading to interpret the dip of the beds in the same direction (fig. 26).

Near the bridge between Thonje and Tilje a number of transverse faults cross the valley in north-south direction. These are the same faults and clefts, which caused the terrace of Naje, 1.5 km south-east of Thonje. (See also phot. 25.)

At Tilje village we are in the series of calcsilicate gneisses, containing plenty of granitic and pegmatitic layers. The further profile sketch is given in fig. 25.

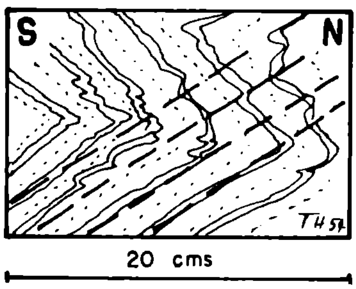


Fig. 26. Clivage in Folded Gneiss
(300 m above Thonje)
The clivage is dipping southwest.

East of peak 4692 m, where there is a remarkable steep step in the gradient of the valley, we find granite with abundant pegmatite layers and dykes, on the surface crumbled to grit.

The granite is thrust over migmatites, with fine-grained biotite-gneisses interbedded with lenticular coarse-grained orthoclas porphyroblasts and pegmatites. Surprising enough, dykes in the lower part of the overthrust granite are cut by minor thrustplanes, indicating that the upper part has locally been gliding in a reverse sense, that means towards the northeast.

From this place, we gain a rapidly improving view on the surrounding high mountains. Peak 6398 m, matched by few Himalayan mountains by its boldness, shows steeply dipping and folded crystalline series, basically of syncline character (see phot. 20 and fig. 29).

On the opposite side of the valley, peak 4692, seen from the east, shows also a complicated structure with two thrustplanes and folding of the central portion (fig. 27).

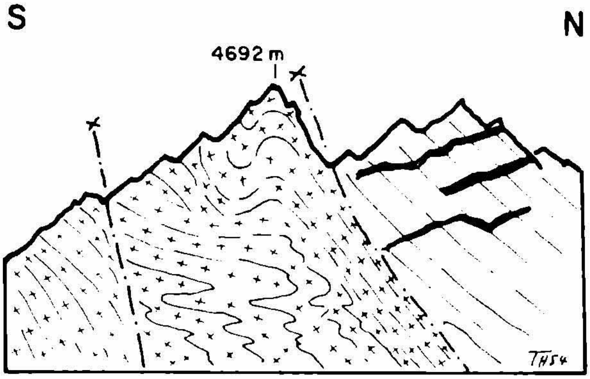
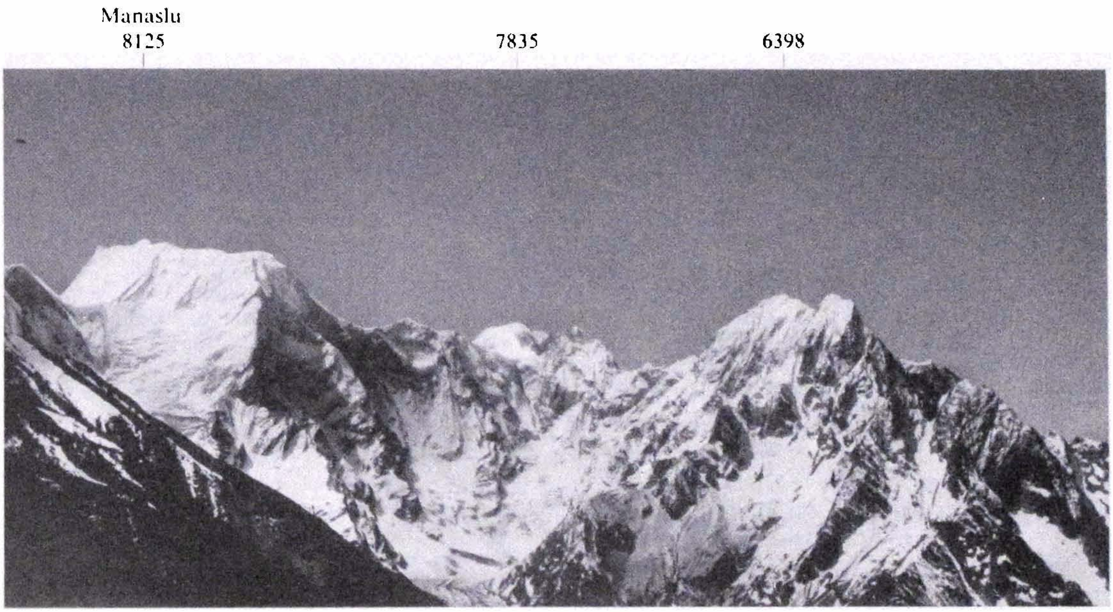


Fig. 27. Peak 4692 m, Northwestern Flank of the Dudh Valley
(seen from the east)

Three thrustsheets can be recognized. The two lower sheets consist of granite-gneiss, while the upper portion is built by mixed gneisses, in which the oblique pegmatite dykes are intruded.

The topmost portion contains huge pegmatite dykes, directed at right angle to the beds and also under angle towards the northeast, which is characteristic for the topmost crystalline series underlying the sediments of the Tibetan marginal synclinorium.

2 km below Bimtakothi the beautiful coniferous mountain forests decrease and the view is getting free on one of the most impressive sceneries of the Himalayas: The tremendous northwestern flank of



Phot. 20. The Northwestern Flank of the Manaslu Group
(seen from the Bimtakothi glacier)
(Compare the geology given in fig. 29.)

the Manaslu (8125 m), which drops from 8000 m right down to 4000 m echoing the ever thundering avalanches of snow and ice which nourrish the big glaciers at the foot of the wall (fig. 29, phot. 20).

The Quarter-inch Map of the area is not quite correct: The Bimtakothi glacier reaches much further down, than shown in the map. Its end is 1.5 km south of Bimtakothi. The trail crosses the glacier, which, however, is covered by a thick morain.

The Bimtakothi glacier is an example for many other glaciers in the Himalayas, which have at present not sufficient force to do away with the morains, and thus flow on a thick morainic under-cover, high elevated above the valley bottom (fig. 28).

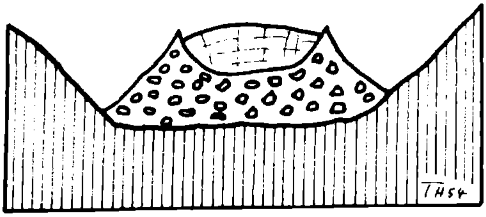


Fig. 28. The Bimtakothi Glacier
Flowing elevated on its own morains 120 m above the bottom of the valley.

4. Geology of the Upper Part of the Dudh Valley

The geology of the whole catchment area of the Dudh Khola is relatively monotonous, since granite-gneisses and granites are predominant. However the tectonics are not so simple as the first glance may make appear.

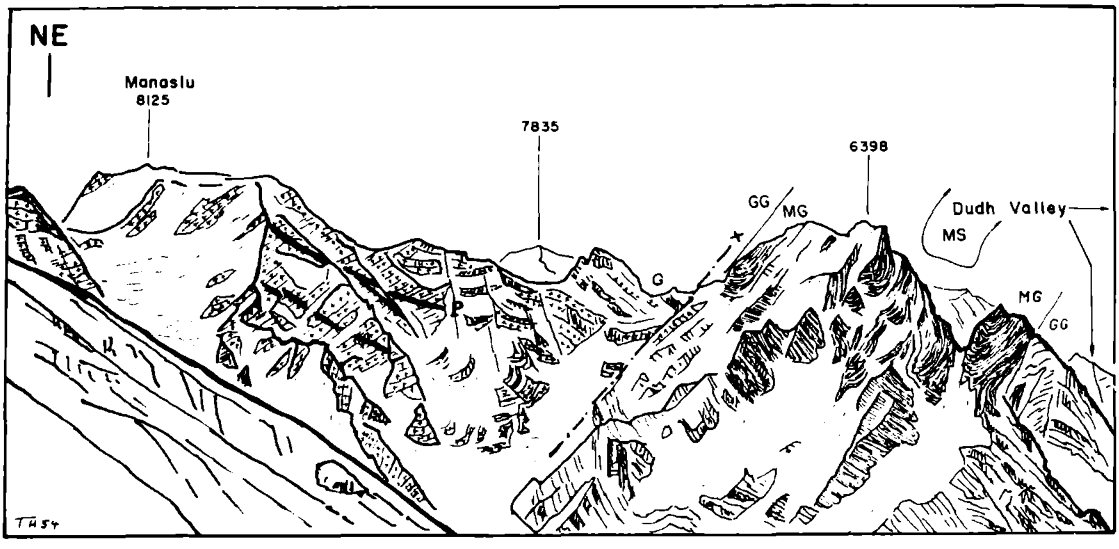


Fig. 29. The Northeastern Flank of the Manaslu Group

P	pegmatites	G	granites	MS	Manang synclinorium
MG	mixed gneisses	GG	granite-gneisses		

The granites of the Manaslu itself are thrusted upon the granite-gneisses of the basement of Peak 6398. The latter shows a narrow-pressed and slightly towards southwest overturned synclinal structure. The syncline is filled with mixed gneisses.
This is the western continuation of the Manang synclinorium, in this area expressed in the crystalline basement due to axial rise toward the southeast.
The granites at the summit of the Manaslu are interbedded with gneisses and limestones of probably Silurian age. Thus we have there just the boundary between the crystalline basement and the Tibetan sediment series.
(Compare also phot. 20.)

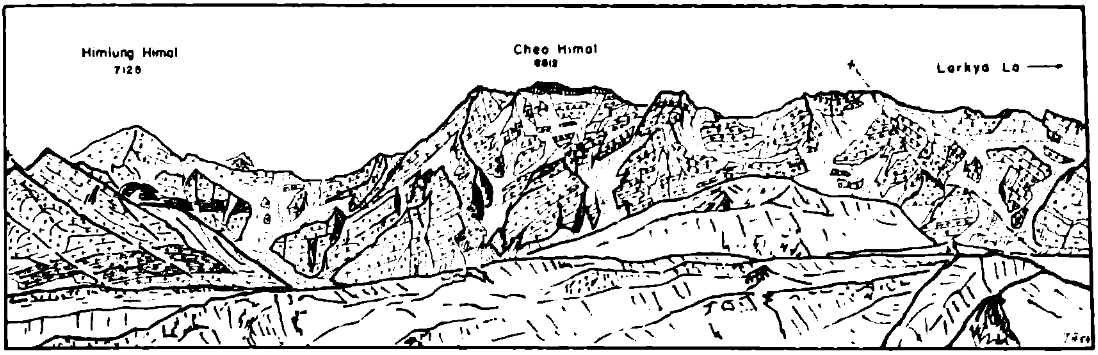


Fig. 30. The Mountain Range between Himlung Himal and the Larkya La
(seen from the south)
The range is built by granites and granite-gneisses. The Larkya series (Manaslu granite) is thrust under angle unconformity upon the series of the Cheo Himal. The latter shows slight folding, with general western and west-southwestern dip. The Himlung Himal is built by a flat anticline. A dark series of mixed gneisses can be recognized in the middle of the eastern flank of the Himlung Himal, and also west of the eastern branch of the Bimtakothi glacier. Sediments occur on the top of Cheo Himal. These were also found in the middle morain of the Bimtakothi glacier. As it was observed from the eastern side, this is not yet the contact with the Tibetan sediment zone, but just an isolated layer left within the intruded granite.
(Compare also fig. 32 and 33 and the geological map plate II.)

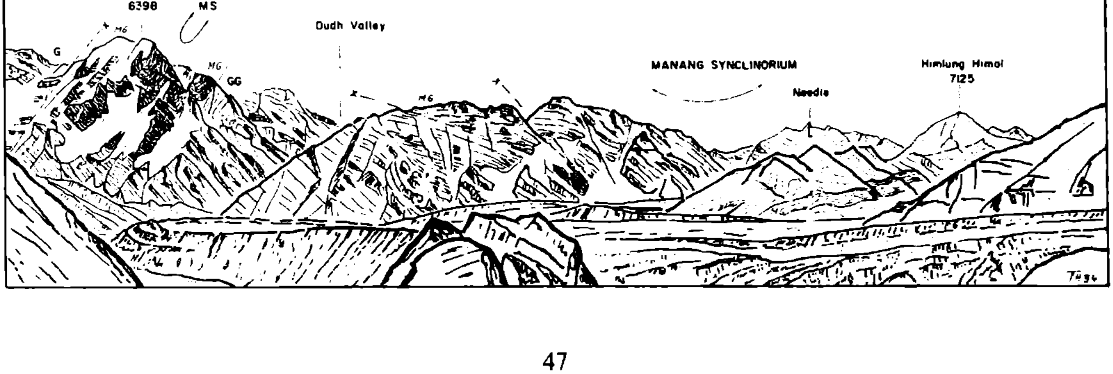
The tremendous flank of the Manaslu (8125 m) and the ridge which connects with the peak 6398 m show tremendous folding, especially in the latter part (see fig. 29).

The Manaslu granite is thrust along a steeply northeastern dipping thrustplane on the granite-gneisses.

In general we can see a huge narrow-pressed syncline in Peak 6398 m which is overturned towards the southwest (compare also plate III, profile 13). The filling of the syncline consists of mixed gneisses (see fig. 29 and 31).

This is the eastern termination of the Manang synclinorium, however in this area expressed in the crystalline bottom of the said synclinorium. It proves that the Tibetan marginal synclinorium, filled with Mesozoic sediments is not just a superficial tectonic feature, but reaches deep into the crystalline basement. Due to the strong axial rise towards east, this interpretation is made evident.

Fig. 31. The Mountains at the Western Side of the Bimtakothi Glacier
(view from the eastern morain towards the west; legend see fig. 29) The mountain range stretching from the needle towards south and southeast shows two different secundary tectonic units, separated by two thrustplanes from each other. The lower portion has northeastern dip while the upper, overthrust part shows northwestern dipping. The latter indicates the close neighbourhood of the Manang synclinorium. Indeed this synclinorium is illustrated by the synclinal structure of the range of the needle.
This figure is the left hand (southwestern) continuation of fig. 30; compare also the geological map plate II.
The western branch of the Bimtakothi glacier (right hand foreground) is sunk in between his lateral morains, indicating the recession of this glacier.



The Manaslu (8125) shows a regular northeastern dip of the huge granite masses. A strong clivage dips steeply towards the southwest. The Manaslu peak itself is just on the margin between the crystalline and the Silurian sediment formations. (However, this can be observed only from the eastern flank.) Pegmatites within the granite cross at right angle to the bedding.

The catchment area of the Bimtakothi glacier is built entirely of granites and granite-gneisses. Only the top of Cheo Himal has a sediment cover. These sediments of carboniferous age (quartzites, sandstones, limestones and Chlorite slates) were found in the middle morain of the glacier, while the lateral morains do not show any sediments. (However, the sediments of Cheo Himal are not yet the base of the Tibetan sediment formations; they are just a wedge left in the intruded Manaslu granite, as was observed from the eastern side of the Larkya La.)

The Manaslu granite of the Larkya La is thrust upon granite-gneisses of the Cheo Himal (see fig. 30 and 32).

The ridge between the eastern and the western branch of the Bimtakothi glacier shows some secondary thrust sheets with clivage that makes appear a northern dip. (See also fig. 31.)

The mountain range from the Needle towards the south shows a flat synclinal structure. This is the eastern termination of the Manang synclinorium. The strong axial rise towards the east makes the crystalline bottom of this synclinorium appear on the surface. The sediments occur only 2 km west of the mountain ranges of the Needle and the Peak 4692 (see geological map plate II and also fig. 31 and 32).

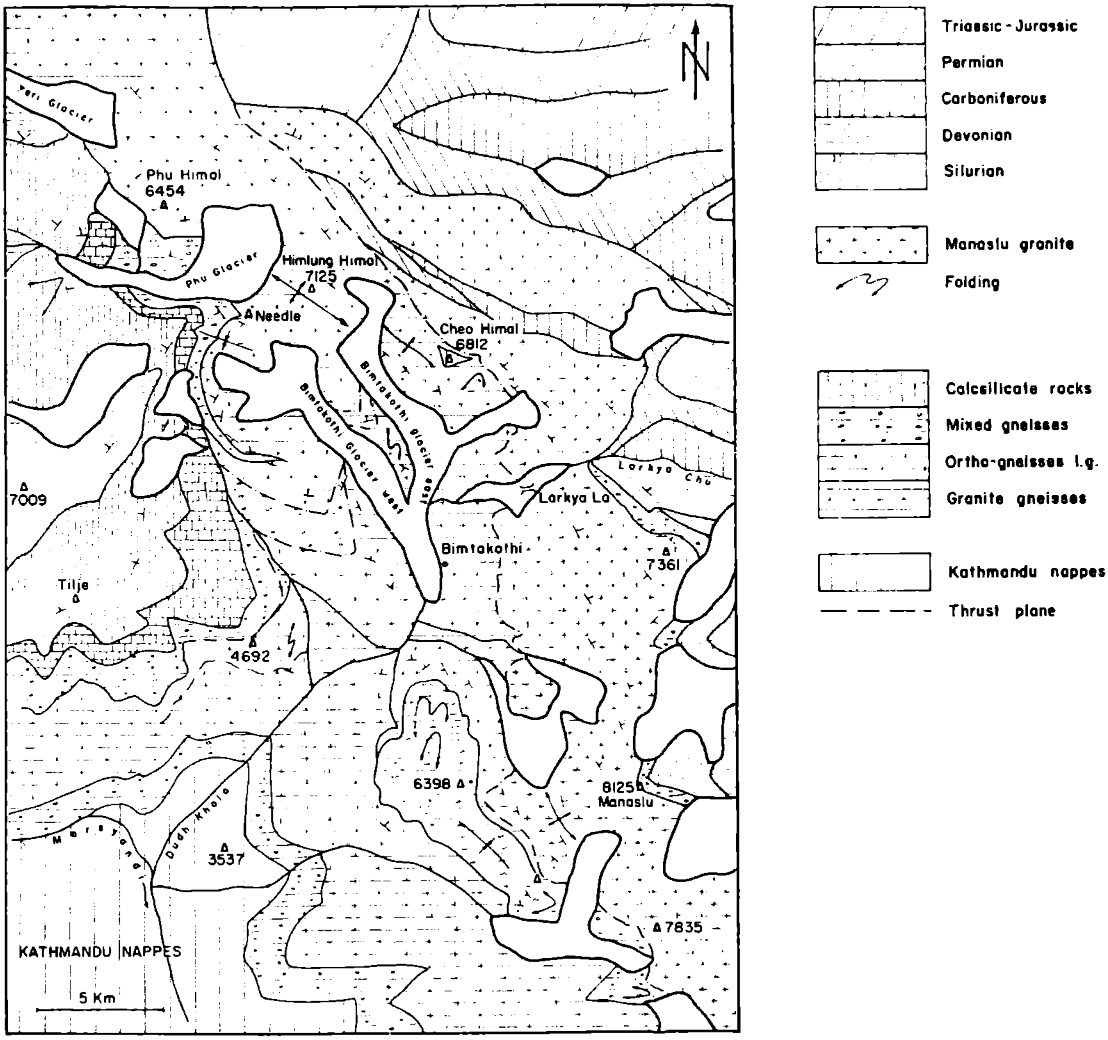
Some mixed gneisses can be observed in the mountain ridge west of the Bimtakothi glacier (fig. 31 and 32), whereby a layer of darker formations occurs between two secondary thrustplanes.

Phot. 21. The Manaslu Granite Underlying the Permo-Carboniferous Formations
(13 km northeast of the Larkya La, view from the southeast)

The sediments of the Tibetan zone occur 10 km northeast of the Cheo Himal (see phot. 21). Granites have intruded Permo-Carboniferous formations. However the boundary between the granite and the sediments is irregular. Towards the northwest, the granites join higher formations (Jurassic and Cretaceous north of Phu Himal) while towards the southeast gradually lower formations occur on the contact with the granite. Thus we find north of Peak 7361 Silurian limestones lying by means of mixed gneisses on the Manaslu granite. (Compare also fig. 32, and the geological map, plate II; the geological profiles IV–VI, plate IV; and the geological cross sections 11–13, plate III.)

From the fig. 29, 30, 31 and 32 may well be seen, that the Manang synclinorium is also in its crystalline bottom by no means a simple syncline. The granites and granite-gneisses of the Manaslu arc strike in northwest–southeast direction, while the general strike of the Annapurna range and the adjoining Manang synclinorium is directed westnorthwest–eastsoutheast. The Manaslu granites have been thrust under angle against the Annapurna arc and the Manang synclinorium and during this thrust from the northeast the mass of the Manaslu granite has been broken up into several thrust sheets.

Fig. 32. Geological Sketch Map of the Dudh Valley
(compare also fig. 33)



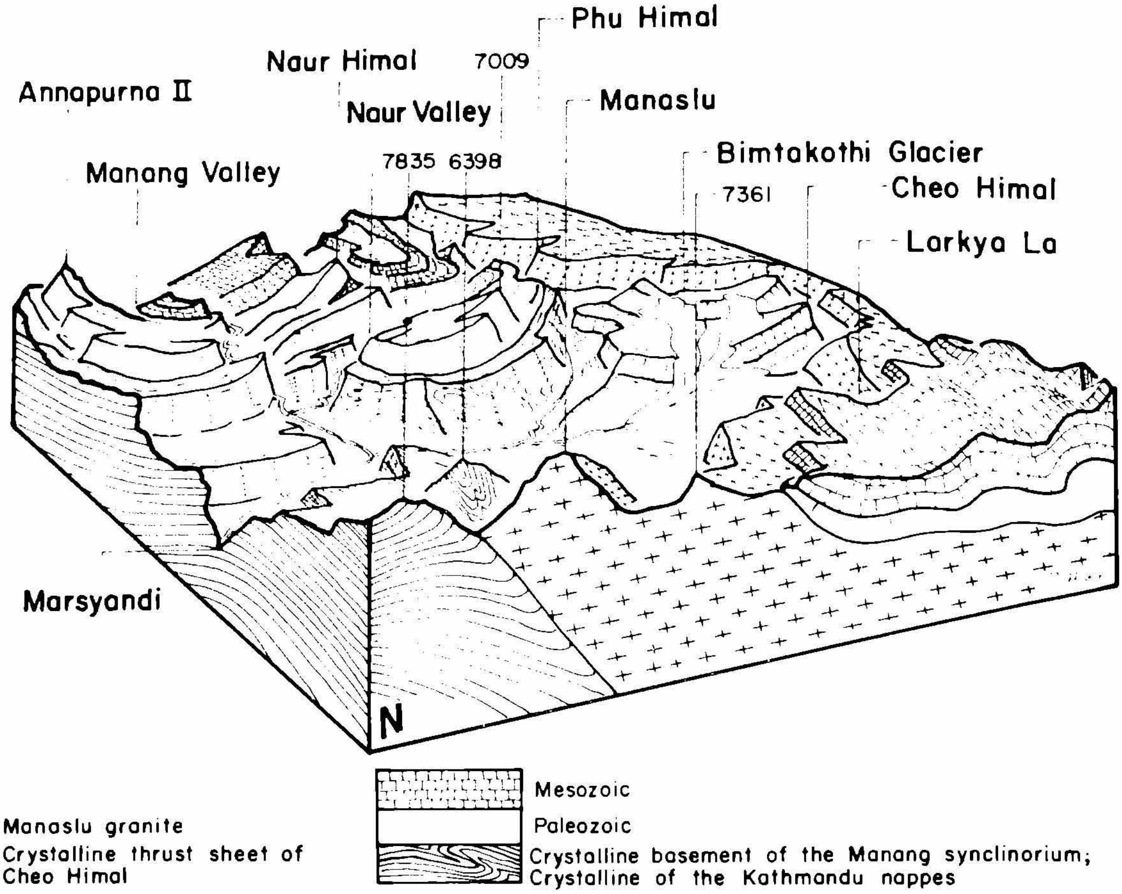


Fig. 33. Block Diagram of the Dudh Valley

Phot. 22. The Manaslu [illegible] *(aerial photo)*

Though the Mana[illegible]
theless a stru[illegible]
limit of th[illegible]
granite [illegible]

5. Geological Itinerary Thonje-Manang

About 1 km south of Naje we found in the crystalline formations a change into calcareous gneisses and calcsilicate rocks. At the bridge of Thonje (see fig. 21) again we find fine-grained calcareous gneiss, with biotite, augit, amphibol, garnet and chlorite. The dips are very flat, more or less horizontal. North of Bagarchhap occur great discordances in these calcsilicate gneisses namely folds, overthrusts and

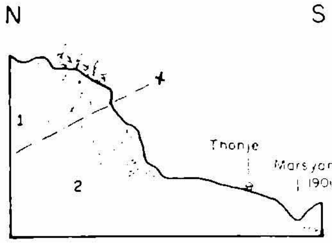


Fig. 34. The Ridge North of Thonje (between Marsyandi and Dudh Khola)

1 calcsilicate rocks; calcareous components dominant

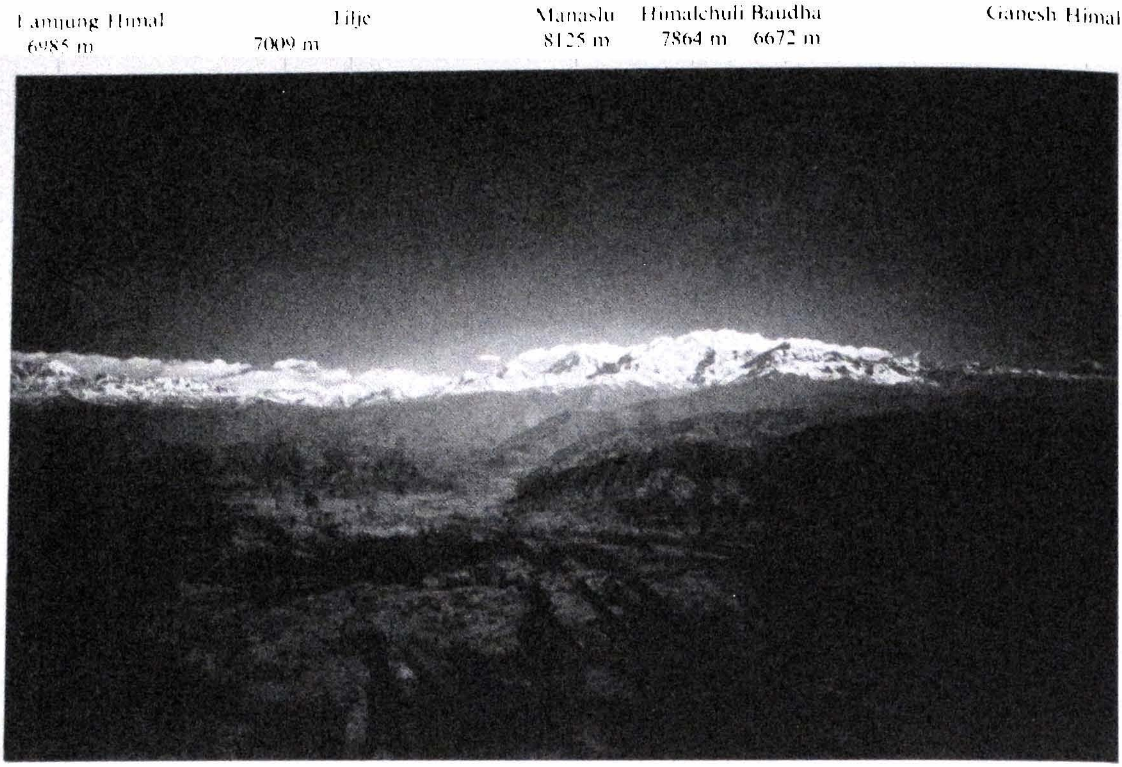
2 calcsilicate rocks; crystalline components dominant (shows with its quartz, felspars and mica macroscopic resemblance to granite)

The two series are separated by a thrustplane, whereby the underlying series are intensively folded.

displacements. One clear fold can be observed above Taje, north of Bagarchhap. The axis of this fold strikes north–south with a dip towards the north (fig. 34). This is at right angle to the normal strike and dip. In the wedge between Taje and Tilje also the general strike turns from the previous normal westnorthwest–eastsoutheast into a northeast and even into north direction. Since on the other hand the ridge east of peak 3537 m shows a southeast strike, a clear anticlinal structure results in the valley of the Dudh Khola. (See also phot. 25.)

Phot. 23. The Manaslu Group above Tarpu Ghat
(seen from southwest)

In the foreground are the northern dipping roots of the Nawakot nappes. The Kathmandu nappes are overthrust where the main tributary from the eastern side (right hand in the photograph) joins the Marsyandi, above Tarpu Ghat.



Phot. 24. The Annapurna and the Manaslu Group
(seen from the south, aerial photo)

This wide-angle photo is taken from a position above Khuncha, in the Nepalese Midlands. It shows the Marsyandi valley between the Annapurna group and the Manaslu group. In the foreground, the system of transverse faults striking out of the Marsyandi gorge towards the south is visible. This transverse fault system extends right through the whole Nepalese Midlands in southern direction to the Mahabharat range and into the Siwaliks.

The clear terrace of Naje in the otherwise uninterrupted slopes of the V-shaped valley is caused by transverse faults, which strike north south. These are a part of the transverse fault system which possibly originated the transverse valley of the Marsyandi. (See also phot. 25, where the ridge in the center foreground is completely cut by numerous vertical fractures and faults, thus deceiving a vertical dip of the horizontally bedded gneiss.)

Possibly, there is an ancient river course of the Marsyandi burried in the terrace of Naje.

Undoubtedly there must be a transverse fault system in the Marsyandi valley, for, further south in the gorge, also the strike is turned towards north south, and still further south, where the Marsyandi leaves the main range of the Himalayas, an extensive system of fractures was observed, striking through the whole Nepalese Midlands right down to the Siwaliks. (Phot. 24.)

The series from Bagarchhap up to a few hundred meters west of the junction of the Naur Khola at Kupar are formed predominantly out of crystalline: first biotite-paragneisses with lenses and small layers of pegmatites and granites, then laminated mixed gneisses, granitic gneisses, thin layers of augengneisses and finally lenticularly banded mixed gneisses. The latter are interbedded with calcsilicate rocks. Close south of Thangja the dip is steep towards north. The valley of Kupar (lower part of the Naur Chu valley) shows a flat syncline parallel to the river course. However this structure is hidden by the strong western axial pitch, which from here on increases towards the west. (See phot. 36 and fig. 37.)

The ridge northeast from Kupar towards the Tilje Peak shows a big fold. A lying fold of granite-gneiss, embedded in calsilicate rocks is directed towards the west (fig. 35). The direction of tectonic pressure points clearly towards the west.

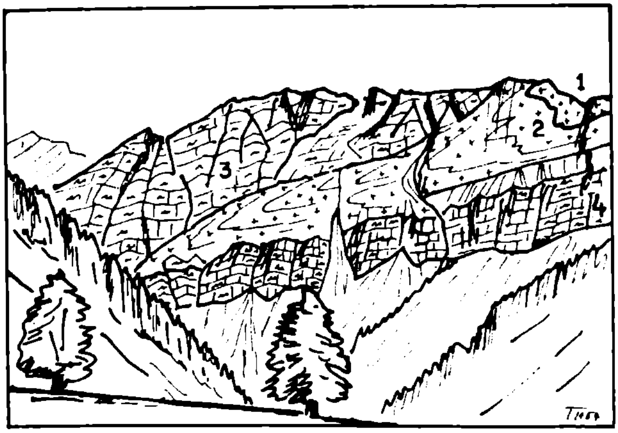


Fig. 35. View from Thangja towards North

A western pitching crystalline fold within the calcsilicate rocks

1 predominantly granite
2 granite-gneiss with abundant pegmatites
3 calcsilicate rocks with pegmatites
4 calcsilicate gneiss with pegmatites

The boundary between the gneisses and the calcsilicate rocks strikes through Chame (fig. 36). The latter overlies mixed gneisses and granite-gneisses. Above Chame, a number of folds can be observed in these calcsilicate rocks, especially at the western flank of the Kupar valley (fig. 37). The relative flat dips shown in the figure 37 are only apparent, since there exists a steep western pitching.

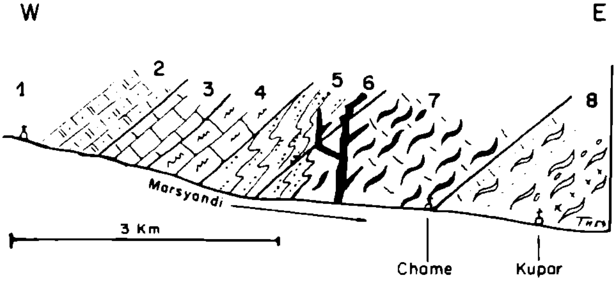


Fig. 36. Profile Sketch Pisang—Chame—Kupar (Marsyandi)

1 Camp of Pisang
2 calcareous dolomite and sandstone, interbedded with nets of shales (this series form the tremendous *fannel* of the western flank of the southern ridge of Naur Himal)
3 laminated sand-grained limestone
4 laminated limestone, slightly marmorized (Devonian?)
5 white folded quartzites in shales
6 topmost pegmatites
7 calcsilicate rocks
8 fine-grained biotite-gneiss, interbedded with granite-gneisses, mixed gneisses and augengneisses

The dip changes gradually from northwestern direction near Kupar to west at the Pisang camp. This is effected by the strong axial rise of the Manang synclinorium towards the east.

The same calcsilicate rocks contain a large number of pegmatites. These are partly developed as layers, partly as dykes, whereby the latter cross the beds under an oblique angle towards the north. Different from the folds at the eastern side of Kupar, here, above Chame they are directed towards the east. Apparently we are at this place at the crosspoint or joint between the two different tectonic arcs of the Annapurna range and the Manaslu group.

2 km west of Chame, towards the sharp river bend of the Marsyandi, we find above the calcsilicate rocks (which show a decreasing metamorphisme towards the west) a coarse-grained quartzite, calcareous slates, brown marl (well-bedded), dark limestones with small lenticular brown marls (containing shells), brown and reddish limestones with a net pattern of clays. The whole series above the quartzite probably belongs to the Devonian. It is the transitional zone between the epi-metamorphosed sediments of the Lower Paleozoic and the non-metamorphic sediment filling in the basin of Manang (fig. 36).

In general, the zone between Naje and Chame shows two distinct units: The large main crystalline series of the Marsyandi gorge, south of Naje is the base for the calcsilicate rocks and marbles of Thonje-Bagarchhap. The latter are overthrust (visible on the thrustplanes with unconformities and the intensive folding) by the crystalline series of Thangja-Kupar. The latter is considered to be the topmost tectonic unit, which forms the base of the Tibetan marginal synclinorium of Manang.

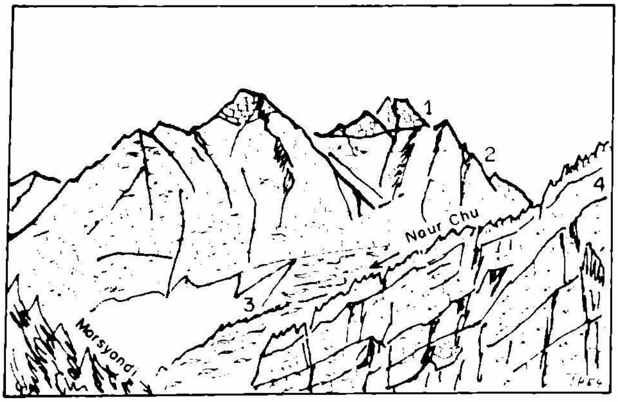


Fig. 37. The Eastern Flank of the Naur Himal
(seen from Thangja;
the main peak is not visible)

1 Silurian limestone
2 calcsilicate rocks with abundant pegmatites, especially in the lower part
3 mixed gneisses
4 calcsilicate-gneisses

All the formations dip towards the west, according to the axial pitch of the Manang synclinorium. The lower part of the calcsilicate rocks is tremendously folded.
(See also phot. 35.)

Since in this sector the longitudinal forces, directed from east and west, are predominant, we now better study the longitudinal profiles (plate IV, profiles VI–VIII).

Profiles VI and VII show the lying, towards the west directed crystalline fold (of fig. 35), with its cover of calcsilicate rocks. Halfway between the Tilje peak and Naur Chu (profile VII) the crystalline underlying of the said fold shows a distinct transverse saddle. This is the cross-point between the two different tectonic arcs of the Annapurna range and the Manaslu range. The Annapurna range strikes in westnorthwest–eastsoutheast direction, while the Manaslu group is turned towards the northwest–southeast direction. The geological strike corresponds in both mentioned mountain ranges to the topographic outlay.

7009 m | Phu Himal 6454 m | Himlung Himal 7125 m | Cheo Himal 6812 m | 6398 m

Phot. 25. Aerial View into the Dudh Valley
(seen from the southwest, aerial photo from 5600 m)

The Manaslu group is at the right side, the mountain ranges in the catchment area of the Bimtakothi glacier in the background. Note the vertical fracturing and faulting, deceiving a vertical dip and south–north strike of the northern dipping crystalline formations in the foreground!

Phot. 26. Lacustrine Deposits West of Thangja (2600 m).

1 river gravel

2 lacustrine clay

The ice-axe points to the boundary between the two formations.

However unsymmetric it may be, the western flank of this anticline is identic with the enormous flexur-like axial rise out of the synclinorium of Manang.

The series on this flank (fig. 37) show an uneven bedding, with a large number of long, but flat-pressed folds. Large-scale recumbent folds do not exist in this zone. The axis of this anticline may be located in the meridian of the Tilje peak (see profile VI plate IV). Further south, in the longitudinal profile through Bagarchhap the axis strikes along the Dudh Khola valley. However it cannot be considered to be the same axis, since it is transposed towards the east.

The description of the Dudh valley was given in earlier chapters. We may — in connection with the above mentioned transverse anticlines — point out, that the lower limit of the Tilje peak limestone formations strikes through the valley north of Peak 4692 m towards northwest. (See phot. 25 and 28.) This is the eastern termination of the Manang synclinorium, which in the northeast is joined by the Manaslu granite, respectively pressed to a narrow steeply northeastern dipping limestone series. (See profile 10 plate III, near Peri Himal.) The Peak 4692 m marks therefore the distinct eastern flank of the Tilje transverse anticline. (See plate IV profile VI, in the valley between the Bimtakothi glacier and the Peak 7009 m, and further profile VII in the Dudh valley.)

Thus, in general there is an anticline structure between the Naur Chu and the Dudh valley. We may call it the Marsyandi transverse structure. It shows anticline character north of the main ranges, and continues towards the south, through the Marsyandi gorge and into the Nepalese Midlands as a zone of faults and fractures.

Thus the transverse valley of the Marsyandi between the Annapurna group and the Manaslu group does not make any exception compared with other major transverse valleys between major mountain groups in the Nepal Himalayas, namely it has also been caused by a transverse structure.

The large terrace southeast of Thangja (2600 m) consists of morainic material. The same terrace can also be observed at the opposite side of the valley. In the small tributary west of Thangja occur lacustrine deposits in form of fine clays (see phot. 26).

Apparently the lacustrine deposits are in connection with the huge morain deposits, which form quite a wall dropping down by 250 m from the big terrace of Thangja towards the east into the lower part of the Marsyandi valley. Apparently, during a recession stage of a late ice age, a terminal morain dammed a big lake in this area.

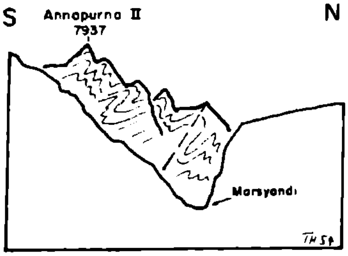


Fig. 38. The Northeastern Flank of Annapurna II (7937 m)

The Palaeozoic sediments (dominantly limestones) show tremendous reverse folding. (See phot. 28.)

Before entering the narrow gorge of the Marsyandi west of Thangja, let us study the northeastern flank of the Annapurna II (7937 m), which drops in a tremendous wall from nearly 8000 m down to 3000 m 3 km northwest of Thangja (see phot. 28). This wall exposes very clear the intensive tectonics, which played their role in this area. A large number of reverse folds (directed towards the north) can be observed in the upper part (fig. 38). The lower part shows also reverse thrustfaults and normal (northern dipping) faults (fig. 39). All these structures show up in rather monotoneous Silurian and Devonian formations of excessive thickness. However the thickness has been caused by tectonic piling.

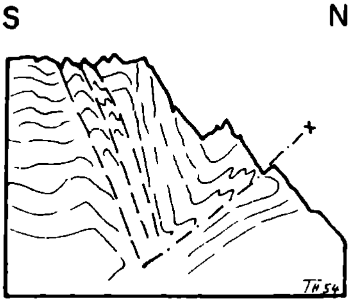


Fig. 39. The Reverse Folds and Fractures and Thrustplanes in the lower part of the Northeastern Flank of Annapurna II

The formations are Carboniferous and Permian.

3 km west of Chame, where the trail changes from the (orographic) left river bank towards the right side, we find the first fossils, however only in the debris. According to the lithological character and the corals, the formations (limestones) may be considered to be Devonian. (See phot. 27.)

The part of the Marsyandi river, which flows in north–south direction follows tremendous dip slopes. These dip slopes form a huge fannel in a semi circle with steep western dip around the distinct river bend 4 km eastsoutheast of Pisang (see geological map plate II). The dip slopes consist of evenly bedded uninterrupted Devonian limestone which drops from 5500 m on the southern ridge of Naur Himal (6114 m) down to 2800 m on the Marsyandi. (See phot. 35 left side, 37 and fig. 60.)

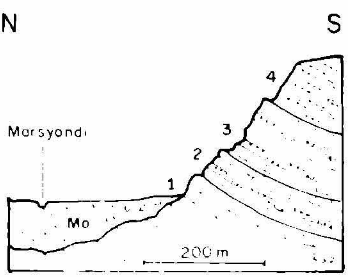
At the above mentioned river bend 4 km southeast of Pisang we enter the wide valley of Manang. (At 3200 m, see also fig. 6.) The distinct steep step at this place is caused not only by the solid rock bottom of the valley, but also by a huge lateral morain of the ancient Marsyandi glacier. The edge of the western edge of the flat valley shows morains, and behind the morains (west of) there is a number of morain lakes.

Phot. 27. Devonian Fossiliferous Limestone with Corals
at the Marsyandi river-bend, 3 km west-northwest of Chame

The wide valley of Manang is built entirely out of sediments with generally syncline structure and the whole character, climatic, topographic and geologically contrasts very much to the crystalline gorge further down. However, the present form and character of the Manang valley has dominantly originated from glacial erosion, glacial and interglacial deposits and landslides.

The sharp bend of the Marsyandi 4 km southeast of Pisang originated by the extremely sharp axial rise of the Devonian limestones towards the east. In the upper part of the valley, until east of Pisang, the Marsyandi follows more or less the bottom of the main axis of the Manang synclinorium. At the place, where the river bends first towards the south and then to the east, it breaks through the Devonian and Silurian formations and below Chame it breaks through the topmost crystalline. Thus the Mar-

Fig. 40. Profile Sketch in the Marsyandi Valley opposite Pisang



Mo morain
1 limestone, with net pattern of clays and shales, also interbedded with yellow and pink dolomite layers (Devonian)
2 gradually out of (1), more dark, interbedded with pink quartzites; the quartzite is partly conglomeratic
3 graphite-phyllites, dotted slates, chlorite-slates, black and red quartzites interbedded with slates (Narebang quartzites), reddish coarse-grained quartzites and quartz-sandstones (Carboniferous)
4 clear quartzites («yellow-band series» of the Carboniferous)

The topmost pegmatites reach up to the Devonian limestone. Further west, the pegmatites reach only to the Silurian formations.

syandi has been deflected by the fannel - like bend of the strike of the series building the southern ridge of the Naur Himal (6114 m). (See phot. 37 and also fig. 6, profile 2, at 3200 m, further fig. 60 and plate V, fig. 1.)

The ridge south-southeast of Pisang, at the opposite flank of the valley, shows the first rock exposure with the Carboniferous and younger formations over the Devonian (fig. 40). The Carboniferous is typical with its yellow-band series. All the formations of this valley flank, especially overlying the Mesozoic, are tremendously faulted and folded, much of it in a reverse sense (directed towards the north, fig. 41). The Devonian (all dipping south) is represented by the typical limestones with a net pattern of clays, and interbedded with yellow and reddish dolomite layers. Towards above, the net pattern of clays

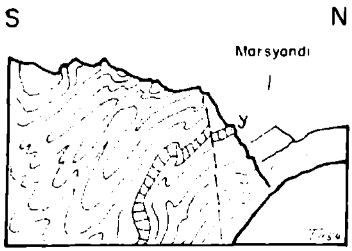
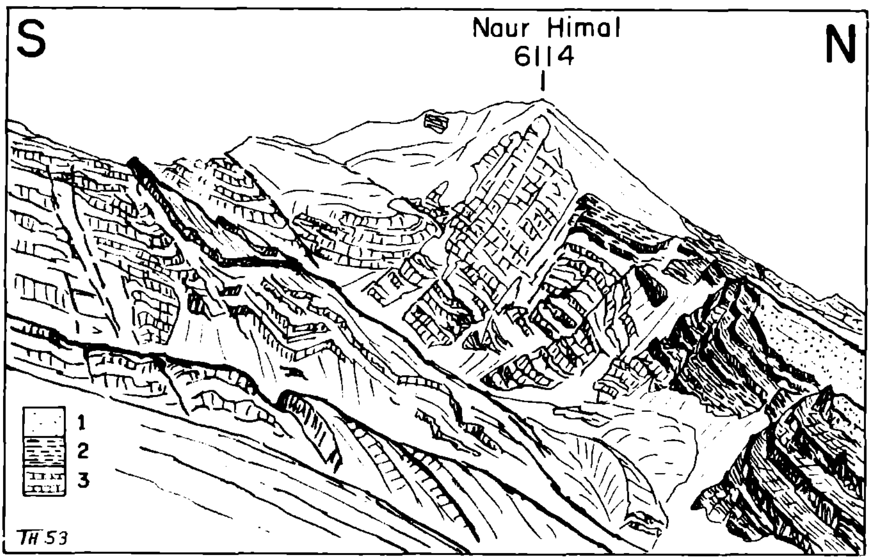


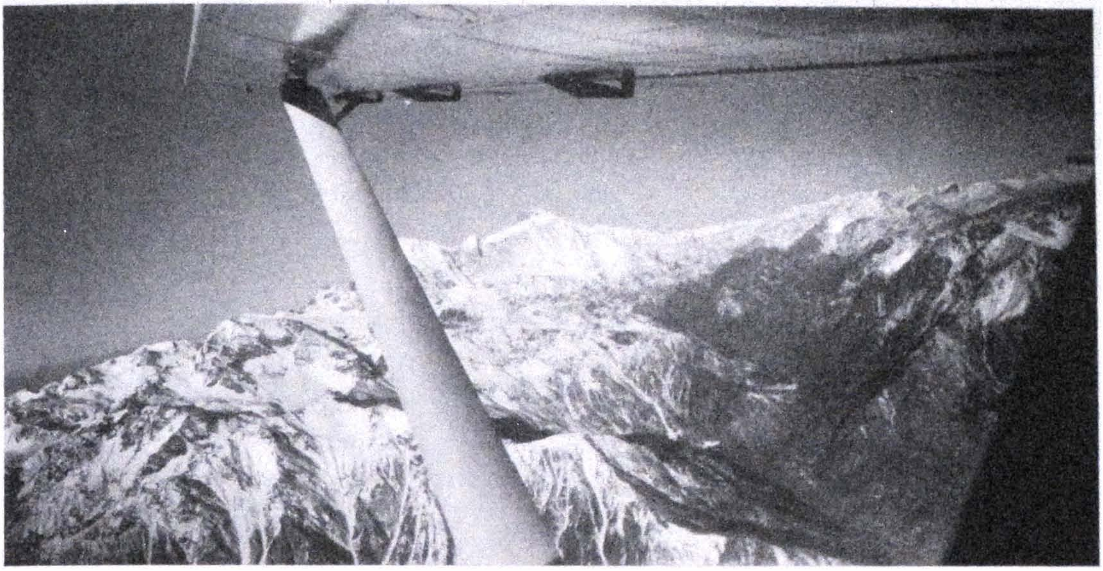
Fig. 41. Detail Sketch of the Northern Flank of Annapurna II, opposite to Pisang.
y yellow-band series (Carboniferous).
The overlying series consist of tremendously reverse folded Mesozoic formations. (Compare also plate III, profile 10.)

increases, whereby the limestone itself is getting darker, with sandy blending. The quartzite changes partly into a conglomeratic facies. On these conglomerates, as first bed of the Carboniferous, we find graphite slates, dotted slates (very typical for Carboniferous) and chlorite slates. Further up follow quartzites, of partly reddish sandy character, broken Narebang quartzite slates and then a pair of clear-coloured, dense quartzites, interbedded in the dark Narebang slates. These latter series have been called "yellow-band" series, and are very typical for the (Upper) Carboniferous (fig. 41 and plate V, fig. 1.) We shall see later on that this yellow-band series has been proved to be Upper Carboniferous by the finding of a Zaphrentis species northwest of Manang (see phot. 39).

Fig. 42 The Naur Himal Seen from the West
1 Permo-Carboniferous (red sandstones)
2 Carboniferous (slates, quartzites and sandstones)
3 Devonian (limestone with net pattern of clay)
Though the dip is generally directed towards the southwest, there are a number of thrustfaults which caused a slight folding (see also fig. 43 southern ridge of Naur Himal and phot. 37).



Lamjung
Namun Himal Annapurna II Naur Himal
5784 m 6985 m 7937 m 6114 m



Phot. 28. View into the Marsyandi Valley between Kupar and Manang, seen from the east
(aerial photo from 5700 m above Thonje)
The Manang synclinorium between Annapurna II and Naur Himal is well-expressed.
Please note the "Gipfelflur" at about 6000 m north (right side) of the Annapurna range. Also an ancient land surface is well expressed through flat slopes and terraces at about 4000–4500 m on both sides of the main range of the Himalaya. Indeed, the Annapurna range is like a "lifted island" ("Hebungsinsel" according to Dhyrenfurth) compared with the surroundings.

The yellow-band series opposite Pisang show the topmost pegmatites, which are crossing the beds under oblique angle towards the north.

The whole mountain range at the northern flank of the Manang valley, from Naur Himal (6114 m) down to Ngawal is built by the well-bedded Devonian limestones, which show a general steep southerly dip. (See phot. 30 and fig. 42 and 43, plate V, fig. 1.) Since this dip is parallel to the flank of the valley,

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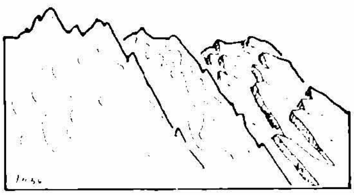


Fig. 43. The Southern Ridge of Naur Himal (6114 m)
(seen from the west)
This ridge is built of huge Devonian formations, mostly limestones and slates, which are tectonically accumulated by several thrustsheets.
The evenly dipping beds at the right side form the tremendous fannel round the bend of the Marsyandi 4 km southeast of Pisang.

only the ridges between the tributary valleys have Carboniferous formations on their top, while the Devonian formations are exposed in the valleys. (See fig. 42; compare also the geological map plate II.) The Naur Himal (6114 m) itself shows a number of reverse thrustfaults, with increasing intensity of tectonics towards north. Hereby the parcels between the thrustfaults have intensively been folded (fig. 42 and 43).

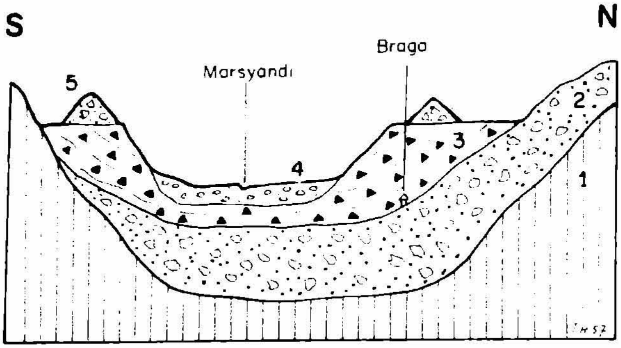


Fig. 44. Cross Section through the Marsyandi Valley at Braga
showing the interglacial landslide of Braga (Compare also phot. 29, 30 and 31 and fig. 45.)

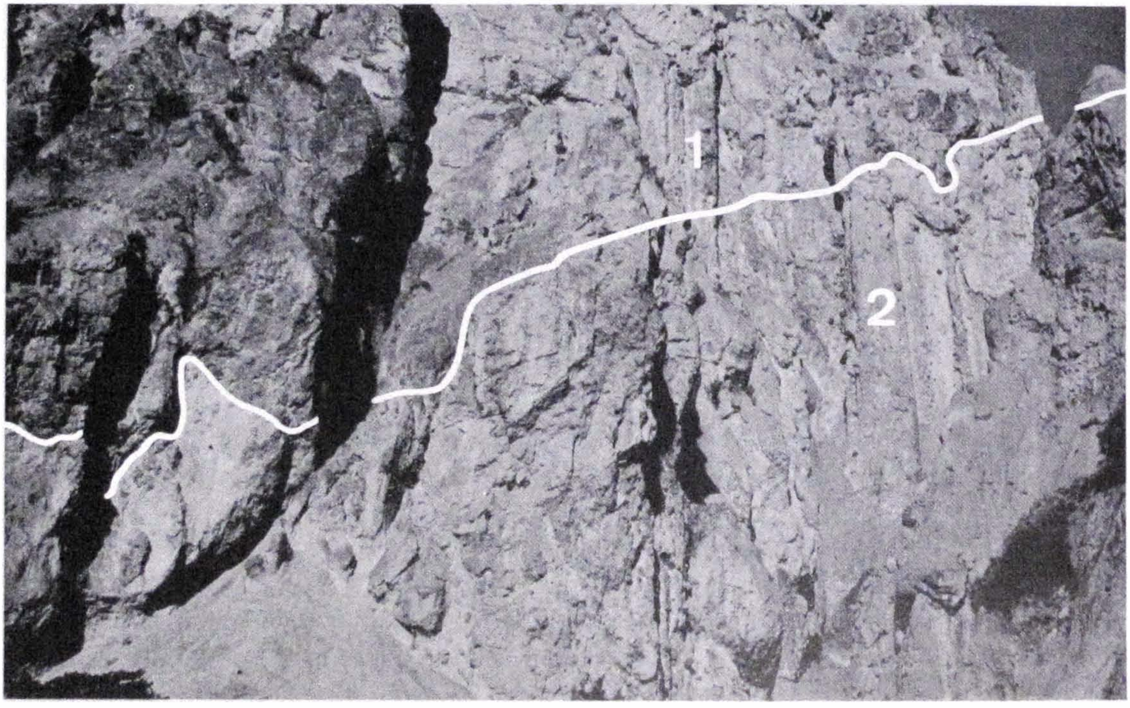
1 rock bottom of the valley
2 ancient ice age ground morain
3 interglacial landslide
4 sub-recent ground morain
5 sub-recent lateral morains of the Marsyandi glacier

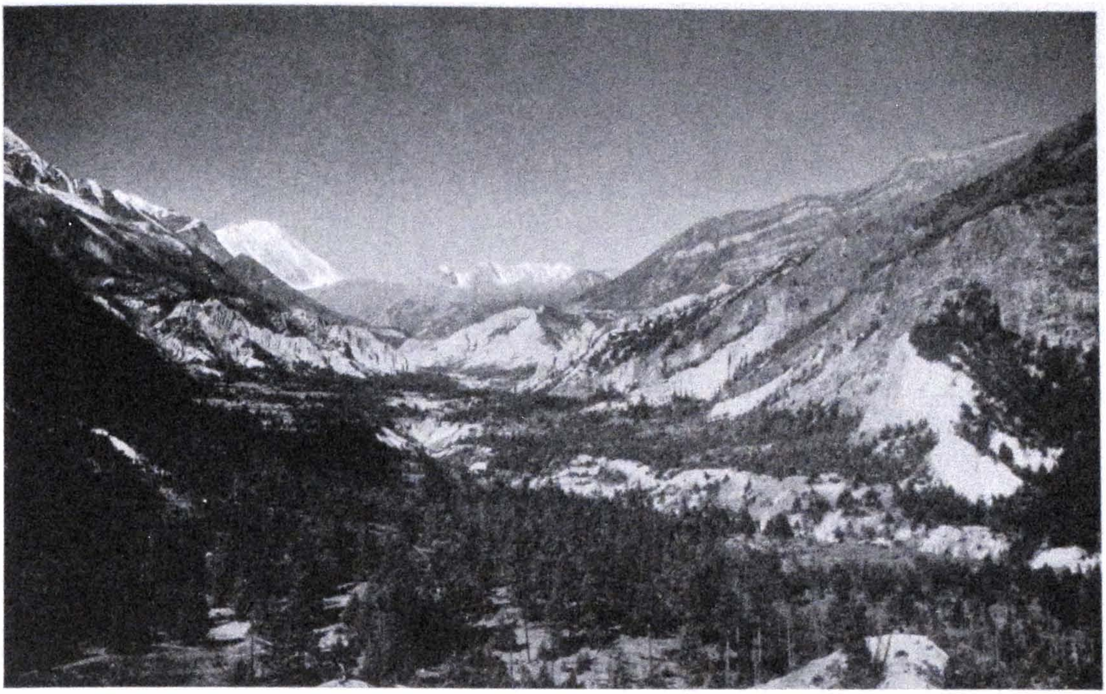
In the valley bottom of Braga, the exposures are rare, since the whole area is covered by immense masses of glacial and fluvioglacial deposits and landslide materials (fig. 44 and 45; plate V; phot. 30–32 and 38 and 37). One can imagine how intensive the former glaciation must have been, when considering how still today the Gangapurna glacier, fed by the Annapurna III (7576 m) and by the Gangapurna (7315 m) reaches right down to the bottom of the valley at Manang. Its recent or subrecent (stage of 1920?) lateral morains dam still today the valley (phot. 31 and 32). Large alluvial plains have filled former glacial morain lakes, which formerly have been caused in the main valley by the lateral tributary

Phot. 29. The Interglacial Landslide of Braga

1 Landslide deposit; bedding is still visible even with its crossing quartz veins; the formations are partly re-cemented, the rocks consist predominantly of Carboniferous slates, Permian sandstones and Triassic limestones and dolomites.
2 morain of former ice age.

The landslide material extends right to the opposite (southern side) of the valley, and is in the bottom of the valley covered by younger morains (of a late ice age stage; compare also phot. 30, 31, 32 and 37; and fig. 44 and 45).





Phot. 30. The Marsyandi Valley near Pisang
(seen from the southeast)

The bottom of the valley consists of morains.
The white series at the foot of either valley flanks are landslide material, originated from the northern flank (right side). The main ridge at the right side shows the southern dipping (parallel to the slope) of the Triassic, the Permian and the Carboniferous formations. (See also phot. 31 and plate V, fig. 1 and 2; and fig. 44 and 45.)

glaciers (fig. 57, phot. 31 and 32). In addition to the glaciation, landslides have also played an important role in shaping the present valleys. Near Braga (fig. 44 and phot. 29–31) we find land slide materials, which has originated from the northern slopes. In the landslide deposit, the bedding (with southern dip) can still be recognized, though broken and recemented. The material consists predominantly of limestones (Devonian), slates and quartzites (Carboniferous), limestones and dolomites (Permian-Triassic). Surprisingly enough, the landslide material is deposited on the top of morainic material with huge boulders, whereby the contact between the landslide and the morains shows also southern dipping. (See phot. 29 and 31.) The landslide has a tremendous dimension and also must have had a tremendous intensity, since it reaches right to the opposite valley flank, thereby surfing by 200 m up the opposite side. (See also sketchmap of fig. 45.)

Based on these facts, we have to consider this landslide of Braga as interglacial. The material has been eroded away in the bottom of the valley later on, leaving the main masses at the flanks. Due to this erosion, the underlying fluvioglacial deposits and the morains have partly been exposed.

The Quaternary history of the Manang valley may be reconstructed as follows: During recession of the last ice age, the main glacier (Marsyandi glacier) left a thick cover of morains in the valley, extending on either flanks by 200 m above the present alluvial bottom. Then the landslide from the northern flank covered the whole valley, reaching at the opposite side about 200 m above the present bottom. Fluviatil erosion and a following diluvial phase levelled an alluvial plain on the top of the landslide deposits.

Phot. 31. The Marsyandi Valley above Braga
(seen from the east; Nilgiri (7148 m) in the background)

The bottom of the valley is now covered by an alluvial plain consisting of morainic material; most probably an ancient lake. The plain is flanked by the landslide material, which is eroded into sharp crests and gullies. The horizontal top of the landslide masses shows a levelled ancient terrace. Lying on the terrace at the southern side (left side in the picture) we find big lateral morains of the ancient valley glacier. (Compare also fig. 44, 45, 57; plate V, fig. 1 and 2 and phot. 38 and 41.) The arrows indicates the detail photograph 29.

New fluviatil and glacial erosion cleaned a new valley into the landslide materials, leaving parts of the former higher alluvial plains in front of the present terraces on either sides. New glaciation (of the Marsyandi glacier) deposited lateral morains on the edges of the old terraces. A last phase of glaciation deposited ground morains in the bottom of the valley.

In general there exist great similarities between the landslide of Braga, and the famous interglacial landslide of Flims in the Swiss Alps. Both have originated from a valley flank, in which the dip of the beds are parallel to the slope; in both the landslides the rocks have glided along bed joints, possibly undercut by glacial erosion at the foot of the valley flanks; and finally, in both the landslides the forces were so tremendous that the masses were surfing up the opposite valley side, hereby damming the main valley to a lake. (Undercutting of the dip slopes by glacial erosion is evident near Manang; see phot. 30, 37 and fig. 50.)

We now devote again to the detail geology of the northern flank of the Manang valley. The geological profile on the ridge north of Braga (fig. 46, 47) shows at the base Carboniferous formations with dark Narebang quartzite, slates and clear quartzites (yellow-band series), clear dotted slates, dark blue-green and red phyllites, dark slates, dark green slates with layers of manganese iron ore (similar to the

Phot. 32. Manang Village with the Gangapurna Glacier Reaching into the Main Valley

The tongue of the glacier dammed a lake in the valley until the Marsyandi cut through.

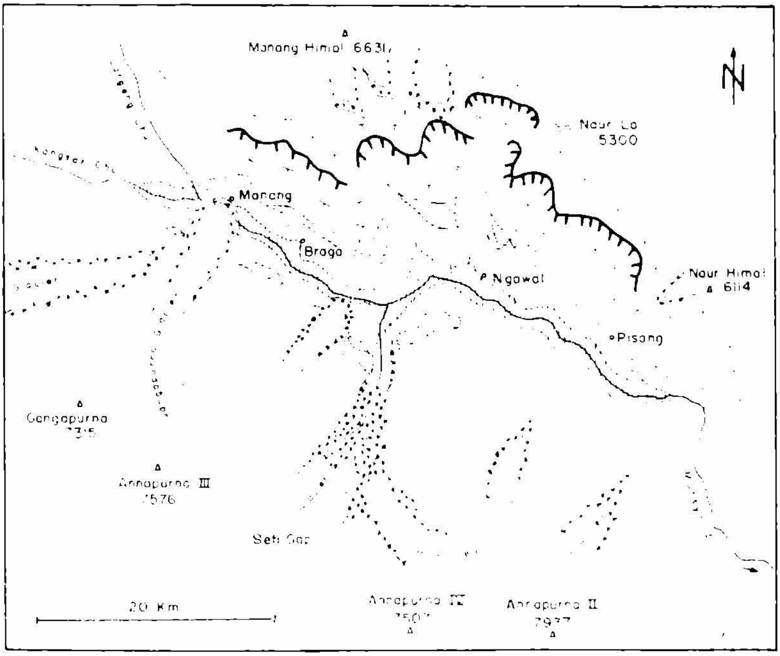
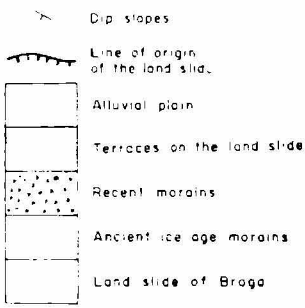
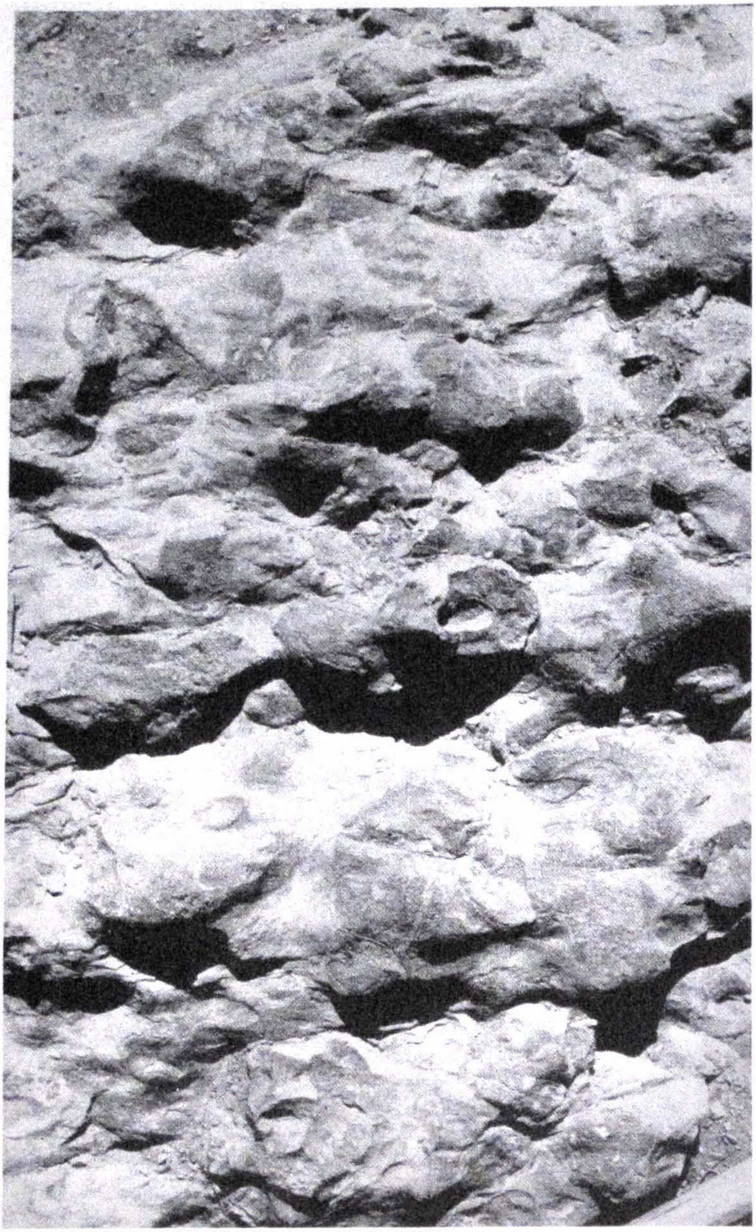


Fig. 45. Sketch Map of the Landslide Area of Braga





Phot. 33. Fossiliferous Nodular Limestone
(seen at the ridge 200 m north of Braga)
The nodules are originated from shells, of which the limestone contains a large number.
The formations are Permian-Triassic.

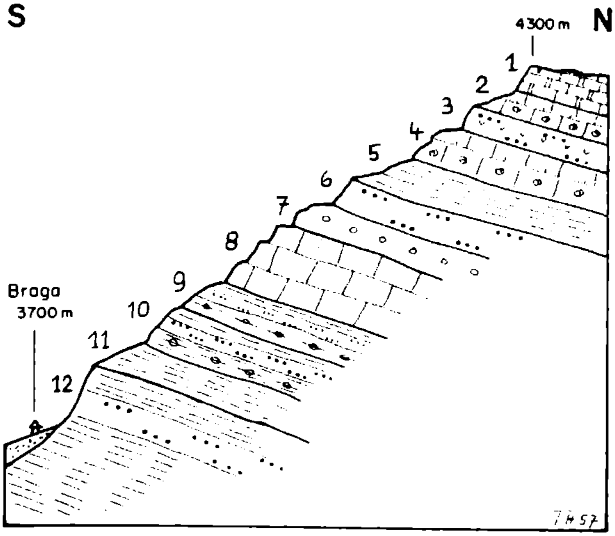


Fig. 46. Detail Profile Sketch of the Ridge North of Braga

1 sandy weathering grey limestones and dolomites
2 nodular limestones (see phot. 33) with brown sandy-marly intercalations
3 quartzites, sandy quartzites, iron quartzite
4 lumashell limestone, nodular marl intercalations
5 fine slates, light green, violet and deep blue
6 red sandstones and sandy quartzites
7 polygene conglomerates ("verrucano" type of the Swiss Alps), dolomites, limestones and mostly quartzites as components in red quartz-sandstone
8 limestone with rosty inclusions
9 dark green slates, interbedded with radiolarite quartzites and manganese ore layers
10 dark slates, interbedded with dense red quartzites and manganese ore
11 slates, dark blue, green and violet (similiar to the type of the sernifite of the Swiss Alps)
12 quartzite layers interbedded in dark violet shales and spotted red sandstones ("Narebang quartzites")

These series are to be considered of Lower Triassic—Permian and Upper Carboniferous.

Takbachhi series below Dhor Patan, see Volume I of this publication series), red dense radiolarite—like quartzite series (similar to the Rukumkot series in the Bheri valley). A limestone with rosty inclusions is found further up (Permian?). After this we find a polygene conglomerate (of the Verrucano type of the Swiss Alps), red sandstones and sandy quartzites. These are undoubtedly Permian formations. Bleach-greenish, steel-blue and violet slates, partly looking like "wood-slates", lead to a series of limestones with numerous lumashells. Lenticularly banded layers of marl divide the limestone in thick beds. Above the lumashell limestone we find a quartzitic zone, with sandy quartzites and iron quartzite. Again follows a series of limestones overlying the quartzites, consisting of nodular limestones (shells and silicious concretions) with brown sandy marly interbeddings (phot. 33). Grey sandy limestones change gradually over to dolomite (at 4500 m altitude). This dolomite was also found as component in breccias whereby the components are cemented by grey sandy limestone (phot. 34). The latter series dip towards the southwest, while the underlying Carboniferous series are intensively folded (fig. 47).

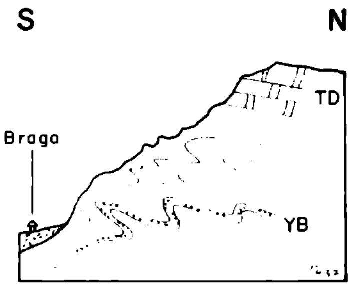
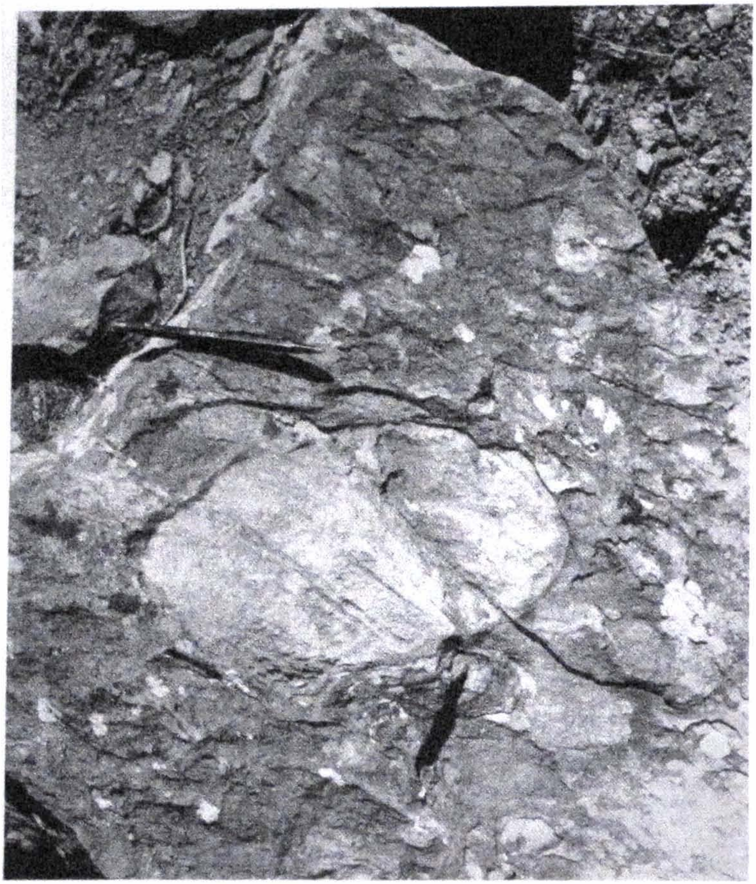


Fig. 47. The Folds in the Eastern Flank of the Ridge North of Braga
(seen from the east; see lithologic detail profile fig. 48)

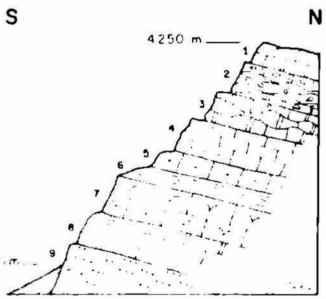
TD Triassic dolomite
YB yellow-band series (Carboniferous)



Phot. 34. Dolomite Conglomerate in Fossiliferous Brown Sandy Limestone (at the ridge 500 m north of Braga) The pencil indicates the scale.

The overlying dolomitic series shows the profile as given in fig. 48. The top is formed by a typical Triassic dolomite, of light brown dense character. The lower part shows on the surface sandy weathering. A Rauhwacke with cellular structure is also present, underlying is a nodular dolomite with limestone. Brick-red and clear red sandstones are followed by banded reddish brown sandy limestone. The following dark and greenish blueish clays recall the "Quartenschiefer" of the Helvetic Triassic in the Swiss

Fig. 48. Profile Sketch of the Ridge Northwest of Braga (Triassic profile)



1 light brown dolomite, surface sandy weathering
2 light dolomite, interbedded with cellular dolomite, net pattern of clay
3 nodular dolomite-limestone
4 bright red and pastell-red banded sandy limestone
5 reddish-brown laminated sandy limestone
6 dark slates, and greenish-blueish slates (similarity with the "Kössener" and "Quarten" shales of the Alps)
7 reddish coral limestone, with layers of light yellow-green clays in net pattern, also with brown sandy clays
8 banded dolomite and limestone, with layers of dark limestone
9 coarse-grained red quartzite, iron quartzite

Alps. These clays are in the lower part increasingly interbedded with pink coral limestones, whereby the clays themselves change their colour to light yellowish-green. These clays form a net pattern in the pink coral limestone together with layers of brown sandy marly limestones. Banded dolomite and limestone, interbedded with dark limestones are followed by a red, coarse-grained iron quartzite.

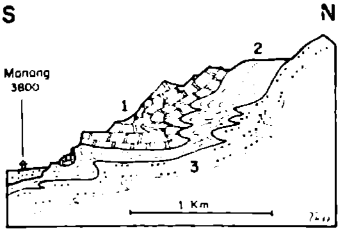


Fig. 49. The Ridge North of Manang
1 dolomite (Triassic)
2 quartzites, sandstones and multi-coloured slates (Permian)
3 «yellow-band» series; quartzites and slates, (Carboniferous)

In general the above mentioned profile is typical for the Triassic. (Later on, in the Thakkhola itself, this was proved by finding of fossils.)

The lower limestones and dolomites correspond to the Muschelkalk level, while the upper thick dolomite is the aequivalent of the Norian Hauptdolomite of the Alps. This main dolomite builds further west the big wall above Manang (fig. 49), and also covers wide areas of the surface from Manang towards the Manang Himal (6631 m), since it strikes and dips more or less parallel to the surface. (Compare also geological map plate II and plate III profile 8, further fig. 50 and phot. 42, the Manang Himal seen from the west.) At the eastern flank of the southern ridge of the Manang Himal (6631 m) the whole Triassic and Permian profile is well exposed right down to the yellow-band series of the Carboniferous and the well bedded Devonian limestones (fig. 50).

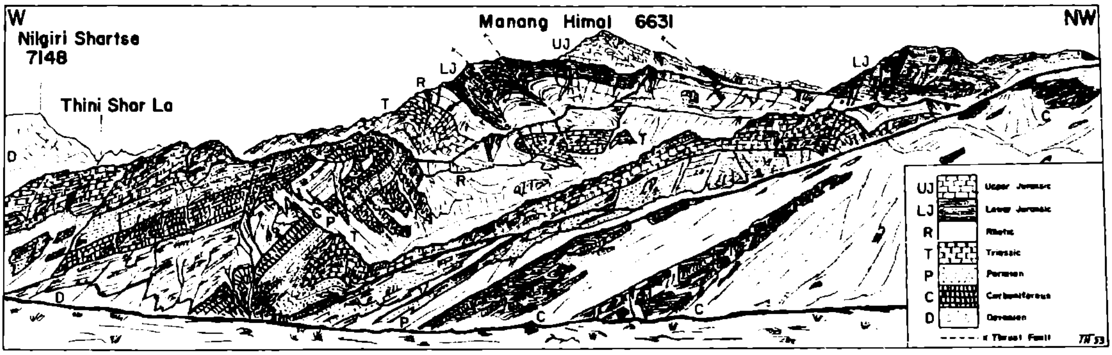


Fig. 50. The Eastern Flank of Manang Himal (6631 m).
The southern ridge (left side) shows a narrow reverse (directed toward north) anticline formed of Devonian, Carboniferous, Permian and Triassic formations. The Rhetic and Jurassic formations of the upper part of the Manang Himal have a (normal) northern dip. Several thrustsheets indicate the forces in this zone directed towards the south.
The interglacial landslide of Braga has its origin in the huge Kar situated at this flank of the Manang Himal. The dip slopes directed parallel to the flank of the valley have encouraged sliding of whole large bed parcels. Probably glacial erosion at the foot of the mountain flank has undercut the beds and thus give reason for the sliding.
The topographic and tectonic similarities with the large interglacial landslide of Flims in the Swiss Alps are evident.

6. Geology of the Mountain Ranges North of the Manang Valley
(Manang Himal--Naur Himal--Naur Chu Valley)

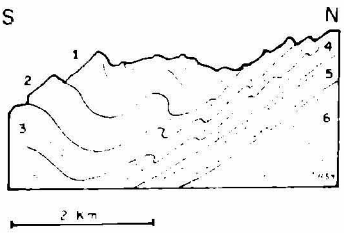


Fig. 51. Profile sketch of the Ridge North of Ghyaru
(seen from the east)

1 Jurassic limestone
2 Lower Jurassic slates
3 Rhetic slates and limestones, dark shales
4 Triassic dolomites
5 Permian quartzites and sandstones
6 Carboniferous quartzites, slates and shales

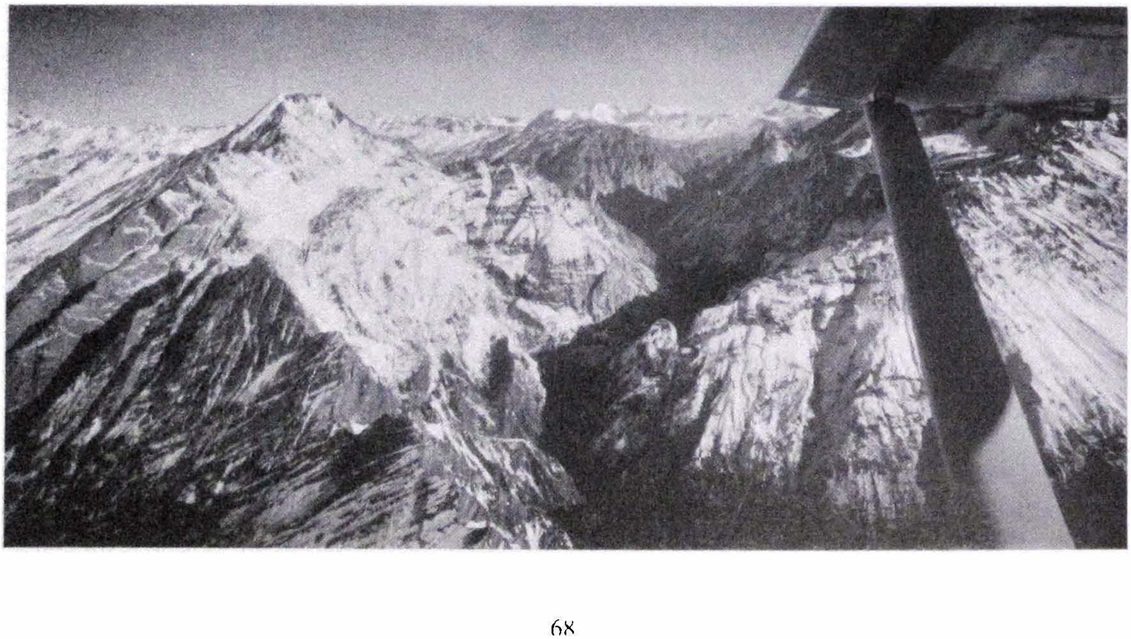
The Mesozoic series have unconformly glided on the Permian formations.

We now go for an excursion from Ghyaru over the Naur La (5300 m) to the Naur village. When climbing from Ghyaru we first move always in the same Devonian limestones, since the beds dip more or less parallel to the slope. At 4500 m we leave these limestones and proceed into the overlying Carboniferous and Mesozoic formations (see fig. 51, 52). With growing altitude, the so far evenly southern dip is replaced by various folds. The Naur La (5300 m) is situated little north of an anticline. Northern dipping Triassic dolomites occur in the gap (fig. 52). North of the Naur La we cross a narrow syncline with Rhetic formations as filling. The syncline is slightly overturned towards the north. (See profile 9 in plate III, and fig. 53.) This syncline strikes towards the eastsoutheast, along the northern flank of Naur Himal (6114 m) and round this peak into the eastern flank of this mountain, where it terminates due

Phot. 35. View into the Naur Valley from the South
(aerial photo from 5700 m above Kupar)

The eastern flank of Naur Himal shows the overturned syncline with Mesozoic filling (right side flank). The ridge at the foreground is built by Devonian limestones with a fannel-like shape (compare also phot. 37 in which F points to the fannel).

Naur Himal 6114 m — Tangetse 6723 m



to the general axial rise of the Manang synclinorium in this area. (Compare also fig. 54 and especially phot. 35, where this Mesozoic wedge is well exposed.) On the ridge southeast of Naur La, towards the Naur Himal, we find a secondary small overturned syncline with Triassic and Rhetic filling

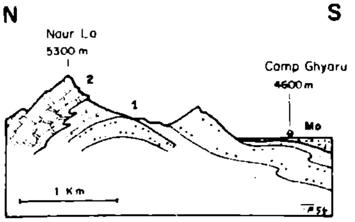


Fig. 52. Detail Sketch of Naur La (5300 m)
1 Permian quartzites and sandstones
2 Triassic sandy dolomites
Mo morain

(see fig. 53 and geological map plate II). Near the Naur village, in the valley striking west–east, Carboniferous formations occur on the top of an anticline, which is exposed in this valley (see fig. 54).

From the Naur La and the ridge east of it we obtain a commanding view on the geological situation of the glaciated mountain range which extends from the Manang Himal (6631 m). (See geological panorama fig. 54). The top of the mountain ridge north of Naur La is built by Jurassic and Rhetie formations in a syncline structure (see profile 9 plate III). The underlying Triassic dolomites are folded and form an anticline, the axis of which strikes from the bottom of the valley near Naur village (where Carboniferous occurs) into the northern flank of the same valley. (See panoramic view fig. 54 from Naur La.) The southeastern flank of Manang Himal (6631 m) shows a quite interesting geological structure (fig. 50). The lower and southern part is built by a large, towards the north overturned anti-

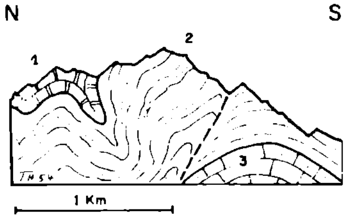


Fig. 53. The Ridge East of the Naur La
(seen from the west)
1 sandy dolomite (Triassic)
2 multi-coloured slates and red sandstone (Permian)
3 sandy limestone (Permian)

cline, followed by an also overturned syncline towards the north. These structures are built of formations from Devonian to Triassic. The valley in the foreground of fig. 50 is the origin of the landslide of Braga as mentioned earlier. The upper part of the Manang Himal shows a number of thrustfaults, which are directed towards the south, that means in the normal direction of the Himalayan Orogen. Thus, the limit between the normal thrust and the counter thrust is about 3 km south of Manang Himal (compare also profile 8 in plate III). The top of Manang Himal consists of Jurassic limestones. (However this was proved on investigations from the other, western flank.) (See also the geological panorama from Thorung La fig. 70, further fig. 62 and 63 and phot. 41 and 42.)

The view from the ridge east of Naur La also provides an excellent view into the Naur Chu valley and the mountain ranges from Phu Himal (6454 m) via the Peak 7009 m to the Tilje (fig. 55). Due to the axial rise of the Manang synclinorium the lower formations (Silurian and Devonian) occur at altitudes up to 7000 m. These formations are extraordinary thick due to piling up in form of thrust sheets and numerous folds. However the thickness is not so large as it may seem, since there is a general dip towards the west (towards the observer) due to the axial pitching.

In the Phu Himal and in the Needle, the Manaslu granite is thrust against the Manang synclinorium. (See also fig. 31 and 33.)

The axis of the Manang synclinorium strikes through the gap between Peak 7009 m and the Tilje, The Silurian limestones in the latter show a dip towards the northwest.

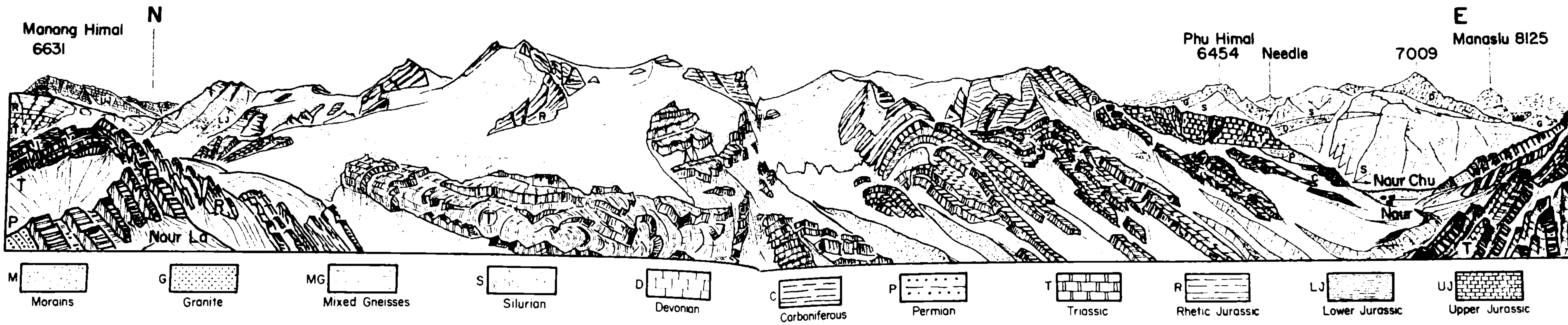


Fig. 54. Geological Panorama from Naur La towards the North and East

The glaciated mountain range is built by Mesozoic formations which are folded in a great variety. In the valley of Naur village (right side) Carboniferous series occur in an anticline.

The mountain range with Peak 7009 m east of the Naur valley is built of Silurian and Devonian series, which are tectonically accumulated to an excessive thickness. (Compare also fig. 55.)

The village of Naur is situated in a morain valley, formed behind the lateral morain of the ancient Naur glacier, flowing in the valley of the Naur Chu.

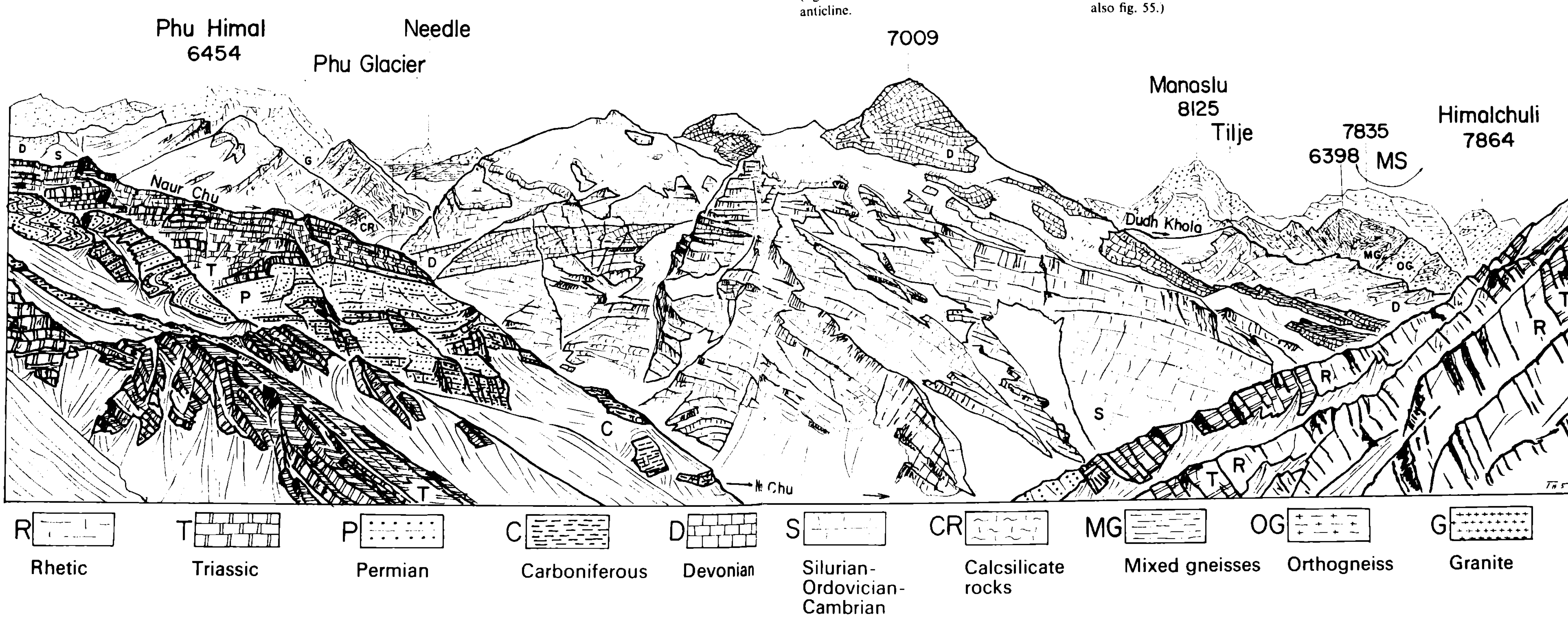
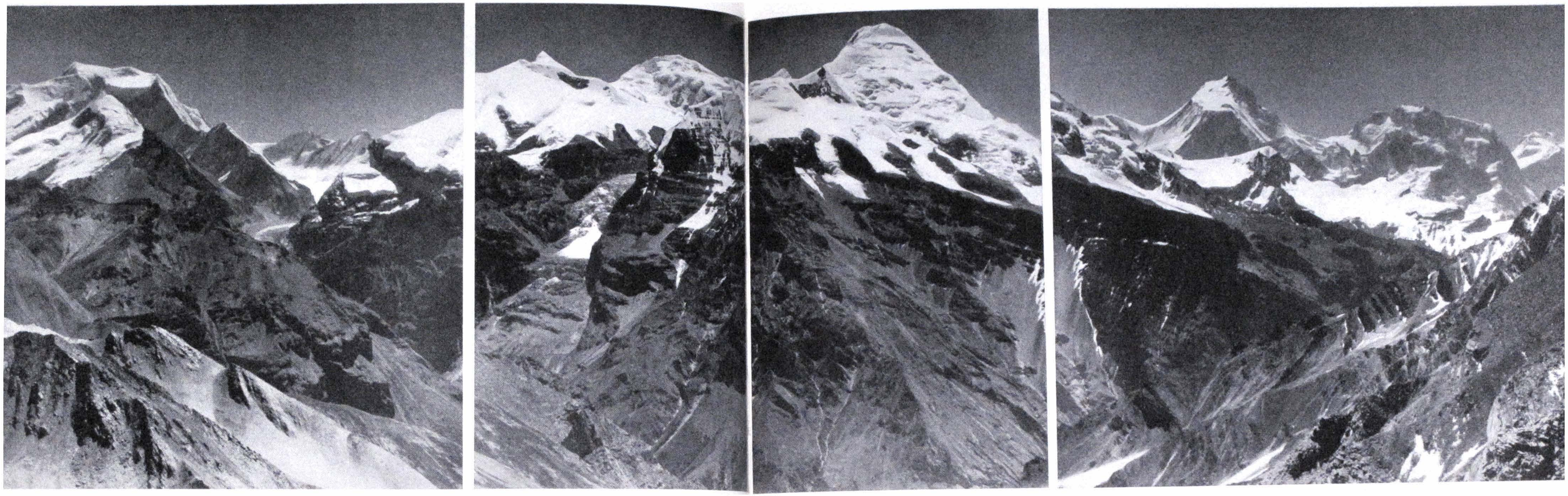


Fig. 55. Geological Panorama from the Naur La (5300 m) towards the East

The eastern [illegible] Naur valley with the peak 7009 [illegible] show the extremely [illegible] formations [illegible] accumulated. A num[illegible] piled [illegible] 700[illegible] is [illegible] synclinorium towards the east, the formations show in general a westerly dip towards the observer (see phot. 36). From the Tilje, the Manang synclinorium strikes through the Peak 6398 m of the Manasly group, where it is shown in its crystalline bottom (see also fig. 29). [illegible] the mountains north of the Phu glacier [illegible] axial rise towards the east. In the [illegible] of Phu glacier the crystalline (the Manaslu granite) is thrust upon the northern flank of the Manang synclinorium. (Compare also figs. 29–31.)

The foreground shows the anticline of Naur village, whereby especially the Permian formations are considerably folded (compare also fig. 54, geological panorama from the Naur La towards the north and east).



Phot. 36. Panoramic View from the Naur La to the East Explanation see in fig. 55

The further continuation of the Manang synclinorium (however only in its crystalline bottom) is further observed in the Manaslu group (see fig. 55). In the peak 6398 m, it is overturned towards the southwest, as already described in fig. 29 and 31.

From Naur La we also enjoy a beautiful view into the whole northern flank of the Annapurna range. (Plate V, fig. 2.)

However the geological description will follow later on, after having explored the whole valley of Manang. We therefore go now back to Manang. The cross section through Manang (fig. 56) shows much more structural complications than the area further east. The main axis of the Manang synclinorium follows more or less the valley (in the section of Manang). However there are a number of complications, since the bottom of the synclinorium is warped up and forms an anticline, in which the Carboniferous formations are exposed. Further, on either sides of this central anticline occur secondary synclines both overturned and directed against each other towards the center of the synclinorium. At the southern flank there exists a further reverse (towards the north overturned) anticline and syncline, on which the thick Devonian limestones of the Gangapurna are overthrust (fig. 56 and plate V fig. 3 and phot. 38, 37).

The general impression is of having a Graben (along the axis of the Manang synclinorium) into which the upper formations from the Horst of either sides have been folded in. We might call this superficial folding resulting from block-tectonics.

The big town of Manang is beautifully situated opposite of the Annapurna, which sends the Gangapurna glacier right down into the main valley, building a barrier with its lateral morains

(phot. 32, 38). The terminal morain is situated on the opposite side of the valley. Until recently, there has been a lake in the main valley dammed by the tongue of the Gangapurna glacier. The Marsyandi has now cut through the morains. There are also arcs of higher terminal morains from an earlier stage, when the tongue of the Gangapurna glacier reached nearly the altitude of the town of Manang (fig. 45).

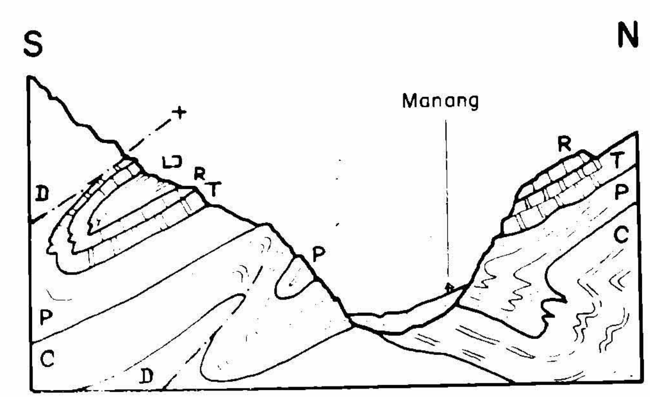


Fig. 56. Geological Profile through Manang

LJ Lower Jurassic
R Rhetic
T Triassic
P Permian
C Carboniferous
D Devonian

The Manang synclinorium shows a number of partial axis, whereby the structures north of the valley are normally directed towards the south, while the structures south of the valley axes are reverse, that means directed towards the north.

Naur Himal 6114 m | Himalchuli 7864 m | F | Annapurna II 7937 m | Annapurna IV 7507 m

Phot. 37. Photographic Panorama of the Manang Valley with Annapurna II and IV and Naur Himal
(seen from 4600 m on the ridge north of Manang, view towards the southeast)
(Compare geological panorama plate V, fig. 1 of the same view.) F indicates the fannel-like shape of the Devonian limestone, marking the western pitch of the Manang synclinorium.

Phot. 38. Gangapurna, Roc Noir and Nilgiri
(seen from the northeast)
The reverse fold in Silurian-Devonian formations on the northern ridge of the Gangapurna is well visible. (Compare geological panoramas of plate V)

Gangapurna 7315 m | Roc Noir 7255 m | Nilgiri Shartse 7148 m

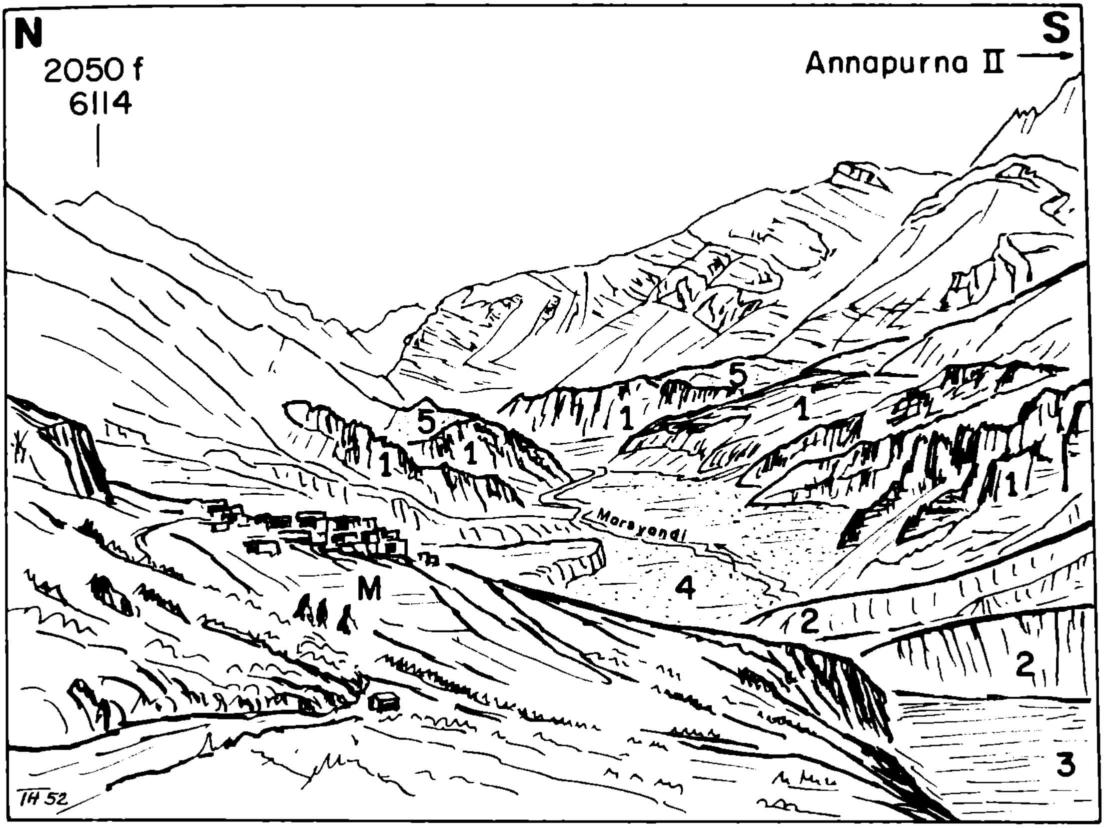


Fig. 57. The Manang Valley with the Town of Manang seen from the west, see also phot. 32)

1 landslide material of the landslide of Braga
2 recent lateral morains of the Gangapurna glacier
3 lake deposits of the lake dammed by the Gangapurna glacier
4 alluvial plain filled with morainic material
5 lateral morains of the ancient Marsyandi glacier
M Manang town

It might also be worthwhile to have a view on the morainic material of the Gangapurna glacier, since the higher parts of the Gangapurna are not accessible for a solo-geologist, but only for a major expedition.

We find the red crinoid-limestone with large pentacrinus, of the same type as found on Chandragiri pass and at Godavari south of and near Kathmandu, where they have been proved to be of Ordovician age. This red Godavari limestone is also found as component in a conglomerate, embedded in red sandstone (Permian?). We further find the blue limestones, black and red quartzites with layers of hematite, multi-coloured slates (Chitlang slates), well bedded limestone, with a net pattern of clays and marl which are all familiar from Phulchok south of Kathmandu, where finding of a Trilobite enabled to determine those series to Devonian.

No pegmatites were found, not to speak of any gneisses and granites, which however are not to be expected in this area. Also the surrounding flanks of the Gangapurna glacier do not show any pegmatites, though Carboniferous, Devonian and Silurian formations are exposed. We recall, that further west, near Pisang, the topmost pegmatites were found right up into the Upper Carboniferous formations (yellow-band series).

The tectonics at Manang are not only expressed by large folds and thrusts, but also by microtectonics, whereby within a particular formation certain beds of low resistance have been glided against harder beds (fig. 58). This again speaks in favour of partly gravitational gliding and folding as explained above. This bed gliding might also have helped causing landslides.

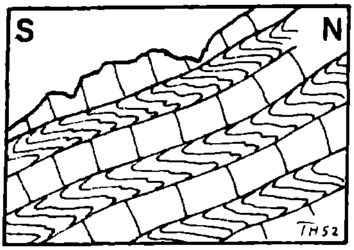


Fig. 58. Bed-Gliding within the Permian Limestones above Manang (location above Manang in fig. 56).

Permian limestones are interbedded with marly clays, which have acted as "lubrication" in the bed-by-bed gliding.

Possibly this type of gliding has initiated the landslide of Braga, since in that area the geological conditions are similar.

From Manang towards the west, the Carboniferous anticline of the valley bottom develops to a narrow, but high and perpendicular structure in the ridge between the Kangsar Chu and the Jargeng Chu (see fig. 59 and 64; compare also plate III, profile 7).

This upstanding high anticline is intersected by a number of horizontal faults, which have broken and transposed the so well visible yellow-band series of the Upper Carboniferous (fig. 59).

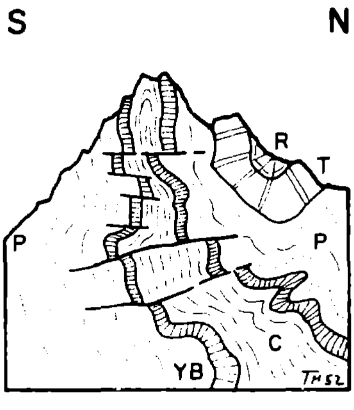


Fig. 59. The Vertical Manang Anticline in the Wedge between Kangsar Chu and Jargeng Chu.

This is the western continuation of the anticline in the bottom of the valley near Manang (see fig. 56). The lithological key horizon of the yellow-band series (Carboniferous) makes the various horizontal (unusual) faults very clear.

R Rhetic
T Triassic
P Permian
C Carboniferous
YB yellow-band series of the Carboniferous

This sketch gives a detail of fig. 64

The Manang synclinorium seems to continue pitching from Manang towards the west since more and more younger formations are involved in the mountain building. The above mentioned high Carboniferous anticline shows a complete cover right up to Upper Jurassic limestones (see fig. 64, 65 and 67). The latter build the Peak F (see geological map plate II) in form of a narrow synclinal wedge (fig. 65).

The extraordinary large and high glaciated plateau which extends between the Nilgiri range of the Annapurna and the Peak G on one hand, and between the Thini Shar La (Shar La = east pass) and Thini Nup La (Nup La = west pass) on the other hand is built by the soft slates of Rhetic and Lower Jurassic formations. (See plate V, fig. 3 and also plate III, profile 6.) At the foot of the northern flank of Nilgiri, there is a reverse series reaching from the Lower Jurassic right to Devonian. The reverse series form the southern flank of an anticline, which is overturned towards the north (later on called the Nilgiri anticline).

7. Geology of the Northern Flank of the Annapurna Range

The northern flank of the Annapurna range is certainly one of the most interesting areas from geological standpoint. In contrast to the southern flank, the whole area is built exclusively by sediments. Those show a great variety, since they reach from Ordovician right through to Upper Jurassic.

Tectonically, the northern flank of the Annapurna range belongs to the Himalayan Marginal Schuppen zone and to the southern flank of the Tibetan marginal synclinorium.

The Himalayan Marginal Schuppen zone is the transitional zone between the crystalline roots of the great nappes and the sediments of the Tibetan marginal synclinorium. While some of the marginal Schuppen are thrust towards south, in the normal sense of the Himalayan Orogenesis, other marginal Schuppen are thrust and folded reverse, that means towards the north.

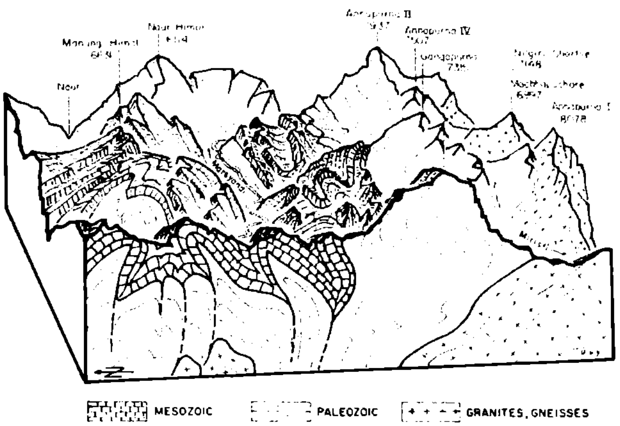


Fig. 60. Block Diagram Showing the Structure of the Manang Valley and the Annapurna, View from the West.

(Compare phot. 41, in which the anticline of the Manang Himal is well shown, as well as the reverse folds of the northern flank of the Annapurna.)

The southern flank of the Tibetan marginal synclinorium shows predominantly reverse folding and faulting. Besides the longitudinal structures, the Annapurna range shows—especially in its western part—also transverse structures. This is caused by the tremendous axial rise of the Tibetan marginal synclinorium of Manang towards the east, and the termination of their respective sediments at the eastern termination of the Annapurna range, a little eastwards of the line Lamjung Himal (6985 m) and the peak 7009 m.

Thus, seen from the east, the Mesozoic formations commence north of Annapurna II (7937 m).

The main axis of the Manang synclinorium (as we may call the Tibetan marginal synclinorium in this area) strikes at Manang through the Marsyandi valley (see fig. 56, and plate III, profile 8), while from here on towards the east the main axis turns into the northern flank of the Annapurna itself and especially through the peak 5291 m (north of Annapurna IV). (See also plate III, profile 9, further plate V, fig. 3.) West of Manang, the main axis of the synclinorium follows the Kangsar Chu (plate III, profile 7) and into the high plateau of the Thini passes (plate III, profile 5, also plate V, fig. 3). However in this area the marginal synclinorium widens up tremendously between the Nilgiri range and the Thorung La and is also getting more complicated, with a large number of deep-reaching folds and thrustfaults. We can therefore from the Thini La towards the west no longer speak of a main axis (see fig. 71).

The Nilgiri group shows a tremendous soft reverse fold in the Devonian limestones (see plate V, fig. 2 and 3; and profiles 6, 4 of plate III). At the northern foot of the Nilgiri Shartse (Shartse means east peak) we find a reverse, steeply southern dipping Mesozoic series. In the long ridge between Nilgiri and Roc Noir we find the same reverse fold in Silurian (?) formations (plate V, fig. 2). The reverse fold in the Silurian/Devonian formation is especially well exposed in the group of the Gangapurna and the Annapurna III (7576 m) (plate V, fig. 2, phot. 38 and profile 8 plate III). The ridge which flanks the big glacier flowing from the flank between Roc Noir and Gangapurna (see geological map) shows two overturned reverse synclines, with Triassic dolomite as filling in the upper one and Jurassic formations as filling in the lower one. (See plate V, fig. 2 and 3; and also phot. 38.)

The tributary valley which drains the Seti gap (plate V, fig. 2) gives also an excellent view into the structure of the eastern flank of the Annapurna III (7576 m). The reverse fold in the Silurian/Devonian formations is greatly developed. The underlying syncline with Mesozoic filling is unsymmetric, the upper flank tectonically squeezed out along a thrustfault, whereby the Devonian limestones are thrust upon the Triassic dolomite (see plate V, fig. 2).

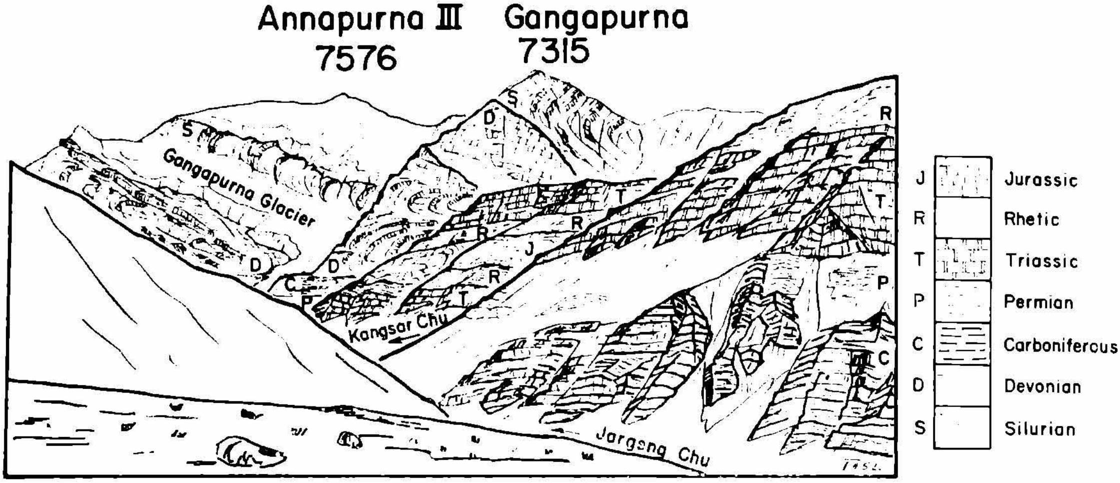
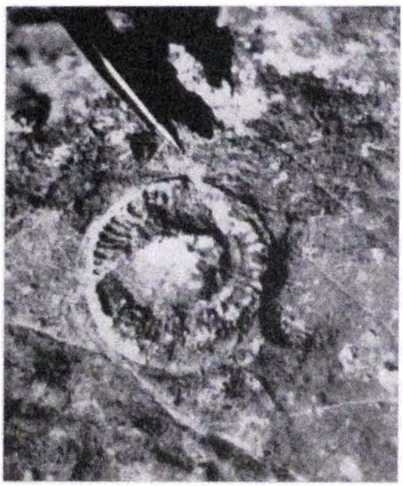


Fig. 61. Annapurna III and Gangapurna Seen from Northwest
(from the Jargeng valley, approx. 4300 m)

The northern flank of this range shows the tremendous reverse fold in Silurian and Devonian formations, with a reverse series in the lower part of the northern ridge of Gangapurna.
The ridge in front of Gangapurna contains a narrow towards the north overturned syncline with Jurassic filling. (See also phot. 42)

The range of peak 5291 m, which is situated in front of Annapurna II and Annapurna IV shows the large Mesozoic filling (up to Jurassic limestones) in the overturned and reverse syncline (plate V, fig. 1 and 2). At the western part of the said mountain range a dolomite anticline (Triassic) is exposed (phot. 37).

The tremendous folding and faulting in Annapurna II (7937 m) is not well visible from this side, since we look straight into the folds (from the front side). It is referred to the fig. 38, 39 and phot. 28, which show the structure seen from the eastern side.



Phot. 39. Zaphrentis Species
(location at 3980 m on the trail above Tengi to Thorung La, 2 km northwest of Manang)
The scale is indicated by the pencil.

8. Geological Itinerary Manang-Thorung La

We now continue our route on the ridge northwest of Manang and Tengi, the highest and last village on the trail to the Thorung La (5300 m). First we climb in Carboniferous formations represented by quartzites, interbedded with limestones, red quartzites, Narebang wood-like chloritoid slates and the lowest bed of the white quartzite of the yellow-band series. At 3980 m we find in the lower bed of the yellow band series a zaphrentis species (phot. 39), which consequently proves the Carboniferous age of the yellow-band series. Also slates with fucoides and other fossils were found at the same place (phot. 40).

Phot. 40. Fucoide Slates with other Fossil Shells
(on the ridge above Tengi)
These fossils occur near a clear-coloured coarse-grained quartzite bed overlying "wood-like" Narebang slates, red quartzites and quartzite interbedded with limestones.

In the valley of the Jargeng Chu we move for a long time in more or less the same formations of the Carboniferous and the Permian. The overlying Triassic dolomite occurs at the eastern flank of the valley much higher due to an axial rise towards the east. (See fig. 62 and 63, Manang Himal.)

At the western side of the Jargeng valley, the Triassic dolomite comes to ly nearly into the bottom of the valley, due to the axial pitch (see overturned dolomite syncline in fig. 64). In the valley, which drains the southwestern flank of the Manang Himal (6631 m) it is well visible, how the Triassic dolomite (which dips at the northern flank of the Manang valley towards the south) is bent to form an anticline and dips towards the north (fig. 62). Hereby, the dolomite is overthrust by Carboniferous formations of a higher tectonic unit. The overthrust Schuppe (slice) dips generally towards north and shows a complete stratigraphic profile from the Carboniferous through the Permian and the Triassic with the typical Norian dolomite to the well-bedded limestones and slates of the Rhetic and Jurassic. The peak of Manang Himal consists of the thickly-bedded limestone of Upper Jurassic age (fig. 62 and 63). However, also this upper Schuppe is still folded and thrustfaulted (fig. 63 and 70).

At the western side of the Jargeng valley (fig. 64) we see now the bent vertical fold of the Manang anticline, which is formed by the Carboniferous formations with a cover of Permian and Triassic series. The extraordinary horizontal faults have been shown in fig. 59. North of the said vertical anticline there is a syncline, overturned towards the north, filled with Rhetic formations (fig. 64).

The Kangsartse Peak, joining northwest of the ridge with the Manang anticline, is built by a complicated syncline which is also overturned towards the north. The filling of the syncline consists of Jurassic limestones, which build the peak itself (see detail fig. 64).

The next big anticline towards the north (see geological map plate II) is also rather complicated, with a vertical fault, along which the northern part has been lifted (fig. 66 and detail fig. 67, seen from further north).

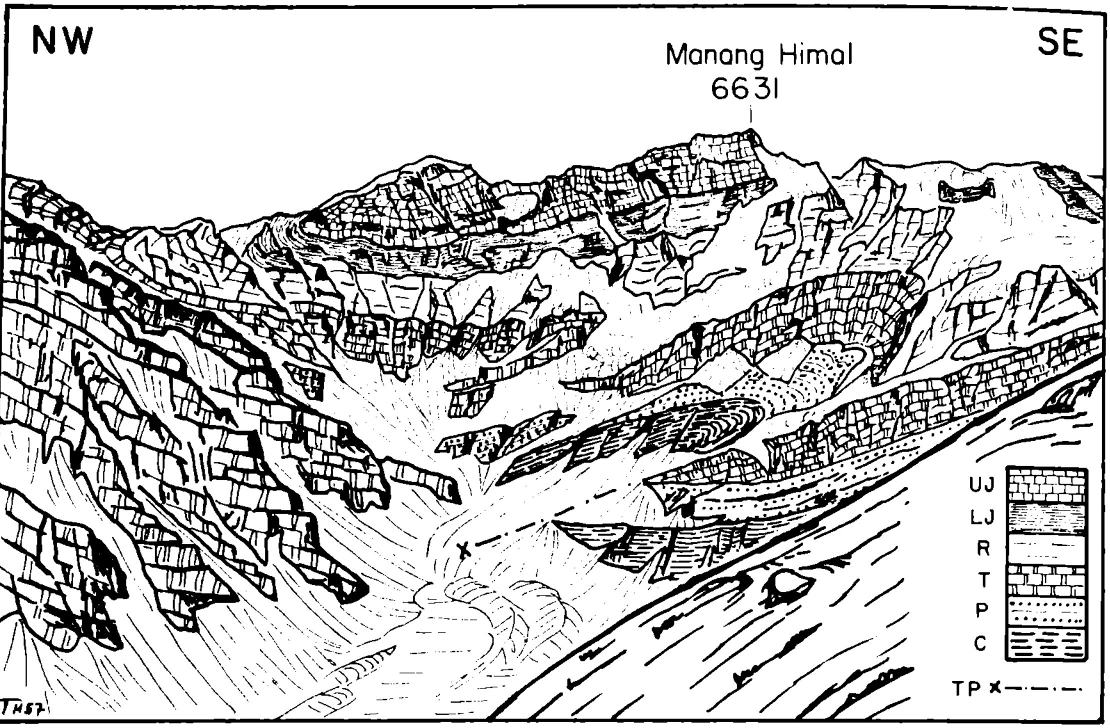


Fig. 62. The Manang Himal Seen from the South-Southwest

UJ	Upper Jurassic	R	Rhetic	P	Permian	TP	Trustplane
LJ	Lower Jurassic	T	Triassic	C	Carboniferous		

The standpoint is about 5000 m, thus, looking upwards, the series are slightly distorted.
It can be observed how through a thrustplane the Triassic dolomite is doubled. Possibly there exists a secondary thrustplane in the upper dolomite in the hanging glacier below the summit. The dolomite series in the left side foreground belongs to the lower thrustsheet. The upper dolomite series (left side on the top) is folded into a overturned syncline. The two series appear to be one and the same due to distortion viewing upwards. However there is a valley between the two series at the left side.

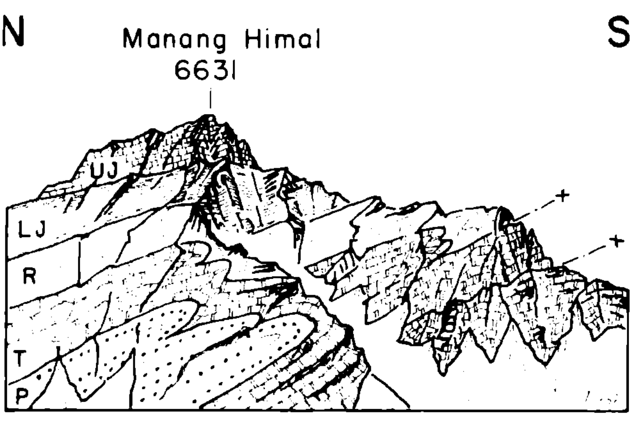


Fig. 63. The Manang Himal Seen from the West-Southwest

The dolomite series are folded and tectonically piled up.

UJ Upper Jurassic
LJ Lower Jurassic
R Rhetic
T Triassic
P Permian

We now consider the profile right up to the Thorung La (fig. 68 and 69). Where the trail crosses the Jargeng Chu (4200 m) and begins to climb steeply on the western flank of the valley, we find ourselves still in the Permo-Carboniferous formations. They consists of well bedded dark slates, interbedded with marly limestones and with quartzites. Overlying is a series of green, bleach-green and dark blue slates. These contain fucoides. The same series also are interbedded with beds of green and red sandy quartzites, partly also coarse-grained green chlorite quartzite of the Ramche type (Trisuli valley above Nawakot). In general, these slaty and quartzitic series recall the Nawakot series of the Nawakot nappes, with the only difference that here in the Tibetan marginal synclinorium they do not show any sign of metamorphism. Quartzites increase towards upwards and finally we arrive at the large dolomite

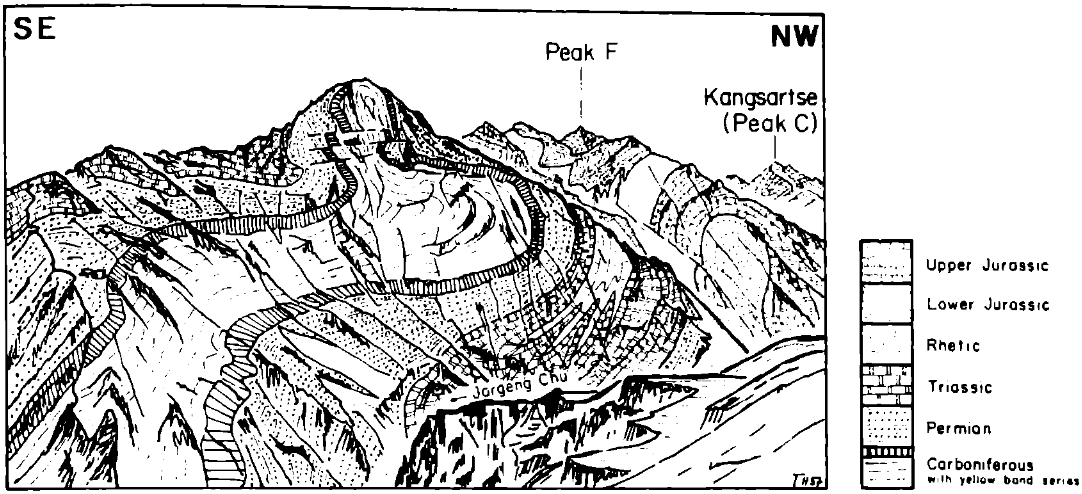


Fig. 64. The Ridge between Jargeng Chu and Kangsar Chu
(seen from the east)

The Carboniferous formation of the Manang anticline is bent and faulted in a complicated way. Peak Kangsartse shows a reverse overturned syncline with Upper Jurassic limestones as filling. (This syncline corresponds to the Jomosom syncline in the Thakkhola; while the Manang anticline is identic with the Syang anticline.) (Compare also plate V, fig. 3, which gives further details of the peak C, Kangsartse.) Peak F is also formed by the Upper Jurassic filling of a northerly overturned syncline. (See also fig. 71.)

series, which forms a distinct barrier through the valley and along either flanks of the valley into the Manang Himal and into the western flank of the Jargeng valley (phot. 42, fig. 70).

Above the main dolomite series we find deep black shales (Kössener facies) with thin beds of quartzites, limestones and lumashell limestones. The whole facies recalls the Rhetic of the Eastalpine formations of the Alps. The age-prove by the lumashell limestones is evident (fig. 68).

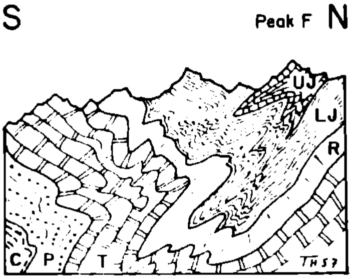
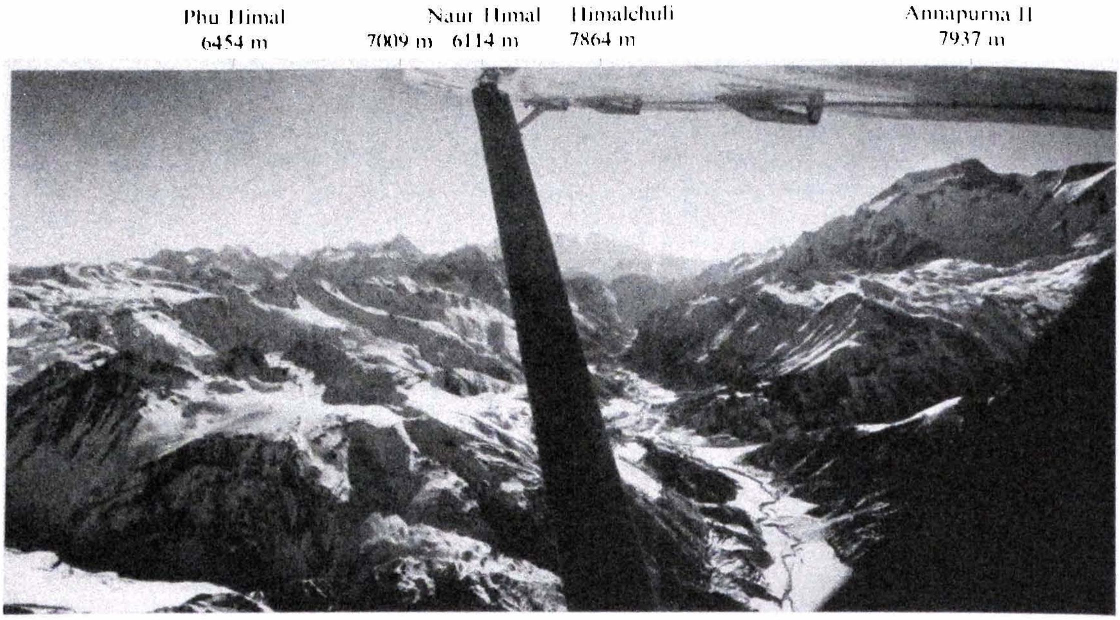


Fig. 65. The Reverse and Overturned Syncline of Peak F
(seen from the east; compare the comprehensive view given in fig. 64 and fig. 71)

UJ Upper Jurassic
LJ Lower Jurassic
R Rhetic
T Triassic
P Permian
C Carboniferous



Phot. 41. The Manang Valley Seen from the West
(aerial photo from 5600 m above the Jargeng valley)

Note the outstanding height of the Annapurna range compared with the Gipfelflur of the mountains north (left side) of it which is about 6000 m only. Note also the ancient land surface at about 5000 m at the northern flank of the Annapurna range and on the mountain ranges north of the Marsyandi valley.

Possibly, the overlying brown sandy quartzites and sandstones, interbedded with clear-coloured thin quartzitic layers might belong to the Lower Jurassic (Liassic especially). Overlying we find, partly under light angle unconformity, clear coloured and brown quartzite. This series is mixed with "autumn-coloured" (herbstlaubfarbene) limestones and pink lenticular coral limestones. It appears, that we all on a sudden are again in lower formations and that the Triassic series are sliced, for, above and overlying, we find again the main dolomite series (Norian) of partly very dense, partly fine-grained conglomeratic character. The black series of the Rhetic appear to thin out towards the east. (Phot. 42, below Manang Himal shows very clear the slicing within the main dolomite series, caused by a number of steep northern dipping thrustfaults.)

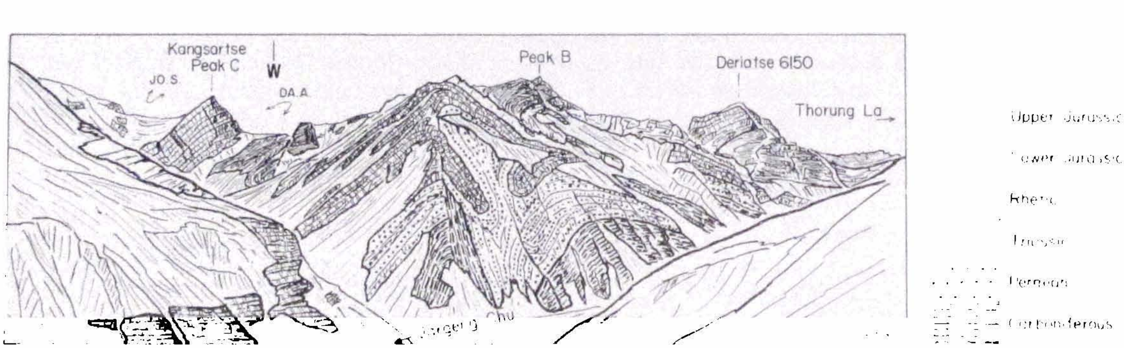
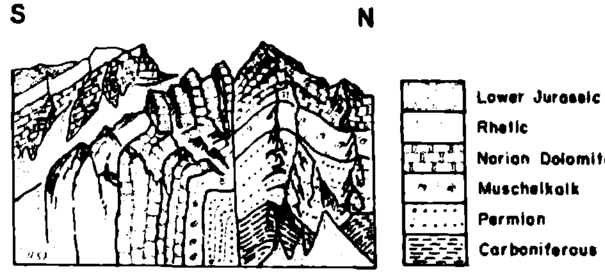


Fig. 66. The Western Flank of the Central Part of the Jargeng Valley
(seen from southeast)

There exists a doubled anticline, with a vertical fault at the southern flank, whereby in both partial axis Carboniferous formations are exposed in the lower flanks of the valley. The anticline is slightly overturned towards the south. (Compare detail of the southern flank of this anticline given in fig. 67.)

Fig. 67. Faulted Anticline at the Western Flank of the Jargeng Valley

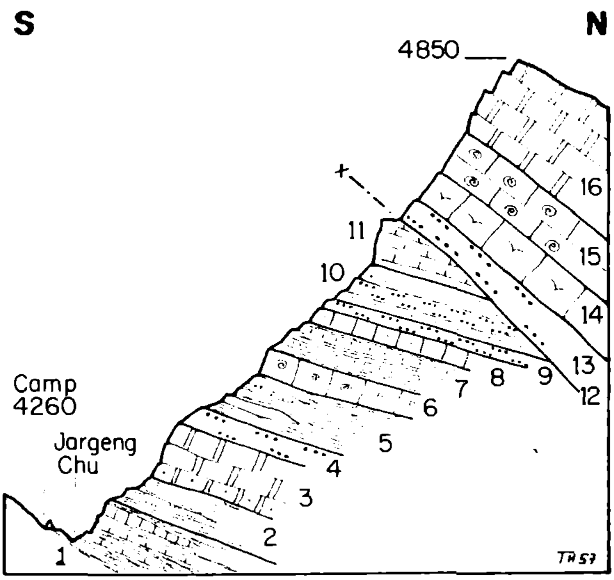
This sketch shows a detail of the anticline given in fig. 66 (seen from northeast), which is however not visible in fig. 67. Along a vertical fault the northern block has been lifted while at the same time the southern block has made its independent tectonics, which caused a considerable discordance on the fault.



Overlying the second main dolomite series (at 4850 m) follow slaty limestones (fig. 69), which make a noise like glassware when walking over it. The limestones are siliceous, partly slaty, partly in clear beds between the slates. Over quartzite layers we find again deep black shales (Kössener facies). The formations above those consist of quartzite layers, iron sandstone, iron oölites, deep black slates, brown sandy limestones with shells, grey limestone with net pattern and oölithic limestones.

On Thorung La (5300 m) occur clear-coloured coarse-grained quartzites embedded in the slates mentioned above. Also echinodermic breccias can be found. In general these series might belong to the Lower Jurassic (Liassic and Dogger facies of the Alps). The whole series dip in the Thorung La towards the north. In the lower part of the southern flank of Thorungtse (6444 m) occur the same series, but tectonically sliced. Towards above follow thickbedded and mighty, clear-coloured limestones, which recall the Malmkalk of the Alps (Upper Jurassic). On Peak Deriatse (6150 m) south of the Thorung La, those limestones occur too, in still greater thickness, dipping steeply north. They are overlying the well-bedded limestones and slates of the Lower Jurassic (Liassic and Dogger). (See also fig. 73 and 74.)

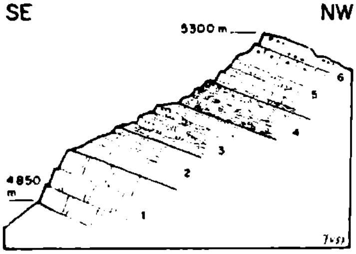
Fig. 68. Detail Profile at the Eastern Side of Thorung La (along the trail from 4200 m up to 4850 m)



1 (camp 4260 m near Jargeng Chu) well-bedded dark slates, interbedded with marly limestones and with quartzites
2 green, bleach-green and dark blue slates with fucoides. Interbedded with red and green sandy quartzites, partly also coarse-grained chlorite quartzites, slates similar to the Nawakot slates. Quartzites increase upwards
3 large dolomite, partly fine-conglomeratic (200 m)
4 beds of quartzites
5 quartzites, interbededd with fine black shales ("Kössener" facies of the Alps) and dark limestones
6 lumashell limestone
7 calcareous slates
8 calcareous sandstones
9 beds of quartzite (10 m)
10 brown sandy quartzites and sandstones
11 marly limestone, brownish-yellowish ("Herbstlaub"-coloured of the Rhetic of the eastalpine facies of the Alps)
12 thrustplane
13 quartzite, clear-coloured, when fresh; brown weathering
14 pink lenticular-coloured coral limestone
15 lumashell limestone
16 Norian dolomite series, well-bedded, clear grey-coloured

The thrustplane (12) cuts the series (4)-(11) under oblique angle, thus they form a wedge between the underlying dolomite and the overlying thrustplane.

Fig. 69. Detail Profile on the Eastern Side of the Thorung La



1 large dolomite series (Norian)
2 calcareous slates, make a sound like broken glass when walking over them
3 quartzites interbedded with dark slates
4 very black fine shales (very typical "Kössener" facies of the eastalpine Rhetic of the Alps)
5 single beds of quartzites, iron sandstone, black shales, iron oölites, brown sandy limestone with shells, grey limestone with net pattern of clays, oölitic limestones
6 clear-coloured coarse-grained quartzites (in the pass 5300 m)

9. Geology of the Catchment Area of the Jargeng Chu

The eye-catching main dolomite series below the Thorung La at the eastern side is a very good key horizon for the analysis of the structure of the surrounding mountains (see phot. 42). This same dolomite was by fossils proved to be of Norian age.

The dolomite forms in the Jargeng valley at the southeastern side of the Thorung La a distinct barrier (see phot. 42). From this barrier (in which the dolomite however is faulted, see phot. 42), the hard series strike in southsoutheast direction towards the southern ridge of the Manang Himal (6631 m), where it is identic with the overthrust dolomite Schuppe described in fig. 70 and 63. A number of thrustfaults cut the dolomite series in the flank of the Manang Himal (see phot. 42). However the dip is generally directed towards the north. The clear limestone (Upper Jurassic) which builds the summit of Manang Himal (6631 m) is slightly bent in the northern ridge of the said mountain and also thrust within itself under unconformity (fig. 70). In the pass, which leads to the east and over into the Naur valley (south of Jargeng La fig. 70) the same Upper Jurassic limestone dips steeper towards the north. We find an overturned anticline, which is thrust from north. The anticline contains Lower Jurassic slates in the core.

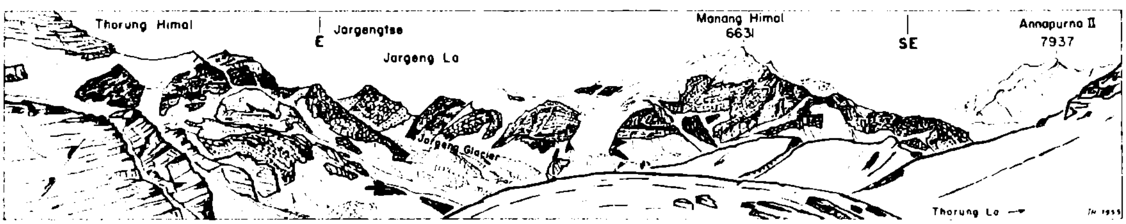
Another thrustplane strikes through the Jargeng La (fig. 70) with Permian formations (sandstones and conglomerates, Muschelkalk) on the thrustplane.

In the mountain range, which extends from Jargeng La towards the Thorungtse (6444 m) we find increasing tectonic complications from east to west (fig. 70). The magnitude of the anticline of Jargeng La increases, while at the same time, due to an axial pitch towards the west, the Permian formations disappear underneath the Triassic, Rhetic and Jurassic formations. Great dip slopes are formed by the Norian dolomite. Upon the Jurassic limestone there occur still younger formations, predominantly quartzites and dark slates (possibly Cretaceous?). Already in the Thorung La those "cheese"-structured (with holes) and extreme hard quartzites and sandy quartzites were found.

Fig. 70. The Eastern Flank of the Jargeng Valley from Jargengtse to Manang Himal
(seen from the Thorung La [5300 m])

The whole range shows many Schuppen, whereby all the tectonics are directed towards the south. The key horizon of the Norian dolomite crosses at the right side (in the picture below Manang Himal and Annapurna II). Compare also phot. 42.

Fig. 63 gives the view behind the ridge leading from the right side to Manang Himal



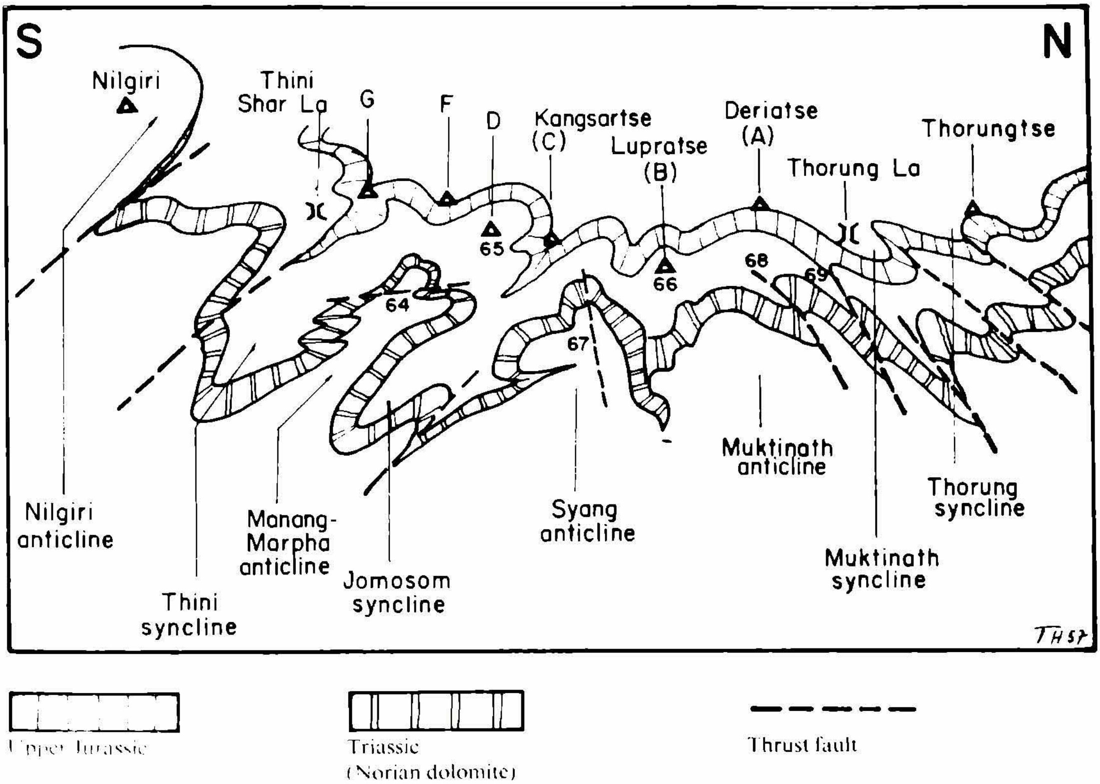
Phot. 42. Photographic Panorama from below the Thorung La towards the Southeast
(Compare geological sketch fig. 70.)

The Thorungtse (6444 m) itself shows a very complicated structure with a number of thrustfaults and folds. This features will be dealt with later on, since this mountain range can be studied much better from the western and southwestern side.

While the western flank of the Jargeng valley, with the mountains of Jargengtse and Manang Himal (6631 m) are now pretty clear, the mountain range forming the watershed between the Marsyandi

Fig. 71. Schematic and much Simplified Comprehensive Profile of the Mountain Range between the Nilgiri and the Thorungtse

The triangles denote the various mountain peaks and their respective locations with regard to the formations and the structures. The numbers indicate the location of the respective text figures.



and the Kali Gandaki, that means the range from the Nilgiri up to the Thorungtse (6444 m) represents still many problems. These are not only caused by the geology, but far more by the bewildering topography, with a large number of peaks, but none of them outstanding, and also by erronous reproduction and gaps in the Quarter-inch map (1 : 250000). The greatest errors were found northeast of Manang Himal-Jargengtse. (Later on also the northern adjacent area towards the Damodar Himal was found greatly wrong in the existing map.) It has been tried to identify the numerous peaks around 6000 m, but with the total lack of local names (the area is completely uninhabited) we named the peaks with letters to begin with (A–G). Later on we were able to give local names according to the nearest villages in some places.

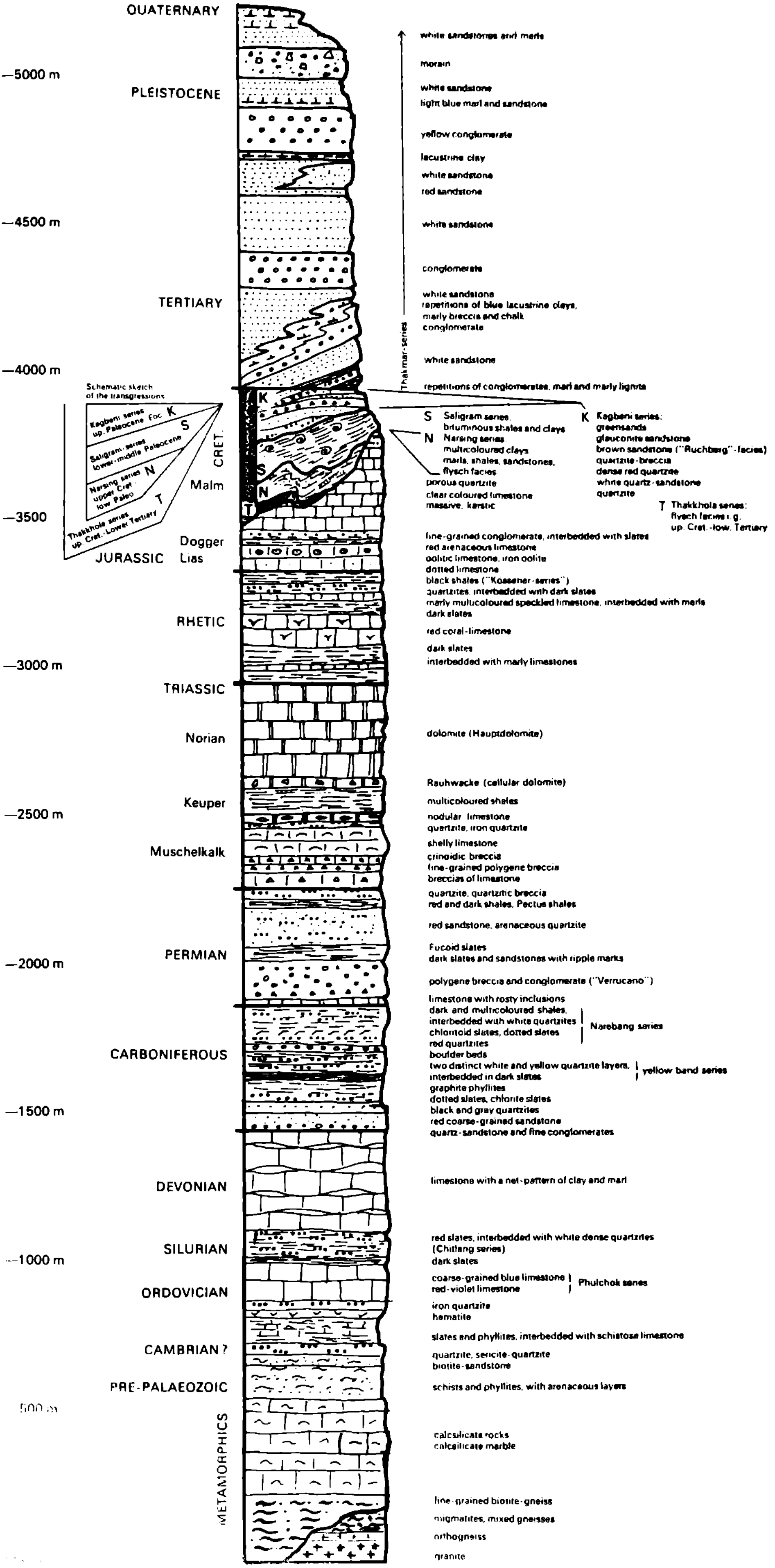
In order to fit the geological structures into the topographic outlay a much simplified and comprehensive schematic cross section has been constructed from the Nilgiri to the Thorungtse (fig. 71). All the peaks have been entered into this schematic profile and reference is given to the text figures with their respective numbers in the profile.

As we may see, all the peaks between Thorungtse and Thini Shar La are situated either in the Upper Jurassic or in the Lower Jurassic. In general, the comprehensive profile shows clearly the character of the synclinorium, with a large number of partial synclines and anticlines and thrustfaults. From both edges of the synclinorium the structures are directed towards the center, consequently the southern portion of the structures are reverse. The present structures indicate clearly the former Graben structure of the synclinorium. From the edges of the horsts (flanking the Graben) the formations have been folded into the Graben.

At present we do not go into the details of the particular partial structures. For a better understanding, names given in the Thakkhola (at the other side of the mountain range), have been introduced already now. The numbers in fig. 71 (64–69) give the location of the respective text figures in the geological profile. Further reference is also given to profiles 7 and 8 in plate III.

Since we have so far on our itinerary covered pretty complete stratigraphic profiles, we shall give the stratigraphic-lithologic columnar section at this place (fig. 72).

Fig. 72 (opposite)
Stratigraphic-lithologic
Columnar section



QUATERNARY
—5000 m
PLEISTOCENE
—4500 m
TERTIARY
—4000 m
Schematic sketch of the transgressions
Kagbeni series up. Paleocene Eoc. K
Saligram series lower-middle Paleocene S
Narsing series upper Cret. low Paleo. N
Thakkhola series up. Cret.-Lower Tertiary T
CRET.
Malm
—3500
Dogger
JURASSIC
Lias
RHETIC
—3000 m
TRIASSIC
Norian
Keuper
—2500 m
Muschelkalk
PERMIAN
—2000 m
CARBONIFEROUS
—1500 m
DEVONIAN
SILURIAN
—1000 m
ORDOVICIAN
CAMBRIAN ?
PRE-PALAEOZOIC
500 m
METAMORPHICS
Thakmar-series
white sandstones and marls
moraın
white sandstone
light blue marl and sandstone
yellow conglomerate
lacustrine clay
white sandstone
red sandstone
white sandstone
conglomerate
white sandstone
repetitions of blue lacustrine clays,
marly breccia and chalk
conglomerate
white sandstone
repetitions of conglomerates, marl and marly lignite
S Saligram series,
bituminous shales and clays
N Narsing series
multicoloured clays
marls, shales, sandstones,
flysch facies
porous quartzite
clear coloured limestone
massive, karstic
K Kagbeni series:
greensands
glauconite sandstone
brown sandstone ("Ruchberg"-facies)
quartzite-breccia
dense red quartzite
white quartz-sandstone
quartzite
T Thakkhola series:
flysch facies i.g.
up. Cret.-low. Tertiary
fine-grained conglomerate, interbedded with slates
red arenaceous limestone
oolitic limestone, iron oolite
dotted limestone
black shales ("Kössener-series")
quartzites, interbedded with dark slates
marly multicoloured speckled limestone, interbedded with marls
dark slates
red coral-limestone
dark slates
interbedded with marly limestones
dolomite (Hauptdolomite)
Rauhwacke (cellular dolomite)
multicoloured shales
nodular limestone
quartzite, iron quartzite
shelly limestone
crinoidic breccia
fine-grained polygene breccia
breccias of limestone
quartzite, quartzitic breccia
red and dark shales, Pectus shales
red sandstone, arenaceous quartzite
Fucoid slates
dark slates and sandstones with ripple marks
polygene breccia and conglomerate ("Verrucano")
limestone with rosty inclusions
dark and multicoloured shales,
interbedded with white quartzites
chloritoid slates, dotted slates
Narebang series
red quartzites
boulder beds
two distinct white and yellow quartzite layers,
interbedded in dark slates
yellow band series
graphite phyllites
dotted slates, chlorite slates
black and gray quartzites
red coarse-grained sandstone
quartz-sandstone and fine conglomerates
limestone with a net-pattern of clay and marl
red slates, interbedded with white dense quartzites
(Chitlang series)
dark slates
coarse-grained blue limestone
red-violet limestone
Phulchok series
iron quartzite
hematite
slates and phyllites, interbedded with schistose limestone
quartzite, sericite-quartzite
biotite-sandstone
schists and phyllites, with arenaceous layers
calcsilicate rocks
calcsilicate marble
fine-grained biotite-gneiss
migmatites, mixed gneisses
orthogneiss
granite

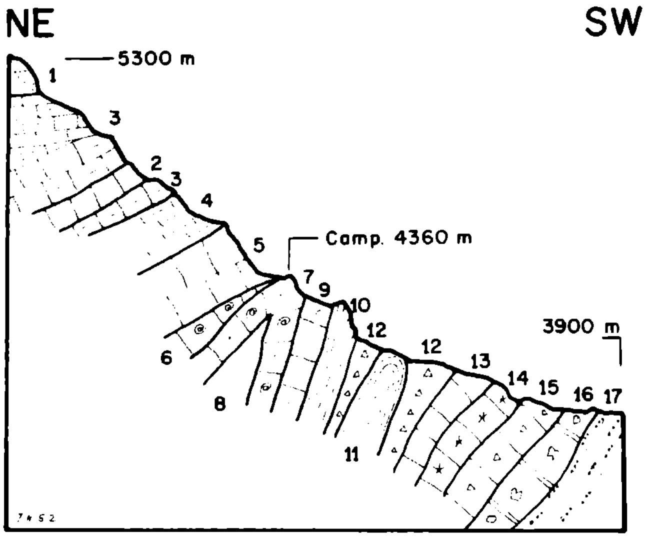
III Geological Observations in the Northern Part of the Thakkhola

(between Muktinath and the Tibetan border)

1. Geology of the Muktinath Area

We have seen already from the eastern side that the Thorung Himal shows a very complicated structure. However, the western side gives still a much better exposure (fig. 74, 75, 76, 79, 81 and 82). Let us first descend on the western flank of the Thorung La (5300 m) down to Muktinath. (See detail profile fig. 73.) First we meet again the same calcareous slates and oölites of the Lower Jurassic as we have seen at the eastern side of the pass. At the place, where the trail leaves the screes and climbs

Fig. 73. Detail Profile at the Western Flank of the Thorung La



1 on the pass 5300 m itself were found, however not sure whether not as debris from the Thorungtse: dotted limestones (Lias?), red sandy limestones with shells (Dogger?), sandstones and fine-grained conglomerates (Dogger?), clear-coloured limestones with Karst weathering (Malm) porous quartzites (Cretaceous?)

2 light-coloured limestone

3 reddish-brown limestone and calcareous slates

4 calcareous slates, sandy brown calcareous slates (sound like glassware when walking over them, type of the Lias slates of the East-alpine facies of the Alps).

5 limestone (Lias?)

6 lumashell limestone

7 dotted limestone (fine-grained conglomerate, with pentacrinus, type of the Lias formation of the eastalpine facies of the Alps).

8 red slates, with fucoids, (this series forms a narrow anticline)

9 lumashell limestone

10 white and green slates, calcareous slates with pentacrinus

11 black slates, with fucoids (this series forms a narrow anticline)

12 fine-grained polygene breccia with red components of limestone

13 dense grey limestone

14 dotted limestone with crinoidal breccia

15 breccious limestone

16 Rauhwacke (cellular dolomite)

17 black slates, red quartzites with ripple marks

However, this profile cannot be considered as a normal succession, since there are a number of repetitions caused by folding. (Compare also fig. 76 and 82, which show the tectonic complications.)

the ridge in the saddle of the pass, we find lumashell limestones of the Rhetic. The slates of the Lower Jurassic and of the Rhetic reach in the saddle of the pass very deep towards the west, nearly down to Muktinath (fig. 76, 81 and 82). The underlying Triassic dolomite appears at the northern flank of the pass-valley leading from the pass down to Muktinath, and in the western ridge of the Thorung Himal.

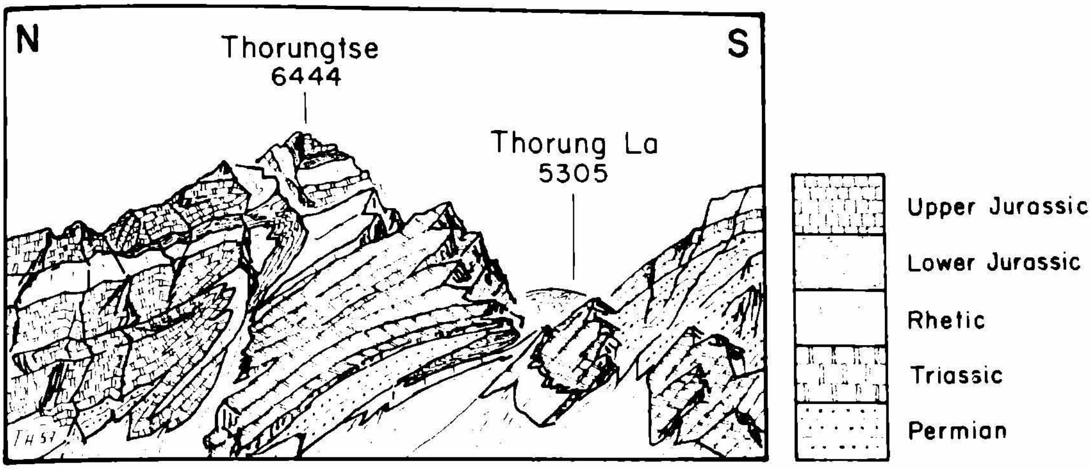


Fig. 74. The Thorungtse (6444 m), Seen from Muktinath

This sketch shows especially the lower part of the western flank of the Thorungtse with the various folds in the Permian and Triassic formations. The upper part of the mountain is distorted, due to looking steeply upwards, especially, the Cretaceous top cannot be seen. The summit is better shown in fig. 79, 81 and 82.

Phot. 43. View on Muktinath

Deriatse (6150 m) left side, Lupratse (5911 m) right side.
(Compare fig. 75 and geological panorama plate VI, fig. 2.)

The transverse fault of Muktinath strikes along the foot of the mountain range. It can clearly be recognized especially on the leftern side, how the folds in the Norian dolomite are cut.

The natural gas of Muktinath appears in this fault, where the Paleocene Saligram series join the Triassic and Permian formations in the fault itself.

It forms a narrow anticline which is overturned towards the south. The southern (lower) flank of the anticline is almost squeezed out (fig. 81 and 82). North of it, a new very narrow syncline adjoins to the north of this dolomite anticline. Also this syncline closure of the Triassic dolomite is just exposed over the screes filling above Chhego (fig. 81). This same dolomite forms again a folded anticline in the western ridge of the Thorungtse, from where it can be observed in the upper part of the Thorungtse striking towards the north (fig. 81).

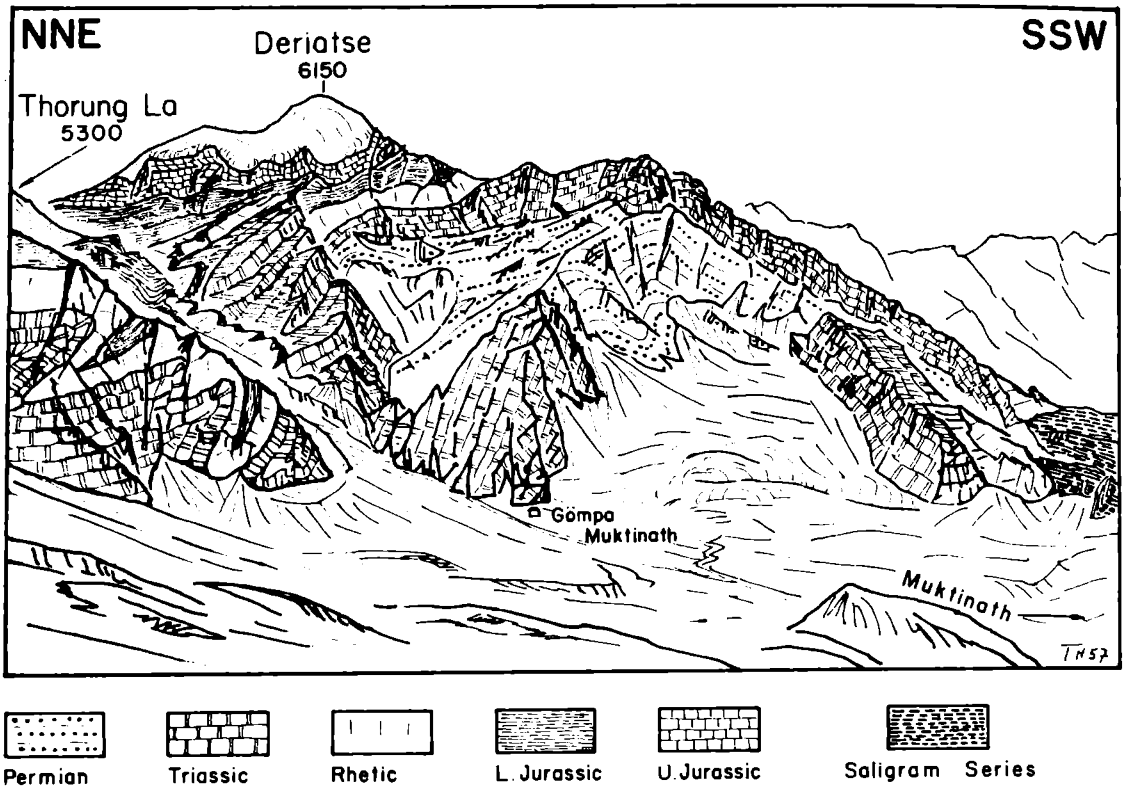


Fig. 75. The Western and Northwestern Flank of Thorung La and Deriatse (6150 m)
The large Muktinath anticline is eroded down to the Permian formations. The axis of the anticline pitches steeply from the Deriatse (6150 m) down to the west. The Saligram series (right side) join the Rhetic formations under angle unconformity. The major transverse fault strikes in north-south direction along the foot of the mountain, through the Gömpa of Muktinath. In this fault occur the springs and the natural gas, nourrishing the sacred eternal flame. Compare also phot. 43.

In the valley which drains the northwestern flank of the Thorungtse the Permian formations are exposed, underlying the Triassic dolomite (fig. 79, 81 and 114, and plate VI, fig. 1 and 2). The Permian formations are the core of a big anticline, which shows a strong western axial pitch (fig. 79, 81, and 82). This is the Chehang anticline (see fig. 82, and plate III, profile 6). On the ridge north of this valley (fig. 79 and 81) the dolomites occur again, folded in itself, but steeply dipping towards the west. Overlying to these dolomites we find limestones of the Rhetic and Lower Jurassic, proved by fossils (fig. 79, 80, 81, phot. 43).

At Muktinath itself of course we are interested in the sacred permanent flame, which is a pilgrimage place for both the Buddhists from Tibet, Nepal, India and Ceylon as well as for the Hindus from Nepal and India.

For this reason, the sacred place has got two different names: Muktinath is the Nepalese name, while Chumik Ghyatsa is the Tibetan name.

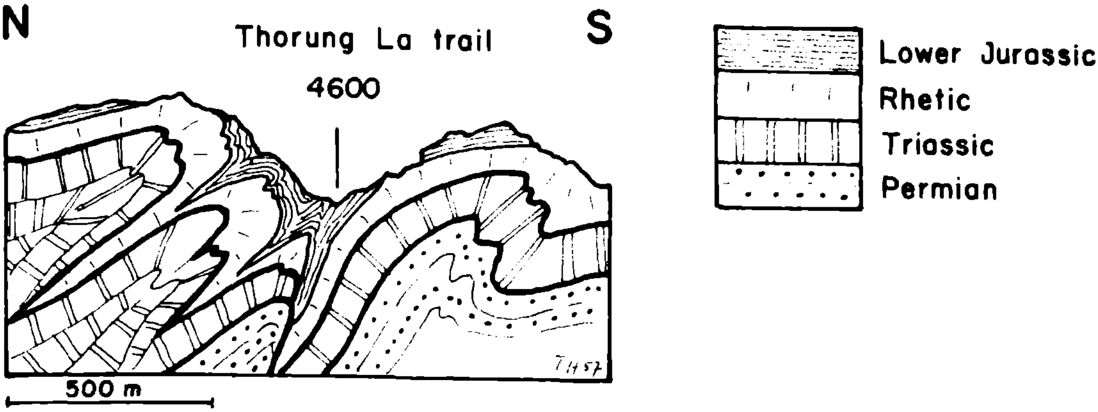


Fig. 76. Comprehensive Profile at the Western Flank of Thorung La
The complicated Thorung syncline strikes through the Thorung valley. The Muktinath anticline (right side, south) is relatively simple, while the Chehang anticline (northern side) is again complicated with a number of overturned folds.

The detail profile along the rock exposures above the screes, from the temple towards the south (fig. 77) shows first the steeply western dipping Triassic dolomite (fig. 75, 79 and phot.43). This dolomite is of coarse-grained blueish-grey type. Some layers of polygene breccias are found in the upper part. Towards the south, the strike, which, north of the temple was west–east, changes to a northeast-southwest strike. The dip changes likewise from northern direction to a western dip. By moving south, lower formations occur (fig. 77 and 78), namely red and dark slates with small layers of echinoidal breccias. Findings of pectus allow a safe determination of these formations to Lower Triassic-Permian.

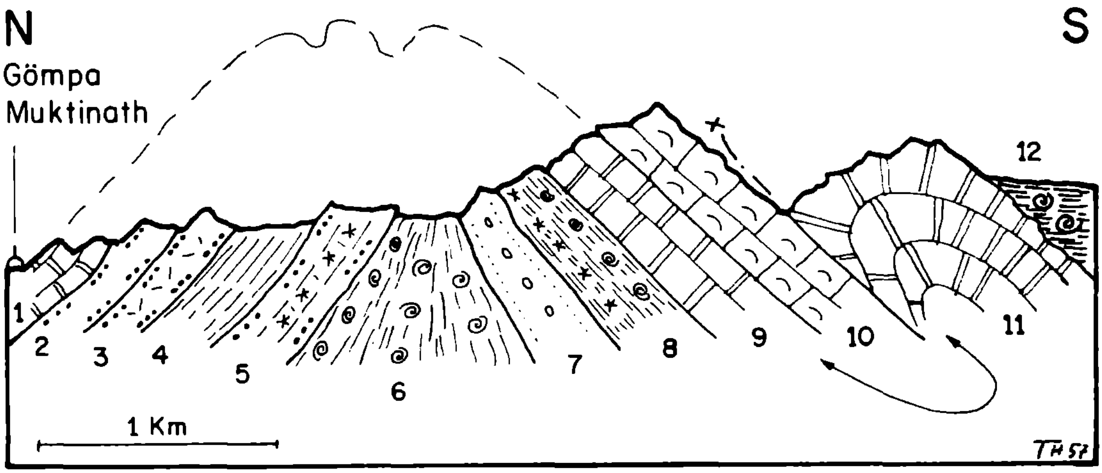
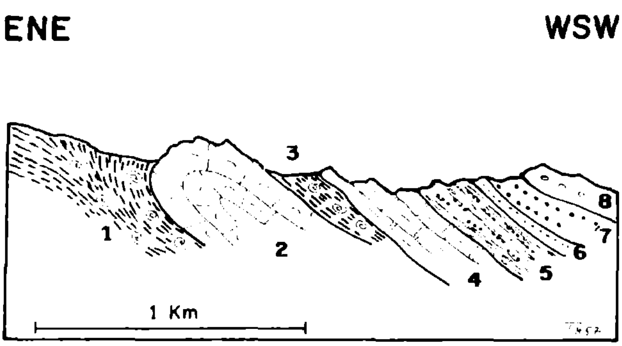


Fig. 77. Detail Profile from the Muktinath Gömpa towards the South

1 Norian dolomite
2 quartzite, coarse-grained, blueish green
3 quartzitic breccias
4 red and dark slates
5 quartzitic breccia, with thin layers of echinoidal breccia
6 slates with pectus
7 sandstones and conglomerates (polygenous, quartzitic; components in quartz-sandstone; type of the "verrucano" of the Swiss Alps); echinoidal breccia, with gastropods and nerinea species
8 dolomite
9 shelly limestone
10 transgression of black slates with saligrams

Fig. 78. Detail Profile on the Ridge 4 km South of Muktinath
(this profile continues from fig. 77 towards south, right side in the picture)



1 Saligram series, black slates and argillaceous slates with calcareous boulders containing ammonites
2 shelly limestone, formed to an overturned anticline; the contact between (1) and (2) is partly unconform
3 black argillaceous slates with greensands (glauconite)
4 marly limestone, oölitic, thin-bedded; with extraordinary transverse clefts, interbedded with silver-grey slates
5 black saligram slates interbedded in dark red slates, also beds of very dense red quartzite (radiolarite type)
6 glauconite greensand, fine-grained
7 glauconite greensand, coarse-grained
8 conglomerate of quartzites

The latter is represented by red sandstones and conglomerates. The echinoidal breccias also contain a nerinea species and gastropods. Due to a change of strike we reach further south again into the overlying formations and the Triassic dolomite occurs again at the foot of the western ridge of the Deriatse (see fig. 75 and 78). At this place, it is overlain by the lumashell limestones of the Rhetic. The Rhetic formations show also marly limestones, interbedded with slates (fig. 80). The limestones show a characteristic transverse clivage which was found also at other places in the same formations. The folds in the marly limestones have their axis in northnortheast–southsouthwest direction, with a strong axial pitch towards the southwest. That means the axis of the folds are nearly at right angle to the normal east–west strike.

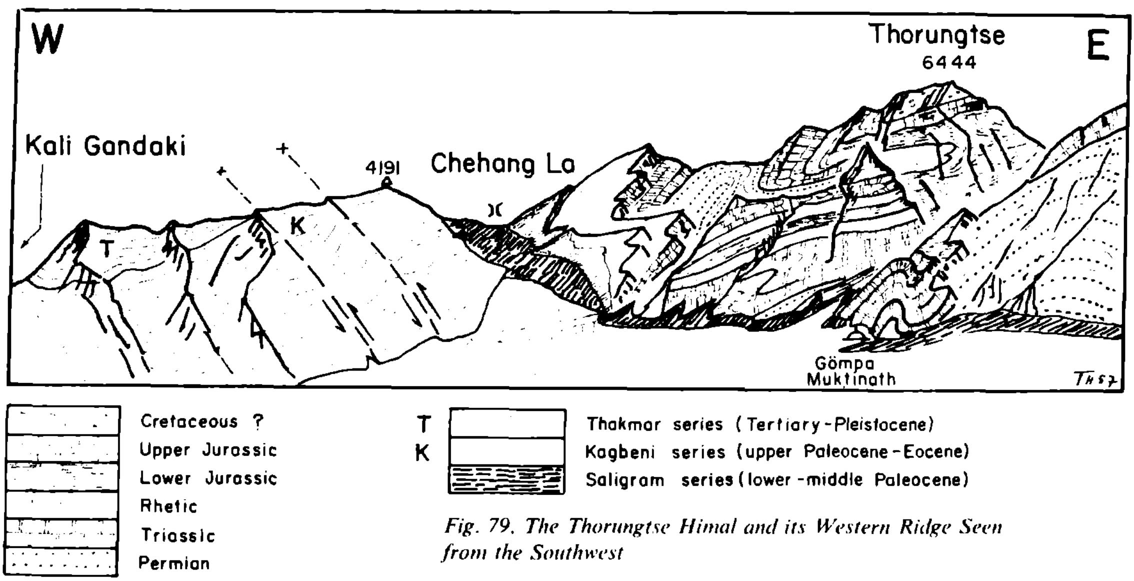


Fig. 79. The Thorungtse Himal and its Western Ridge Seen from the Southwest

All the formations show a strong axial pitch towards west. On Chehang La (left side) we find the transgression of the Saligram series on the Lower Jurassic slates. The Gömpa of Muktinath is situated just on the transgression contact between the Saligram series und the Triassic dolomite. (See also plate VI, fig. 2.)
In addition to the strong axial pitch, also a number of south–north faults strike through the zone of Muktinath, whereby the western portions have been sunk. (Compare also fig. 81 and 136, phot. 46 and 70, profile V in plate IV.)

Dark bituminous shales, partly of sulphuric smell overly the Rhetic formations at places under unconformity. The dark shales contain large boulders of calcareous concretions, which are the famous saligrams. Saligram is the Hindi name for the ammonites, which have caused the concretions. The saligrams are sacred for the Hindus. According to their believe, they contain gold, and bring good luck to the owner. They are sold in Calcutta for up to 100 US$ each. The ammonites are (in this area) of Jurassic and Cretaceous age. Undoubtedly, these series were deposited during the Upper Cretaceous-Paleocene period under circumstances which were especially favourable for calcification and thus preserving the abundant ammonites. We shall from now on call these formations the Saligram series. It is a key horizon, which has been transgressed over various Mesozoic formations, as we shall see later on.

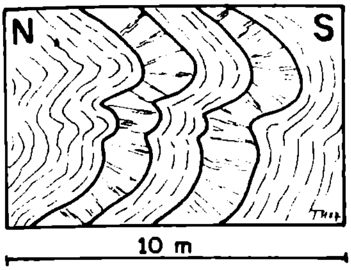


Fig. 80. Rhetic Marly Limestones Interbedded in Slates
(2 km south of Chahar)
The limestones show the characteristic transverse clivage. The axis of the folds is directed towards the Thorungtse, that means in west—east direction, with a strong pitch towards the west.

At the said ridge 2 km south of Chahar, the Saligram series are directly transgressed on the Rhetic formations. Though their age has to be considered as upper Cretaceous or even post Cretaceous. The Saligram series are however also folded into the folds of the Rhetic formations, which indicates that mountain building forces continued to work after their deposition.

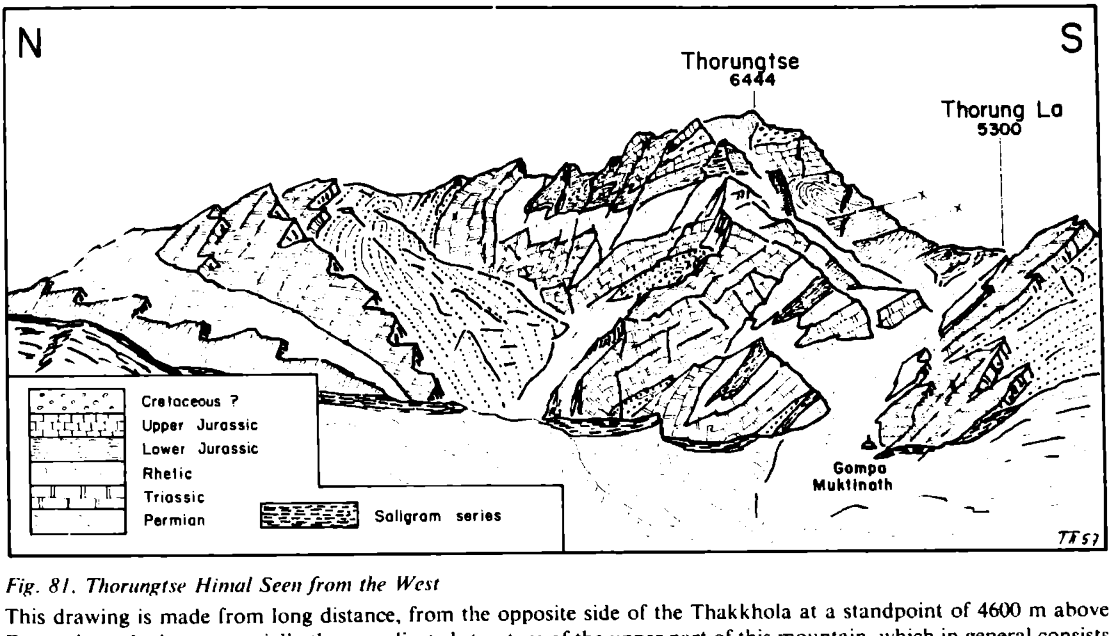


Fig. 81. Thorungtse Himal Seen from the West
This drawing is made from long distance, from the opposite side of the Thakkhola at a standpoint of 4600 m above Dangarjong. It shows especially the complicated structure of the upper part of this mountain, which in general consists of a syncline which is overturned towards the south (the Thorung syncline). Adjoining to the north we find the Chehang anticline, in which the Permian formations reach right up to the main ridge of the mountain. Also the Chehang anticline is overturned towards the south.
All the structures of the Thorung Himal show a steep western pitching (towards the observer). Thus the Saligram series which are more flat are in unconform contact with various formations, from Permian to Lower Jurassic. It is evident, that the Saligram series have been deposited on a previous erosional surface.

The Saligram series are only about 100–200 m thick. They are overlain by greensands, which are interbedded in red and dark slates. Also beds of dense and deep red quartzites (radiolarite type) are found in these formations. Since all these beds dip towards the west, we move into higher formations along the ridge towards the west.

We find overlying quartzite conglomerates. There is little doubt that we are at this place in Paleocene or even Eocene formations.

On our way back from Chahar to the Muktinath Gömpa (Gömpa = temple) we take a route a little bit further west. Thus we follow the Saligram series, and find to our astonishment, that these series transgress over various Mesozoic formations: They overly Rhetic Lumashell limestones 2 km south of Chahar, then Norian dolomite southwest of Chahar, then Permian slates and sandstones weast of Chahar and finally again Norian dolomites near the temple of Muktinath (see plate VI, fig. 2). Further north, the Saligram series reach far up into the valley of the Thorung La, where they are again in direct contact with Rhetic lumashell limestones (fig. 74, 79, 81 and plate IV, profile V).

The transgression of the Saligram series is not only a stratigraphic one, but at this place also (or rather) a tectonic one: It cuts the Muktinath anticline at its western flank (fig. 75 and 79). This anticline was to a large degree eroded and opened from the Upper Jurassic formations at the summit of Deriatse (6150 m) right down to the Permian formations between Muktinath and Chahar. The Saligram series were deposited on the eroded flank of this anticline, coming into contact with Rhetic formations on the southern and northern flank of the anticline, while covering Permian formations in the center. We may also conclude, that the tremendous western axial pitch of this anticline was effected not only before the transgression of the Saligram series, but also during and even after the Saligram stage: True, the Saligram series also dip towards the west, but much less than the axis of the Muktinath anticline. (See also plate VI, fig. 2, and plate IV, profile V.)

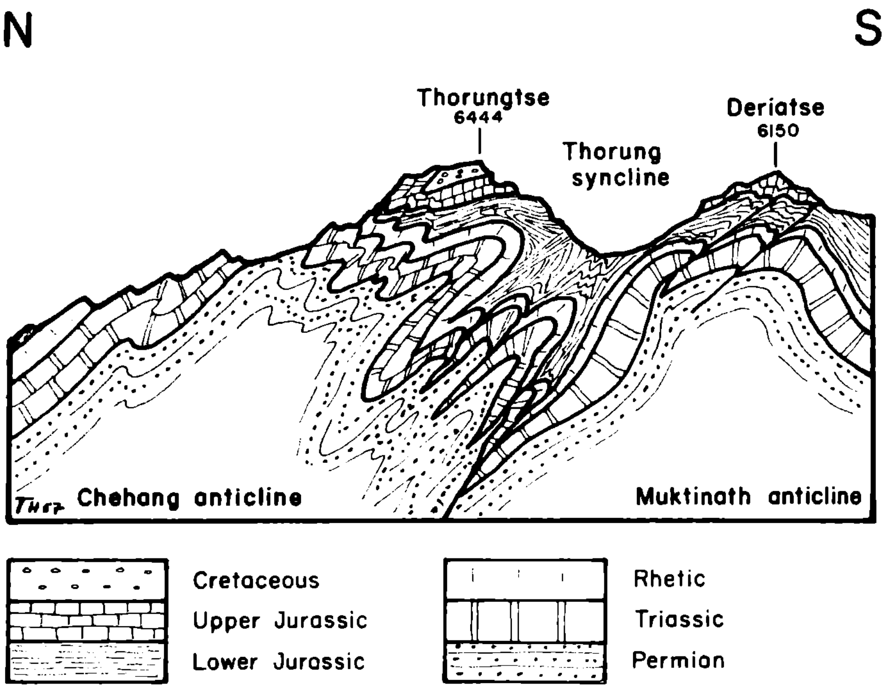


Fig. 82. Comprehensive Profile Sketch of the Thorungtse

Coming back to the sacred flame of Muktinath, we now find the explanation easily. The natural gas appears exactly in the transgression contact between the Norian dolomite and the Saligram series. The Saligram series are pretty bituminous, they contain even possibly Petroleum in the basin of the Thakkhola. The gas climbs in the western dipping Saligram series out of the Thakkhola basin and appears on the surface where the Saligram series has its eastern margin, namely at the contact with the Triassic formations. However, it is evident that also transverse faults in that area have helped the natural gas to occur at the surface (see profile V in plate IV; phot. 43 and fig. 136). It appears as if the western flank of the Thorung Himal and the Deriatse were cut by such a transverse fault, whereby the Thakkhola basin has sunk in (in form of a Graben). There are a number of such faults also further west (see phot. 46 and fig. 85 and 136).

At the same place, where the natural gas occurs in the shrine of the temple of Muktinath, also a spring appears. It is the people's belief, that God has made the water burning at this place, to show his almight. Also in the close surroundings of the temple, there occur a great number of other springs, the water of which is used for water plays and according to the people's belief—is supposed to have miraculous effect on the pilgrims when drunk.

The dark bituminous Saligram series, the red slates and the greensands fill up the whole valley of Muktinath (fig. 79, 81 and panorama from Dangarjong plate VI, fig. 2). Surprisingly, the structure in these young formations coincide by no means with the tectonics of the surrounding mountains built of Mesozoic formations. The structures of these Upper Cretaceous and Tertiary formations are totally discordant to those of the Mesozoic mountains. In general the structural axis of the Tertiary formations are directed north–south, whereby the pressure of the orogenesis originated from the east (fig. 79, 84 and 85, see also profiles IV and V of plate IV). We shall see later on, that also within the Tertiary formations we find different structures. Thus for example the ridge which extends from the peak 4191 m towards the south (fig. 84) shows transverse faults and folding, which is directed towards the west, all the strikes and the axis of the folds being north–south. This structure in the said ridge is especially well exposed, since the dark greensands (Kagbeni series) are overlain by clear-coloured sandstones (Thakmar series) (fig. 84).

Also transgressions within the Tertiary formations can be observed, whereby younger formations transgress in a straight line over ancient folds (fig. 86, northeast of Khingsar). Also south of Chahar, the Tertiary formations show separate structures, whereby a narrow anticline is erected steeply towards the east. (See the panorama seen from Dangarjong, plate VI, fig. 2, and phot. 69, 70 and 46.) In this ridge, which is situated between the Muktinath Chu and the Lupra Chu, general northwestern dipping prevails (see phot. 1, 69, 70 and 46). Though some structures can be observed. The strike is here at right angle to the normal west–east strike of the Mesozoic formations.

Little south of Kagbeni there is an anticline in the Tertiary formations the axis of which is directed in north–south direction. (See panorama from Dangarjong, plate VI, fig. 2.) The same abnormal strike we find also in the ridge of peak 4191 m north of the Muktinath Chu (see phot. 46, and fig. 79, 84 and 85). However, the western flank of this ridge, east of Kagbeni, shows again different structures (fig. 87).

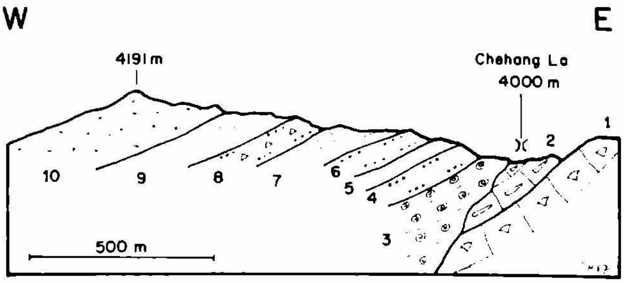
Besides the Tertiary formations, also the Quaternary deposits play an important role in the shaping of the landscape of Muktinath. Huge morains are prove of the ancient ice ages, in which large glaciers were flowing down the tributary valleys. This is especially true in the valley of the Thorung La and in the Chehang valley, which drains the northwestern flank of the Thorungtse (fig. 79 and 81). Large river terraces further down as well as terraced morains resulted from important interglacial stages. Further, a landslide originated from the eroded Permian core of the Muktinath anticline, just south of the Gömpa (fig. 75 and phot. 43 and 46). However, we shall try later on to give a classification of the Quaternary events in the Thakkhola basin, when we shall have covered the whole area and collected more data.

2. Tetang–Narsing Chu

On our trip from Muktinath towards the north we have first to cross the Chehang La, that is the pass a few hundred meters east of peak 4191 m. On this route, just northeast of the Chhego village we find again the black shales of the Saligram series with the large boulders which contain saligrams (ammonites, fig. 81).

Fig. 83. Detail Profile from the Chehang La to the Peak 4191 m

1 limestone and calcareous slates with cardinies
2 limestone with belemnites
3 Saligram series
4 grey coarse-grained quartzite
5 white sandstone
6 red dense quartzite
7 dark sandy slates
8 quartzite breccia
9 sandstone ("Ruchsandstein")
10 brown and green sandstones, fine conglomerates, glauconite sandstone



From the large number of collected ammonites were some determined in the field as Hoplites Berriasiella (Portlandian–Purbeckian). At this place, the Saligram series is much tectonized, with the axes of the folds directed north–south. The exposure is close to the Norian dolomite, which covers the northern flank of the Thorung valley (fig. 81). In general the Saligram series dips at this place towards the west, while the mentioned dolomite shows a normal northnortheast dip. The unconformity of the Eocene Saligram series upon the Triassic dolomite is thus practically under right angle.

Phot. 44. Finding of Fossils on the Trail from Chehang towards North
Cardinias embedded with belemnites

Phot. 45. Belemnites near the Saligram Transgression of Peak 4191 m East (Chehang La)

In the small brook northeast of Chhego we can also observe, how the above-mentioned dolomite shows a synclinal closure and connects with the higher dolomite series. The filling consists of Rhetic and Liassic slates and limestones (fig. 81 and 79).

The valley north of Chhego has an extraordinary thick cover of morains. A distinct terrace of morainic material is found at 3800 m (fig. 79 and 75). But also further up, towards the Chehang La, we find several lateral morains lying upon the said terrace.

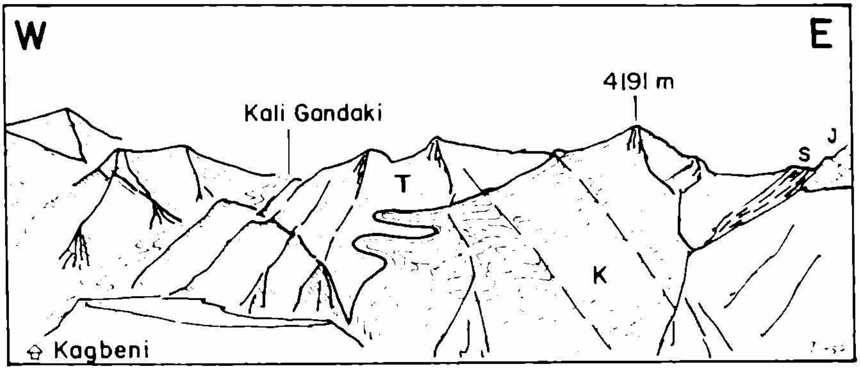


Fig. 84. View on the Northern Flank of the Muktinath Valley

T Thakmar series (clear-coloured sandstones, red shales, boulderbeds and lacustrine chalk; Upper Tertiary – Quaternary)

K Kagbeni series (dark sandstones and slates, greensands, grey sandstones, quartzites, breccias and glauconite sandstone; Paleocene – Eocene).

S Saligram series (Lower – Middle Paleocene)

J Jurassic

The Thakmar series are folded-in into the Kagbeni series, whereby the structural axis are directed north – south. Compare phot. 46.

The trail towards the Chehang La follows more or less the transgression of the Saligram series upon the Mesozoic. Close southeast of the pass the black shales of the Saligram series join the lumashell limestones of the Rhetic. Preliminarily we were able to determine Cardinias Hybridia (phot. 44). Just north of the pass we find beds with abundant, well preserved belemnites (fig. 83 and phot. 45). In the same locality we also found a large ammonite, namely a Virgatites Virgatus (fig. 83). All these Mesozoic series dip towards the west. The transgressing Saligram series however seems not to overly the Mesozoic formations concordantly, since the Saligram series join in a straight prolongation to the dip of the Jurassic limestone.

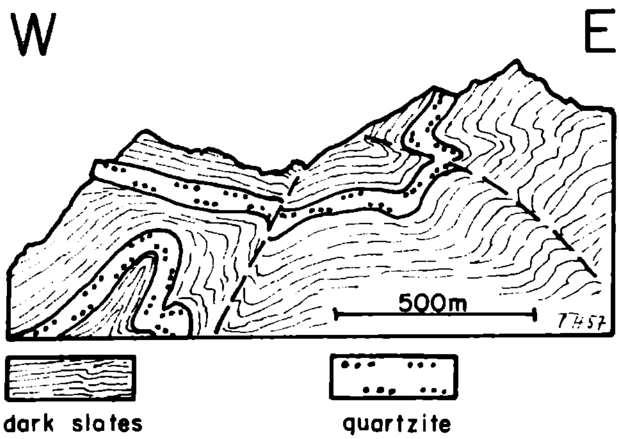


Fig. 85. Faults and Folding within the Eocene Kagbeni Series
(west of Muktinath)

Already south of Muktinath we have made the observation, that the Saligram series are in contact with Permian, Triassic, Rhetic, Lower Jurassic and Upper Jurassic formations. While near Muktinath and Chhego, the transgression shows right-angle unconformity (Triassic dolomite dips north, Saligram series dip west), we find at the Chehang La a western dip in both the Mesozoic and Saligram series. However, there is also at this place an unconformity, since the plane of transgression dips steeper towards the west than the Mesozoic formations (see fig. 79 and 83).

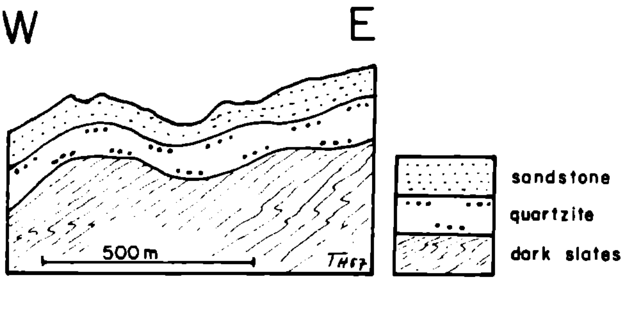


Fig. 86. Transgression within the Eocene Kagbeni Series
(northeast of Khingsar, 4 km east-southeast of Kagbeni)
Quartzitic formations lying under unconformity upon black slates.

From this we may conclude that further down in the underground (towards the west and towards the Kali Gandaki river, covered by the screes) the transgression again covers lower formations (Triassic). Also, we have to keep in mind the possibility of a transverse fault, similar to the Muktinath fault. (See plate IV, profile IV.)

Let us first study the section of the transgression on the Malm (Upper Jurassic limestone). The black shales of the Saligram series contain large size saligrams (fig. 83). The thickness of the Saligram series is about 200 m. Above the Saligram series we find white coarse-grained quartzites (fig. 83), then new layers of black shales interbedded with dense red quartzite. A breccia of quartzite changes to quartzite sandstone. The latter is in the lower portion brownish-grey, but changes the colour to green in the upper part. The whole sandstone series recall the Ruchbergsandstone of the Alps. In the peak 4191 m we find predominant the green sandstone, which resembles much the Assiline greensand of the Helvetic Tertiary of the Alps. However, no nummulites were found at this place.

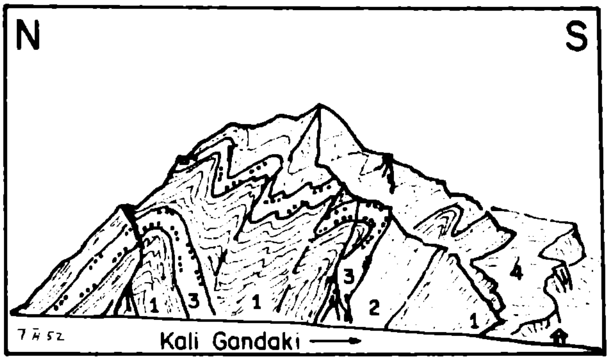


Fig. 87. The Eastern Flank of the Kali Gandaki Valley North of Kagbeni

The Kagbeni series are intensively folded and faulted

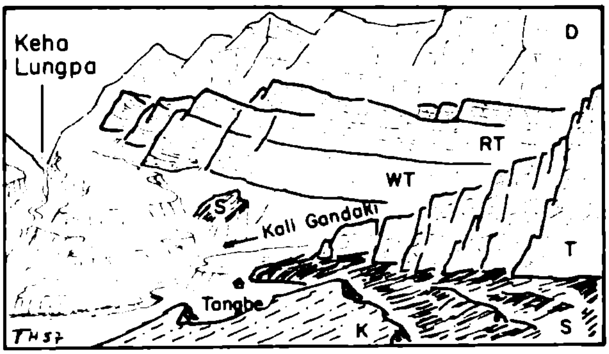
1 black slates, partly calcareous
2 sandstone
3 quartzite
4 river terrace

Kagbeni is at the lower right corner

In the valley east of Tangbe, the black shales of the Saligram series extend right down to the Kali Gandaki river (fig. 88). There they form an anticline structure with axial strike in north-northwest–south-southwest direction. The eastern flank of the said anticline is flat, while the western flank is steep. (Compare also profile sketch Tangbe–Kagbeni, fig. 116.) Brown and clear grey sandstones, interbedded with lacustrine shales transgress with flat west-northwestern dipping over the Saligram series (fig. 89). At the western side of the Kali Gandaki the northern component of the dip is predominant (compare also fig. 88). That means a rise of these 400 m thick sandstone series towards the south, that is towards the main range of the Himalaya (see phot. 57).

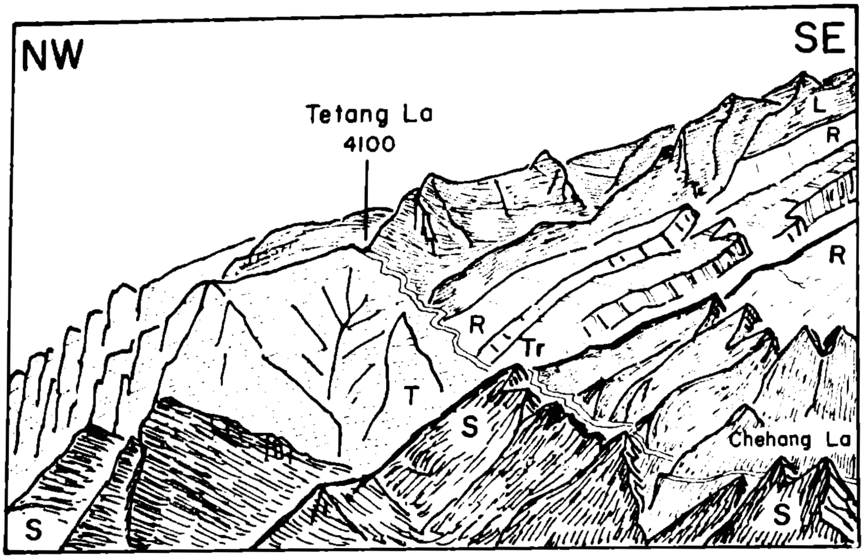
The trail from the Chehang La towards the northeast keeps more or less the same altitude and follows always more or less the transgression of the Saligram series on the Mesozoic formations (fig. 89). We can observe, how the transgression covers higher formations.

Fig. 88. View from Peak 4191 m towards the North



D Devonian
T Thakmar series in general (Tertiary—Pleistocene)
RT Red Thakmar series
WT White Thakmar series
K Kagbeni series (Upper Paleocene—Eocene)
S Saligram series (Lower—Middle Paleocene)

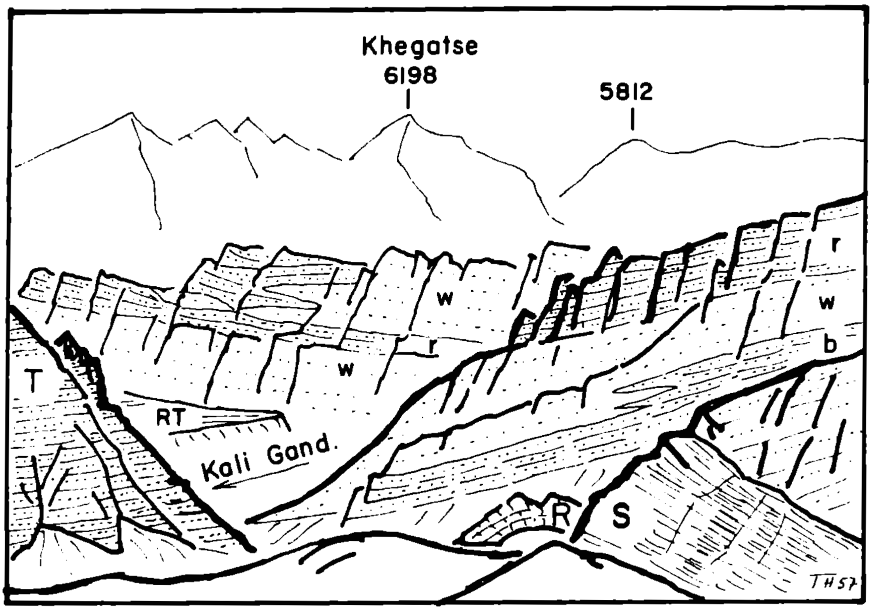
The Saligram series reaches from Chehang La right down to Tangbe village near the Kali Gandaki river. Also at the opposite side of the valley Saligram series occur.
Note the western dip of the Thakmar series at the eastern flank of the Kali Gandaki valley (right side in the sketch) and the northern dip of the same series at the western flank of the valley.



T Thakmar series
S Saligram series
L Liassic (Lower Jurassic)
R Rhetic
Tr Triassic

Fig. 89. View on the Trail between Chehang La and Tetang La

The trail follows the boundary between the Mesozoic and the Saligram series and the Thakmar series respectively. Below Tetang La the Saligram series are locally bent up with eastern dip. The Thakmar series join both the Mesozoic as well as the Saligram series under angle unconformity. The Thakmar series themselves show a strong western dip. For details on the Tetang La see fig. 91.



RT river terraces
T Thakmar series (Tertiary–Quaternary)
w white sandstones and gravels
r red sandstones and gravels
b brown sandstones and shales
S Saligram series
R Rhetic

Fig. 90. Geological Sketch of the Tetang Valley
(view from the southeast)

The Thakmar series are transgressed under angle unconformity upon the Saligram series (right side). Apparently the latter form an anticline in this valley. Note the western dipping of the Thakmar series at the eastern side of the Kali Gandaki valley (right side in the picture) and the predominant northern dip at the opposite side (in the background).

Khegatse 6198 m   Mustangtse 6476 m

Phot. 46. The Thakkhola Graben North of Muktinath
(aerial photo from 5800 m above Muktinath, view towards the north)
The main transverse fault strikes along the eastern foot of the mountain range in the left side of the picture. (Compare plate VII, fig. 3 and 2.)
The fault of the opposite side of the Graben is of lesser magnitude. Instead, the whole Cretaceous and Tertiary filling of the Graben shows a considerable dip to the west (left side in the picture).

Over the series with the belemnites we find dark limestones, with a net pattern of calcite veins, then slates and thin-bedded limestones, interbedded with quartzite beds, then polygene breccias (type of the Lias breccia of the Eastalpine facies of the Alps), and finally yellow arenaceous quartzites (Dogger?) (see fig. 89).

In the first small valley (2 km northeast of the Chehang La) the above-mentioned series are folded, whereby their axis strike in north–south direction. That is a right angle to the normal strike.

Just south of the first pass (approximately 3 km northeast of peak 4191 m) we find Rhetic limestones, whereby characteristically the limestones show transverse clivage and are interbedded with slates (compare also fig. 80 of the area south of Chahar). A few meters of layers and lenses of quartzite overly the Rhetic limestones. Further up we find blueish-grey coral limestone, overlain by breccias. The Saligram series transgresses on the latter. The profile above the transgression is given in fig. 94 and 95 and phot. 49. Surprisingly, we find only a few meters above the Saligram series river gravels of limestone and dolomite and also the first granite boulders of the Mustang granite (phot. 51 and 52).

In the tributary valley of the Narsing Chu, into which the trail descends for crossing the river we find thick morains. Proves of former glaciation are also found in glacial thrust marks on Lias breccias (phot. 50). Triassic dolomite occurs in the background of this tributary valley (fig. 95). This is anticlinally folded.

The trail crosses on its further course Rhetic limestones. However, in the lower part of the valley we enter again the Saligram series.

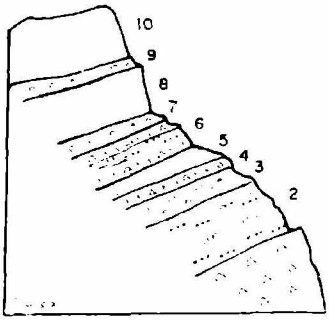
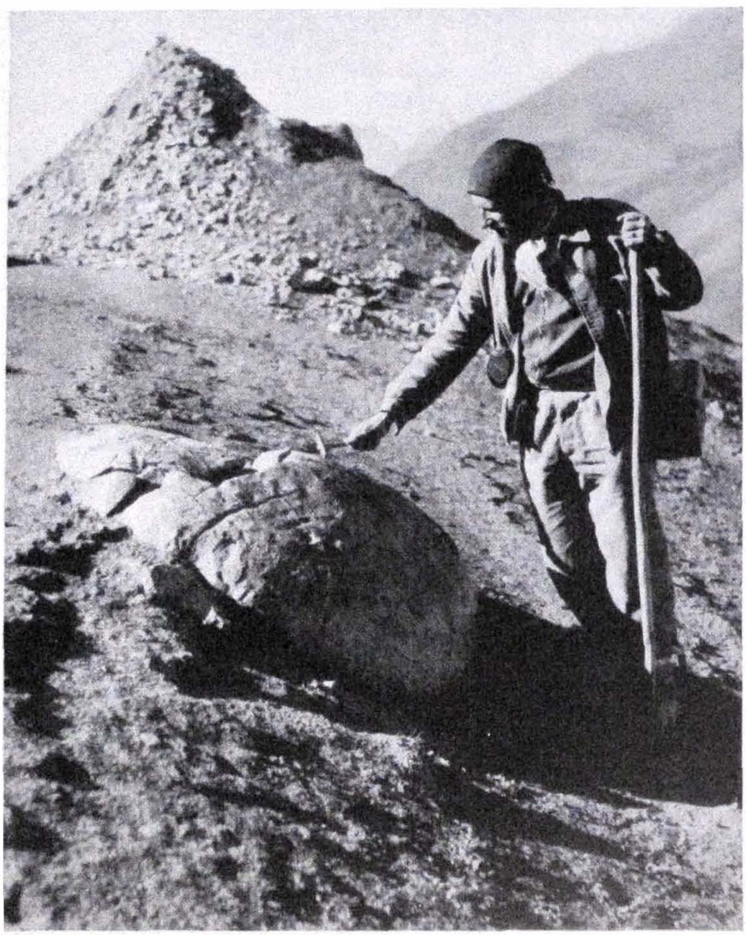


Fig. 91. The Tertiary on Tetang La
(Tetang La is situated 3.75 km southeast of Tetang, see location in fig. 89)

1 transgression breccia of the Lower Jurassic (Liassic), 20 m (see also phot.49)
2 quartzite with saligrams, 50 m
3 river gravels, (dolomite, limestone and granite)
4 marl breccia, 1 m
5 blue lacustrine shales, 2 m
6 marl breccia with beds of red iron quartzite
7 river gravels, 1 m
8 white sandstone, 30 m
9 river gravels, 2 m
10 red sandstone

For the first time we find in this valley between the Saligram series and the Mesozoic formations a new series of violet and pink well-bedded sandstones and slates of the flysch-type of the Alps (fig. 92–94, 97). Directly on the Saligram series occur sandstones with red boulders of breccias, overlain by light-blue lacustrine shales and clear-coloured sandstones. Overlying to these series we find brown sandstones (phot. 52) and river gravels, and finally thick formations of white lacustrine chalk. We shall call these series from now on the *Narsing series*. All those formations show a strong dip towards west-northwest. The violet flysch-type series are folded under unconformity on the Jurassic formations, and



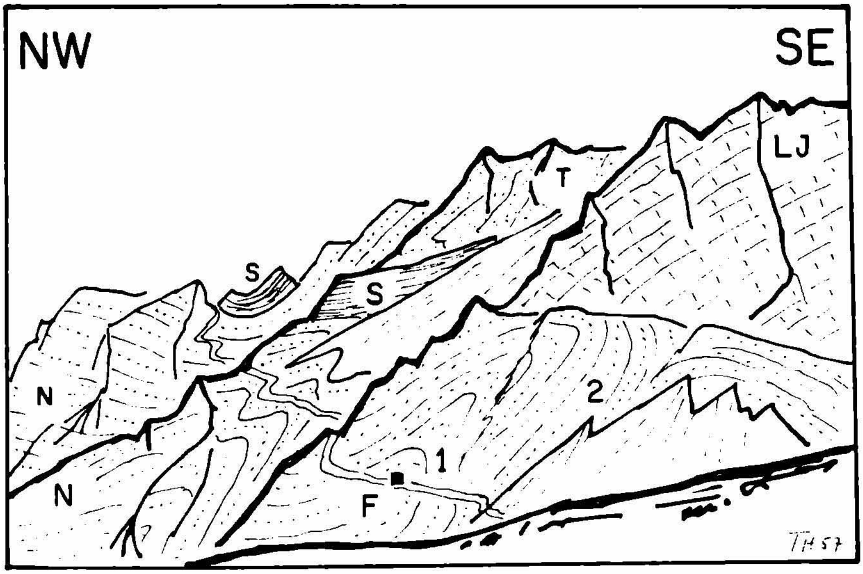
Phot. 47. A Saligram Boulder on the Trail to Chehang La

Phot. 48. Belemnites on Chehang La

Fig. 92. View on the Northern Flank of the Narsing Valley

T Thakmar series (Middle Tertiary—Quaternary)
S Saligram series (Lower—Middle Paleocene)
N Narsing flysch (Upper Cretaceous—Lower Paleocene) 1 yellow and red marly sandstone
2 blue shales
LJ Lower Jurassic (thin-bedded dark and spotted limestones and slates)
F Fossil finding (turritella) on the trail

The Mesozoic formations show general northwestern dip, while the Narsing flysch is involved in separate tectonics.



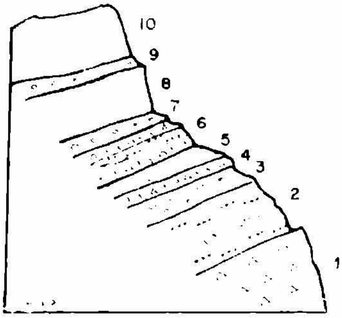
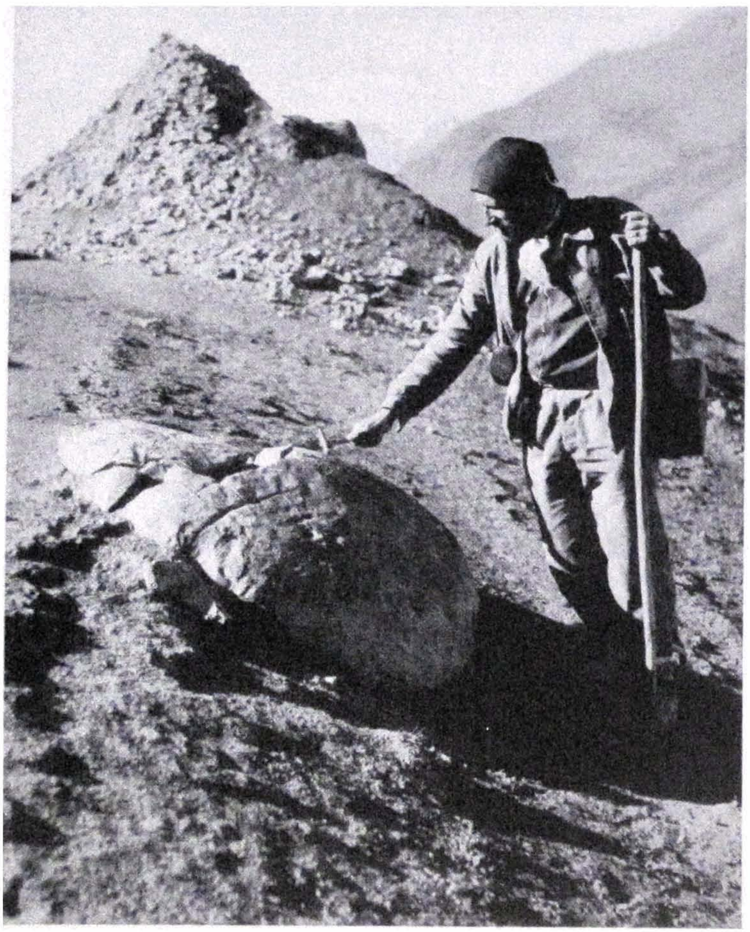


Fig. 91. The Tertiary on Tetang La
(Tetang La is situated 3.75 km southeast of Tetang, see location in fig. 89)
1 transgression breccia of the Lower Jurassic (Liassic), 20 m (see also phot. 49)
2 quartzite with saligrams, 50 m
3 river gravels, (dolomite, limestone and granite)
4 marl breccia, 1 m
5 blue lacustrine shales, 2 m
6 marl breccia with beds of red iron quartzite
7 river gravels, 1 m
8 white sandstone, 30 m
9 river gravels, 2 m
10 red sandstone

For the first time we find in this valley between the Saligram series and the Mesozoic formations a new series of violet and pink well-bedded sandstones and slates of the flysch-type of the Alps (fig. 92–94, 97). Directly on the Saligram series occur sandstones with red boulders of breccias, overlain by light-blue lacustrine shales and clear-coloured sandstones. Overlying to these series we find brown sandstones (phot. 52) and river gravels, and finally thick formations of white lacustrine chalk. We shall call these series from now on the *Narsing series*. All those formations show a strong dip towards west-northwest. The violet flysch-type series are folded under unconformity on the Jurassic formations, and



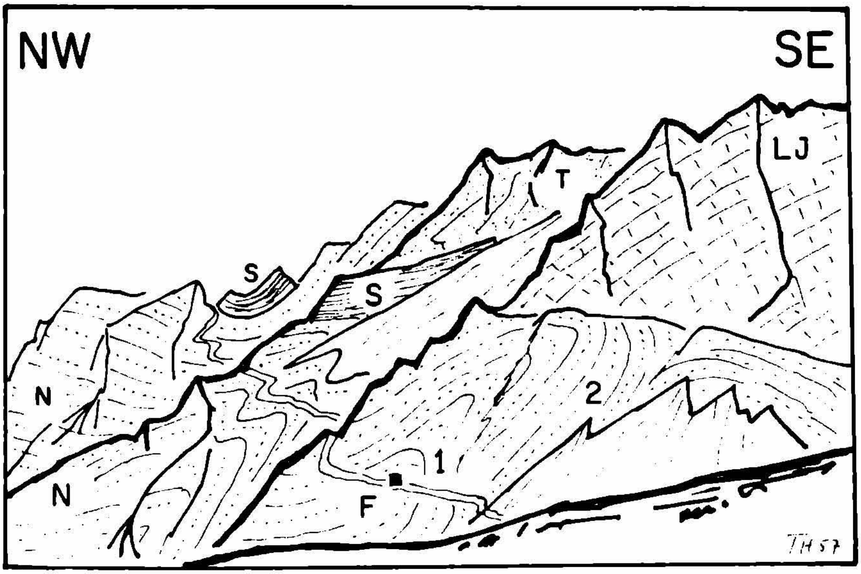
Phot. 47. A Saligram Boulder on the Trail to Chehang La

Phot. 48. Belemnites on Chehang La

Fig. 92. View on the Northern Flank of the Narsing Valley

T Thakmar series (Middle Tertiary—Quaternary)
S Saligram series (Lower—Middle Paleocene)
N Narsing flysch (Upper Cretaceous—Lower Paleocene) 1 yellow and red marly sandstone
2 blue shales
LJ Lower Jurassic (thin-bedded dark and spotted limestones and slates)
F Fossil finding (turritella) on the trail

The Mesozoic formations show general northwestern dip, while the Narsing flysch is involved in separate tectonics.



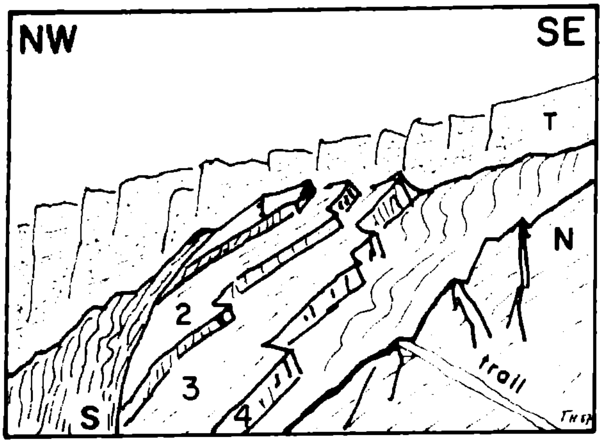


Fig. 93. Sketch of the Lower Part of the Narsing Valley

T Thakmar series (Upper Tertiary—Quaternary)
S Saligram series (Lower—Middle Paleocene)
N Narsing flysch (Upper Cretaceous—Lower Paleocene)
1 greyish blue shales
2 red shales
3 violet shales
4 calcareous slates

The Narsing flysch is much tectonized. The Saligram series overly the Narsing flysch under unconformity.
(Compare also phot. 53.)

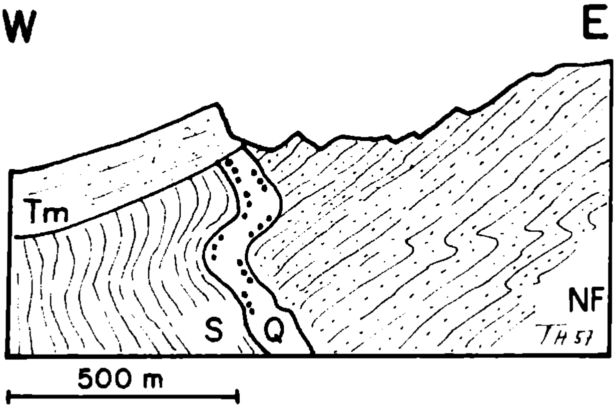


Fig. 94. Profile Sketch Showing the two Transgressions in the Narsing Valley

Tm Thakmar series (Upper Tertiary)
S Saligram series (Lower—Middle Paleocene)
Q quartzite
NF Narsing series (Lower Paleocene—Upper Cretaceous flysch)

The two transgressions prove a continued orogenesis through the whole of the Tertiary.

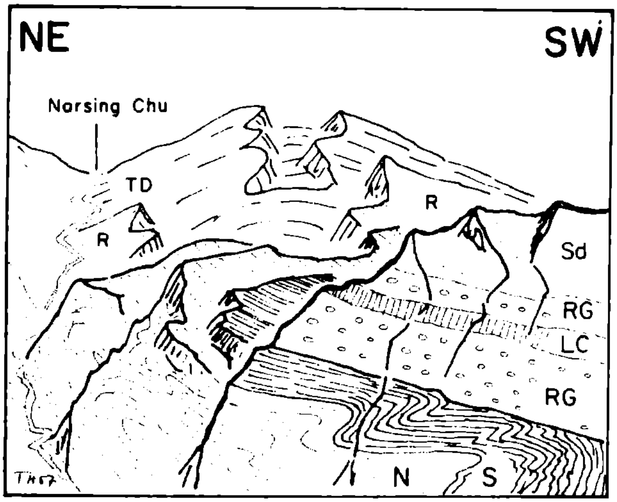


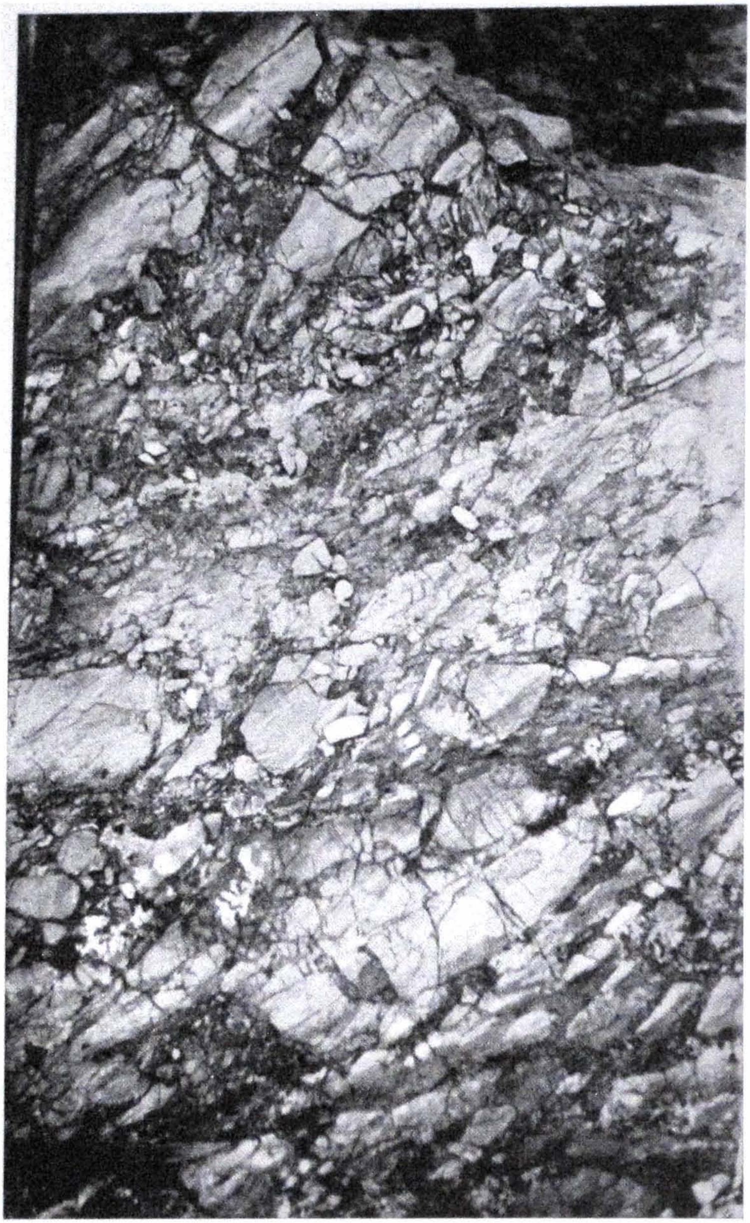
Fig. 95. View into the Upper Part of the Narsing Valley

Thakmar series
(Upper Tertiary—Lower Quaternary)
Sd sandstone
RG river gravel
LC lacustrine chalk
S Saligram series (Lower—Middle Paleocene)
N Narsing flysch (Upper Cretaceous—Lower Paleocene)
R Rhetic
TD Triassic dolomite

Phot. 49. Transgression Breccia of the Lower Jurassic
(between Chehang La and Narsing valley)
The Saligram series has transgressed on these breccias.

the Saligram series again transgressed under unconformity on the flysch-type violet series. (See fig. 94, 96 and 97.)

Those two unconformities are still much more clear at the northern flank of the Narsing valley, when climbing on the trail from the resthouse (fig. 92 and 97). The multi-coloured series (violet, red-brown and yellow sandstones, slates and marly limestones) are folded on the west-southwestern dipping Jurassic limestones (fig. 97). 150 m above the resthouse we find a number of fossils in the brown sandstones and in the marly limestones, of which one was determined as a turritella (fig. 92). Consequently, we may consider the flysch-type series as Upper Cretaceous — Paleocene. The Saligram series come hereby to be Lower to Middle Paleocene.



Phot. 50. Glacial Thrustmarks on Lower Jurassic Breccia
(at the southern flank of the Narsing valley)

Fig. 96. Detail Profile at the Southern Flank of the Narsing La

Tm Thakmar series (Middle Tertiary – Quaternary)
S Saligram series (Lower – Middle Paleocene)
Narsing flysch (Upper Cretaceous – Lower Paleocene)
1 marly limestones and slates
2 violet shales
3 thin-bedded marls, quartzites and shales, transgression of the Narsing flysch upon the Mesozoic
LJ Lower Jurassic

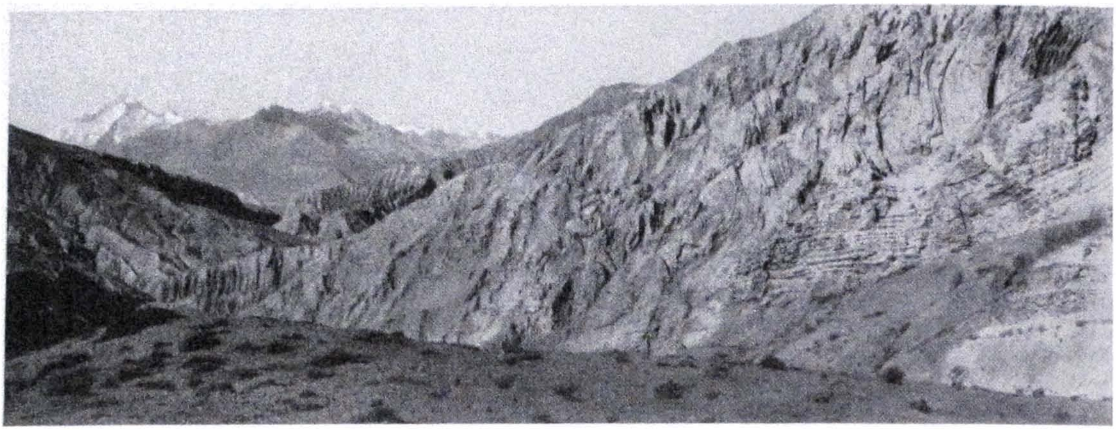
Finding of an oppelia species of 15 cm diameter in these series (see also phot. 56).

Phot. 51. River Gravels Overlying the Saligram Series
(on the Tetang La [4100 m] southeast of Tetang)
The gravels consist of dolomite, limestone and the most southern boulders of the Mustang granite.

Phot. 52. The Fluviatil Gravels and Lacustrine Shales in the Narsing Valley
1 brown sandstone
2 light blue lacustrine shale
3 large boulder bed (components consisting of breccia)
All the formations are tilted.
(See also fig. 97 and phot. 57.)

Phot. 53. Tectonics in the Narsing Flysch
(at the northern flank of the Narsing valley)
1 violet shales
2 light sandstones
3 blue marls

Also at the northern flank of the Narsing valley, the Narsing series (the flysch-type of the violet and pink sandstones) are intensively folded (fig. 95 and 97, phot. 53, 54, 55). Just north of the resthouse, in the Narsing Chu, the strike of the Narsing flysch is directed north–south, the dip vertical; higher up, towards the Narsing La, the strike changes to southeast–northwest direction. The thin-bedded flysch contains in this zone a large number of small folds and microfolds.



Phot. 54. The Northern Flank of the Narsing Valley with its Folded Series of Narsing Flysch
(Dhaulagiri in the left hand background)

3. Narsing La

In the valley, which leads to the Narsing La, we find Saligram series which dip towards the southwest. The Saligram series lie under unconformity on the Narsing flysch. We have, surprisingly enough, to conclude, that the Saligram series have been deposited in this valley, which was eroded in the Narsing flysch. On the ridges on either side of this valley we find—again under unconformity—on the vertically bedded Narsing flysch the Tertiary sandstones, lacustrine shales and river gravels, with a gentle western dipping (fig. 93 and 94). The Saligram series is missing between the Narsing flysch and the Tertiary formations on the ridges. It appears again further down (fig. 97).

These data hint on the evolution of the present complicated structures and of the correlation of the various formations: After deposition of the Paleocene Narsing flysch, thrust from the northeast lifted the flysch out of the sea, folded the flysch formation (apparently through gravity gliding towards the west) and erected the same to steep and vertical position (see fig. 97 and phot. 54).

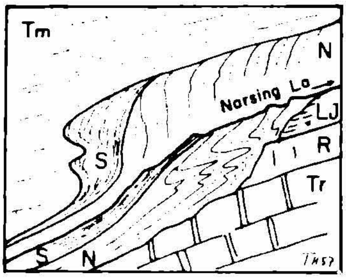


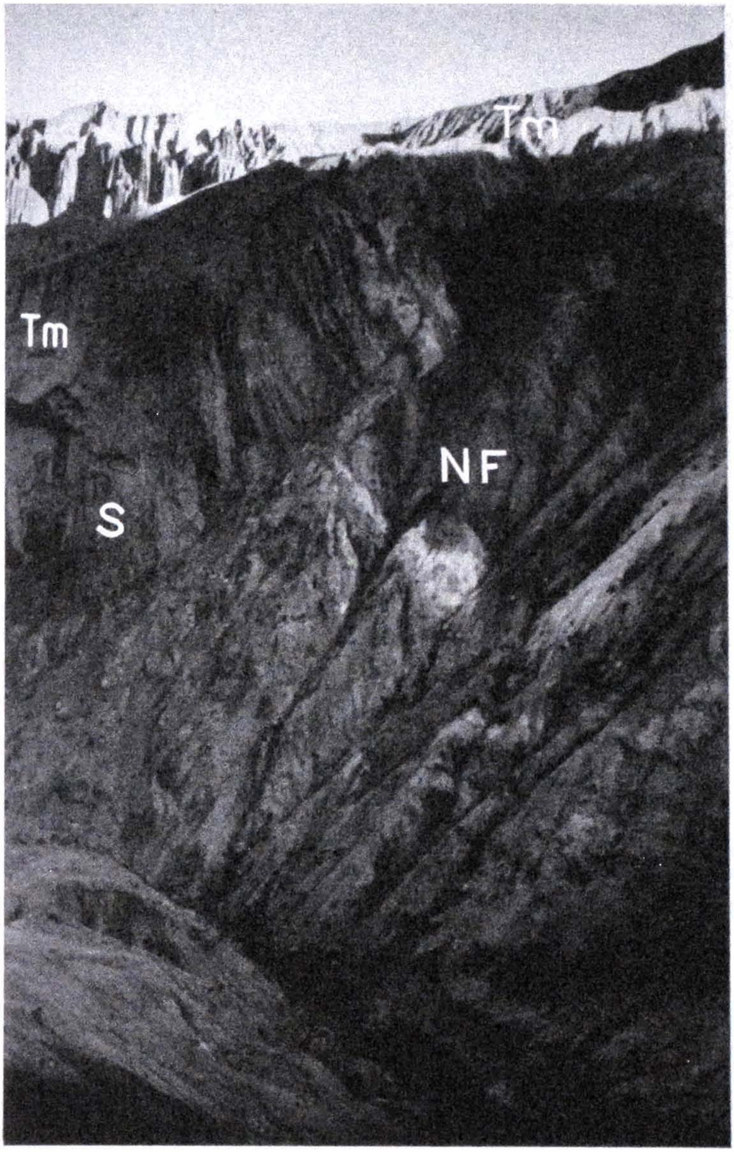
Fig. 97. Schematic Profile Sketch of the two Ridges on either Sides of the Valley Leading to the Narsing La

Tm Thakmar series (Middle Tertiary – Quaternary)
S Saligram series (Lower – Middle Paleocene)
N Narsing flysch (Upper Cretaceous – Lower Paleocene)
LJ Lower Jurassic
R Rhetic
Tr Triassic

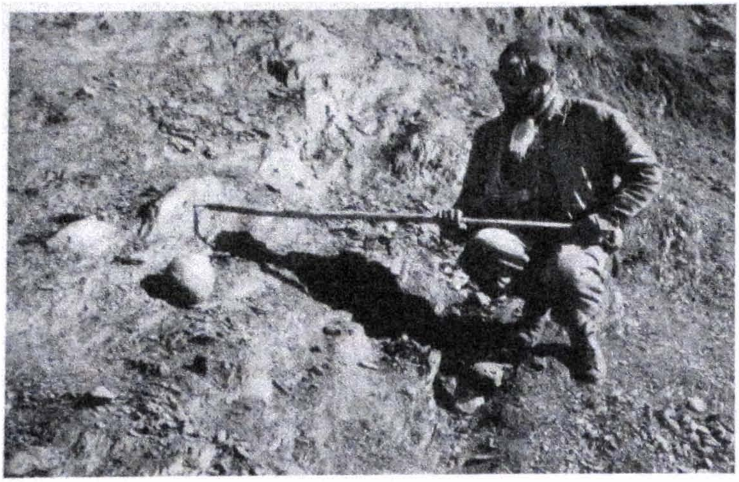
Phot. 55. The Unconform Transgressions between the Narsing Flysch, the Saligram Series and the Thakmar Series

(Compare also fig. 97.)

Tm Thakmar series
S Saligram series
NF Narsing flysch



The erosion formed and shaped valleys. New inundation deposited the Saligram series on the eroded surface, under angle unconformity. The cover by the sea was however not complete, since the ridges of the mountains were above the sea level, especially in the eastern part. In this zone, the Upper Tertiary sandstones, river gravels and lacustrine shales (Thakmar series) were deposited directly on the flysch (Narsing series). In the western part, the ridges covered by the flysch, were also inundated. In this part consequently the Saligram series was deposited not only in the valleys, but also on the ridges (fig. 97 and phot. 54).



Phot. 56. Finding of a Large-size Oppelia Species on Narsing La

In the upper part of the valley, which leads from the resthouse to the Tetang La 4100 m we find lateral morains of an ancient glacier. (At this place we found also the only water, in the otherwise completely dry area.) The morains contain mainly Rhetic and Liassic limestones. The same formations were also found in the rock exposures just west of the Tetang La. A finding of a big oppelia species at the same place has to be mentioned (phot. 56).

The last pass before descending to Tange may be called Tange La (4300 m). It is according to the Quarter-inch map situated 2 km north of the peak 4825 m, which erronously is named in the said map with Damodar Kund (Damodar = Goddess; Kund = lake). The real Damodar Kund is a sacred place

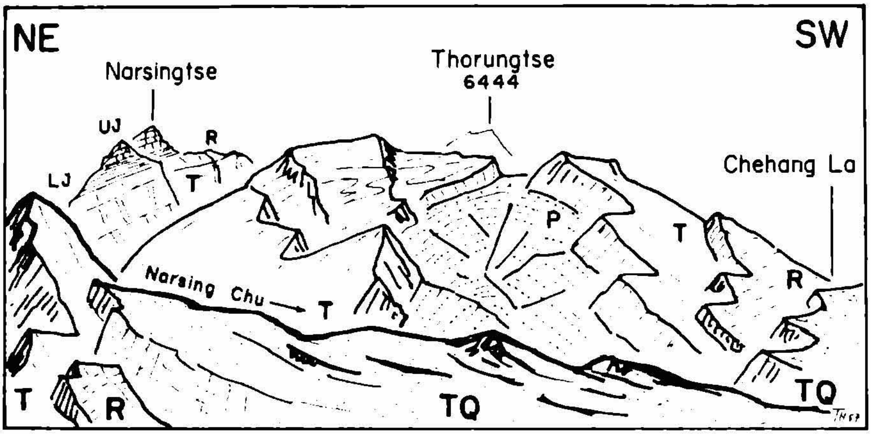


Fig. 98. View from the Tange La towards the Southeast into the Narsing Valley.

TQ Tertiary—Quaternary (Thakmar series, Saligram series, Narsing series) R Rhetic
UJ Upper Jurassic T Triassic
LJ Lower Jurassic P Permian

The southern flank of the upper part of the Narsing valley is built by a large anticline, in the core of which Permian formations appear. (See also geological map, plate II.)

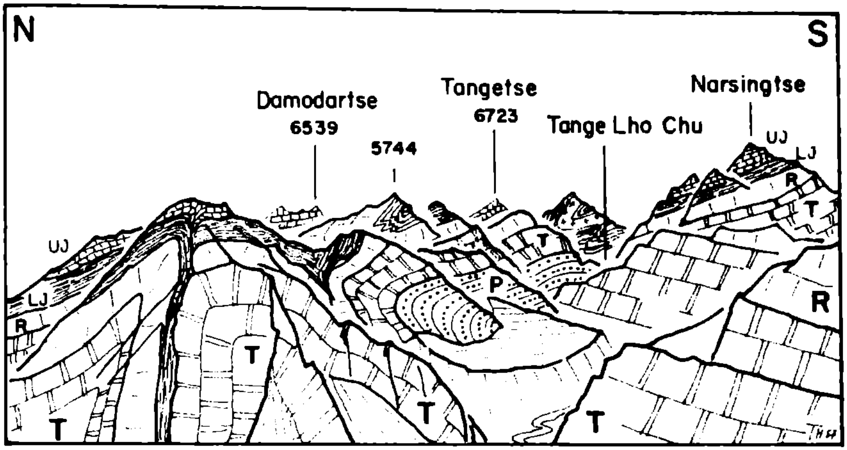
and is said to be a famous pilgrimage place, and is situated approximately 20 km more northeast than indicated in the Quarter-inch map, namely in the valley of the Damodar Chu. (See map plate I.)

We enjoy an excellent view from the Tange La into the mountain ranges north of the Thorungtse (fig. 98). The Mesozoic forms in general a flat anticline, the axis of which strikes in south-southeast-north-northeast direction, with an axial pitch in the latter direction. We can easily recognize, how the Tertiary formations are also involved in the anticline structure. Consequently, the anticline, at least its last phase is later than Eocene. For the time being however it is an unsolved problem, why not more lower formations are exposed from the Chehang La towards the east. For, the Triassic dolomites of the said anticline seem to strike out into the air towards the north-northeast (see fig. 89 and 95 and plate VI, fig. 1).

On the Tange La (4300 m) itself we find Rhetic limestones with a gentle local dip towards the east. Narsing flysch is with western dip transgressed upon the Rhetic formations. The black Saligram series is missing at the altitude of the pass, since the light-coloured sandstones, the blue lacustrine shales and the river gravels of the Thakmar series are deposited directly on the Narsing flysch, whereby they dip more gently towards the west than the underlying Narsing flysch. On the top we find large boulders, predominantly of Mustang granite.

Fig. 99. View into the Tange Lho Valley

UJ Upper Jurassic
LJ Lower Jurassic
R Rhetic
T Triassic
P Permian



The Mesozoic formations show intensive tectonics. The anticline following the Tange Lho valley is eroded right down to the Permian formations. The unnamed peak in the background of the valley contains granitic layers and pegmatites in the Lower Jurassic formations (indicated by crosses).
An old river terrace surprises through its huge dimensions.

The considerable western dipping of the whole Tertiary formations in the Thakkhola north of the Tange La is extraordinary (see fig. 89, 90, 93, 94 and plate VII, fig. 3).

Triassic dolomite occurs north of the Tange La. This forms the whole southern flank of the Tange valley, with a general west-southwestern dip. The same dolomite appears to form a flat anticline in the upper course of the Tange Chu, the axis of which follows the river course (fig. 99). Narsingtse (in the main ridge between Thorungtse and Damodar Himal) shows above the dolomite the well-bedded Jurassic limestones. The Peak itself might consist of the Upper Jurassic limestones (Malm) according to the thickly-bedded clear-coloured limestones (fig. 98, plate VI, fig. 1).

The eastern flank of the Tange valley, especially in the lower part, shows tectonic complications (fig. 99). The peak 5744 m is built by a syncline, which is opened towards the south and apparently formed by Lower Jurassic limestones and slates. At the flank just east of the Tange La an anticline with a normal west-east axial strike occurs. The northern flank of this anticline is very steep. Steeply northern dipping dolomites are pushed along a thrustfault to this anticline (fig. 99).

In the valley of Tange the black Saligram series are predominant (plate VI, fig. 1). In the tributary northeast of Tange they are again bedded between the underlying violet Narsing flysch and the overlying clear-coloured and multi-coloured sandstones of the Tertiary (Thakmar series). It can clearly be observed how the Saligram series are deposited only in the valleys. Consequently at the time of their deposition the relief must have been shaped generally in the present form. This can be recognized especially well in the east where the Saligram series are lying in valleys like glaciers, and in the lower part of these valleys has flown downwards in form of blockstreams and screestreams. Apparently the soft black bituminous shales were predestinated for causing blockstreams (fig. 100).

In the valley northeast of Tange we find in the Saligram series a fault with north-northeast–south-southwest strike. Evidently this fault must be of young age (see fig. 136).

4. Damodar Kund

We have seen above that the Damodar Kund is erronously located in the Quarter-inch map. At Tange village we got finally the information about the mysterious Damodar Kund. It's a two-days trip to the lake, whereby there must be two localities with the same name, the farther being about a five-days trip from Tange. Villagers at Tange confirmed the rich saligrams at the nearer lake Damodar Kund.

However the information was not too clear, thus we took a local guide with us from Tange. The approach from Tange village has to cross two passes, whereby the first one is 4250 m and the second one 5200 m (plate VI, fig. 1). The Damodar Kund is situated in the valley, which originates northwest of the Damodartse (6539 m) and the river of which—the Damodar Chu—joins the Tange Chu near Tange village. There is no direct approach from the Tange village to the Damodar Kund, since the Damodar valley has in the lower part cañon-like gorges, which are unpassable. Measured in a straight line, the Damodar Kund is situated 13 km east-southeast from Tange.

The climb from Tange to the first pass (we may call it Damodar Nup La; that is Damodar west pass) passes first in the black Saligram series (plate VI, fig. 1). Abundant fossils are found, especially ammonites (berriasiella) and belemnites. More important however are the finding of fossils in the Mesozoic rocks northwest of the pass, where we found ammonites and especially rhynchonellas in abundant quantities. Thus, as expected, these series are determined as Rhetic-Lower Jurassic (Liassic). (See plate VI, fig. 1.)

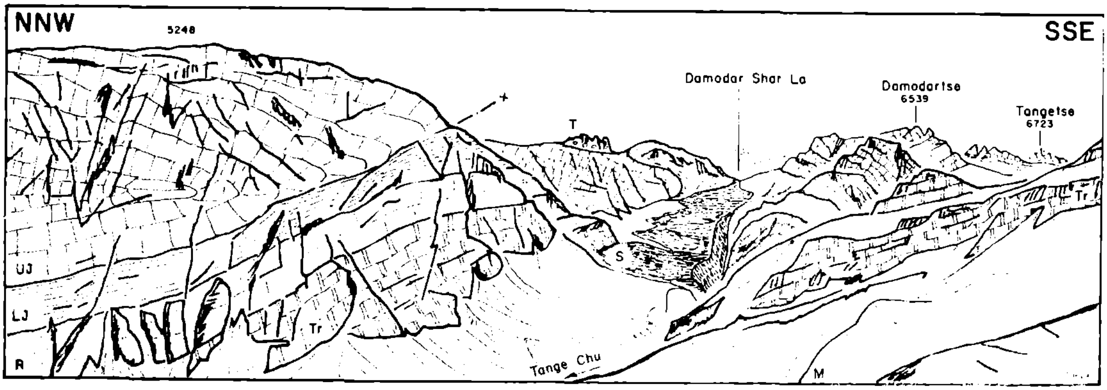
On the Damodar Nup La (4250 m) we obtain an excellent geological view towards the east into the Damodar Shar La (Damodar east pass) (fig. 100). The dolomite underlying the Rhetic series of the Damodar Nup La appears again in the western flank of Damodar Shar La at 4100 m. It forms there an anticline. A large number of fossils again prove the Rhetic and Liassic age of the series, which overly the dolomite anticline (fig. 100). From this place, the dolomite strikes with rising anticline axis into the upper part of the Tange valley, towards the Tangetse (6723 m) (fig. 100).

The valley which descends from the Damodar Shar La towards the west corresponds to an anticline with western pitching.

Fig. 100. View from Damodar Nup La towards East to the Damodar Shar La

The valley at the western side of the Damodar Shar La is in principle an anticlinal valley. However the northern flank of this anticline shows some complications, since the Upper Jurassic limestones made their own tectonics in form of a fold, thrust over the Lower Jurassic formation. There is a considerable axial pitch towards the west in the whole valley. The Saligram series (lying unconform on the Mesozoic basement) fill the upper part of the valley. Problematic is the Tertiary conglomerate on the ridge north of the Damodar Shar La.

M	morain	UJ	Upper Jurassic	Tr	Triassic
T	Tertiary conglomerates	LJ	Lower Jurassic	R	Rhetic
S	Saligram series				



Overlying the dolomite, which forms the core of the anticline, we find Rhetic limestones, well-bedded Liassic limestones and slates, oölitic limestones, quartz sandstones and quartzites. Also breccias of the Liassic type were found, further, red coral limestones of the Rhetic type. At the western flank of the valley, massive limestone overly the above-mentioned series. These might belong to the Malm (Upper Jurassic). The said massive limestone as well as the underlying Liassic slates are folded, whereby the fold is directed towards the south (fig. 100). In the peak 5248 m just northwest of the Damodar Shar La we find conglomerates (type of the Nagelfluh of the Molasse in the Alps). The conglomerate lies directly upon the Malm limestone. Thus this is the most complete profile found so far, reaching from the Triassic dolomite right through to the Tertiary. It is lithologically well defined and all the Mesozoic formations proved by finding of fossils (fig. 100).

The Saligram series occurs in the valley at the western flank of the Damodar Shar La, whereby it covers from top (in the pass) to bottom all the Mesozoic formations, from Lower Jurassic right down to the Triassic. However, as seen already in the Narsing valley, the Saligram series does not cover the ridges on either sides of the valley. And with the finding of the Tertiary conglomerate on peak 5248 m we may also say, that it has never deposited on the ridge, but instead we have to consider a primary stratigraphic gap on those ridges. Similarly as in the Narsing valley, also here the saligram sea apparently covered only the valleys, while the mountain ridges were above the sea level.

In the Damodar valley, east of the Damodar Shar La we find predominant the well-bedded slates and limestones of the Liassic formations as well as oölitic limestones and quartzites of the Dogger. The dip is directed more or less towards the north. The Damodartse (6539 m) consists of the massive limestones of the Upper Jurassic (Malm), which strike towards north into the flat mountain ranges north of the Damodar valley (fig. 101).

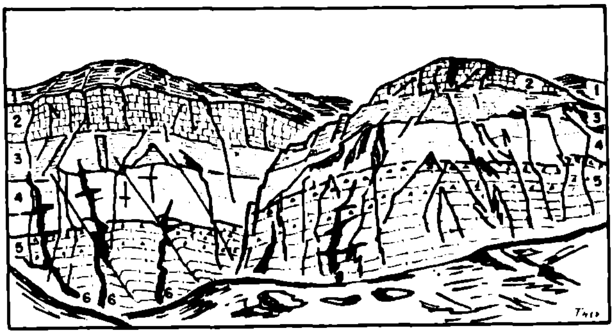


Fig. 101. The Mountain Range Northeast of Damodar Kund

1 Cretaceous flysch (black slates and shales)
2 Upper Jurassic limestone
3 Lower Jurassic slates, oölitic limestones, quartzites
4 Lower Jurassic limestones and calcareous slates
5 Rhetic pink and greyish-green limestones, breccias
6 pegmatite layers and dykes reach up to the Middle Jurassic

Steeply eastern dipping faults strike north—south; western portions are sunk

The position of the strata is practically undisturbed; we find ourselves at the margin of the Tibetan Plateau s.str. Accordingly, stratigraphically the profile is here pretty complete. While the western more peak north of the Damodar valley consists of the massive Upper Jurassic limestones, the eastern peak shows dark slates overlying the massive limestones. These are undoubtedly of Upper Cretaceous-Eocene age, and, different from the equivalent Saligram series further south. Consequently we call them Thakkhola series. They are deposited normally, that means without any unconformity upon the Upper Jurassic limestones. Thus, this is the most southern spot, where the Upper Cretaceous-Eocene Thakkhola series was found overlying normally the Upper Jurassic formations. (See plate VI, fig. 1.)

In the same zone we also find the lowest pegmatites, namely in the Lower Liassic and Rhetic.

The whole flank of this mountain range (north of the Damodar valley) is cut by faults which strike north-south. Microfolds on those faults indicate clearly the thrust from east to west (fig. 101).

The Intrusions are partly layers, partly dykes, and are involved by the north south striking faults. The latter have consequently to be dated as very young, provided the granitic and pegmatitic intrusions are considered as Tertiary or even as Upper Tertiary (or Pleistocene?).

The Saligram series occurs in the Damodar valley however in the upper part of the valley only.

As mentioned above, the ridge southeast of peak 5248 m (fig. 100) is covered by the Tertiary conglomerate (Nagelfluh). Peak 5744 m shows some folds in the Liassic limestone. The Damodar valley is in general situated in the lower part of an anticline structure, whereby the Triassic dolomite as lowest formation occurs far towards the west in the bottom of the valley. The said anticline thus shows a western pitch.

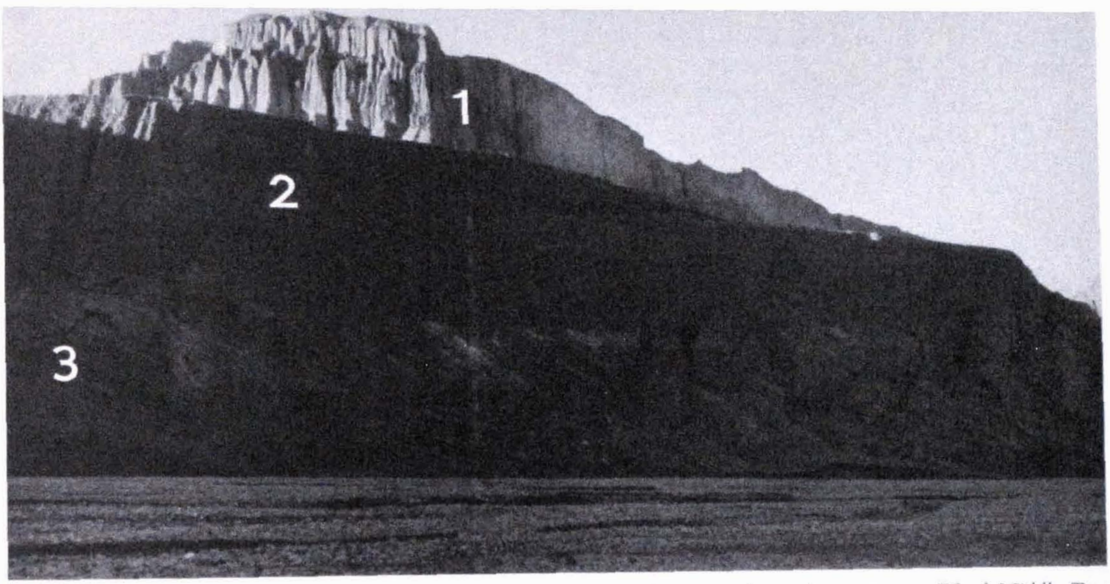
The reality of Damodar Kund as sacred pilgrimage place did not meet the expectations. The rest-house is just a ruin, can hardly been used for staying over night, and also the "abundant saligrams", which were expected to be found are missing. Thus, there is more legend than reality in the stories going around in Nepal of the miracolous Damodar lake.

Phot. 57. View from the Narsing La towards the Southwest

The Dangarjong fault strikes along the foot of the mountain range.
Note the northwestern dipping Thakmar series. (Compare plate VII fig. 2 and 3.)

5. The Tertiary and Quaternary of Tange-Kehami

After the excursion to the Damodar Kund, we now study again the Tertiary in the valley of Tange. West of the village of Tange it shows on both sides of the Tange Chu a strong dip towards the west-southwest (phot. 58 and 59). At the northern river bank of the Tange Chu, 3 km west of the Tange village we find an interesting profile (fig. 102 and phot. 59 and 60). This profile shows at the base conglomerates. These are overlain by grey marly sandstones, which include marly coal. Over these series follows formations of sandstones and conglomerates, the same type as above Thakmar. A layer of light-blue lacustrine shales divides the red sandstones. On the top we find the large conglomerate series (similar to the Upper Siwaliks), interbedded by marls and blue lacustrine shales.

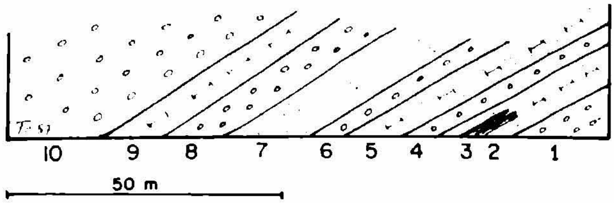


Phot. 58. Quaternary River Gravels and Conglomerates on Tilted Middle Tertiary
(at the southern river bank of Tange Chu, 3 km west of Tange village)
1 Pleistocene sandstones, lacustrine shales and chalk
2 Quaternary river gravels and conglomerates
3 Middle Tertiary sandstones, marls and conglomerates
(These series correspond to those given in fig. 102 and phot. 59.)
The Middle Tertiary sandstones dip west and show a few hundred meters further west the tectonics given in phot. 61.

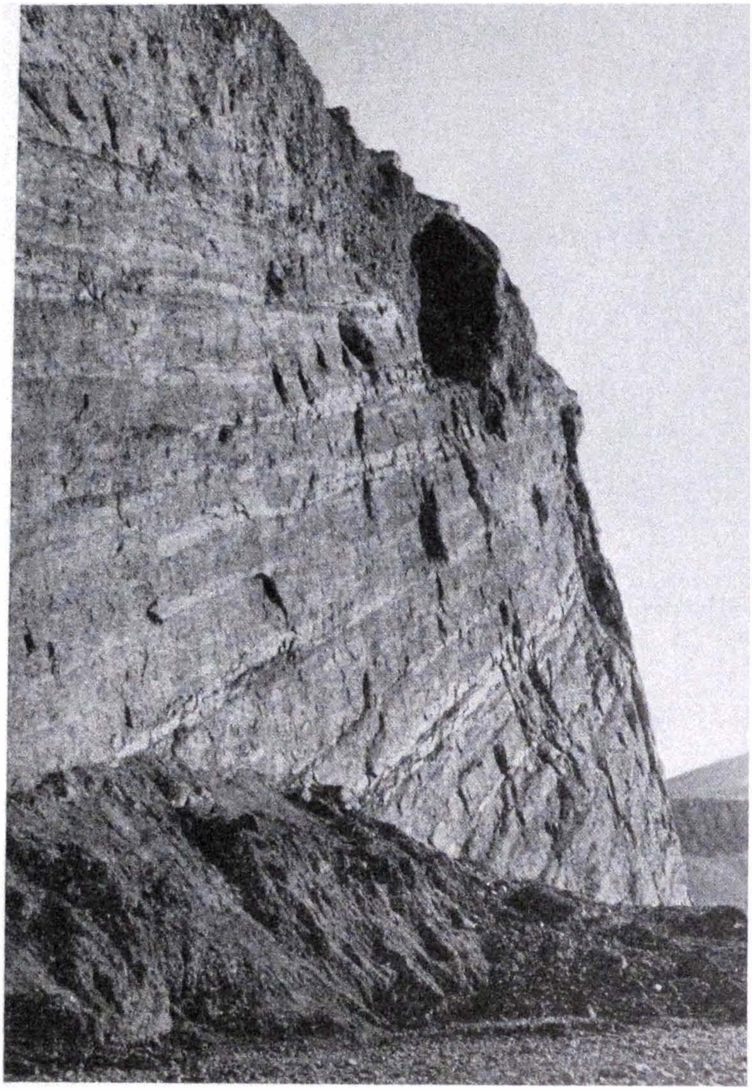
The above-mentioned succession of sediments is repeated several times. Consequently we may speak of a cyclic sedimentation. The dip of all those series is considerable, we measured 50 west, with a strike more or less due north (phot. 59). The cyclic sedimentation is repeated five times, always separated from each other by large conglomerate series.

Fig. 102. Detail Sketch of the Tertiary
(right river bank of the Tange Chu, 2 km west of Tange)

(Compare also phot. 59, which shows the same exposure and phot. 60, which shows the marly coal of 3 below.)



1	Conglomerate	5	grey marly sandstones	9	light blue lacustrine shale
2	arenaceous marl	6	conglomerate	10	large conglomerate series, interbedded with marls and blue lacustrine shales.
3	marly coal (within the marl)	7	red and brown sandstones		
4	conglomerate	8	red conglomerates		



Phot. 59. Cyclic Sedimentation in the Tertiary
(northern river bank of the Tange Chu, 2 km west of Tange)
The formations dip strongly west. (Compare fig. 102, which gives the lithologic details.)

At the southern river bank of the Tange Chu, 1 km east of its confluence with the Kali Gandaki we can observe in the Tertiary an intensive tectonics, like thrustfaults, folds, overthrusts and faults. All the axis of those structures strike north–south, that is at right angle to the normal east–west strike. The tectonics are well visible in thickbedded marly sandstones with interbedded dark carbonous shales (phot. 61). The red sandstones are directly transgressed upon those formations horizontally under unconformity.

Phot. 60. Marly Coal in the Middle Tertiary
(as described of fig. 102 and phot. 59)

A further unconform transgression can be observed at the western river bank of the Kali Gandaki, opposite of the confluence of the Tange Chu (fig. 103). Flat south-southwestern dipping conglomerates (Nagelfluh) transgress over steeper dipping blue and black shales and marly sandstones. The red series of sandstones appears to change gradually into the conglomerates. On the top occur horizontally bedded light-blue lacustrine shales and marly sandstones (fig. 103).

At the eastern river bank of the Kali Gandaki and north of the confluence of the Tange Chu we again find thrustfaults in the Tertiary formations. Those strike 94° east and have disposed the series of marly sandstones and marly coal (phot. 60) so that the southeastern part appears to have sunk. Recent river gravels transgress across the thrustfault (fig. 104).

Near the confluence of the Kehami Chu with the Kali Gandaki we meet large morains, originated from the ancient glacier of the tributary valley of Kyugoma, which enters the Thakkhola at Kehami (fig. 105 and phot. 62).

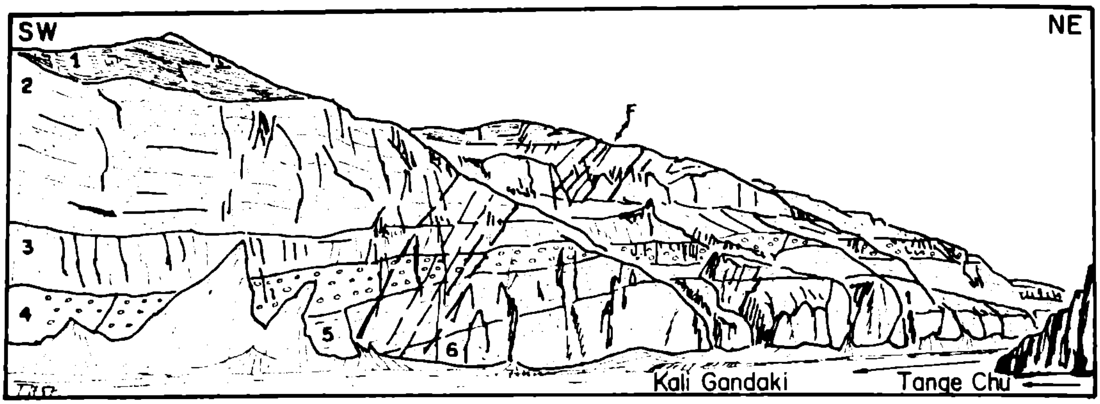


Fig. 103. The Tertiary–Quaternary at the Junction of the Tange Chu with the Kali Gandaki

1 lacustrine shales
2 red and white sandstones and marls
3 red sandstones
4 conglomerate
5 blue-black shales
6 clear-coloured sandstones and marls
F faults

(1) lacustrine shales and (2) sandstones might belong to the Pleistocene. The underlying are Middle–Upper Tertiary. The Tertiary shows a flat anticline with western pitching. The faults F strike north–south with steep western dip. They apparently belong to the system of the Thakkhola Graben. It appears to be a transgression unconformity between (3) and (4).

The rock exposures with the multi-coloured, light-blue, yellow and (at the base) red Tertiary formations show still west of the Kali Gandaki the same west-southwestern dipping as it is general at the eastern side.

However, locally, we find at this place at the eastern river bank an eastern dipping (fig. 105). It appears that there is a flat transverse anticline striking through the Kali Gandaki river course, with axis in north–south direction (and possibly a transverse fault in its axis). The age of this anticline has to be considered as upper Tertiary or even Pleistocene.

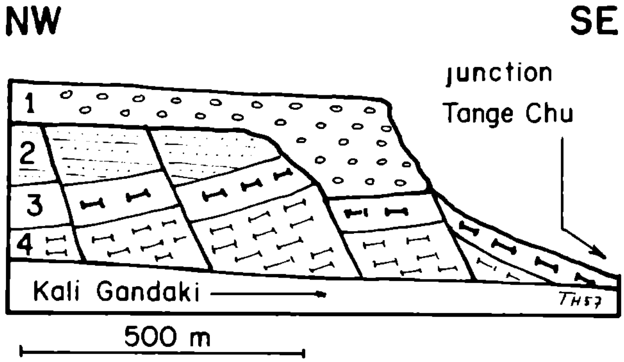
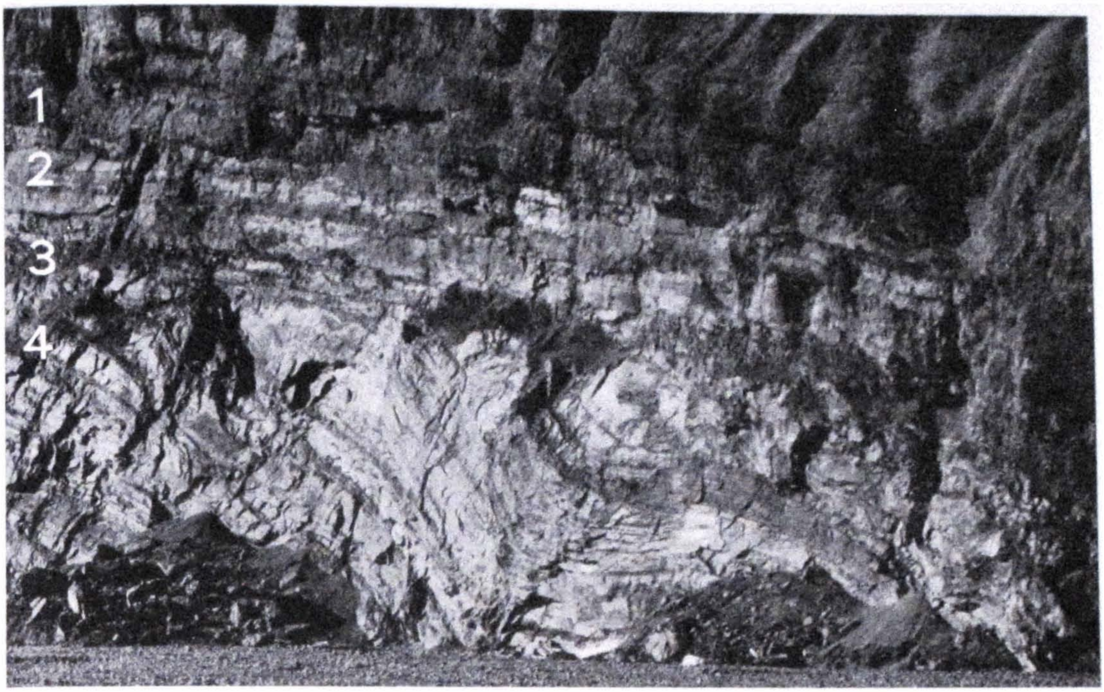


Fig. 104. Faults in the Tertiary at the Junction Tange Chu—Kali Gandaki

1 river gravel
2 white sandstones
3 dark marls, with marly coal
4 clear-coloured marls

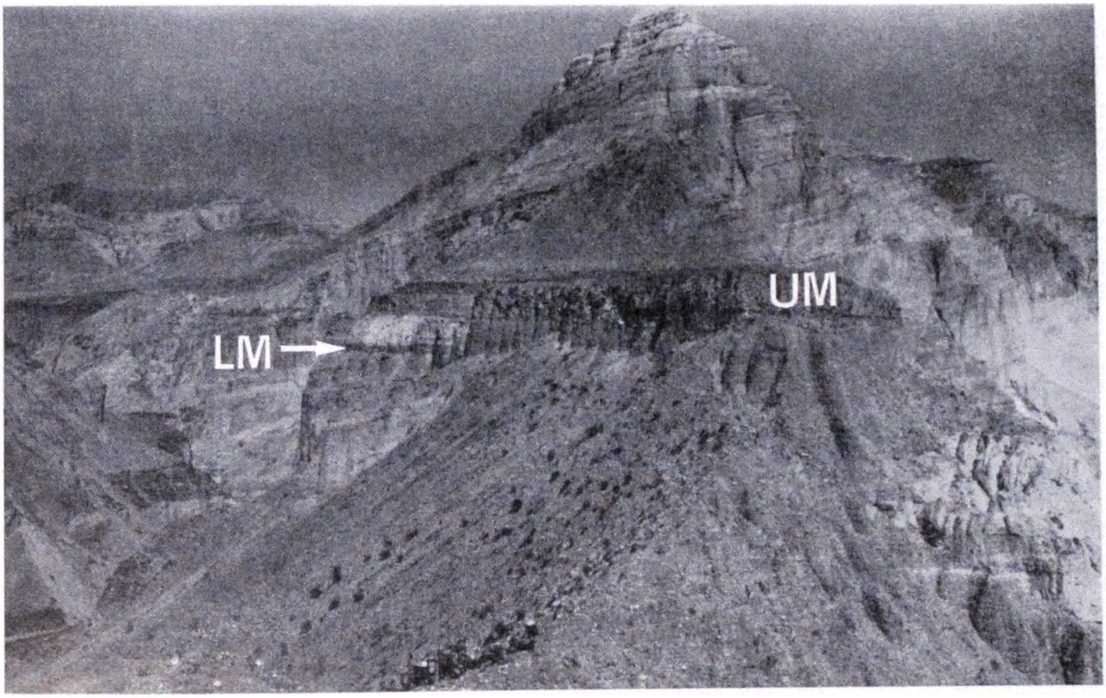
The morains lie in a horizontal position in the Kyugoma valley. There are two distinct layers of morains each of them a few meters thick, and separated from each other by 60 m river gravels (fig. 105 and phot. 62). The boulders in the morains have diameters up to 2 meters. They consist predominantly of Devonian limestones and quartzites of the Upper Cretaceous. The latter shows partly interesting metamorphism like biotite-schists, staurolite and garnet-schists. Undoubtedly this metamorphism was caused by the near Mustang granite, boulders of which were also found in the morains.



Phot. 61. Tectonics in the Middle Tertiary Formations, 4 km West of Tange Village

1 conglomerates
2 white sandstones and marls
3 conglomerates
4 white sandstones, marls and shales

The conglomerates of 3) have transgressed on a levelled surface of 4)



Phot. 62. Tertiary and Quaternary at the Confluence of the Kyugoma Chu with the Kali Gandaki River
(See also sketch fig. 105.)

UM upper morain
LM lower morain

Possibly, these two morains in the Kehami valley, as described above, belong to the last two ice ages. The 60 m river gravels might indicate the separating interglacial stage. (?)

At the place, where the Kyugoma Chu leaves the tributary Kyugoma valley and enters the main valley of the Thakkhola, we find a number of lateral and terminal morains (fig. 108 and plate VII, fig. 2). Two terminal morains are especially distinct. We might—according to their altitude of 3700 m—assign them to the Bühl stage. (Last recession stage of the last ice age.) The present glaciers on the Kehamitse (6004 m) are not lower than 5600 m.

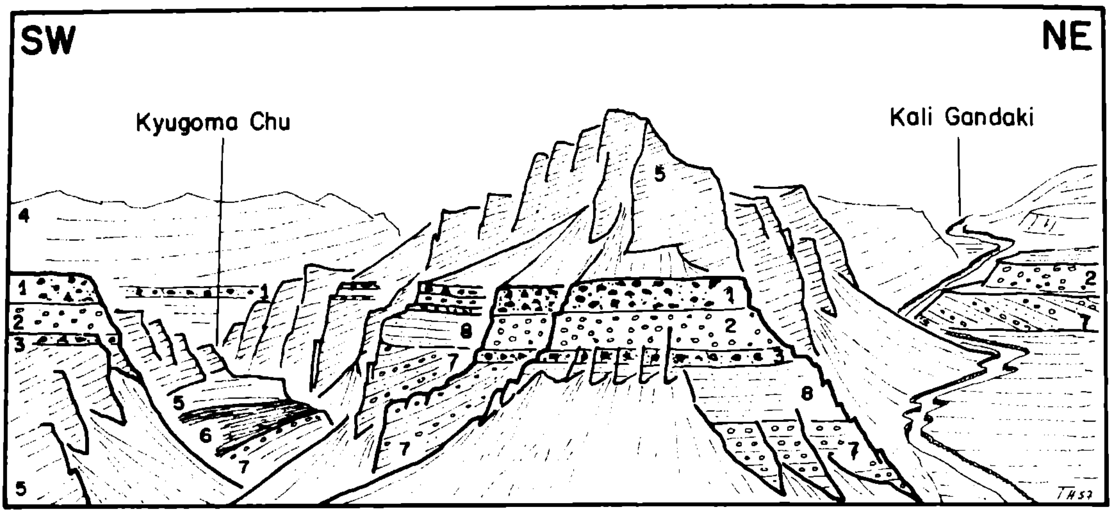


Fig. 105. The Tertiary and Quaternary at the Junction of the Kyugoma Chu with the Kali Gandaki
(Compare also phot. 62.)

1 upper ground morain
2 river gravels (60 m)
3 lower morain
4 light blue marls and sandstones
5 light blue and dark marls
6 coaly marl
7 yellow conglomerates and sandstones
8 white sandstone

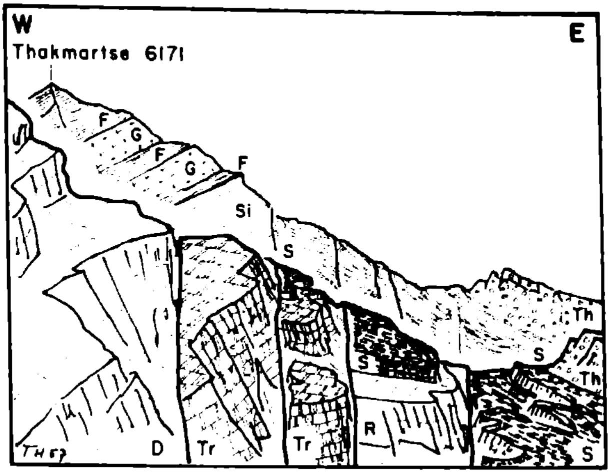
The two morainic layers originate from the ice age Kyugoma glacier. They were deposited in a valley previously cut into the Upper Tertiary formations. The series under (4) might be of Pleistocene age, since they also contain lacustrine chalk in the upper part.

6. The Thakmartse 6171 m

Let us now climb a mountain, which is situated at the eastern flank of the Thakmartse (6171 m), west-northwest of Kehami. In the small tributary valley, which extends 2 km west-northwest of Kehami towards the northwest, we find the black Saligram series again. They contain a number of fossils similar to the Muktinath area. Contrary to Muktinath, the beds dip here towards the east, that means towards the Kali Gandaki river (fig. 106, 107 and 108). It is noted that the dip increases with gaining altitude (climbing west).

The Saligram series are in the said tributary valley transgressed on typical Rhetic formations (fig. 110) namely dolomitic limestones, thin-bedded marly limestones, interbedded with slates (whereby the marly limestones show the characteristic transverse clivage), multi-coloured and pink-brown and yellowish limestones and slates ("herbstlaubfarbene Kalke" of the Rhetic of the Eastalpine facies of the Alps). Lenses and layers of quartz, accompanied by slight metamorphism of the adjoining rocks (spotted slates) indicate the neighbourhood of the Mustang granite. These Rhetic formations dip in the same way as the overlying Saligram series, namely towards the east.

Fig. 106. View from the Eastern Ridge of Kyugomatse 5200 m towards the North



Th Thakmar series (Upper Tertiary—Quaternary)
S Saligram series (Paleocene)
F Thakkhola series (Upper Cretaceous—Paleocene flysch)
R Rhetic
Tr Triassic
D Devonian
Si Silurian
G Mustang granite

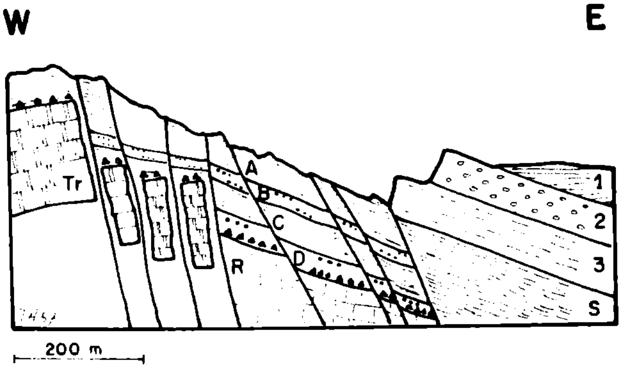
In the ridge in the foreground the Palaeozoic formations have been lifted in a staircase fault system, so that the Saligram series now are situated at the same level as the Devonian. In the eastern ridge of Thakmartse the Saligram series connects with the Thakkhola series. (Compare also geological map plate II.)

Further up, at 3700 m at the foot of the rock wall (fig. 109) we find fine-grained conglomerates. These are overlain by coarse-grained limestones, which towards above gradually change into arenaceous limestones. The latter, of brown colour, are interbedded with layers of breccious quartzites, polygenous breccias, fluidal arenaceous limestones and quartzites. The breccias contain partly components of quartzite. The whole series is about 600 m thick and contains turmaline pegmatites, originated from the Mustang granite.

At 4600 m, the described series is overlain by about 400 m of thickly-bedded limestones. In the lower part it is marmorized to a coarse-grained marble. In the upper part, an arenaceous facies is predominant. The latter contains large (up to 10 cm) Encrinus Liliformis. The whole upper part is full of fossil remnants, which, however could not be determined in the field. The whole series recall the Phulchok limestone and marble south of Kathmandu, which has been proved to be of Ordovician age.

Fig. 107. Detail Profile West of Thakmar

1 Pleistocene (sandstones and lacustrine shales) Thakmar series
2 Upper Tertiary (brown conglomerate, "molasse") Thakmar series
3 flysch (arenaceous slates)



S Saligram series
  A black slates
  B quartzite
  C quartzitic slates
  D quartzite, with transgression breccia
R Rhetic (marly limestones and calcareous slates)
Tr Triassic (dolomite)

The sketch shows the staircase fault system, along which the eastern part has sunk in. The Saligram series transgresses over various horizons of the Mesozoic, with a transgression breccia at its base (indicated by black triangles).

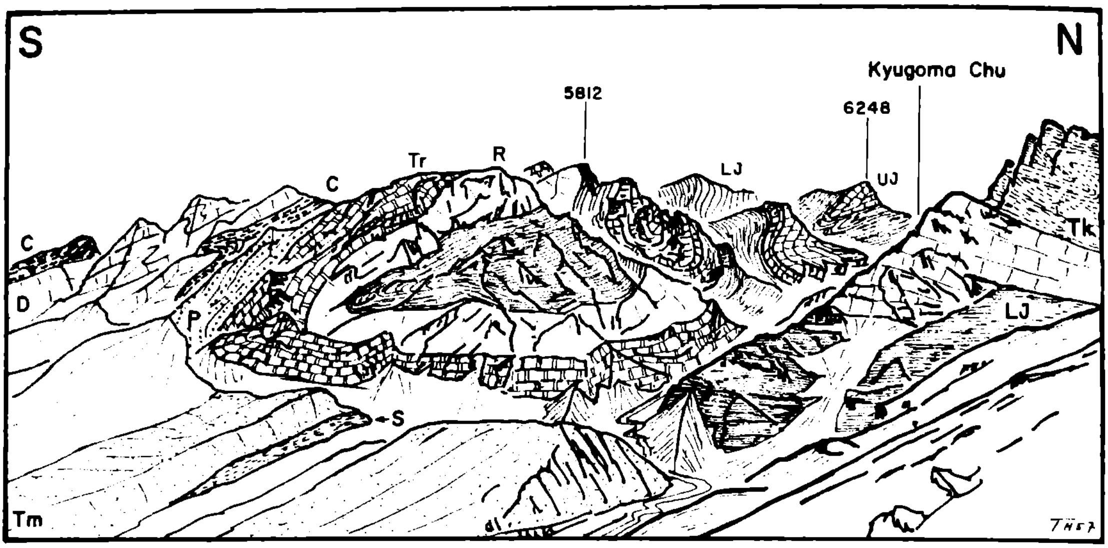
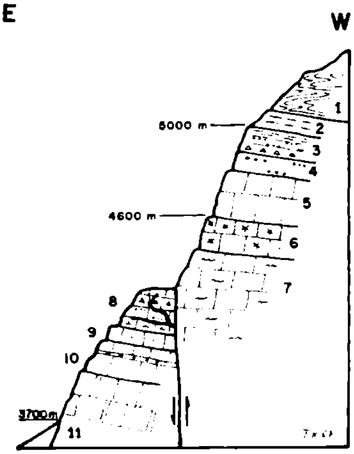


Fig. 108. The Mountains on Either Sides of the Kyugoma Valley West of Kehami

Tm	Thakmar series (Middle Tertiary—Quaternary)	R	Rhetic
Tk	Thakkhola series (Upper Cretaceous—Paleocene)	Tr	Triassic
S	Saligram series (Upper—Middle Paleocene)	P	Permian
UJ	Upper Jurassic	C	Carboniferous
LJ	Lower Jurassic	D	Devonian-Silurian

On the right side ridge the Devonian appears to overlie the Lower Jurassic formations. This is however not the fact, since the main transverse fault strikes through the boundary between the two formations, whereby the Lower Jurassic formations have sunk, thus coming apparently to underly the Palaeozoic series. (Compare also plate VII, fig. 2 and 3.) The mountain range south of the Kyugoma Chu is built by a syncline which is overturned towards the north. The filling of the syncline consists of Jurassic series. North of Kyugoma valley we see the transgression of the Upper Cretaceous–Paleocene Thakkhola flysch upon the Palaeozoic. (Compare also fig. 111 and profiles 1 and 2 plate III.)

Fig. 109. Detail Profile 3 km Northwest of Kehami



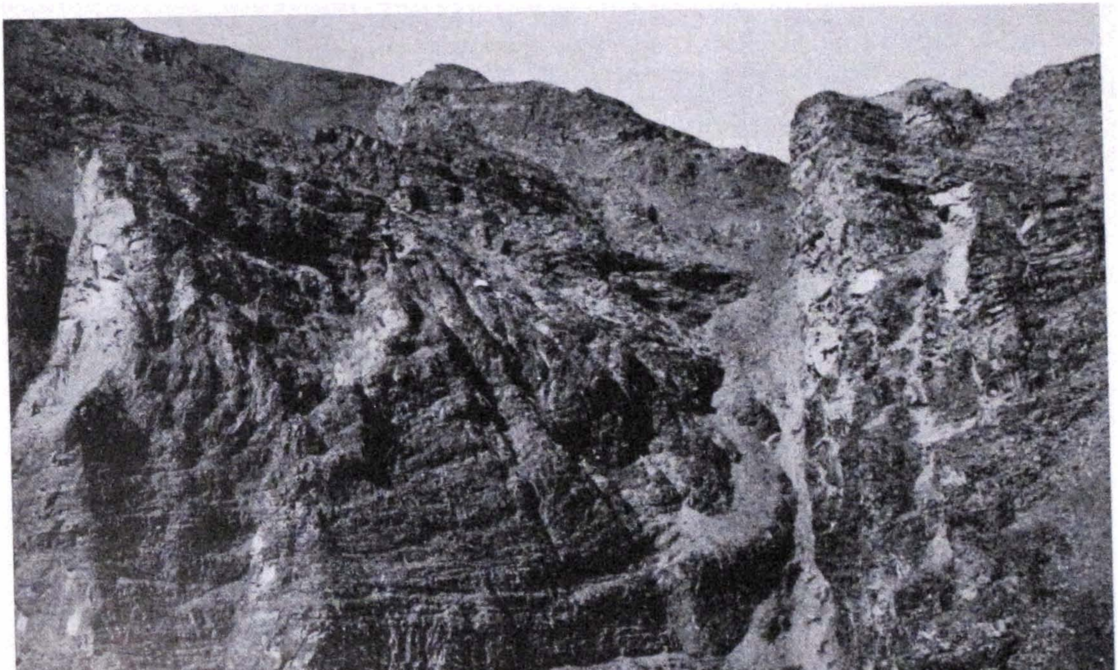
1 Thakkhola series: large black flysch series of sandstones, slates, shales and quartzites; much tectonized (see phot. 63).
2 (at 5000 m) spotted slates, spotted sandstones
3 sandstones, arenaceous quartzite, breccias
4 quartzite, dense white and brown
5 thickly-bedded limestone, organogenic
6 arenaceous limestone, coarse-grained, crinoidal
7 white marble
8 brown arenaceous limestone, breccious quartzite, quartzite layers, layers of polygenous breccias, layers of fluidal brown arenaceous limestones, ("Dogger"?), pegmatites
9 arenaceous limestone
10 coarse-grained limestone, with layers of fine-grained conglomerates
11 dolomitic limestones, marly limestone with transverse clivage (Rhetic), calcareous slates, multi-coloured marly limestone.

Between (7) and (8) strikes the main transverse fault, which brings the Palaeozoic formations of (5), (6) and (7) side by side to the Middle Jurassic series of (8).

A totally different series of white and brown quartzite sandstones and arenaceous quartzites, and breccious quartzites transgresses upon the limestones. At 5000 m occur spotted slates ("Tüpfelschiefer" and "Stäbchenschiefer") and spotted sandstones. Those are overlain by black shales wich reach right up the summit of the Thakmartse (6171 m). The large series of black shale is interbedded by well-bedded quartzites and arenaceous quartzites. The whole series recall the flysch of the Alps and also to some extent the Saligram series, to which they might correspond regarding the age. Evidence for this conclusion was found further north, where a continued connection between the Saligram series at the foot of the mountain with the black flysch at the top was observed (fig. 107 and 113; also plate VII, fig. 2).

The series of breccias, conglomerates and quartzites underlying the fossiliferous limestone might belong to the Permian. However, for the time being the existence of Rhetic formations below the above-mentioned Permian formations creates some problems. We shall deal with it on the following pages.

Phot. 63. Folding and Fault in the Thakkhola Series on Thakmartse
(seen from the east)
The fold (an overturned syncline) has been cut by the fault, whereby the northern portion has been lifted. (North is right side, south is left side.)



7. The Kehami Peak

The view from our standpoint at 5000 m towards the north reveils a large number of transverse faults, striking north–south. Hereby the western series are lifted, while the eastern block has sunk (fig. 106, 107 and 110). Due to these transverse faults, the Saligram series, which at the foot of the mountain flank transgresses on Rhetic, gradually overlies lower formations. Thus, only 1 km further north, the Saligram series lies directly on the Ordovician limestones (fig. 113). But also this one Ordovician series are in themselves tremendously cut and faulted and rises towards the west step-wise in form of a "staircase". The Saligram series overlies all those different faults and steps and connects indeed with the large black flysch series in the upper part of the peak 6582 m, the Thakmartse (6171 m) and the Kyugomatse (6131 m). (See also geological map plate II and profile II and III plate IV, further plate VII, fig. 2, panorama from Damodar Nup La.)

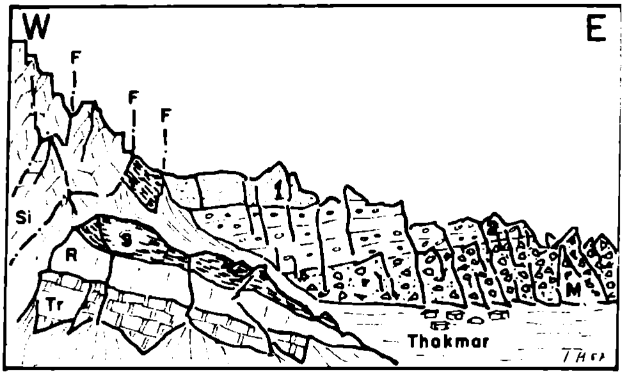


Fig. 110. The Main Transverse Fault West of Thakmar

Thakmar series (Quaternary—Upper Tertiary)
- 1 clear-coloured sandstones
- 2 red conglomerate
- m morainic material

S Saligram series (Upper Paleocene)
R Rhetic
Tr Triassic
Si Silurian
F main transverse faults

In general we may speak of a "Grabentreppe" (a term also applied in the Jordan Graben in Israel). That means there is not just one main fault at the margin of a Graben but a number of faults, which caused the Graben to sink in step-wise in form of a "staircase".

But also the southern flank of the Kyugoma valley at the Kehamitse (6004 m) is still faulted by the same north–south striking transverse faults. Lumashell limestones (Rhetic) have been discovered east of the foot of the eastern flank, which are bedded more or less horizontally (fig. 108, profile II in plate IV).

South of this locality, in the wall, we find coarse-grained limestones, intersected by pegmatites and dykes. These belong to the Silurian-Devonian formations, which form the southern flank of the overturned northern flank of the Kyugoma syncline.

An anticline axis strikes through the Kyugoma valley. This structure is however unsymmetrically heavily faulted, overturned towards the south and with a deep syncline (Kyugoma syncline) just south of the fault. Thus, the same Silurian-Devonian series strike south of Kehamitse (6004 m) steeply up and forms between the said peak and the Khegatse that flat anticline, the excessive height of which surprised since we observed it for the first time. (See profile 2, plate III, and plate VII, fig. 2 and 3.) The core of the said anticline consists of Devonian limestone (in the Keha Lungpa valley). Consequently, the Kehamitse 6004 m is built as a syncline. This syncline, however, is not of normal character, since the southern flank is overturned towards the north, while its northern flank is overturned towards the south. The zone of this syncline therefore forms the boundary between two different mountain-building forces, which acted from the north and from the south. The area south of the Keha Lungpa valley belongs to the zone of the reverse folding, which covers the whole range between Tukuchatse (6915 m) and the Keha Lungpa valley (see fig. 137). The zone of reverse folding (directed towards the north) joins the roots of the Katmandu nappes. The area north of the Kyugoma valley belongs to the southern edge of the Tibetan Plateau, which has been thrust towards the south. The syncline filling in the Kehamitse (6004 m) consists of Jurassic series (well-bedded limestones, slates, and quartzites).

In addition, the valley of the Kyugoma Chu forms still another important border line: south of it, the formations are complete from Silurian right through to Jurassic, while north of the Kyugoma valley the Upper Cretaceous-Tertiary flysch is transgressed directly on the Palaeozoic crinoidal limestone. This latter zone must have been uncovered by the sea during a prolonged period. (Compare fig. 113 and profile I, plate III.)

However it is well possible that the Mesozoic formations originally were complete and were totally eroded in the preliminary phase of the orogenesis. All the mountains at the western flank of the Thakkhola, from the Dhaulagiri right through to the Mustang Himal, show an astonishing, evenly and gently towards the north dipping plane (Gipfelflur, phot. 46). This is undoubtedly an ancient erosional surface. Viewing those mountains from the opposite valley flank (for example from Damodar Nup La (plate VII, fig. 2 and 3, see phot. 57) or especially from airplane (phot. 46) one just cannot help to apply this interpretation. The Dhaulagiri surmounts with its 8172 m everything. The northern joining Tukuchatse (6915 m) is more than 1000 m lower. Up from here the level of the peaks (Gipfelflur) dips gradually and gently to 6100 m north of the Kyugoma Chu, but then rises again toward north for about 300 m to the Mustangtse (6474 m). It appears that the Kyugoma syncline is of ancient character, but possibly re-activated later on. It is also expressed in the bend of the peak level, and moreover, indicates the real southern edge of the Tibetan Plateau.

We have still other proves that the southern edge of the Tibetan Plateau has during the Tertiary actively thrust towards the south, namely the intensive folding in the northern flank of the Kyugoma valley (fig. 113, phot. 63 and plate VII, fig. 2). A well-visible thrustplane strikes along the whole, said mountain flank towards the west. In general, this series gives a picture which is characteristic also for the flysch in the Swiss Alps, both for lithology and tectonics. The thrustplane which strikes into the Kyugoma valley, rises towards the west, and gets thus gradually into higher formations, from Devonian to Upper Jurassic (compare geological map).

In the upper part of this flysch we find pegmatites. Towards the north those pegmatites increase in number and size and change gradually into the Mustang granite (fig. 113 and profile I, plate III, further plate VII, fig. 2). At the southern flank of the Maharang valley the granites build the whole basement of the mountain range. Moreover, also peak 6262 m in the main ridge consists of granite (compare geological profile I, plate III and geological map plate II and plate VII, fig. 2). Again, the whole flank of this range is cut by a number of north south striking transverse faults.

Phot. 64. The Thakmar Series at Thakmar Village

The lower portion consists of ice age morainic material. The upper part is built of red conglomerates, yellow and light blue sandstones and lacustrine shales.

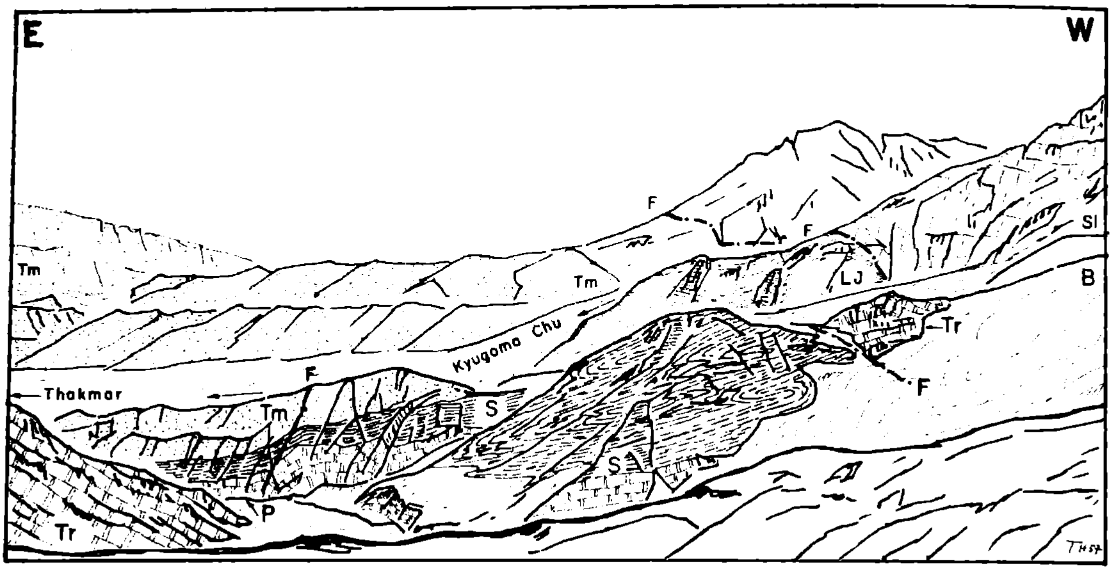


Fig. 111. The Saligram Transgression and the Main Transverse Faults in the Upper Part of the Thakmar Valley.

Tm Thakmar series (Quaternary—Upper Tertiary)
S Saligram series (Upper Paleocene)
Tr Triassic—Rhetic
Si Silurian
F transverse faults
B blockstrom of morainic material
P denotes the position of phot. 65 and 66

The Saligram series right side are tremendously folded, and contain *pegmatites*.
Note how the Saligram series and especially the underlying Mesozoic rise towards the west, upon the «Grabentreppe» (Graben staircase).

8. Thakmar

Thakmar means red rock (Thak = red, mar = rock). Indeed, the formations near the village of Thakmar surprise by its dense red and yellow colours. They consist in the lower part of fluviatil deposited morainic material, which contains much limestone (phot. 64 and plate VI, fig. 1). All the Thakmar series dip in the area of Thak towards the east (fig. 111). Just west of the village we find eastern dipping violet flysch series (of the Narsing type) and overlying in the black Saligram series. Northwest of Thakmar village we find Mesozoic formations underlying the violet flysch. The Mesozoic consists of Triassic dolomites, dark limestones and cellular dolomite (Rauhwacke) and thin-bedded Rhetic marly limestones (with the characteristic transverse clivage). The transgression breccia of the Mesozoic (phot. 65), on which, with a small Saligram series or flysch, the Thakmar morain is deposited, occurs especially well. While at the eastern exposure the Mesozoic is bedded horizontally it rises towards the west, cut by a number of transverse faults in form of a staircase (phot. 66). By this step-wise rise we find further west quartzites which might belong to the Lower Triassic or even to the Permian underlying the dolomites.

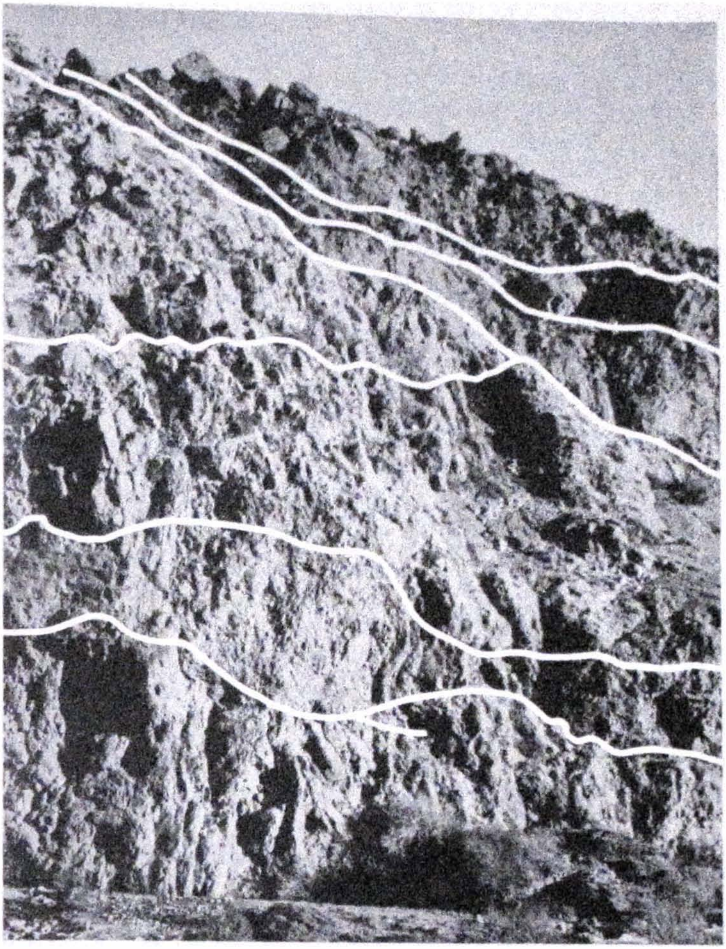
The latter are intensively folded. In addition, also breccias consisting of siliceous dolomite components embedded in dolomite and limestones were found (phot. 67). The transgression breccia reaches over and across the staircase originated by the transverse faults and rises towards the west.

Underneath the said quartzite and dolomite we find thin-bedded light-blue and yellow marls with dolomite lenses. The whole series recalls the Keuper formation of the Alps. The strike is directed north–south, the dip steeply towards the east. If the said series were not clearly situated underneath the Triassic dolomite, one might be tempted to assign it to the lower Narsing flysch. Under this assumption they would have been lifted by a transverse fault to the present position relative to the

Phot. 65. The Transgression of Saligram Series upon the Mesozoic (in the valley 3 km west of Thakmar)

Tm Thakmar series (morainic material)
S Saligram series (Upper Paleocene)
TB Transgression breccia
ML marly limestone (Rhetic)
Td Triassic dolomite
Rw Rauhwacke (cellular dolomite)

The breccia has transgressed under angle unconformity.



The Mesozoic at this place consists of dolomite, marly dolomite, coral limestone and blue and yellow marly slates. Terebratulas, ammonites and a waltzia species were found at this rock exposure.

dolomite. The comprehensive interpretation, however, counts rather for a Triassic facies (corresponding to the Keuper in the Alps), for, further west quartzites and black slates of the Saligram series join the violet shales under right-angle unconformity (fig. 111). Further west, climbing in the small valley, we find a series of black slates, intersected by pegmatites, dipping in general towards the east. This series is intensively faulted and thrust (fig. 111). A folded quartzite series overlies these slates and along a transverse (north south) fault, the whole slate formation is situated side by side to the earlier-mentioned Palaeozoic limestone. The upper portion of the slates also reaches into the top of those Palaeozoic limestones. Concluding we see that the black slates originating from the Saligram series at the eastern foot of the mountain connects continuously into the large Cretaceous-Eocene (Thakkhola series) covering the mountain range north of the Kyugoma valley. Consequently, the uppermost Cretaceous (including the Paleocene) are transgressed directly upon the Palaeozoic.

9. Karr Gömpa

It seems, that from here on towards the north, the stratigraphic profiles get more complete again. On the flat saddle near the Karr Gömpa we were able to determine in the exposed rocks: Hoplites (Berriasiella), Callisto (Portlandian); Exogyra virgula (Kimmeridge); Pseudo virgatites spec. (Portlandian); Cosmoceras Theobaldi (Maestrichtian); Perisphinctes Bononsiensis (Portlandian).

Northwest of the Karr Gömpa (Gömpa   Buddhist monastery) we find again "staircase" transverse faults. They are especially well-visible in the Triassic dolomite. The latter contains here larger masses of the intruded Mustang granite (fig. 112).

The Karr Chu has cut an extraordinary gorge into the mountain range [5 km south of Karrtse (6297 m)]. The basement of the Karrtse consists of massive granite (fig. 113). The upper part is built of the dark Cretaceous flysch series, intersected by numerous pegmatites. However, underneath the granite occur again sediments. These are Jurassic limestones and slates and strike towards the north like fingers as far as the middle between peak 6261 m and Mustangtse (6476 m).

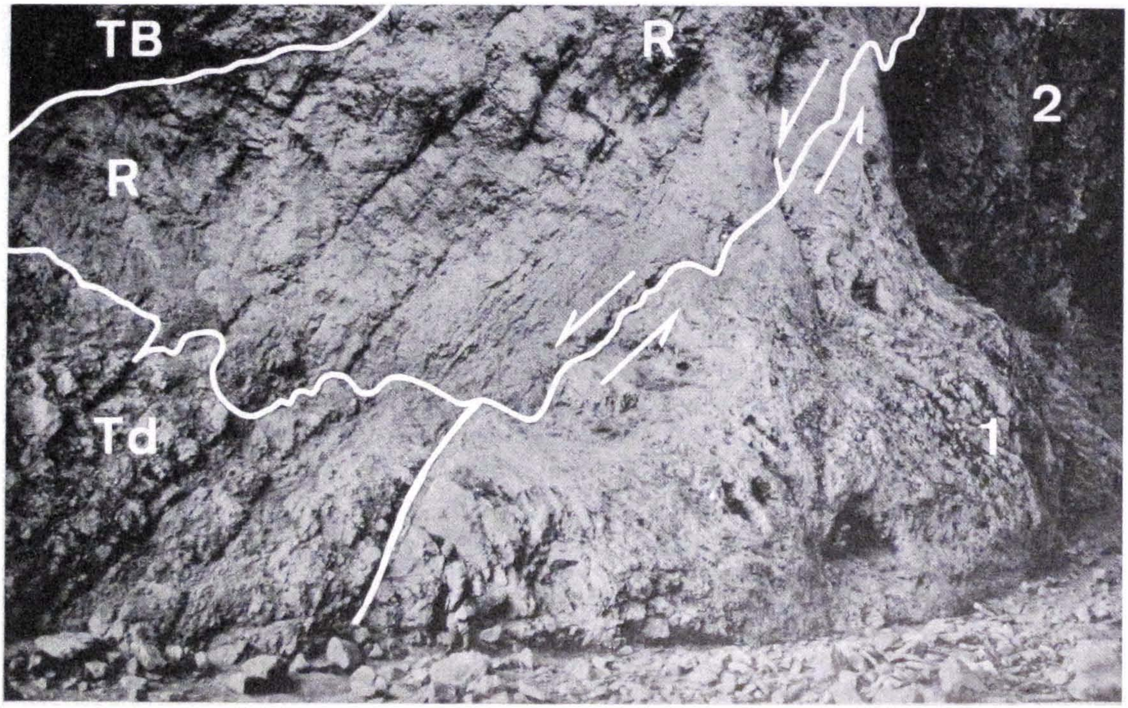
The structures north of the Karr gully are flatly warped with a syncline 1 km south of peak 6297 m, the axis of which strikes west-northwest (fig. 113). A flat anticline appears 4 km south of Mustangtse (6476 m) and a last anticline just north of the same peak (plate VII, fig. 2).

All the mentioned structures show a considerable axial pitch towards the west-northwest. The pitch increases further north, as can be recognized in the most distant peaks, lying in Tibet (fig. 113),

Phot. 66. The Main Transverse Fault in the Thakmar Valley

TB transgression breccia
R Rhetic (marly limestone)
Td Triassic dolomite

The Mesozoic formations are generally horizontal. The strong eastern dip (in the picture to the left side) is apparent only. This is just clivage caused by the steeply eastern dipping main transverse fault system. Some parcels between partial faults have turned the dip strongly west at 1) and steeply east at 2).



on the most distant peak northwest of Tinglibhoto the granite is covered again by sediments. Those are thick-bedded limestones which might correspond to the Upper Jurassic.

The transverse gully of Karr has still a further significance: The massive limestone occurring north of the trench is like cut; in vain we search for the southern continuation. Instead, we find opposite of them granites. Those correspond apparently to the overlying granites north of the Karr Chu. On the granites south of the Karr Chu we find the black Cretaceous-Tertiary flysch series directly deposited on the granite. (Compare fig. 113 further geological map plate II and geological profile I

Phot. 67. Polygenic Breccia in the Thakmar Valley

Components of siliceous dolomite are bedded in arenaceous limestone, dolomites and fine-grained breccias.

plate III.) It appears that the gully of the Karr Chu is an ancient trench, which was originated as an longitudinal fault already before transgression. South of it there was a swell, on which the flysch was deposited directly on Lower Jurassic and Rhetic, while north of it, also the Upper Jurassic formations were deposited.

The last stage of the Karr longitudinal fault has slightly sunk the southern block. However, this should not mislead to a wrong conclusion: In the main ancient phase the southern block has been lifted. For, how otherwise could it be explained that the Paleozoic is now at the same level as the

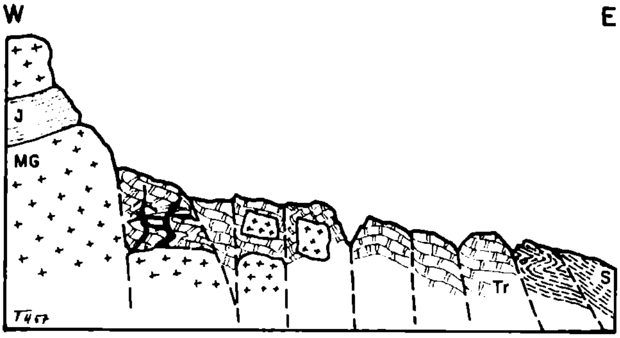


Fig. 112. The Main Transverse Fault System Northwest of Karr Gömpa

S Saligram series (Upper Paleocene)
J Jurassic
Tr Triassic
MG Mustang granite

Some of the dolomite formations contain pegmatites. The transverse fault system forms a trench staircase (Grabentreppe).

Mesozoic. Undoubtedly, the Dangarjong transverse fault also played an important role, since in the Karr longitudinal fault the Dangarjong fault, which south of it shows a vertical movement of nearly 3000 m, looses at once its magnitude north of the Karr fault. This break of magnitude has also the equivalent in the south, where near Dangarjong also the Dangarjong fault ends suddenly.

In the valley between Karr Chu and Mustang Chu occur the northern most Saligram series, at the foot of the eastern flank of the mountain range. Further north, the Quaternary formations (Thakmar series) join directly the granite. This will not mean, that the Saligram series are not existing underneath the (probably Pleistocene) lacustrine formations. This coincides also with the eastern flank of the Kali Gandaki valley, where north of the meridian of Mustang they were also not found.

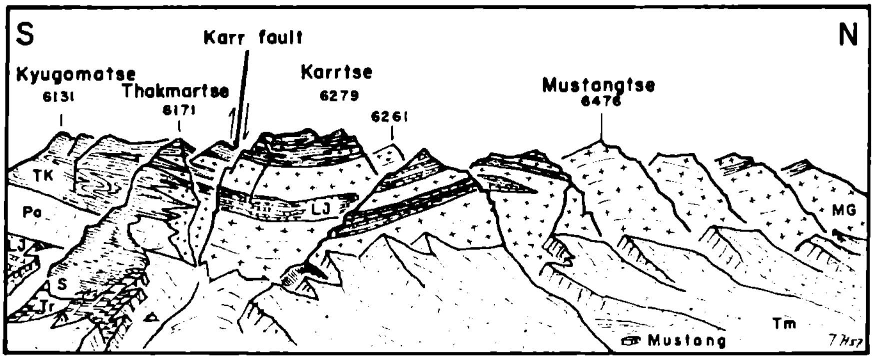


Fig. 113. View of the Mountain Range West of Karr Gömpa—Mustang

Tm Thakmar series (Quaternary—Upper Tertiary)
S Saligram series (Lower—Middle Paleocene)
Tk Thakkhola series (Lower Tertiary—Upper Cretaceous)
LJ Lower Jurassic
Tr Triassic
Pa Palaeozoic

The main transverse fault system strikes along the foot of this mountain range. Thereby the Palaeozoic formations come to lie above the Lower Jurassic (left side of the sketch).
Just south of Karr Gömpa, the Saligram series connects directly with the Thakkhola series on the top of the mountains due to the trench staircase structure, in combination with a strong eastern dip of the said series. (Compare also plate VII, fig. 2.)

10. The Quaternary and Upper Tertiary

We now study the huge Thakmar formations. (See plate VI, fig. 1 and plate VII, fig. 2 and 3, and phot. 46, 57, 58 and 64). In the whole area of the northern Thakkhola we find the thick formations of clear-coloured, light-blue sandstones (which resemble lithologically the Middle Siwalik sandstones), red sandstones and conglomerates similar to the Upper Siwaliks and on the top the granitic gravels. As mentioned earlier, the most southern granite boulders occur on the Narsing La (phot. 51) at the western flank of the Thakkhola. At the eastern flank, we found the most southern granitic gravels on the pass south of Ghiling along the main trail from Mustang to Kagbeni. At Mustang we found in the upper portion of the Thakmar series lacustrine chalk. It appears that this upper portion belongs to the Pleistocene.

All the valleys at the western part of the Thakkhola, which drain the range west of the Thakkhola, show surprising large morainic deposits. All the confluences of the tributary valleys with the main valley of the Kali Gandaki show well-preserved lateral and terminal morains (Kyugoma, Thakmar, Karr, Charang, and Mustang) (see fig. 108 and plate VII, fig. 2). These belong to the various recession stages of the last ice age. Some of the big lateral morains continue far down into the Kali Gandaki valley, to the areas where we find today the settlements (that means down to 3600 m). In addition, we find in those valleys also more ancient morain layers, which partly are covered by interglacial fluviatil gravels. (See fig. 105 and phot. 62, 64.)

Those morains only enabled the settlements of Mustang, Maharang Thakmar, Karr, Kehami, Ghiling and Samar, since only on these impermeable morainic layers water occurs on the surface. The sandstones of the Thakmar series are so dry and permeable that no water at all can be found on the surface.

The Tertiary and the Quaternary with the lacustrine deposits cover also the pass of Tinglibhoto, which leads from Mustang over to Tibet (catchment area of the Tsangpo). The watershed between the Kali Gandaki and the Tsangpo is situated little further north. However, the fact, that Upper Tertiary and Quaternary deposits are found in a saddle of only 4500 m above sea level is surprising, while the Cretaceous flysch covers the top of the neighboured mountain ranges which reaches altitudes of 6000 m and more. (See fig. 113 and plate VII, fig. 2.)

11. The Mountains North of Mustang

As far as can be recognized from the rock exposures on both sides of the Tinglibhoto pass, the saddle of the pass is situated in a local partial transverse anticline. We have seen above how the mountain range west of Mustang shows a western axial pitch. (See fig. 106 and 113, and plate VII, fig. 2.) Similarly, the mountain ranges at the northeastern flank of the Thakkhola have also a strong dip towards the east (plate VI, fig. 1). The real axis of the Tinglibhoto transverse anticline strikes in northeast-southwest direction through the upper course of the Chudidi Chu, east of peak 5196 m (fig. 135). Thus, the axis does not strike exactly through the Tinglibhoto pass, but is situated a little bit further east. Also east of the pass the dip of the rocks which are interbedded with granites and pegmatites is directed towards the west. (See plate VI, fig. 1.) From these exposures we may conclude with a fair certainty that the granites on either sides of the Tinglibhoto transverse anticline connect underneath the Quaternary filling. (See profiles I and II, plate IV.) At the eastern side of the pass we find higher formations towards the east and more sediments (plate VI, fig. 1). Especially, two larger granite masses occur. Further east appears the well-bedded Devonian limestones, the dark slates with the yellow-band series (Carboniferous) and the clear-coloured, well-bedded quartzites of the Permian (at the northern flank of the valley, which joins the Kali Gandaki from the east opposite Mustang (plate VI, fig. 1). In the area of the Meridian of Mustang the main range (Samjung Kang-Chudiditse) shows southern dipping in the Devonian formations. Consequently, we find towards the south gradually younger formations. South of the above-mentioned tributary valley (Chudidi Chu) a west–east striking range east of Dih is built of the Triassic dolomite (plate II and VI, fig. 1). Adjoining to the south occur Jurassic formations, which are folded. The Upper Jurassic limestone is well recognizable; it shows a strong southern dip in its northern most outcrop, but is folded in the lower part (plate VI, fig. 1). From this place the Upper Jurassic limestone connects through a flat syncline with the basement of the Tehatse (6010 m) which carries the northernmost glacier of this range (fig. 101, which shows the same mountain group from the Damodar valley). The above-mentioned syncline is filled with the dark flysch series of the Upper Cretaceous-Lower Tertiary (Thakkhola series).

While, as mentioned above, the northernmost part of this mountain range northeast of Mustang shows an eastern dip of its formations (caused by the Tinglibhoto transverse anticline) we find a change with this regard south of the range, which is built by the Triassic dolomite. All the Mesozoic formations dip west, that means towards the Kali Gandaki valley (see fig. 98, 99 and 100 and plate VI, fig. 1). The same feature was already observed further south, for example near Muktinath (fig. 75, 79, 81 and plate VI, fig. 2) or in the Narsing valley (fig. 92 and 93). The Triassic and Jurassic formations occur surprisingly far down into the Kali Gandaki valley, especially in the Damodar valley. The Damodar valley, is by the way, (as it can be observed from Mustang), built by a flat anticline (the Tetang anticline, fig. 135). This has to be considered as a transverse structure. Further evidence of transverse structures are found west of the Chudiditse (5835 m), which area is cut by a number of north–south striking faults (see map of faults, fig. 136 and geological map plate II). Some of those transverse faults strike through south as far as Tange, where they occur in the Saligram series.

If we try to connect the structures of the mountain ranges flanking the eastern side of the Thakkhola with those at the western side, we meet considerable difficulties. They generally do not coincide. One must not be especially surprised about this fact, since the various transverse structures and faults lying in between might have disturbed and hidden the direct connections. Also, of course, there is a lack of exposures due to the Quaternary filling of the Thakkhola. The anticline through the Mustangtse (6476 m) at the western flank appears to correspond with the large anticline in the eastern mountain range (fig. 135). However, while in the west the range consists predominantly of granite, with few and minor layers of Jurassic formations, we find the eastern mountain range (Samjung Kang-Chudiditse) built of predominantly sediments of lower formations, from the Carboniferous downwards.

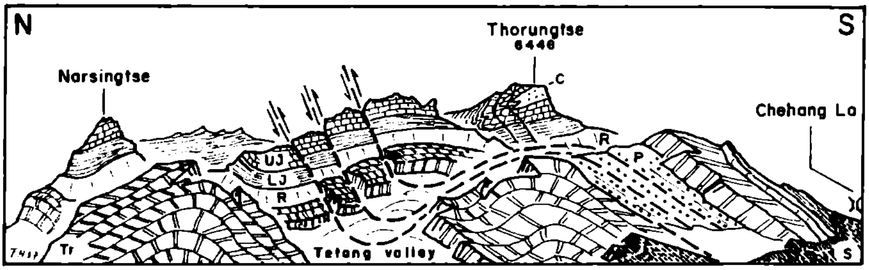


Fig. 114. Schematic Sketch of the Mountain Range Thorungtse—Narsingtse

(seen from the west, from Ghiling La)

S	Saligram series	R	Rhetic
C	Cretaceous	Tr	Triassic
UJ	Upper Jurassic	P	Permian
LJ	Lower Jurassic		

A system of northeast—southwest striking faults intersects this mountain range, whereby the northwestern portions have sunk. The same formations, involved in this transverse fault system, show in addition a strong western dip, forming the eastern flank of the Thakkhola trench. In addition, there is a transverse anticline, striking through the upper part of the Tetang valley and the western flank of Thorungtse. Compare also plate VI, fig. 1 and 2, and text figure 136.)

The synclinal zone of the Tehatse (6010 m) at the eastern flank (plate VII, fig. 1) appears to correspond to the Karr syncline (fig. 135). The anticlinorium of the Damodar Himal Tange valley corresponds to the large anticline zone between Kyugoma valley and Keha Lungpa valley with Khegatse and Kehamitse (compare plate VI, fig. 2 and 3). However, the respective axis does not quite coincide (fig. 135).

However, also in this central part of the Thakkhola the difference in the tectonics between the western flank and the eastern flank is striking. While at the western mountain range, between the Kyugoma valley and the Keha Lungpa valley we have one single regular anticline of great magnitude (plate VI, fig. 2 and 3) there is a number of anticline structures at the opposite side of the valley, corresponding to the large western anticline, namely the Tange anticline (fig. 100), the Narsing anticline (fig. 99) and the Tetang anticline (fig. 98 and 114). Furthermore, while the axis of the western anticline (we may call it the Samar anticline) strikes due west-southwest, the above-mentioned eastern anticlines strike east-southeast west-northwest (fig. 135). Furthermore, the three mentioned anticlines are not so simple compared with the western one. It appears that the Manaslu arc, which strikes in northwest-southeast direction and has pushed towards the southwest shows its influence right into the Thakkhola. (Compare also map of the structures and faults, given in fig. 135 and 136.)

Phot. 68. View from the East into the Samar Valley

The big terrace consists of morainic material. It has been deposited in a valley cut into the Upper Tertiary conglomerates. In the gully at right side occurs the transgression of the Lower Tertiary upon the Palaeozoic formations. (Compare fig. 115.)

The main transverse fault strikes along the foot of the high wall, which consists of Palaeozoic formations reaching from probably Pre-Cambrian gneisses right up to Carboniferous.

12. Mustang–Kehami

We now continue our trip from Mustang towards the south along the main trade route. The Quaternary formations are of monotoneous character on this route, quite different from our approach route to Mustang, where we moved along the margin of the Quaternary. On the Kehami La we found a number of turritellas, the exact species we were, however, unable to determine.

In the Kehami Chu and especially in the morainic deposits occur metamorphic slates whit large turmaline and rutil crystals, as well as biotite-slates and biotite-schists and garnet schists. A dense greenish quartzite of extraordinary hardness was also found.

On the pass south of Ghiling we find on the Quaternary formations large boulders and gravels of the Mustang granite. The formations in the lower parts, possibly Upper Tertiary, consist of fine lacustrine shales and clear-coloured sandstones.

West of Ghiling, at 3800 m occur Devonian limestones, flat-bedded, however much tectonized, with a large number of flat-lying narrow folds and also thrusts (plate VI, fig. 2 and 3). A detail profile of this mountain flank shows typical Devonian formations, with brown fluidal limestones, banded limestones with a net pattern of clay and marl, arenaceous limestones, slight metamorphic limestones with sericite and calcsilicate rocks. The Carboniferous is represented by quartzite breccias and layers of iron ore. In general, this zone is so much tectonized, that the real structure is recognizable only with difficulties.

13. Samar–Chhuk

On the trail north of the Samar pass we find spotted slates and barred slates ("Stäbchenschiefer").

These same formations occur also in the brook 2 km north-northeast of Samar, with a dip towards the east-northeast. At the same locality we find also Chitlang quartzites (pink quartzites interbedded with violet and blue shales), which towards above gradually change into arenaceous limestone (the latter being similar to the Ratomata limestone north of Gurkha). Undoubtedly, these series belong to lower formations, probably Silurian or even Cambrian. Further, we find also pegmatites and even migmatites, thus being undoubtedly in the Cambrian formations, comparable with the migmatites of the Kathmandu nappes. A little further up in the same brook (Samar Chu) occur fine-grained arenaceous biotite-gneisses, quartzite-gneisses with quartz veins as marginal remnants of the pegmatites and arenaceous augengneisses. Pegmatites cross these formations at right angle right up to the (probably Silurian) arenaceous limestones.

From Samargaon we enjoy an excellent view into the mountain group east of the Kali Gandaki valley (fig. 114) between Damodar Himal and Thorungtse. Narsingtse has on its top, as mentioned earlier (see fig. 99) the thickly-bedded Upper Jurassic limestone. The same series appear again in the long ridge north of the Thorungtse, especially in its northern part. The dip shows towards the north, however, it would not explain the rise from the valley north of peak 5744 m to the peak north of it. We can see from here now quite clear that this zone is intersected by a number of faults, which strike in southwest–northeast direction (fig. 114). The northwestern parts are sunk along these faults, resulting in a staircase-like rise of the formations towards the southeast. This solves also the problem which occurred on our trip from Muktinath via the Chehang La towards the north, where the Triassic dolomite alway appeared to strike out towards the north and east into the air, while along the 20 km long more or less horizontal trail we always met the same dolomite again and again. These dolomites have by the staircase of the faults repeatedly been sunk (fig. 114).

A flat anticline (Tetang anticline) strikes in northwest–southeast direction with axial pitch to the northwest through the ridge north of Thorungtse (6444 m) (fig. 114). At the same time we find west of it the Chehang anticline which strikes in west–east direction with axial pitch to the west. Thus the area 3 km northwest of the Thorungtse is a dome-like structure, formed by the cross point of the two different anticlines. This explains the occurrence of the Permian in an altitude of more than 5000 m, and the apparent outcrop of the Triassic dolomite along the trail at 4000 m into the air. (See also plate VI, fig. 2.)

In the brook just north of Samar (fig. 115) occur Ordovician limestones. However, by a system of north-south striking faults, the series is totally broken and partly weathered to grit. The dip shows flat east. This is the same fault system which was found earlier on Kehami peak, which marks the western margin of the Thakkhola Graben.

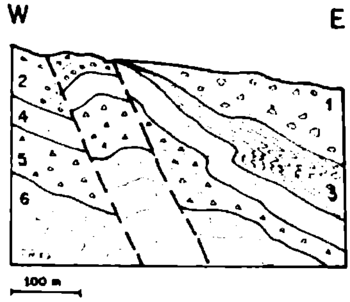


Fig. 115. Sketch on the Tertiary Transgression upon the Palaeozoic near Samar
1 morains (probably of ice age glaciation)
2 sandstones and conglomerates (Thakmar series, Upper Tertiary)
3 Saligram series (Upper Paleocene)
4 sandstones (comparable with the Paleocene Narsing series)
5 transgression breccia (consisting of Silurian material)
6 Silurian limestone
The two faults are marginal faults of the main transverse fault.

But we find still another fault system which is directed west–east and with steeply southern dipping faults. The southern parts have been lifted which is well visible by small hook-folding. This fault system continues to the west, where the corresponding fault-folding can be seen in the northern flank of the Keha Lungpa valley (plate VII, fig. 3).

The material of the morains around Samar consists of fluidal limestones with quartz veins and pegmatites. The peak west of Samar (Khegatse 6198 m) appears to consist of Triassic formations, also recognizable through the well-exposed Carboniferous yellow-band series, below the top.

At the base of the wall (phot. 68) occur banded calcsilicate rocks and marbles, which are intersected by quartzites and pegmatites. These series appear to belong to the Silurian. Further down in the same brook we also observe the transgression of the Paleocene upon the Silurian (fig. 115). Lying on the flat western dipping Silurian banded limestones and marbles occur a typical transgression breccia of the same material. Overlying we find a Paleocene sandstone, as well disposed by the transverse faults as the underlying Silurian series; finally the Saligram series is represented by the typical black shales. Directly on the latter a morain has been deposited (fig. 115).

In the valley of Samar we find the same type of huge red morains as at Thakmar. The whole big terrace is built of it (phot. 68). It contains a lot of Triassic dolomites and Rhetic limestones. Possibly not the whole of the huge deposit can be considered as pure genuine morain. A portion of it may be alluvially deposited morainic material. The valley of Samar is cut into conglomerates ("Nagelfluh"). The red morain is situated within this valley (phot. 68).

Descending from Samar to Chele one traverses the huge conglomerates and sandstones of the Upper Tertiary, which are interbedded with lacustrine shales and also with calcareous marls. The clear-coloured sandstone recalls the Tertiary Middle Siwalik sandstones.

The peak west of Samar (Khegatse 6198 m) consists of Triassic dolomites, recognizable on the yellow-band series of the Carboniferous in the lower part. These are some folded in the southeastern ridge of the said mountain (plate VII, fig. 2 and 4).

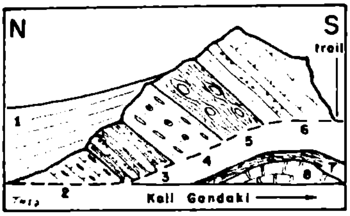
West of Khega occur Silurian limestones, dipping towards the east and slightly folded. In the valley of Khega also an isolated tower of the red Thakmar morain is left over from erosion. The same red morain occurs again in the wall near Chele where the Kali Gandaki leaves its cañon and enters the alluvial plain which stretches down right to Dumpu.

14. Chhuk–Kagbeni

South of Chhuk occur lacustrine shales and marls, clear-coloured sandstones (of the type of the Middle Siwaliks) under unconformity upon black slates. The latter dip southwest.

South of Tangbe occur the clear-coloured Upper Tertiary sandstones and lacustrine shales. Its dip towards the north has been mentioned earlier (fig. 88 and phot. 57). These series (Thakmar series) overly under unconformity the Upper Paleocene Saligram series, which at this place dip south, with a strike of east–west. Underlying the Saligram series we find here Narsing flysch, consisting of multi-coloured, well-bedded marly limestones, which contain plenty of nummulites. Thus the Paleocene age of the Narsing flysch appears to be pretty safe. The marly limestones gradually change upwards into black shales, interbedded with quartzites and sandstones (fig. 116). Besides the dark and red quartzite layers within the black shales we find also arenaceous, light-brown quartzites, with a strong clivage at right angle to the strata. Overlying the Saligram series (we have to consider the black shales with quartzites as saligram series, though no real Saligrams are found here) occur the Greensand series with a number of fossils.

Fig. 116. Detail Profile Tange—Kagbeni



1 lacustrine shales, marls and chalk (Thakmar series).
2 multi-coloured marly limestones with plenty of nummulites
3 black shales with beds of quartzite and sandstones, the latter showing transverse clivage (similar to the Saligram series)
4 Greensand series with shells and nummulites (assilina)
5 black slates with calcareous concretions
6 sandstone series of brown, grey and green colour, arenaceous quartzite and greensand (glauconite greensand), partly marly sandstones.
7 Saligram series (Upper Paleocene)
8 Rhetic-Triassic dolomites and dolomitic limestones

The series (4)–(6) belong to the Kagbeni series, which is considered to be of Eocene age (overlying the Saligram series). A number of fossils have been found in these Kagbeni series. (See text below)
This detail profile has been taken at the eastern river bank of the Kali Gandaki river. However, at the western side the beds show quite a different dip and strike. (Compare the complicated tectonics of this zone in fig. 118 and 119.)

Of those the following were preliminarily determined in the field:

Unio trucatosus Michaud (Paleocene, Londinian)
Pectus
Ostrea spec. (in the greensand)
Paludina Suesonensis (Londinian)
Limnea Longiscata (Eocene, Ledian)

Strange enough, above this greensand series occurs the Saligram series with very large saligrams. (Normally, as found near Muktinath and in the Narsing valley, the greensands overly the Saligram series.) Apparently there might be a disturbance at this place, possibly a transverse fault, bringing the Saligram series above the greensands. Over the Saligram series occur brown, grey and green sandstones, interbedded with layers of arenaceous quartzites and minor marly shales. Towards Tangbe, that means towards the south, the strike of these formations turns to north–south direction, the dip into western direction. At the opposite riverbank of the Kali Gandaki we find a transverse fault, along which the western portion has been transposed to the south (fig. 136). Further south we find such a transverse fault also on the eastern river bank, thus explaining the overlying of the Saligram series over the greensands as mentioned above. The greensands, which steeply dip east, are cut by a staircase-like system of vertical faults, which strike in north–south direction, whereby the western portions have sunk in. On the ancient erosional surface we find a transgression breccia (fig. 117). Also the overlying molasse (Upper Tertiary conglomerates) is transgressed over the greensand transgression breccia. By means of the greensands the age of the transverse fault system can be considered as Upper Paleocene.

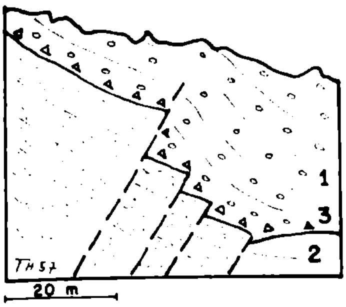


Fig. 117. Staircase Fault System South of Tange

1 Upper Tertiary conglomerate ("molasse", Thakmar series)
2 Greensand series (Kagbeni series)
3 transgression breccie

The molasse has transgressed over the staircase faults.

In the same series at the eastern river bank of the Kali Gandaki between Tangbe and Kagbeni occurs also the (topographically seen) lowest Mesozoic: Triassic dolomites and dolomitic limestones and than bedded marly limestones of the Rhetic. The dip is directed towards the north-northeast, while the overlying greensands dip east. Faults within these series dip steeply southwest.

A general view on the upper part of the flank between Tangbe and Kagbeni can better be obtained from the opposite flank of the valley (fig. 118). We can observe the succession of the formations which overly the profile as given in fig. 83 and 84, at the eastern flank of the peak 4191 m. The clear-coloured sandstones, which build the peak, are folded in at the southern flank (fig. 84). The greensands are clearly above the Saligram series (as found already on Chehang La, fig. 83).

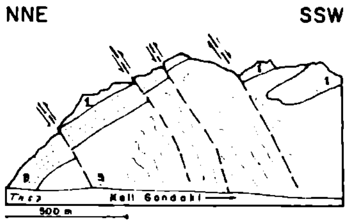


Fig. 118. Tectonics in the Northwestern Flank of Peak 4191 m, North of Kagbeni

1 clear-coloured sandstone
2 Greensand series
3 black slates, interbedded with sandstones and quartzites

All the formations belong to the Kagbeni series

In general the formations at the western flank of peak 4191 m dip towards the north. Only near Kagbeni, that means further south we find vertical beds (fig. 119). The whole area is intersected by faults, which strike in general southwest–northeast. However, a general and regular movement along these transverse faults could not be found, nor have the western or eastern part generally sunk in. Rather, the transverse faults caused a variety of up and down movements (fig. 118).

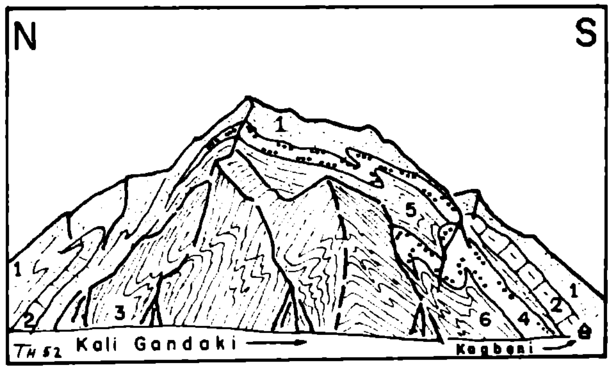


Fig. 119. The Western Flank of Peak 4191 m (seen from the west)

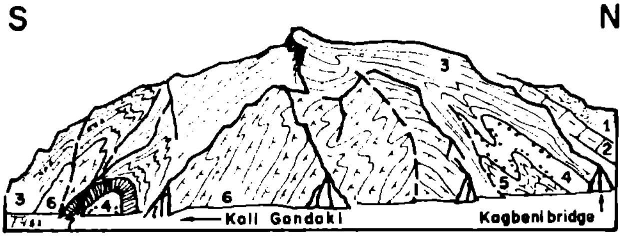
1 sandstone, clear-coloured
2 calcareous marls
3 black slates
4 quartzite
5 slates, interbedded with quartzites and sandstones
6 multi-coloured slates

All the formations excepted the top one, belong to the Kagbeni series. (Compare also plate VI, fig. 2.)

15. Kagbeni–Dangarjong

The Tertiary profile is very well-exposed at the western river bank of the Kali Gandaki, opposite Kagbeni (fig. 120 and 121). We find a narrow steeply erected anticline (see also plate VII, fig. 3). The core of the anticline consists of greensands, which contain large layers of breccias. Glauconite sandstones are found too. A number of findings gave preliminarily nummulites, ostreas and pectus. The latter show extraordinary large dimensions, namely up to 7 cm. Also a fossiliferous tree trunk was found. The breccias occur predominantly in the lower part and underlying the greensands. The strike is generally west–east, that means at right angle to the Kali Gandaki river course. However, further down the strike changes into south–north direction at the western river bank. On the opposite river bank (eastern side) the strike of the Tertiary formations remains at west–east. Undoubtedly also in this section a transverse fault strikes through the river course of the Kali Gandaki (as it was found also further north. (See fig. 136.)

Fig. 120. The Western Flank of the Kali Gandaki Valley opposite to Kagbeni (seen from the east)



1 sandstone
2 marly limestone
3 black slates, interbedded with sandstones (greensands) and quartzites
4 white quartzite
5 calcareous slates, multi-coloured
6 calcareous marls
7 carbonaceous marl, with fossiliferous trees

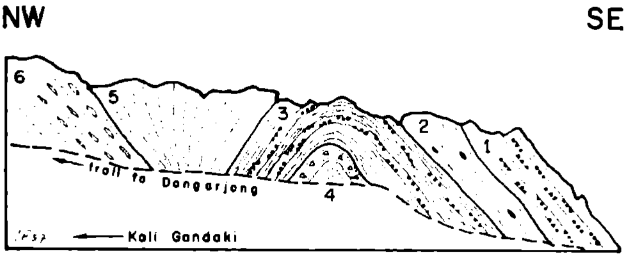
All the formations belong to the Kagbeni series. The tectonics on either sides of the Kali Gandaki river do correspond only partially (compare fig. 119 of the opposite side). It seems that a transverse fault strikes through the Kali Gandaki river. (See fig. 136 and plate VI, fig. 2.)

The hill 2 km northeast of Dangarjong, which is separated from the mountain flank by the pass (Dangarjong Chang La), over which the trail leads to Sangdak, consists of Tertiary formations (quartzites, sandstones, greensands, rich in fossils at its southern flank), clear-coloured quartzites on the top. The strike is in the whole area of the said hill directed to the east-northeast, the dip steeply towards north-northwest (plate VII, fig. 3 and 4).

Dealing once more with the age of all those formations we can now conclude with a fair certainty that the greensands have to be considered as Upper Paleocene-Eocene, while the Saligram series necessarily have to belong to the Lower/Middle Paleocene.

The area of Dangarjong and the eastern flank of the Dangartse (5721 m) take such a key position

Fig. 121. Detail Profile on the Trail from Kagbeni to Dangarjong (western river bank of the Kali Gandaki)



1 greensands, interbedded with layers of quartzite
2 black slates with silicious concretions
3 black slates containing two layers of white quartzite
4 coarse-grained assilina greensand, interbedded with breccias
5 Greensand series, with deep green glauconite greensand
6 greensands with nummulites and large size pects (6 cm) and ostrea species

All the formations belong to the Kagbeni series (this figure joins fig. 120 to the south).

from standpoint of view of geology, that we now study this section with fig. 1, 2 and 3 in plate VII: The main transverse fault strikes through the Dangarjong Lho La (Lho La means south pass) and through the Dangarjong Chang La (Chang La means north pass). That is at the foot of the eastern flank of the Dangartse mountain. On Dangarjong Lho La the Triassic dolomites on either sides of the Dangarjong fault nearly connect. But from there on towards the north the said series separate rapidly. The dolomites on the eastern side of the fault show a northern dip, while the same formation at the opposite side rises steeply, exposing the underlying Permian and Carboniferous formations. The latter form the narrow and steeply erected Dangarjong anticline in the core of which even Devonian limestones are exposed, just west of the fault. The Triassic dolomite and higher series appear again in the summit of the Dangartse (5721 m). Thus, while the vertical movement along the Dangarjong fault on Dangarjong Lho La is only about 100 meters, it reaches 4 km further north about 2500 m.

Just west of Dangarjong village the dolomite which occurs in a small exposure at the eastern side of the fault is situated side by side with the Devonian formations at the other side of the fault. The dolomite at the eastern side of the fault is bent up along the fault, thus dipping steeply east. It is overlain by the Saligram series, which occur along the whole fault from 300 m north of Dangarjong Lho La right into the Keha Lungpa valley. Also the Saligram series dip east; that means they are also bent up along the fault. It is also noted that the Saligram series overly at its most southern exposure Rhetic and Jurassic formations.

The Saligram series are overlain in the central part (fig. 1, plate VII) by the Eocene Kagbeni series, which consists predominantly of greensands and quartzites, all complicated folded. The Thakmar series (here mostly of Pleistocene formations) are the topmost formations, overlying the Kagbeni series in the valley of Tiri village. In the valley of Dangarjong village the Thakmar series overly directly the Saligram series.

Concluding we may say that the main transverse fault at the western margin of the Thakkhola Graben, from Mustang to Dangarjong, ends just south of Dangarjong. However the transverse structure continues further south in a different way, as we shall see later.

IV Geological Observations in the Southern Part of the Thakkhola

(between Muktinath and Dumpu)

1. Dangarjong–Jomosom

The main transverse fault forming the western border of the Thakkhola Graben strikes through the said saddle 2 km northwest of Dangarjong. (Dangarjong Chang La, see fig. 123 and plate VII, fig. 3 and 4.) In this fault, the Tertiary greensands join under right angle western dipping Carboniferous formations, consisting of dark spotted slates, knotted slates, graphitic dotted slates, quartzites, breccias, quartzites, and iron slates and iron quartzites. Just south of the said pass Dangarjong Chang La (Chang means north in Tibetan language), we find underlying the Carboniferous, the Devonian arenaceous limestones, fluidal limestones and the limestones with a net pattern of shales and clays (plate V, fig. 3). All these formations dip west. However, the western dip cannot be considered as the normal one, since it corresponds rather to a western axial pitch. If we consider the transverse section, we find the beds more or less horizontal, with an increasing southern dip more south.

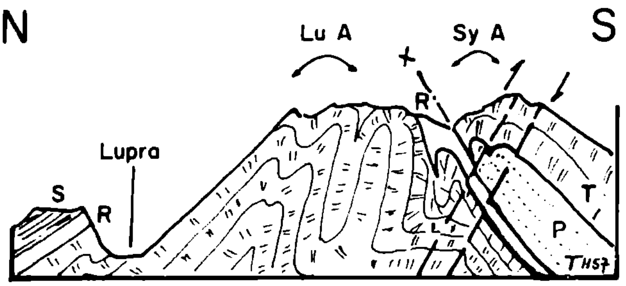


Fig. 122. Schematic Profile Sketch of the Lupra Valley

S	Saligram series (Paleocene)
R	Rhetic
T	Triassic
P	Permian
Lu A	Lupra anticline
Sy A	Syang anticline

The Lupra anticline is the boundary between the normal folding (directed towards the south) and the reverse folding (directed towards the north).
(Compare also plate VI, fig. 3, showing the farther surrounding of the Lupra valley.)

The main vertical transverse fault strikes 100 m west of the Dangarjong village in south-southwest direction, then a few hundred meters west of the Dangarjong Lho La (Dangarjong south pass) in the same direction (plate VII, fig. 1 and 3). Just west of Dangarjong village occur some beds of Triassic dolomite, which dip steeply to the east. This is the basement of the transgression of the Saligram series, which here, at Dangarjong has been rised along the main transverse fault in the same way as further north, in the area of Kyugoma (see plate VII, fig. 2 and 3).

(Compare also geological map plate II and geological profile V, plate IV.)

Further south, the same dolomite builds the barrier through the Kali Gandaki valley (plate VII, fig. 3 and 4, also text figure 122). It forms a narrow-pressed anticline, which is in itself heavily folded. At the northern flank occur Rhetic lumashell limestones with the largest lumashells found so far (6 cm). Belemnites indicated also Jurassic formations. At the southern flank of the Dangarjong Lho La (and at the southern flank of the said anticline) occur iron oölites (Dogger or Middle Jurassic). South of the Dangarjong Lho La no Saligrams series occur. Also the overlying Tertiary is missing completely. Quaternary gravels and morains are deposited directly upon the Mesozoic formations (fig. 122 and plate VII, fig. 3 and 4).

Phot. 69. View into the Northern Part of the Thakkhola from the Ridge East of Jomosom
(Compare plate VII, fig. 4.)
At this place a number of Triassic and Rhetic fossils were found.

At the eastern flank of the Kali Gandaki valley the Saligram series have their southern boundary also in the same section (fig. 122 and plate VI, fig. 3). The last respective occurrence was found 5 km southwest of Muktinath, dipping west in the same sense as the underlying Rhetic limestones (fig. 78). From this locality they continue on the edge of the terrace north of the Lupra valley up to a point 1 km northwest of the Lupra village (fig. 122 and plate VI, fig. 2 and 3). Greensands, quartzites and black slates are overlying the Saligram series at this locality as was seen also in fig. 78. The dip of these Tertiary formation is generally north, however with a narrow anticlinal structure, which is overturned towards the south. The strike is generally southwest-northeast. The structures of the Tertiary do not coincide with those in the underlying Mesozoic, which consists of Triassic and Rhetic formations. The latter are intensively folded, with predominant steeply erected and narrow-pressed anticlines. Especially just north of the Lupra valley, 1,5 km south of Kagbeni we found already in 1952 heavily folded Rhetic marly limestones with the characteristic transverse clivage. In general the Tertiary at the eastern flank of the Kali Gandaki and north of Lupra dips west with axial pitch towards the west. Concluding we see that this is the fact at the whole eastern flank of the Thakkhola, right through to Tinglibhote (plate VII, fig. 1). South of the Lupra Chu no Tertiary formations occur (plate VII, fig. 3 and 4).

Thus, arrived at the southern border of the Tertiary formations, we are now able to recognize the whole size of the Tertiary filling of the Thakkhola Graben: Its southern limit is situated in the section of Dangarjong–Lupra (phot. 46 and 69, and plate VII, fig. 2 and 3). From here towards the north the Tertiary Thakkhola basin extends as far as little north of Mustang, that is a length of 40 km (plate VII, fig. 1). The maximum width of the Tretiary basin can be measured in the section of Tange, where it has 13 km. Near Muktinath the width extends to 11 km only.

The dimensions of the Tertiary Thakkhola basin are of some importance for the economic geology: The natural gas at Muktinath, nourrishing the permanent sacred flame may have its origin in Petroleum, which might occur in the Upper Cretaceous and Lower Paleocene in and underneath the Middle Paleocene Saligram series. Concidering the longitudinal section given in profile V plate IV we may have a fault trap, possibly in connection with a stratigraphic trap.

2. The Main Transverse Fault Dangarjong–Mustang

West of Dangarjong we have found the Devonian limestones dipping to the south into the underground (plate VII, fig. 1 and 3). From here towards the north (in the Keha Lungpa valley) the Devonian climbs high up and builds the basement of the whole mountain range west of the Kali Gandaki valley, from the Keha Lungpa nearly as far as the Kyugoma valley (plate VII, fig. 1). In general, it is a huge anticline (Samar anticline in fig. 135), with a steeply dropping southern flank, a flat culmination north of the Keha Lungpa valley (with minor thrustfaults with hook folds) and a northern overturned structural flank in the Kyugoma valley (Kehami syncline in fig. 135). (Compare profiles 2 and 1 plate III. and text fig. 108.) The said huge anticline is towards the Kali Gandaki valley abruptly cut by the Dangarjong transverse fault (fig. 123 and 136). This main transverse fault has its origin in the north near Mustang, that means on the watershed between the Kali Gandaki and the Tsangpo (fig. 136).

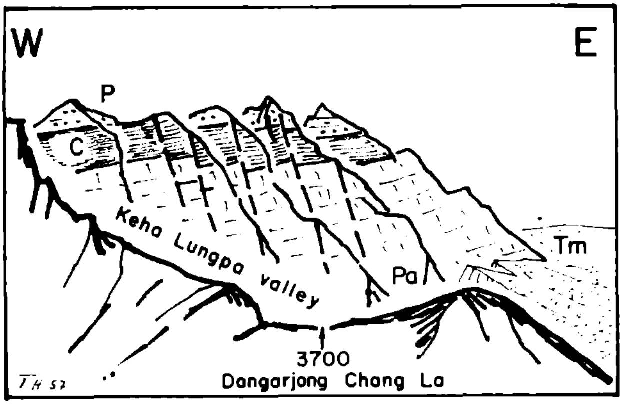


Fig. 123. The Staircase Fault System West of Samar
(seen from Dangarjong Lho La)

Tm Thakmar series (Tertiary)
P Permian
C Carboniferous
Pa Middle Palaeozoic

The eastern portions have sunk in form of a staircase. The main transverse fault strikes along the foot of the eastern mountain flank into the Dangarjong Chang La in the foreground. (Compare also plate VIII, fig. 2 and 3.)

From this watershed to the south as far as the Karr fault and the Kyugoma valley the magnitude of the fault is of no extraordinary character. Besides, instead of one single main fault, we have a number of partial faults, or what we may call a "Grabentreppe" (fault-staircase); in the section of Thakmar the lift of the western portion amounts to the thickness of the Triassic formations, which is several hundred meters. Just north of the Kyugoma tributary valley the Silurian formations are situated at the same level as the Saligram series. The amount of sinking of the eastern part thus amounts to the thickness of the whole Mesozoic formations, including the upper part of the Palaeozoic, which might be approx. 1000 meters in the main fault and 3000 meters including the whole staircase system (see profile III, plate IV). The vertical movement of the Dangarjong fault near Samar, where the Tertiary is situated at the same level as the Cambrian gneisses corresponds to the whole thickness of the series from Cambrian right up to Lower Jurassic, which is approx. 2600 meters. (Compare plate VII, fig. 2 and 3, and phot. 68.) The summit of the Khegatse (6198 m) is built by Triassic dolomites, while near Samar separated by the Dangarjong fault the same Triassic dolomite is at 3800 m. We see also, that the main transverse fault changes its character from north to south, from a staircase-like fault system (north of Thakmar) to a clear single fault (at Dangarjong; see also fig. 136).

3. Lupra–Jomosom

The barrier south of Dangarjong–Lupra is built by a narrow-pressed dolomite anticline. The northern flank of it is intensively folded and thrusted (fig. 122 and plate VII, fig. 1, 3 and 4). The same flank also contains belemnites, which prove existence of Jurassic formations. At the eastern side of the valley, south of Lupra the same anticline is still more complicated by a thrustfault, through which its axial zone is broken. The said thrustfault dips steeply south, whereby the direction of thrust is directed towards the north. A number of folds and hook-folds occur along the thrustfault, especially further

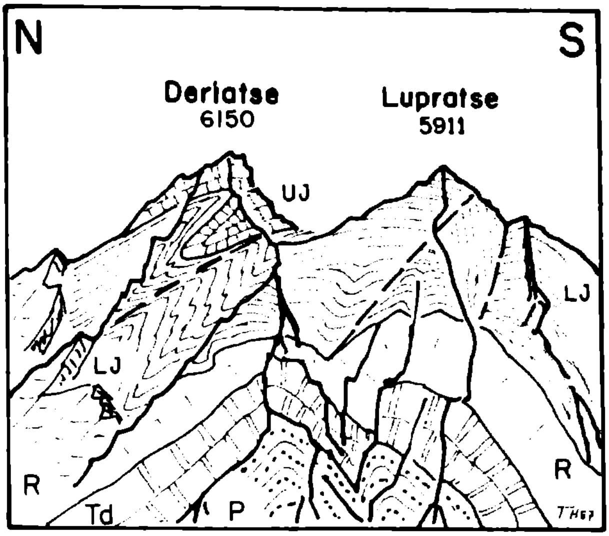


Fig. 124. Deriatse and Lupratse Seen from the West

UJ Upper Jurassic
LJ Lower Jurassic
R Rhetic
Td Triassic
P Permian
(Compare also plate VI, fig. 2 and 3.)

west (plate VI, fig. 3). The anticline (we call it the Lupra anticline, compare fig. 135) is neighboured to the northern situated Muktinath anticline. The latter does not continue across the Kali Gandaki valley towards the west since the axis of the flat Samar anticline (fig. 135) is far more north. This does not surprise, since the Muktinath anticline shows near Muktinath such a strong western axial pitch (fig. 75) that, under assumption of continuation of the same pitch, it must be burried deep under the Kali

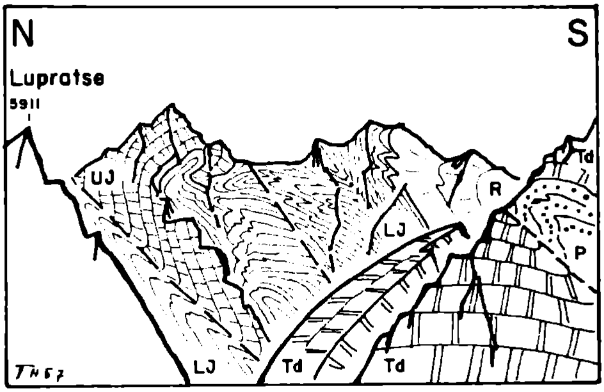


Fig. 125. The Mountains in the Background of the Lupra Valley Seen from the West

UJ Upper Jurassic
LJ Lower Jurassic
R Rhetic
Td Triassic
P Permian

Gandaki (plate VI, fig. 2). While near Muktinath the structure shows direction of pressure towards the south, the Lupra anticline shows reverse forces. Especially further east the Lupra anticline appears gradually to be overturned towards the north (fig. 122 and plate VI, fig. 2 and 3). The Muktinath anticline builds the valley between Deriatse and the Lupratse (5911 m) (fig. 124). The Triassic dolomite of the Muktinath anticline dips just east of the temple steeply towards the north (fig. 75, phot. 43). From here towards the south we find the Permian exposed. From the culmination, the dolomite (Triassic) strikes under some gentle folds steeply towards the south into the Lupra valley (fig. 124). The summit of Lupratse (5911 m) is built by the banded limestones of the Lower Jurassic (fig. 124 and plate VI, fig. 2). Upper Jurassic massive limestone seems to be folded in. As mentioned earlier, the Saligram series transgresses near the Muktinath Gömpa upon Triassic dolomite, then, further south, on Permian and covers on the ridge 5 km south of Muktinath again Triassic dolomite and Rhetic limestones. The latter dips in this ridge to the west (fig. 75). We find the transgression again at the eastern bank of the Kali Gandaki, where it is intensively folded (plate VI, fig. 2, 3 and 4).

Similar as the Muktinath anticline, the Lupra anticline does not continue across the Kali Gandaki valley. At the eastern flank of the valley, in the area of Lupra it does also not continue very far, but joins the southern, neighboured Syang anticline (fig. 135). The latter shows a strong axial rise, towards the east, whereby it increases in magnitude (fig. 122 and plate VI, fig. 2, 3 and 4). Thus, Permian formations occur in the core. The anticline is also intensively folded in itself. In the unnamed peak south of Lupratse (5911 m) the anticline is narrow-pressed, thrust-faulted and folded and heavily reversely overturned to the north (fig. 125).

South of the Syang anticline, we find the *Jomosom syncline* (fig. 135). This structure is at the eastern flank of the valley, near Jomosom narrow-pressed and overturned towards the north (fig. 126 and 128, compare also profile 3, plate III). Furthermore, the southern flank of the Jomosom syncline shows a thrustfault, which strikes through the main ridge between the Kangsartse and the Thinitse (plate VI, fig. 2–4).

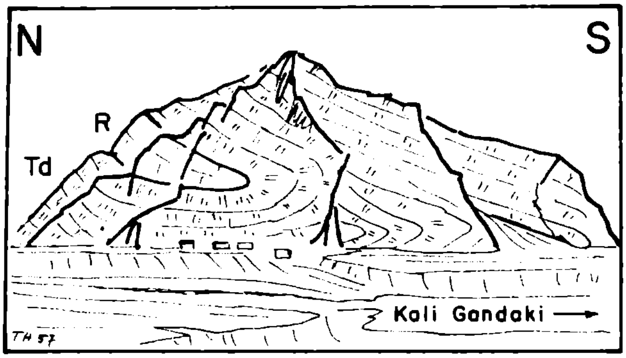


Fig. 126. The Jomosom Syncline
(seen from the west)
R Rhetic
Td Triassic
The syncline consists of Triassic dolomite with Rhetic core and is reversely overturned. The Jomosom village is situated at the foot of the mountain.

Let us now study the geological situation at the western flank of the Kali Gandaki valley (plate VII, fig. 3 and 4). The Jomosom syncline opens and contains Rhetic and Liassic limestones as filling. However, 1 km west of Dangarjong just west of the said transverse fault the Jomosom syncline is lifted and shows a flat, however complicated bottom, in which Triassic dolomite occurs. We do not see a direct connection of the Jomosom syncline across the Kali Gandaki river. This syncline on the ridge between Syang and Marpha (fig. 127) has to be considered as identic with the Jomosom syncline though it is transposed 2.5 km to the southwest and also lifted (fig. 135). The dolomite of the northern flank of the Jomosom syncline strikes far up to the north into the upper part of the Syang valley, appears to cross out into the air and occurs only again north of the Dangarjong anticline below the Dangartse (5712 m). By this means, the Dangarjong anticline develops west of the Dangarjong fault suddenly to a large dome-like anticline, by connecting under angle with the Syang anticline, which strikes through the Syang valley. This is well visible especially through the well exposed yellow-band series of the Carboniferous, which also strikes far up to the north, thereby intensively folded (plate VII, fig. 1, 3 and 4).

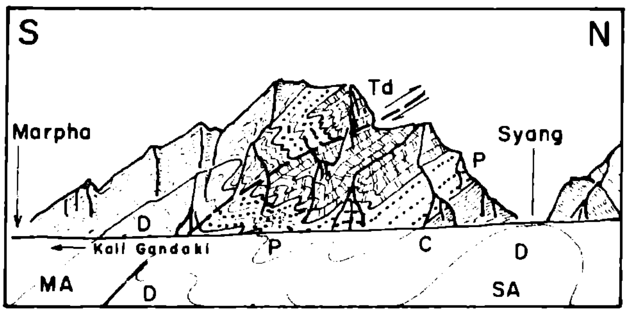


Fig. 127. The Ridge between Marpha and Syang
Td Triassic
P Permian
C Carboniferous
D Devonian
MA Marpha anticline
SA Syang anticline
The syncline lying between (Jomosom syncline) is cut as a fault.
(Compare also plate VII, fig. 3 and 4.)

The Dangartse (5712 m), is built by a syncline of Triassic dolomite, which contains Rhetic and Liassic limestones as filling. The whole syncline is intensively folded and thrust-faulted (plate VII, fig. 1). From Dangartse towards the west, the syncline opens gradually and builds the Sangdaktse (6528 m) and the Syangtse (plate VII, fig. 2 and 3). On the Sangdaktse occur on the top quartzites, overlying the well-bedded and banded Triassic limestones. The quartzite might be of Dogger (Middle Jurassic). The underlying Triassic dolomite strikes into the eastern flank of the said mountain ridge, from here to the south under folds. In the Syangtse occurs a local fold, which is overturned towards the north. Just south of this fold we see a thrustfault (plate VII, fig. 3 and 4).

From the Syangtse, the Triassic dolomite reaches far down to the Syang valley into the Jomosom syncline (plate VII, fig. 4). Underlying, north of Syang we find the familiar yellow-band series of the Carboniferous, which forms an anticline, the *Syang anticline* (fig. 135 and 127). The Syang anticline joins north to the Jomosom syncline. The dolomite wedge south of Syang is intensively folded (fig. 127). Thrustfaults which dip steeply south, intersect the dolomite wedge. Also the underlying Carboniferous is intensively folded (fig. 127). The Carboniferous forms an other anticline south of the Triassic dolomite wedge; this is the *Marpha anticline* (fig. 135). The dolomite wedge of the Jomosom syncline itself opens upwards to a narrow syncline (the Syangtse-Jomosom syncline). From the southern ridge of Syangtse the Triassic dolomite follows the ridge again far down to Marpha, forming a narrow-pressed, deep, northerly overturned syncline. This one appears to correspond to the Thini syncline at the eastern flank of the Kali Gandaki valley (fig. 135, plate VI, fig. 2 and 4). From here, the dolomite strikes into the southern flank of the tributary valley of the Dapa Chu and forms two further narrow-pressed, towards the north overturned synclines, which however do not reach so deep as the northern structures. Also these two ones have to be considered as partial structures of the Thini syncline (fig. 135). South of the Marphatse, the Triassic dolomite strikes (under southern dip) finally into the air (plate VII, fig. 4). From here on towards the south, we find only lower formations.

The Carboniferous of Marpha was proved by a finding of a zaphrentis species of the same type as given in phot. 39 from Tengi in the Manang valley.

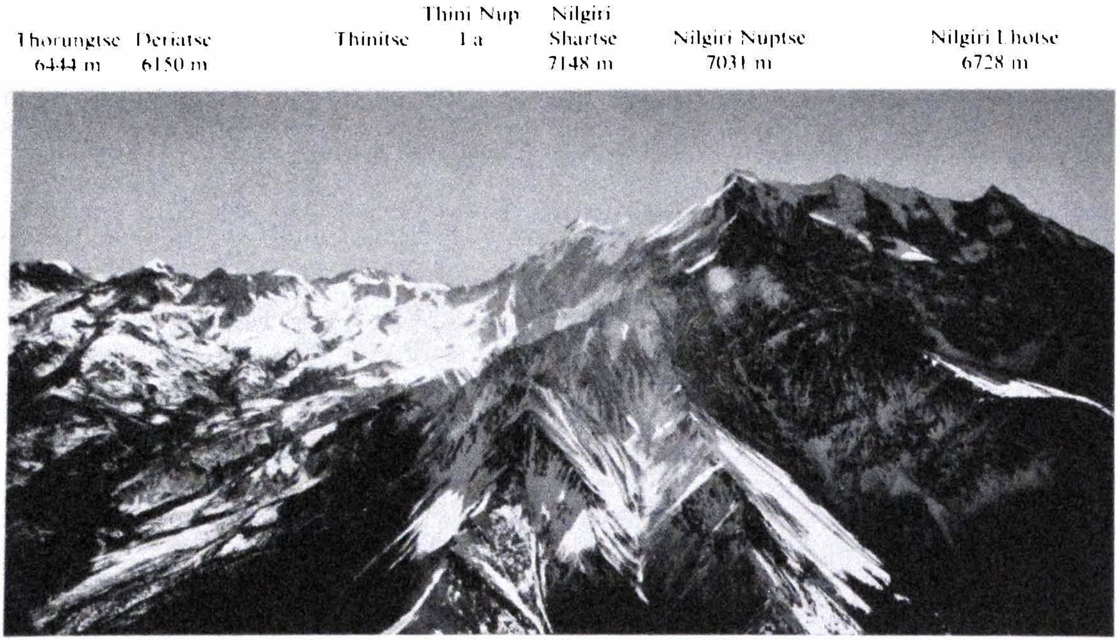
The Marpha anticline is in the lower part doubled, with two cores of Devonian limestones. The main transverse fault of Dangarjong ends as such between Syang and Marpha, just west of the Kali Gandaki river. At this place, no vertical movement can be observed; the formations and also partly the structures correspond pretty well on either sides of the river. This fact is surprising, after having seen the fault east of the Dangartse with its tremendous relative movement of 2500 m and still on Dangarjong Lho La of a few hundred meters. However, the missing vertical movement south of Dangarjong is substituted by a tremendous axial pitch of all the formations towards the east. (See plate VII, fig. 3 and 4.)

However, the fault system continues towards the south in a different way. At least 3 partial faults, which are situated west of the main Dangarjong fault can be observed. The most western one shows on the ridge north of Syang even a vertical movement, whereby the eastern portion has sunk by about 50 meters.

Before moving further south into the Palaeozoic, let us study the geology at the eastern flank of the Kali Gandaki valley. The dolomite of the southern flank of the Jomosom syncline strikes uphill towards northeast (plate VI, fig. 2–4). When climbing the ridge east of Jomosom, one enters from the Norian dolomite gradually Lower Triassic formations. These are proved by finding of numerous fossils (phot. 69). A preliminary determination in the field resulted as follows.

Ammonite spec.
Terebratula Gregaria (Rhetic)
Rhynchonella (Rhetic)
Loxonema obsoletum (Muschelkalk)
Myophoria Goldfussi (Lower Keuper)
Encrinus Liliformis (Muschelkalk)

However, we have right here to point out a problem: The localities of the fossils (all on solid rock exposures though heavy snow cover) do not allow to say whether there is a normal single series or whether the formations are sliced. Heavy snow did not allow to study a gapless profile.



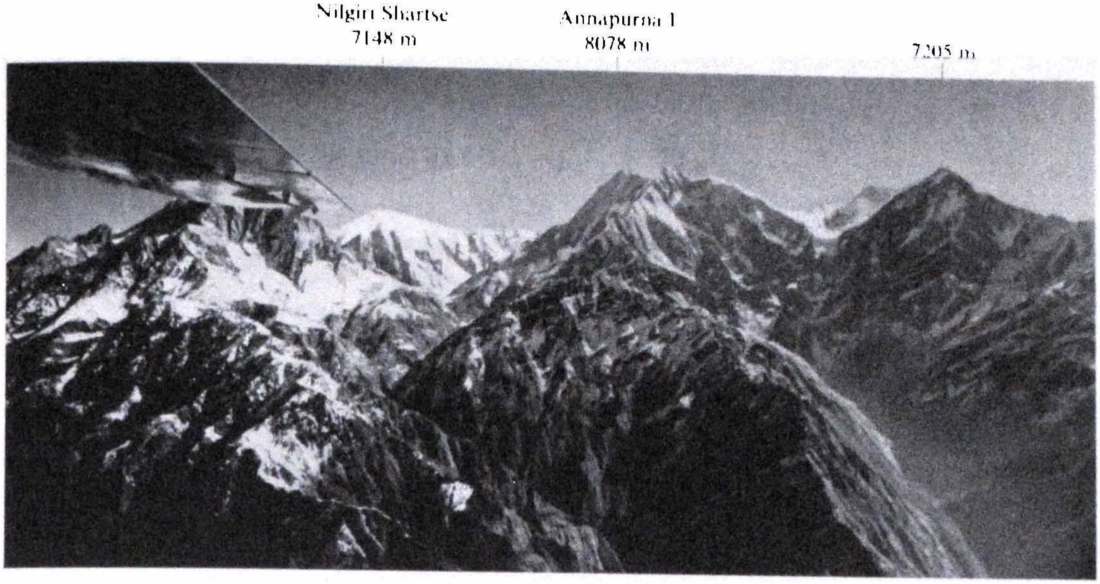
Phot. 70. The Southern Part of the Thakkhola from Thorungtse to the South Including the Nilgiri Group
(aerial photo from 5000 m above Tukucha)
Note the outstanding height of the Annapurna range compared with the "Gipfelflur" of the mountains north of it. The large fold in the Nilgiri group is well-expressed. (Compare fig. 128, and plate VI, fig. 4.)

4. Jomosom–Tukucha

The eastern flank of the Kali Gandaki valley, opposite of Syang, shows an extraordinary complicated structure (fig. 128). The above-mentioned Triassic dolomites of the Jomosom syncline are followed towards the south in a normal succession by the Permian quartzites, conglomerates and slates, then the Carboniferous formations with the yellow-band series. The latter show an increasing southern dip which gradually changes to vertical position and finally turns to normal steep northern dip. These latter series form a much thrust-faulted and sliced anticline (the Marpha anticline, see fig. 135), which shows still the direction of the forces towards the north. The Carboniferous series contain pegmatites, which partly are involved in the folding, partly cross the beds under oblique angle upwards. This anticline corresponds to the Marpha anticline of the western flank of the Kali Gandaki valley. South of the Thini Chu occur Devonian limestones (fig. 128), which also show folding and slicing towards northern direction. The overlying Carboniferous with the yellow-band series is especially heavily folded (fig. 129). These series contain pegmatites. Opposite Marpha the Devonian limestones form a flat anticline (fig. 130). Separated by black Carboniferous slates follow three further Devonian Schuppen, all of them thrust towards the north in a reverse sense. The lowest one of those Schuppen shows in its upper part a folding towards the south (fig. 130).

The *Marpha anticline* strikes through the Thini valley eastwards right to the main watershed between the Kali Gandaki and the Marsyandi (fig. 135 and 128). The axial rise to the east is so strong, that even the Permian formations strike out into the air in the Syang anticline (fig. 128 and plate VI, fig. 4).

A syncline, the Thini syncline, follows to the south, with a wedge of Jurassic limestones as filling (on Thini Nup La, fig. 128). The series from this syncline to the south right to the Nilgiri of the Annapurna range are a normal succession consisting of Lower Jurassic limestones, Triassic dolomites, Permian slates and quartzites, yellow-band series and slates of the Carboniferous and finally the Devonian limestones with the net pattern of clays and marls. The dip is generally to the south; the whole



Phot. 71. The Annapurna Group Seen from the West
(aerial photo from 5000 m above Tukucha)
(Compare geological panorama given in plate VI, fig. 4.)
The photographs 70–72 form an almost panoramic view.

series reversely overturned towards the north. This is caused by a huge reverse fold in the northern flank of the Nilgiri (fig. 128 and phot. 70 and plate VI, fig. 2 and 4). The Devonian and Silurian limestones are in the Nilgiri group tectonically accumulated to a huge thickness of 3 km. This is usual in the Schuppen zone just north of the crystalline nappe roots. They build in the Nilgiri a large reverse anticline in the northern flank of the main ridge which extends from Nilgiri Shartse (7148 m) to Nilgiri Nuptse (7031 m) (phot. 70; plate III, profile 4; plate VI, fig. 2 and 4). This anticline is called the *Nilgiri anticline* (fig. 135). Further south in the ridge between Nilgiri Nuptse (7031 m) and Nilgiri Lhotse (6726 m) the Devonian formations form a flat syncline (plate VI, fig. 4 and phot. 70 and 71). This syncline is called the Tukucha syncline (see fig. 135).

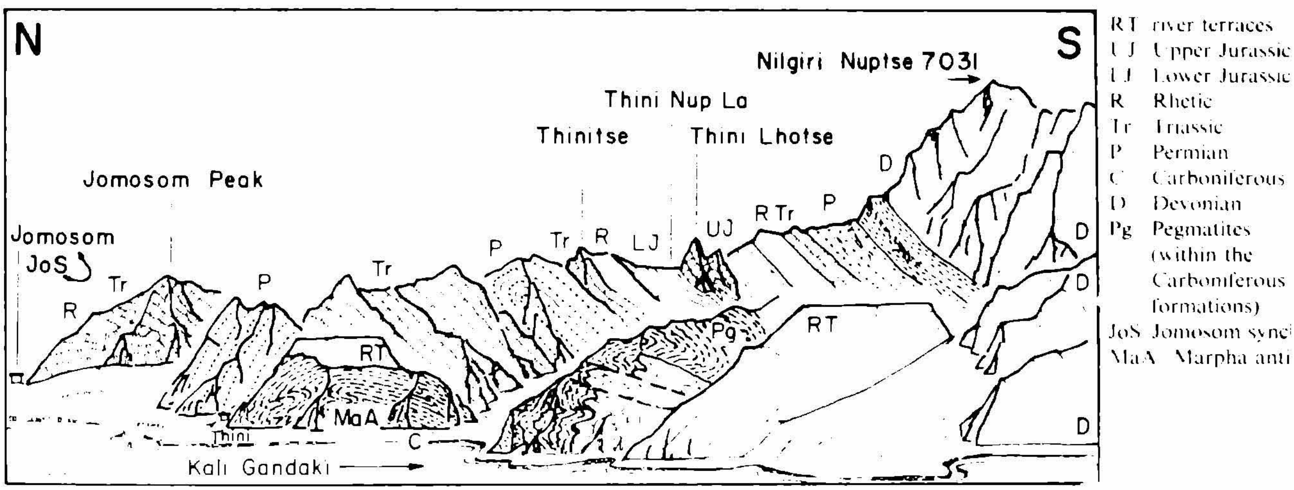


Fig. 128. The Eastern Flank of the Kali Gandaki Valley opposite to Syang–Marpha
The sketch shows the reversely (northerly) folded series of Palaeozoic and Mesozoic formations. Due to distortion looking towards the main ridge extending from the Nilgiri range towards the north appears less inpressive than it really is.

South of Nilgiri Lhotse (6728 m) the Devonian limestones dip north and overlie the Silurian limestones, slates and quartzites with the underlying crystalline (fig. 131 and phot. 71).

In the northwest ridge of Nilgiri Shartse (7148 m) the Triassic dolomite which joins to the south in the Thini syncline continues right down the Thini valley as far as 4000 m (plate VI, fig. 3 and 4).

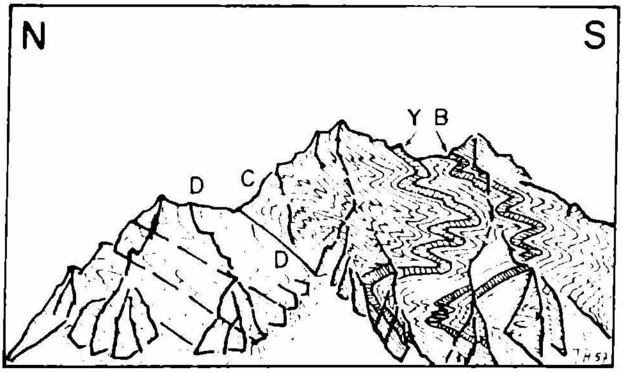


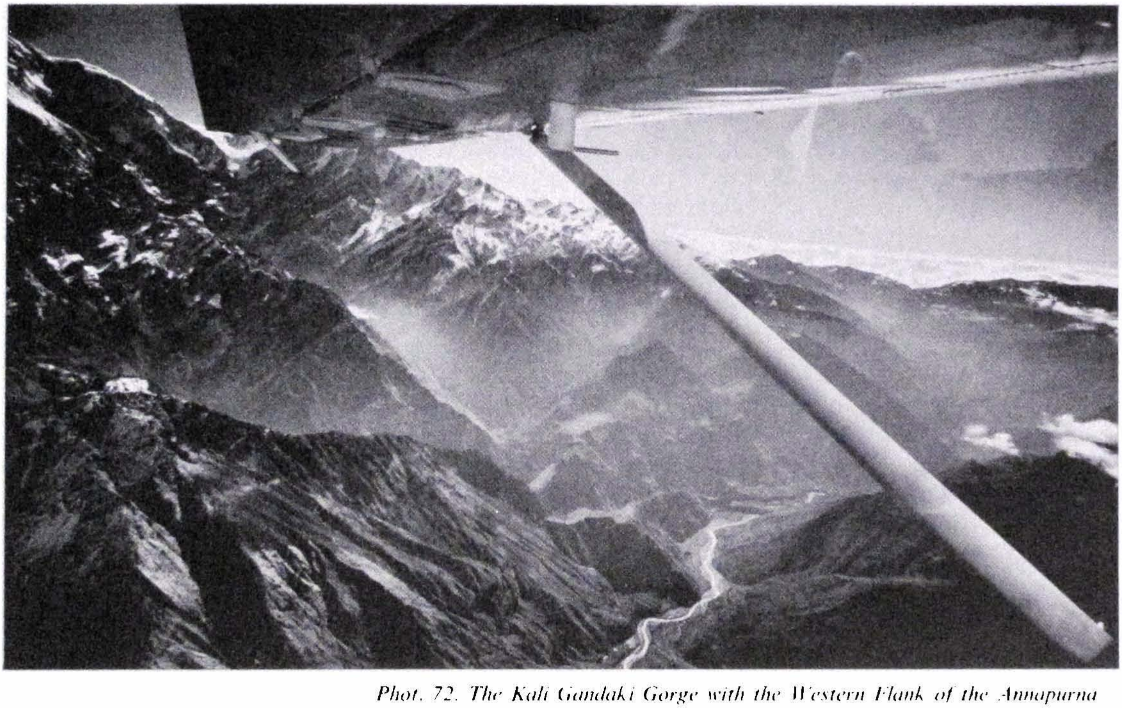
Fig. 129. Detail Sketch of the Tectonics in the Carboniferous at the Eastern Flank of the Kali Gandaki Valley opposite to Marpha.

C Carboniferous
YB yellow-band series (within the Upper Carboniferous)
D Devonian

The tectonics is well expressed by the yellow-band series. These formations contain pegmatites, which partly cross the folds and partly are involved in the folding.

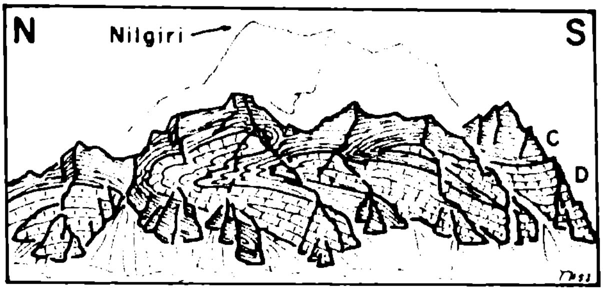
The Silurian limestones build the barrier southwest of Tukucha (opposite to Larjung). This shows a transverse structure in form of a transverse anticline, with axis north-south (plate VI, fig. 4 and phot. 2). In addition we find in this zone—especially well to see from airplane—a number of transverse faults and fractures (see phot. 2) which all strike north south. The transverse anticline does not surprise, since we have such structures in all the main Himalayan transverse gorges. The faults and structures are the southern continuation of the Thakkhola Graben faults. They extend still further south, as we shall see later on.

Annapurna I 7205 m Ulleri pass



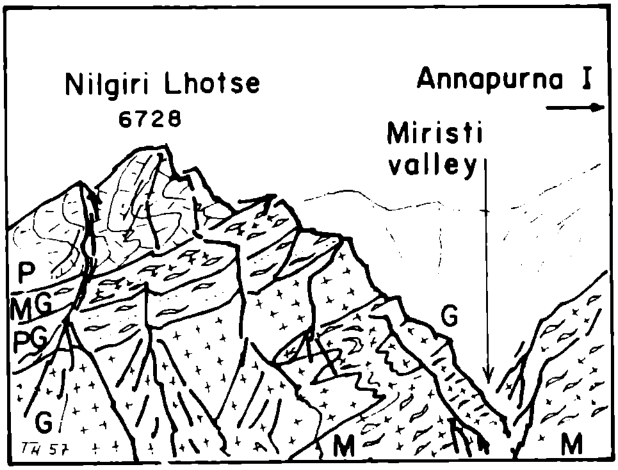
Phot. 72. The Kali Gandaki Gorge with the Western Flank of the Annapurna (aerial photo from 4500 m above Ghasa)

Fig. 130. The Reverse Folding in the Carboniferous—Devonian Formations at the Eastern Flank of the Kali Gandaki Valley near Chairo Village
C Carboniferous
D Devonian



We now study the western flank of the Kali Gandaki below Marpha. While further north, the two sides of the valley do geologically not coincide, we can from now on easily find the corresponding formations and structures on both sides of the valley. The Devonian limestones build a first doubled reverse fold in the Marpha anticline (fig. 127). The whole mountain range of Dapa Chu and Tukucha Chu is built by Devonian limestones, which form at its southern flank towards Tukucha huge dip-slopes. South of Marpha we find a strong axial pitch towards the west. In the wedge west of Tukucha which descends from Tukuchatse (6915 m) (fig. 132) we find also folds with axial striking north-south. This transverse folding belongs to the transverse structure which strikes through the lower part of the Thakkhola into the Kali Gandaki gorge. It might be considered to be the southern continuation of the Dangarjong transverse fault. It appears that this transverse fault was temporarily "swallowed" in the main phasis of the orogenic during overthrust of the large nappes and the pressing out of the crystalline roots, but than afterwards reactivated in a late phase of the orogenesis (Tertiary–Lower Quaternary). We find this transverse structure to continue still further south, in the southeastern ridge of Dhaulagiri (plate VII, fig. 4 and phot. 2), here again as transverse fault. It appears to turn from here into south-southwest direction towards the Dhor Patan valley.

Fig. 131. The Nilgiri Lhotse 6728 m Seen from the West
S Silurian
MG mixed gneisses with granitic layers
PG predominant paragneisses
G predominant granites and orthogneisses
M migmatites, with granitic layers and pegmatites
(Compare phot. 70 and 71.)



Arenaceous biotite-gneiss occurs in the Dapa Chu. It is a reverse fold and Schuppe, which brings these old formations (Cambrian) so high up amidst the Tibetan sediments (fig. 132) and corresponds to the Nilgiri anticline (fig. 135). The same Schuppe builds (with southerly dipping formations) the Tukuchatse (6915 m) (fig. 132 and phot. 73, right side). The upper part of the peak seems to consist of Carboniferous series, since it appears that the yellow-band series could be recognized. The structure of the Tukucha range is well-visible by the well-bedded Devonian limestones and Carboniferous slates and quartzites. Especially in the southern flank of the Tukuchatse the beds are tremendously folded and tectonized (fig. 132 and phot. 73). Pegmatites reach up to the Upper Devonian.

Phot. 73. The Dhaulagiri (8172 m), Seen from the East (aerial photo) (Compare fig. 132.)

In general, we find a huge syncline between the Tukuchatse and the Dhaulagiri, the *Dhaulagiri syncline* (fig. 135), for towards the Dhaulagiri the dip changes to normal northern direction (phot. 73). The ridge, just north of the Dhaulagiri glacier (which flows down into the Tukucha basin) shows the most southern reverse fold. It appears to be Carboniferous, which is intersected by swarms of granites and pegmatites (fig. 132, phot. 73).

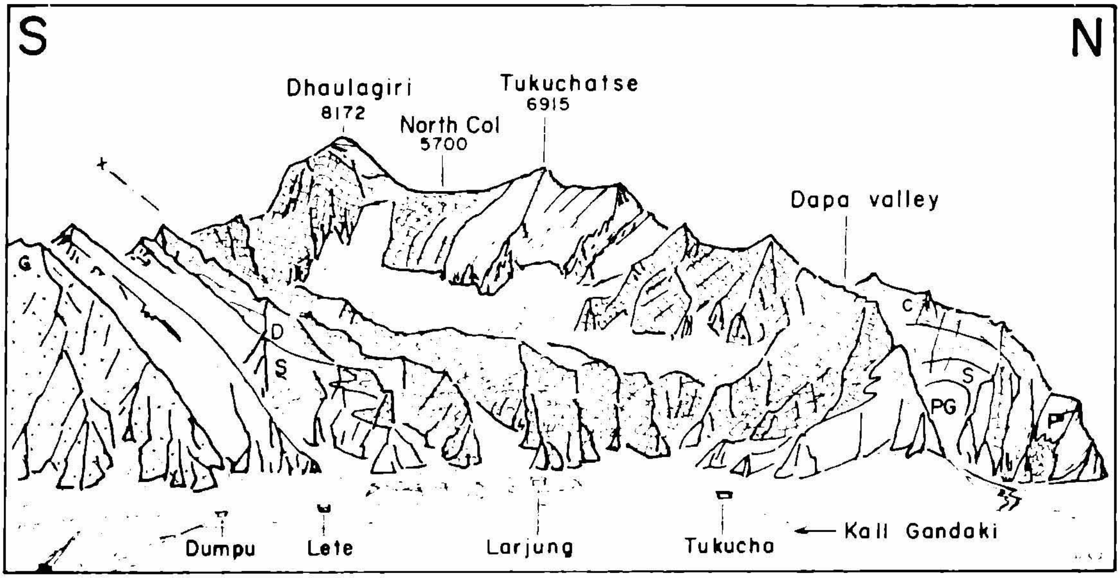
Fig. 132. The Eastern Flank of the Dhaulagiri Group with the Tukucha Basin

The Silurian and Devonian formations are tectonically piled up to an excessive thickness. The Tukuchatse (6915 m) is built by a overturned syncline (reverse) with Carboniferous filling.

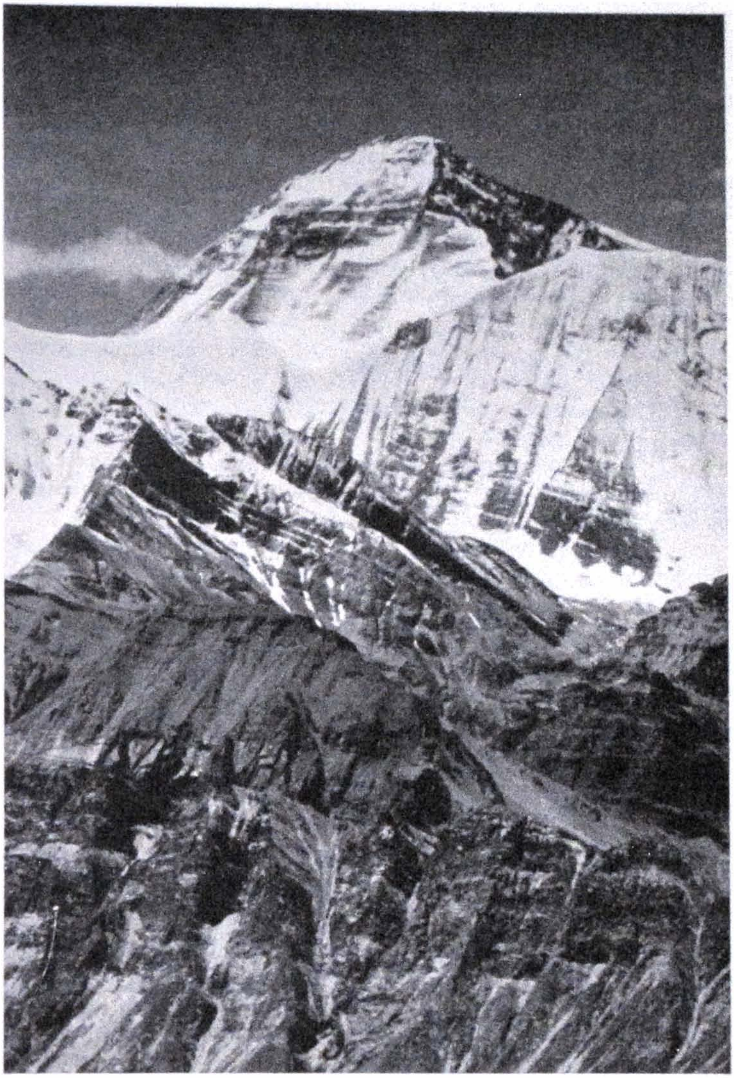
The Dhaulagiri Schuppe is separated by a thrustplane from the basement, with an angle unconformity along the thrustplane.

For the structure of the Dhaulagiri upper part compare also phot. 73.

P	Permian	D	Devonian
C	Carboniferous (on Dhaulagiri summit possibly Permo—Carboniferous)	S	Silurian
		PG	paragneiss (in the Dapa valley)
G	granite-gneiss of the topmost Katmandu nappe, pegmatites reach up on Dhaulagiri to 5400 m		



Phot. 74. The Dhaulagiri (8172 m), Seen from the Northwest



The summit is built by the well-bedded and northern dipping Permo-Carboniferous formations.

The snow-covered ridge crossing the whole picture from right to left connects Little Dhaulagiri (7751 m) via French Col with the Tukuchatse (6915 m). This ridge is built by Devonian and Carboniferous formations, which are dipping south and form a reverse fold (right side of the picture).

The Mukut valley is seen in the foreground. The sourrounding mountains of this valley are built by Mesozoic formations, which are reversely folded. (Compare geological map plate II.)

The bold peak of Dhaulagiri (8172 m) itself might consists of Permo-Carboniferous formations. This was concluded from the tectonics as well as from a rocksample, which kindly was handed over to [illegible] members of the successful Swiss Dhaulagiri expedition (1960).

We recognize, that the huge masses of Silurian-Devonian limestones, which form the Tukucha basin, are tectonically accumulated. We also can separate a Dhaulagiri Schuppe (fig. 132 and phot. 73). The separating thrustplane strikes into the air in the southeastern ridge of the Dhaulagiri at approx. 4500 m (see fig. 132 and phot. 73). The overthrust series dip northeast and more flat than the series underneath the thrustplane. The latter thus is a clear tectonic unconformity.

The Dhaulagiri Schuppe shows intensive reverse folds in its northern part, while the series underlying the thrustplane show an even northern dipping into the depth and form the root of the topmost crystalline nappe. (See phot. 74.)

The Dhaulagiri Schuppe is partly a fold, since also the reverse angle of the Schuppe is developed, and the crystalline of the Schuppe is not in direct contact with the Silurian-Devonian limestones of the underlying nappe root.

The crystalline of the topmost nappe root occurs at Dumpu (fig. 134). It strikes exactly through the riverbend of the Kali Gandaki, and from this place towards southwest up to the southeastern ridge of the Dhaulagiri. It appears that there is a bend in the strike, originated from the above-mentioned transverse anticline. East of the Kali Gandaki river the strike is directed towards the southeast, while west of it it shows western direction. This can be observed especially well from airplane (see phot. 2 and 72). Especially phot. 72 shows how a number of transverse faults strike through the western flank of the Annapurna range in southeast direction. The same photograph also shows the general northeastern dip of the said mountain flank, which is not normal.

The topmost crystalline consists of granite-gneiss near Dumpu. The Silurian limestone is overlying partly directly the granite-gneiss at Dumpu, only at places occur intermediate micaceous sandstones (fig. 134). This is different from most other places on the back of the crystalline roots. The Silurian limestone is marmorized, partly changes to calcsilicate rocks (fig. 134).

The equivalent of the Dhaulagiri Schuppe is uncertain to be recognized on the Annapurna, at the opposite side of the valley. The well-bedded Devonian limestones show in the Nilgiri Lhotse (6728 m) a sligt reverse fold (fig. 131). Underneath we find layers of dark paragneisses, granites and mixed gneisses. The contents of granites increase downwards, but always intersected by layers of dark paragneisses. The latter show also structures, namely a syncline which is overturned to the south on the southern ridge of Nilgiri Lhotse (6728 m) (fig. 131). This is the lowest structure, for, further down, all the formations dip evenly to the north-northeast (at least in the Nilgiri range). A separation of a Schuppe equivalent to the Dhaulagiri Schuppe could be only justified (if any) between the evenly northeastern dipping gneisses and the overlying syncline structure.

5. The Quaternary between Jomosom and Lete

One of the most interesting phenomena of the Thakkhola is probably the large plain north of Dumpu or the flat river course of the Kali Gandaki north of Dumpu in general (phot. 1 and 2). The main break in the gradient at Dumpu is at 2400 m, and it corresponds exactly with the upper margin of the crystalline, that means with the upper boundary of the topmost nappe (fig. 6, 134). The Kali Gandaki river flows at Dumpu over the granite-gneiss, just before it begins to drop into the Kali Gandaki gorge. Indeed a very impressive picture, when standing on that bridge and looking north into the large plain of Tukucha, which is completely flat with meandering rivers and which extends 8 km right up to Tukucha and 40 km as far as Chele—where the Kali Gandaki leaves the last cañon—like gorge cut into the Thakmar series. When turning around and viewing south, the waters of the Kali Gandaki, which from the north down to here have been meandering in several river branches, are pressed into the gorge and with tremendous power are dropping all on a sudden into its gorge.

Regarding the big river terraces, we found them only north of Marpha (plate VI, fig. 4, plate VII, fig. 4 and phot. 1 and 69). They are missing further south. Instead, we found a number of large ice age lateral and terminal morains.

At Jomosom a terminal morain consisting of predominantly Devonian limestones, barriers the valley (plate VII, fig. 4, phot. 1). Concluding from the material, it must be a morain of the ancient main valley glacier, since Devonian formations occur only further north, in the Keha Lungpa valley, the Kyugoma valley and the Chudidi Chu. No Devonian formations occur in the tributary valleys near Jomosom.

Further south near Thini village we find large morains which were deposited by the ancient ice age glacier originating in the Thini valley. Still today the limit of permanent snow and glaciation is relatively low, namely at 3500 m only. However, this cannot be considered the normal limit of glaciation, since the respective glacier is nourrished by the avalanches from the northern flank of the Nilgiri, which is still in the reach of the monsoon. With its altitude of 7000 m the Nilgiri range gets all precipitation in form of snow.

Further large morain deposits occur at the confluence of the Tukucha Khola from the ancient tributary Tukucha glacier, and near Larjung from the ice age Dhaulagiri glacier form the eastern flank of Dhaulagiri. The latter must have filled a large portion of the Tukucha basin, since lateral morains have been found even at the opposite valley flank. It is possible, that the Tukucha basin is not only of tectonic origin (as we shall see later) but has also been eroded to a reverse gradient by ice age glacial erosion.

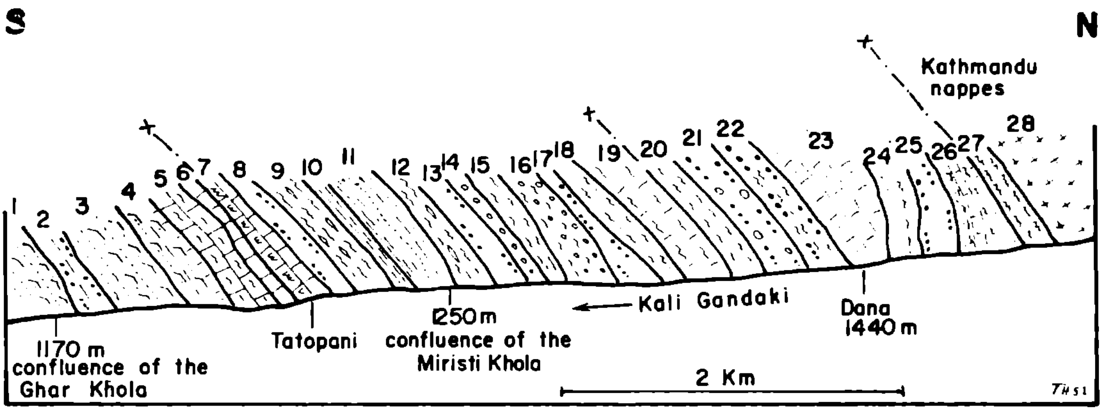


Fig. 133. Geological Detail Profile in the Kali Gandaki Gorge
The whole series from (1) to (26) are typical formations of the Nawakot nappes, Muri zone and Jajarkot zone. (See the continuation to the north in fig. 134.)

1 hard dark green, chlorite-quartz sandstone
2 white, dense, banded and platy quartzite
3 very hard chlorite-quartz sandstone (forms the high wall north of the Ghar Khola junction), however the flanks on either sides of the river do not correspond, it seems that the western flank is transposed towards the south by a transverse fault through the river
4 gradual change out of (3) above, getting, slaty and calcareous
5 arenaceous chlorite-calc mica-schist
6 tectonized zone with limestone
7 white marble (200 m), containing microfolds
8 white platy quartzites, with pyrites
9 phyllites, with quartz lenses, tectonized (abundant microfolds)
10 fine black slates
11 black-blue arenaceous slates, interbedded with banded coarse-grained sandstones (in the upper part): tectonized; strike is parallel to the Kali Gandaki river at the Miristi confluence, apparently caused by a transverse fault.
12 phyllites, with quartz veins and lenses, strong clivage dipping south
13 white quartzite
14 conglomerate (similar to those near Nawakot), develop gradually out of (13) above
15 sericite-phyllite
16 phyllites, interbedded with conglomerates
17 hard blueish grey fine-grained quartzite
18 arenaceous phyllites
19 calc mica-schist
20 graphitic phyllites, heavily tectonized
21 conglomerates and conglomeratic quartzite
22 white dense quartzite, with layers of sericite-quartzite
23 calcareous sandstone, spotted with quartz grains
24 massive hard coarse-grained sandstone, with layers of mica-schists
25 white dense platy quartzite, with sericite
26 multi-coloured micaceous quartz sandstone, slightly calcareous in the bed joints, biotite
27 mica-schists
28 biotite-granite, with pegmatites

6. The Thakkhola Gorge

As we have seen above we enter the crystalline of the Kathmandu nappes, respectively their roots at Dumpu. The Kathmandu nappes reach as far down as Dana (see fig. 133 and 134). The various crystalline masses are interbedded by sediments, which are tectonized and form the boundaries between the various nappes (fig. 134). The strike is generally west–east, the dip north. However, at some places this normal strike is disturbed (for example near the confluence of the Miristi Khola) where it is directed north–south. Undoubtedly some transverse faults and fractures strike through the gorge.

Below Dana we find quite different formations, mostly sediments with low and only partial metamorphism (fig. 133). These belong to the Jajarkot and Muri Zone and to the Nawakot nappes.

The lower part of the gorge, below Kabre shows huge ancient river terraces. Different from the Thakkhola further north they show a dip to the south. It seems that they have been tilted in a late phase of the orogenesis, originated by the rise of the crystalline roots.

In general, there is flat anticline structure striking through the Thakkhola gorge. At the eastern flank the strike is directed northwest–southeast (see phot. 72), while the western flank of the valley shows a west–east strike.

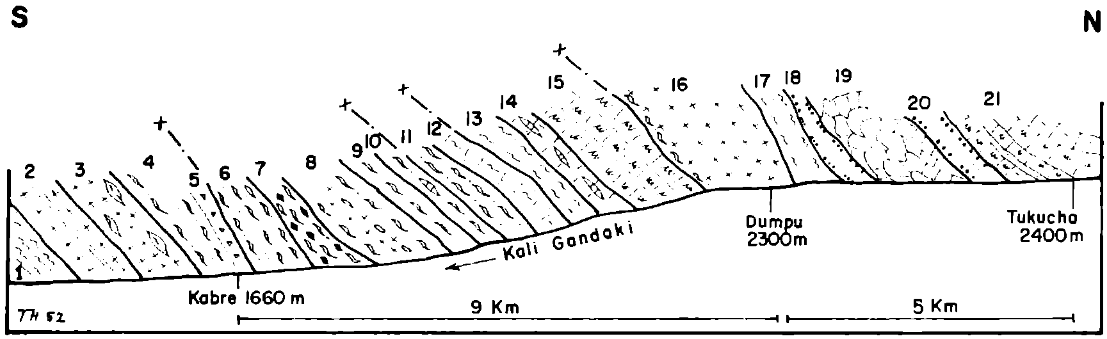


Fig. 134. Geological Detail Profile of the Northern Part of the Kali Gandaki Gorge
The section between Lete and Tukucha is not to scale; it is compressed with regard to the intensive folding and repetition of the series. This profile continues from fig. 133 to the north; (1) in this figure corresponds to (27) in fig. 133.

1 biotite-mica-schists
2 biotite-granite, in the upper part containing iron ore and red slates
3 granite-gneiss, with inclusions of migmatites
4 arenaceous biotite-gneiss (at Khabre, forming the wall with the tributary waterfall)
5 calcareous breccia
6 arenaceous biotite-gneiss
7 garnet-biotite-gneiss
8 banded arenaceous gneiss, with layers of migmatite (this series forms the gorge as given in phot. 4)
9 clear-coloured very acid gneiss
10 tectonized zone of slices of arenaceous gneisses and marble, the latter in small layers and lenses
11 thickly-bedded biotite-sandstone and arenaceous coarse-grained biotite-gneiss
12 calcareous biotite-sandstone
13 biotite-sandstone
14 calcareous sandstone, with fluidal arenaceous limestone
15 white and greenish coarse-grained micaceous marble
16 series of granites and porphyric granites
17 micaceous sandstone
18 quartzite
19 series of limestone, in the lower part yellow and pink arenaceous, in the upper part blue-banded, this series shows the big folds at the western flank of the basin between Lete and Tukucha
20 platy, dark blue arenaceous quartzite
21 coarse-grained marble, banded, with layers of sandstone, weathering yellow, much tectonized
22 limestones and marble, banded with silicious layers, in the upper part slaty and greenish with sericite

V The Structural Pattern of the Thakkhola

After having studied the details of the geology of the Thakkhola we now try to obtain a general understanding of the geology and the possible evolution of the respective area. The bewildering number of structures and faults in all directions are possible to put in some order. For this purpose we have given one special simplified map showing the structures only (fig. 135) and one map containing the faults only (fig. 136). However, we want to make clear right now, that also most of our structures have mostly originated out of faults.

Basing on these special maps, we can pretty well divide the Thakkhola in different geological and tectonic zones, namely (fig. 137)

a) the plateau zone
b) the zone of flat warping
c) the zone of moderate anticlinal folding
d) the zone of intensive normal (southerly directed) fault-folding
e) the zone of intensive reverse (northerly directed) fault-folding
f) the Schuppen zone
g) the crystalline roots zone of the Katmandu nappes.

The plateau zone belongs (geologically spoken) to the Tibetan Plateau. It gradually changes towards the south into the zone of flat warping, that means into flat anticlines and synclines. Thus there is no distinct boundary between the plateau zone and the zone of flat warping.

The zone of the normal southerly directed intensive folding ends in the west on the Kali Gandaki river (fig. 137). At Lupra it shows a width of only a few kilometers. But to the east it widens and this still more beyond the area of fig. 137, and reaches a maximum width of 12 km between the Naur village and the Manaslu granite of Peri Himal (see geological map plate II).

The zone of intensive reverse fault-folding crosses through the Thakkhola and extends beyond the investigated area along the whole main range of the Himalaya in Nepal.

However the tectonic picture may be complicated, it is more understandable when we consider the pattern of the various fault systems, which are superimposed on the structural pattern. Thus, west of the Kali Gandaki river the boundary between the zone of flat warping and the zone of moderate folding is divided by the longitudinal thrustfault of the Kyugoma valley. In general, the eastern flank of the Thakkhola is geologically much more complicated than the western flank. This is explained by the all dominating transverse trench of the Thakkhola, which separates two distinct zones seen from a more general standpoint of view (fig. 136).

The Thakkhola Graben shows an unsymmetric lay-out with regard to its axis. The western margin is formed by a main fault system, along which the trench has sunk in, with a maximum vertical movement of 3000 m east of the Thakmartse. While there is between the Kyugoma valley and Dangarjong one clear cut, we find further north a staircase fault, that means the main fault is accompanied by a number of partial faults (fig. 136). However, these partial faults are not much separated from the main fault.

The eastern margin of the Thakkhola trench is quite different. A clear main fault of the magnitude of that one of the western flank is missing. There are a number of transverse faults (fig. 136), especially in the southern part south of the Narsing valley. However, their respective movement is minor compared with the Dangarjong fault. On the other hand, corresponding formations and structures on either sides of the Thakkhola trench are at about the same altitude [or slightly higher at the eastern mountain range from Thorungtse (6444 m) to the Damodartse (6539 m)].

The 3000 meters movement in the Dangarjong fault is balanced by a general strong axial dip from the eastern mountain range to the west. The bottom of the transverse Thakkhola Graben forms a

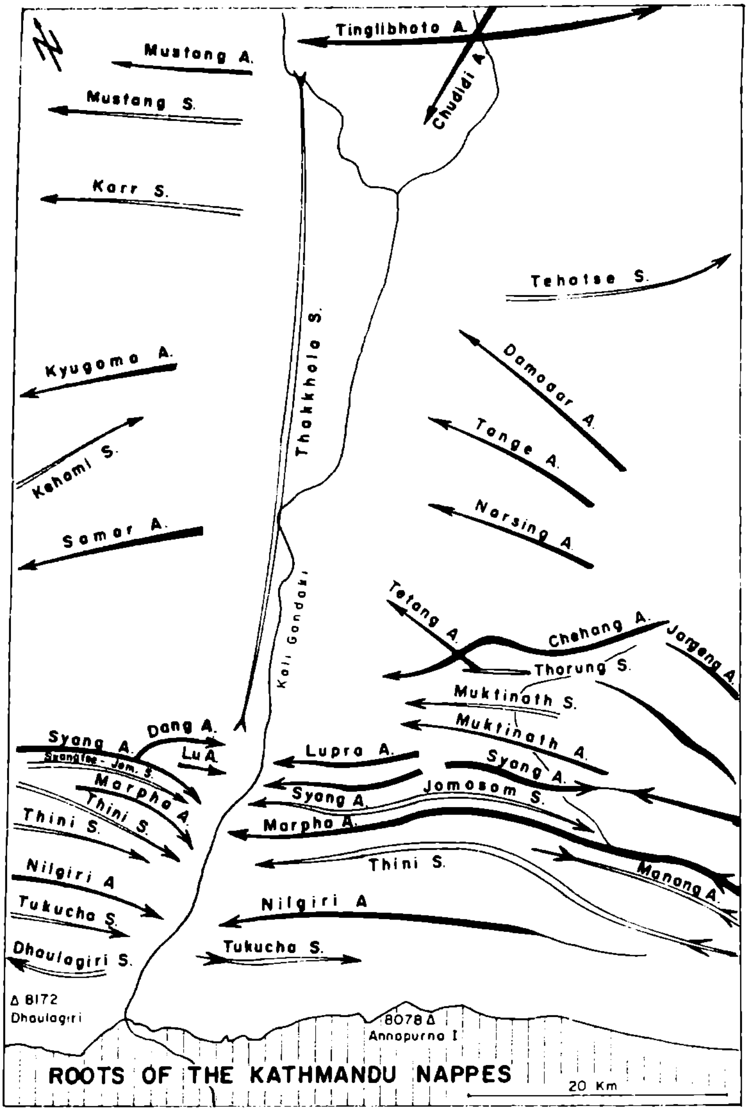


Fig. 135. Sketch Map of the Thakkhola. Showing the Structures

The arrows indicate the axial pitch

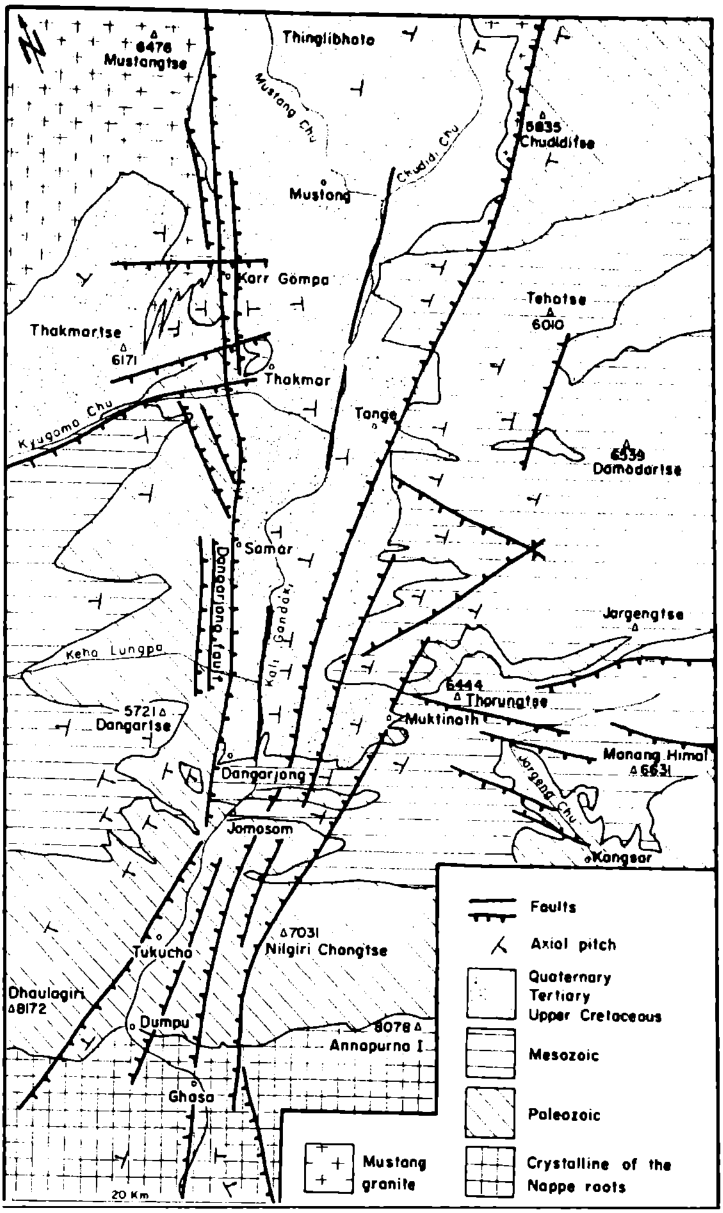
A = anticline

S = syncline

syncline, since also at the western margin the underlying Mesozoic series are bent up along the Dangarjong fault. Due to the unsymmetric character of the trench as outlined above, the "synclinal" axis of the Thakkhola Graben is shifted to the west, close to the Dangarjong fault (fig. 135).

The general western pitch of the eastern mountain range (phot. 46) continues further west, beyond the Dangarjong fault, however more flat (fig. 135). The western pitch of the western mountain flank ends in the south with the Dangarjong fault: South of Dangarjong all the reverse structures show a strong axial pitch towards the east (fig. 135). Thus, this southern part of the Thakkhola is a distinct syncline valley. This however changes again further south, in the Schuppen zone and in the Main Himalaya Range, where the structures pitch away from the axis of the Kali Gandaki valley (fig. 135), that means we have a transverse anticline in this part.

Fig. 136. Sketch Map of the Thakkhola, Showing the Faults



If we want to understand (geologically spoken) the difference between the western side of the Thakkhola trench and its eastern side, we have to evaluate the geological conditions of a larger area. Already in fig. 135 and 136 we can see that there are more structures and more complicated structures at the eastern flank. Also, the number of longitudinal faults increase towards the east. Thereby a distinct change of the general strike from the normal west-northwest–east-southeast direction to northwest southeast takes place.

This is the influence of the tectonic Manaslu arc, which joins with its northwest-southeast strike the west-eastern striking Annapurna arc under angle (see geological map plate II).

VI On the Evolution of the Thakkhola and the Adjacent Areas

In the first volume of these publications it was lined out, how the great Himalayan range by no means form one single range, but is by the large transverse valleys cut into several segments or rather tectonic arcs. Thereby the transverse valleys show in general anticline structure, while the arcs of the high range in between have syncline character accompanied with tremendous ancient transverse faults. In addition, we have different phases of mountain building, otherwise it can not be explained how the

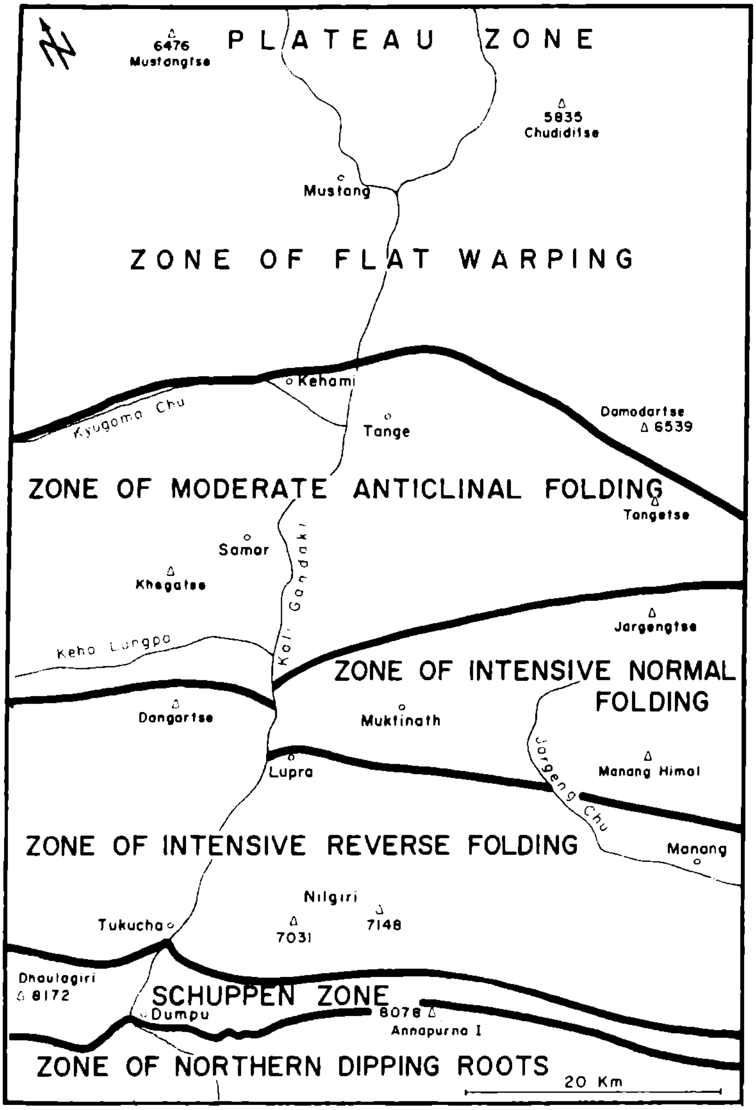


Fig. 137. Sketch Map of the Thakkhola, Showing the Main Tectonic Zones

main transverse rivers have their origin in the north on a much lower mountain range (the Tibetan Marginal Range) with altitudes of not more than 6500 meters, and break through the great Himalaya range, which is much higher (more than 8000 meters).

It is evident, that the crystalline Kathmandu nappes, which build the backbone of the Main Himalaya Range, are very young, while the Tibetan Marginal Range originated much earlier, thereby forming right from the beginning the main watershed between the Ganges system and the Tsangpo system.

The Thakkhola illustrates those different phases very well. The first phase has been called the Thorung phase*. The Tibetan Marginal Range has been built during this phase (Upper Mesozoic), due to horizontal pressure of the Tibetan bloc (later the Tibetan Plateau). The Tibetan Marginal Range builds the Thorungtse–Jargengtse–Damodartse and at the western flank the ranges south of the Kyugoma valley. This includes the zone of the moderate folding and parts of the zone of intensive normal folding as given in fig. 137. The zone between this primary mountain range and the later root zone of the Kathmandu nappes in the south sank in and formed a longitudinal Graben, the Tibetan marginal synclinorium in which the complete Mesozoic formations were deposited (now including the zones of intensive normal folding and the zone of intensive reverse folding shown in fig. 137). This convergent folding (forming a synclinorium) was caused by continuous pressure of the Tibetan Plateau from the north, which found in the south a rigid counterbloc in the nucleous crystalline zone of the Kathmandu nappes. The Proto Kali Gandaki valley, that means the Proto Thakkhola was existing during that time, probably with a primary outlay through the ancient Thakkhola transverse fault, which caused a zone of weakeness right from the beginning. Upper Cretacious and Tertiary formations were deposited in this growing trench, formations which are elsewhere totally missing in the surroundings.

Much later (Lower–Middle Tertiary), the Kathmandu nappes began to build the main range of the Himalayas, with overthrusting of huge crystalline masses far to the south. During the first stage of this phase the Kali Gandaki was able to erode his bed gradually into the rising Main Himalaya Range. But in the last phase of the Himalayan orogenesis, the roots of the nappes (due to continuous horizontal pressure from the north) rose so rapidly, so that the Kali Gandaki could not cope with the erosion. A huge tectonic lake was formed in the Thakkhola. Apparently, the rise of the nappe roots in the south continues still today, since also the Pleistocene lacustrine deposits, and the Quaternary gravels show a clear dip away from the Main Himalayan Range to the north (phot. 57). Also the southern limit of the present alluvial plain in the Thakkhola is at Dumpu, exactly on the topmost granite-gneiss of the Kathmandu roots.

In the Thakkhola trench itself the tectonics were active throughout the whole Tertiary: The respective formations show tremendous tectonics, which partly do not at all coincide with the ancient Mesozoic structures of the Tibetan Marginal Range and the Mesozoic filling of the former longitudinal trench.

The forming of the Manaslu arc, whereby the Manaslu granite has pressed under angle to the Annapurna arc, has narrowed the in-between lying Manang synclinorium, thereby complicating it and lifting its crystalline bottom in the east.

The intrusion of the Mustang granite has also to be dated very late, Upper Tertiary or even Pleistocene (granitic debris and river gravels are found on top of the Pleistocene lacustrine deposits). Though there is no direct visible connection between the Manaslu granite and the Mustang granite, both appear to belong to the same succession. Also in between occur granites on the Samjung Kang, east of Tinglibhoto. However, there is a difference between the granites on either side of the Thakkhola trench: West of it, they have intruded (as far as can be observed) Mesozoic, Cretaceous and Tertiary formations, while east of the Thakkhola trench they occur in Palaeozoic formations. North of the Manaslu, the granite is found with irregular boundary from Palaeozoic to the Mesozoic. It must also be mentioned that west of the Thakkhola trench the Mustang granite does not extend further south than the longitudinal Kyugoma fault. Instead it extends far to the west, forming the northern limit of the Langu basin and finally connecting with the crystalline of the Katmandu nappes, similarly as the Manaslu granite also connects with the Katmandu nappes in the east.

* Hagen, T. Mount Everest, Oxford University Press, London, 1963

Of course many problems are left and are still to be solved. It must be pointed out, that this survey is only a reconnaissance survey, not leaving the author much time for detailed studies of certain areas or for repeated visits of key areas.

This note on the evolution of the mountains in the Thakkhola area is just a brief one. The reader who wants to learn more about the evolution of the Nepal Himalayas is invited to read the first volume of this publication series.