# Report on the Geological Survey of Nepal

by Toni Hagen

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





Volume 1:

PRELIMINARY RECONNAISSANCE

Attached plates

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Mémoires de la Société Helvétique des Sciences Naturelles
Band/Vol. LXXXVI/1

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*To my dear, brave wife*
*who sacrificed most for this work*

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# PREFACE

This volume starts a series of publications on the Geology of Nepal. The author has carried out fieldwork in Nepal from 1950 until 1959, and has in this period covered the whole country.

The work started under the bilateral Technical Assistance Programme from Switzerland. Then for an interval of some months the Nepal Government employed the author under direct contract. The major portion of the fieldwork however was carried out on behalf of the United Nations Technical Assistance Administration for His Majesty's Government of Nepal.

The general observations regarding the natural resources and the economy of the country have been condensed in a report, submitted to H. M. Government of Nepal by the United Nations Technical Assistance Administration in October 1958. The following publications deal with the scientific-geological aspects, with the aim of providing a basis for further geological investigations.

It was first intended to number the volumes from east to west, each volume dealing with a certain area. When working out the material however, it proved necessary to provide a preliminary volume covering the general geological situation and especially the nomenclature of the geological series and the tectonic units. These names given right at the beginning will facilitate the reading and understanding of the successive volumes which will deal with the detailed description of the itineraries.

Further, the publication of my material got an undue delay due to various circumstances. First, an agreement between H.M. Government of Nepal and the Government of India did not work out as expected. Then, my duties in Nepal as the director of the Basic Survey Department under the OPEX Programme of the United Nations (1960–1962) did not leave me much time to work on the scientific publications, especially with regard to the fact that I was engaged in all my free time as the Chief Delegate of the International Committee of the Red Cross for building up the relief programme for the Tibetan refugees. – Finally, on 15th December, 1960, there was a change of Government in Nepal, and, though the previous Government had agreed to the publications, it took the new Government until January 1964 to de-restrict the first volume.

Thus, with regard to the delay (my manuscript was submitted in October 1960) it appears to be justified to begin with a comprehensive volume in order to get a general picture of the geology of Nepal within due time.

It may seem to be risky to write the comprehensive volume before instead of after, the evaluation of the entire field material. Consequently, it might be necessary to modify or even change certain interpretations, when all the rock examinations, laboratory tests and determinations of the large collection of fossils are worked out. However, the gain in understanding the texts of the succeeding volumes seemed to me to exceed the risk of later modifications. I want to point out, that the present comprehensive volume has thus the character of a *preliminary* edition only.

It should be mentioned that a popularly written book on the origin and structure of the Nepal Himalayas, with special reference to the Everest region, has appeared already before these scientific volumes. This is the Monograph of Everest*, with contributions from other scientists and explorers, covering the history of exploration of the Everest group, the ethnology of the Sherpas and modern mapping methods in the Everest area.

The publication of the following volumes in the present form is the result of happy international co-operation. The Swiss bilateral Technical Assistance started the project and the United Nations granted the main portion of my services to Nepal. Nepal contributed right from the beginning financially (local costs) as well as "in kind" with the wonderful services of the Sherpas and porters.

* "Mount Everest," Orell Füssli Ltd., Zürich, 1959.

The Technical Assistance Programme of the Swiss Federal Government granted the necessary contribution to publish this first volume. I want to thank for their generosity.

Prof. A. Gansser read my manuscript in 1962, when he had it in hand for an extended period of time. I am grateful for his valuable suggestions, which were incorporated in the texts. Prof. A. Gansser is himself familiar with the geology of the Himalaya*. Also Prof. L. Vonderschmitt read my proof copy, for which I want to express my sincere thanks.

Since the second volume (dealing with the geology of the Thakkhola) has been accepted by the Denkschriften Kommission of the Schweizerische Naturforschende Gesellschaft for publication in their Memoirs, also this first volume has been published by the said commission. I owe great thanks to the Denkschriften Kommission, especially to it's President, Prof. Dr. Max Geiger-Huber.

I do not know where to begin my thanks for all the kind support and help I have enjoyed during the nine years of my work in Nepal. One gentleman is outstanding in my many fine experiences: Col. Khadga Narsing Rana, the former Director of the Nepal Bureau of Mines.

My Sherpa Aila has accompanied me for 8 years, through all the hardship as well through the more enjoyable experiences in the beautiful country with its lovable people. There would be an unlimited number of Nepali friends to whom I would wish to express my thanks, if I began to mention further names.

I enjoyed the strong support of all the various Governments since 1950. In the decisive stage during the past two years, the Honbl. Prime Minister, B. P. Koirala took an especially keen interest in my work. The assistance of Mr. N. P. Thapa, Foreign Secretary and Mr. Kulenath Lohani, Secretary of Planning, has also been most valuable. Mr. P. B. Malla, at that time Mining Engineer of the Nepal Bureau of Mines, accompanied me to my great pleasure on a major trip.

Excellent personal relations connect me with several Geologists of the Geological Survey of India, some of them having been with me on field tours.

Common trips with experts of the United States Operations Mission to Nepal (USOM) also belong to my best experiences, and whenever I needed any help from that Mission I was never forgotten.

When my own mailing system to and from Kathmandu and the supply during long trips functioned well, it was to the credit of Father M. D. Moran and Father H. N. Niesen of the St. Xavier's Schools in Patna and Kathmandu.

The various offices of the United Nations Technical Assistance Administration worked in every way to give me all possible facilities. I want to thank all the respective Chiefs, officers and secretaries.

For many years all my contact with the rest of the world went by my own post runners through the office of the Resident Representative of the United Nations Technical Assistance Board in New Delhi. I have to mention especially Mr. James Keen, who always gave a personal and encouraging approach in his letters, addressed to me in my lonely camps in some of the most remote corners of the world.

Finally, I have to thank Norman F. Hughes, Cambridge University, for reading the manuscripts and the proofs.

It is my wish that my work would show some benefit in some way for Nepal, which I came to love so much and which has become my second home.

*Technique of the Geological fieldwork*

The author entered Nepal for the first time in October 1950, and completed the fieldwork in April 1958 (see fig. 1). During these 8 years, 1810 days (or approximately 5 years) were spent actually in Nepal. In 1951, and from 1954 in every year, several months were spent in Switzerland to

* A. Gansser "Geology of the Himalayas" Interscience Publishers, London, 1964.

work on the material and to feed up again. Out of the 1810 days in Nepal 1235 days were spent on actual fieldwork, which means in tents in the wilderness. This gives an average of 68% fieldwork of the total time spent in Nepal. 19 expeditions were carried out between 1950 and 1958; the shortest one was of a few days duration only, while the longest one lasted six and a half months.

While on the first expeditions only 42% of the Nepal-days were spent on fieldwork, the percentage gradually increased with my growing experience. During the last expedition 1957–1958, fully 93% of the time in Nepal was spent in the field. Preparations for this last season (supply, porters, Sherpas) needed the record time of 2 days only in Kathmandu. (While for example in 1950 one month was hardly enough to arrange the first trip of 3 weeks duration!)

Nepal has no transport system outside the capital. The Nepalese country people have been living in the same way for the past 500 years. Fieldwork in Nepal therefore means all travelling to be done on foot, living in tents and eating the same simple and monotonous food as the farmers on the hillside, being alone for 4–7 months with only a few Sherpas and porters, acting as his own leader of the expedition and physician, and having contact with the rest of the world every 3–4 weeks only through his own post runners.

While at the beginning a main portion of my energy was absorbed in moving and directing my field party and with camping etc., since 1953 I have been able to devote myself fully to my proper work. Since then I have had the same porters and the same Sherpas, and the efficiency of my fieldwork increased accordingly. This may be seen from fig. 1, showing the areas covered in fieldwork year by year. A special technique of geological survey has been developed by the author for this kind of exploration.

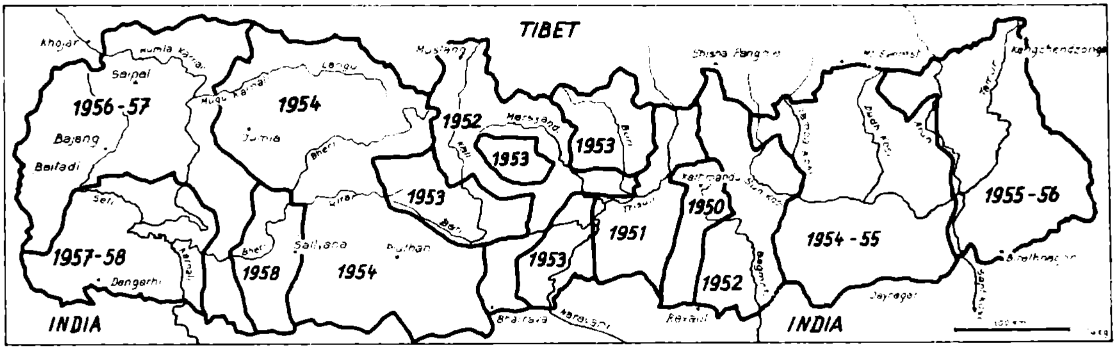



Fig. 1 The areas covered and mapped 1950–1958

The author started the reconnaissance survey in the center of the country, around Kathmandu. From the capital, he gradually extended his investigations toward west and east. It can easily be seen from the sketch, how the areas covered in the later years were larger than at the beginning. It reflects the better outfit and especially the increase of efficiency due to familiarity with local conditions and with the porters. In the average, the particular expeditions after 1954 lasted between 5 and 6 months (October–March).

Owing to the east-west strike of the geological structure of the Himalayas, the routes of the fieldwork had to be chosen in a north-south direction.

Every day an average of 7 hours was spent walking, the camp being erected every evening at a new place. There were very few exceptions (due to sickness or detailed studies) when more than one night was spent at the same camping place. Each evening for another 2–3 hours, after the daily seven hours walk, the fieldwork notes were completed, the geological cross-sections drawn, and the manuscript typed as far as possible.

I do not wish to give the impression that I am such an extremely hard worker by nature, but the excessive hard work was for me the only way to overcome the loneliness. For the same reason, I could not stand rest days; even when I tried to have a full rest on Sundays, at the latest by 11 a.m. the lonely feeling forced me to start work again and to move the camp. My loneliness during my expeditions was much more complete than for example that of the crew of the South Pole station. I had no radio and there is no regular postal system in the country areas, which would enable me to send mail to foreign countries. It was a fine contribution from UNTA to facilitate my fieldwork when two special Sherpas were paid as my own postrunners. My two Sherpas were doing a wonderful job, but on the average I have had mail every 3–4 weeks only. Many of my letters were safely carried to Kathmandu, over long distances, but then were lost between Kathmandu and my family in Switzerland.

At the beginning, the survey was started with the surroundings of Kathmandu. From this center, toward the east and west the survey was carried on in a systematic way. Near the capital, the area could be covered in relatively short expeditions, while the far west and the far east needed longer expeditions. Those areas, far from Kathmandu, could be approached only through India, and could therefore be covered in long expeditions only. That was the reason, why I sent my family back to Switzerland in 1954, since they would have been alone in Kathmandu for 5 or 6 months every season.

After having had a narrow escape in the monsoon in 1954 due to malnutrition, floods and sickness, the further fieldseasons lasted from the end of September until March-April. This is the so-called dry season, which however is not so dry in the hills. I was always in a dilemma when starting the fieldwork in the autumn; to approach the far eastern or the far western part of Nepal, I had to travel by railway through India and then to cross the Terai during the most malarious and dangerous time at the end of September. Postponement of the start would have made the approach much safer and more pleasant. On the other hand I had to hurry to get to the high altitudes in the northern part, before it was too cold.

The weather was mostly fine in the Himalayas until the end of the year, but in December (1954 in November) temperatures were getting extremely low. For months I was camping on ice and snow with temperatures considerably below freezing point.

My being in the position to complete 8 years long exploring in Nepal, was possible thanks to a few fortunate circumstances. First of all, my physical condition was amazingly predestined to this kind of work. Extremely keen on climbing and skiing in the Swiss Alps since I was a school boy, my previous sporting activities seemed to have been just a preparation for my task in Nepal.

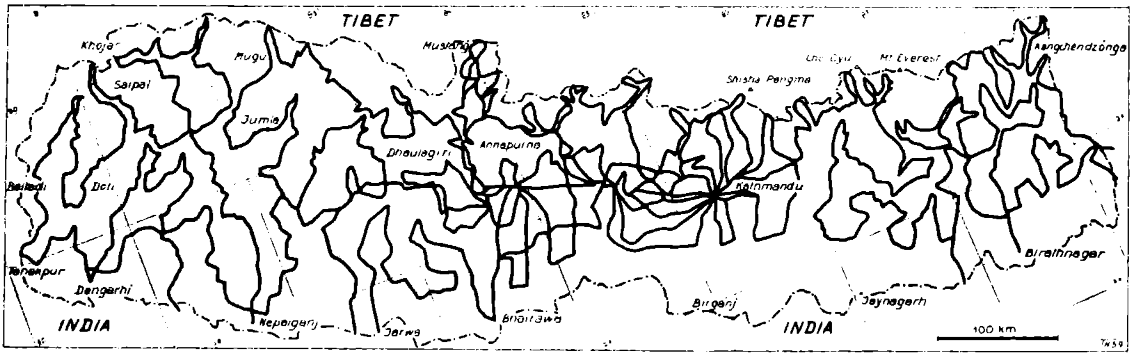



Fig. 2 Itinerary of Toni Hagen in Nepal

The author covered between 1950 and 1958 a distance of over 14 000 kilometers on foot, which corresponds to the distance from the North Pole to Capetown. The total of the heights climbed amounts to at least 950 kilometers or more than one hundred times of Mount Everest, measured from the Ganges plain.

Nevertheless, if I had done this work about 20 years earlier, before penicillin and the new antibiotics were invented, I would certainly not be alive.

Of course, I took certain precautions, but experience has shown again and again that a too sterile behaviour is not only no protection against infective diseases, but makes people weak against infections. Those experts who took special food only and who avoided contact with local food and local people were always the first to fall sick and were more severely ill. I was only careful not to drink unboiled water, when there were human settlements above the spring. However, I never had any guarantee of what was happening to my water in my kitchen and in the hands of my Sherpas, and I just could not keep an eye on the cooking pots of my Sherpas all the time.

Approximately 25% of the whole Nepalese population are permanently suffering from diseases. Besides cholera, smallpox, typhus, malaria, tuberculosis, syphilis, infective jaundice and dysenteries, there are many other, still un-named infective fevers. An expert travelling in Nepal, cannot avoid sooner or later getting one of those fevers. My whole family had infective jaundice at the same time in 1953. Mrs. Hagen had a light bout of smallpox, in spite of the vaccination and I myself had frequent dysenteries. The worst sickness broke out in 1954 when I was in the most remote area of the country. I had to walk back for 5 endless weeks over high passes taking heavy doses of Aureomycin and other drugs. From this treatment and because of malnutrition, a kind of Beri Beri broke out and I lost all my fingernails. Back in Switzerland I recovered fully in only two weeks. It was then that the United Nations Medical Services decided that I should not spend more than 6 months in consecutive field work in Nepal. This decision was wise and I want to express my thanks for the fine understanding I have received from Headquarters in this respect.

In 1956/57 we were delayed by Indian customs for about a week and thus just missed a period of fine weather at the end of September. We were locked in the most malarious jungles of western Nepal for a few days in the full blast of the monsoon. Promptly after 10 days the first wave of fever broke out among my porters. Every 3 weeks the wave was repeated, but thanks to my growing experience I was more and more successful with treatment. It was a strange fever, beginning with a frightening collapse and sometimes dangerous side reactions on the kidney tract. After 5 months I had it myself on the very day when I arrived at the Indian border, but in 3 weeks I was entirely fit again.

An explorer in such countries must not be too careful with himself. Even when I was sick, I never allowed myself a rest day. Undoubtedly this strict principle safed my life during the 1954 trip when I fainted frequently due to weakness. I found myself sometimes reflecting that dying would be more pleasant than to walk on!

One of the problems was the deficiency of vitamins as I was living entirely from local food. Vegetables or fruit are mostly unknown and native people are also suffering from chronic deficiency of Vitamin B. Of course I took plenty of Multivitamin tablets which gave quite good results as long as my intestinal tract was in order. But when I had to take antibiotics against dysentery, the vitamins were apparently no longer absorbed. During the first 4 months I was enjoying my reserves from Switzerland but when after 4 months fieldwork a dysentery developed, deficiencies were apparent. Vitamin deficiencies were always first visible on my fingers, when the fingernails became loose. Parallel to this, decrease of general physical strength occurred. It was fortunate that the Missionary Hospital of Pokhara was on my route sometimes, and I was able to get these injections of Vitamin B12.

The last season in 1957/58 was a bad one for my porters. We ran through one wave of Asiatic flu after an other and dysenteries hardly stopped during January and February. I myself escaped entirely and consequently no signs of vitamin deficiency were apparent even after 6½ months fieldwork. There is no doubt that I have become immune to a certain degree and my health was better than that of any of my porters and Sherpas. Now, after all, when thinking back to all my adventures, it seems nearly miraculous that I have come out the past eight years, in better health than before.

The field material collected the past 8 years in Nepal consists of:

- 20 fieldbooks, containing
- 2437 geological sketches and panoramic views
- 96 geological cross sections 1:100 000 from the Ganges plain to the Tibetan border
- approximately 8000 geological negatives
- thousands of colour transparencies, covering Geology as well as human aspects
- the field-original of the Geological map of Nepal 1:250 000
- several hundred rock and mineral samples
- more than 300 complete fossils
- about 1200 pages diary book, containing various observations on the economic pattern and life of the people, and my personal experiences and adventures.

During the 1235 days spent on field work, the whole camp including the tents was erected and packed again 1200 times, by changing the camping place.

Every 1½ months one pair of good Swiss-made climbing boots were totally worn out. The number of boots used between 1950 and 1958 gives a total of 28 pairs.

While the first expedition, which was arranged by the late Maharaja, was carried out in "old fashioned style" with heavy equipment including porcelain, and needed 70 porters, this number could gradually be reduced to about 10–12, by purchasing light and adequate equipment from Switzerland. Nearly two full loads (out of a total of 11) consisted of medicines. On the last expedition, about 2500 Sulphoguanidine tablets were dispensed. In populated areas, nearly every day sick people were treated. In areas, where I had my camp more than one night at the same place, dozens of patients were crowded in front of my tent for treatment. Thus, the people treated or given medicines are numbering at least to 2000. In most cases of course I could not see myself the final result of my medical practice. But several times I met treated people later on again and I got always an enthusiastic reception in those villages where my medical service had been successful. I know several Nepali whose lives I have saved, or whom I saved from becoming cripples.

The exhaustive exploitation of the abundant field material will of course need further time. Some portions of this work have to be carried out by specialists. Some of the fossils will be studied at the Swiss Federal Institute of Technology. Microscopic examinations of the rock and mineral samples are also a task for specialists.

So far, only 7 minor papers on the geology of Nepal have been published as "Communications of the Nepal Bureau of Mines".

Nepal is one of the last countries of the world to remain without a Geological Survey or a Geological map; a geological mag nowadays is simply a basic need for a country, which wants to develop. The general scientific aspect should not to be neglected in that since it is the first time that a main portion of the Himalayas has been surveyed in a systematic way.

The author's survey consisted in producing a first geological map (scale: quarter inch to one mile) of the territory of Nepal (54 000 square miles). There already existed a topographical survey of the country (scale: quarter inch to one mile), which was made by the Survey of India using the plane table in 1926 and 1927. In some 75% of the country, chiefly south of the main chain of the Himalayas, the map proved to be most accurate and it must be regarded as one of the greatest pioneering achievements in topography in general. In the extremely high mountains and in certain regions to the north of the main chain of the Himalayas, on the other hand, there are considerable gaps or else fairly large areas have been falsely reproduced.

All in all, therefore the author had a very good topographical basis on which to work. From the geological standpoint, however, the whole of Nepal was absolutely new country.

The geological structure runs parallel to the Himalayas so that the geological field survey had to be performed at right angles to it in order to obtain as complete an impression as possible of the geological formations. Reconnaissances, always made on foot owing to the lack of suitable roads, thus had a north-south or south-north orientation (fig. 2). Parallel routes were chosen so that the area between two such geological cross-sections could be interpolated with sufficient accuracy. The gap between two reconnaissances or geological cross-sections was about 10 to 20 km (5 to 15 miles). It depended on the topography, geology and visibility conditions. Where feasible, the routes chosen ran along mountain ridges so that as good a view as possible could be had on both sides. Moreover, the rock is better exposed on crests than in valleys filled with residual material. In spring, however, the haze can be so troublesome that visibility is limited to not more than 3 miles. In general the cross-sections chosen had to be narrower in the southern part of the country because, especially in the soft formations of the Kathmandu nappes, the lithological differentiation is poor and cannot be recognized at a greater distance. Intensive cultivation here also makes it difficult to recognize the rocks at a distance. In the Tibetan highlands, on the other hand, it is often possible to survey areas of up to 80 km in width between two dominating heights. The air is very clear there and as the rock appears bare and without vegetation, individual formations can easily be followed for more than 50 km.

The geological survey was carried out continuously along the routes, using the classic method of investigation with hammer and hydrochloric acid. The findings were entered in continuous sections in the field book. The field book sketches were numbered consecutively, the sketch numbers being preceded by those of the book. Sketch No. 10 038, for instance means sketch No. 38 in field book No. 10. At the same time the findings were also entered in the topographical map (quarter inch to one mile) with geological shading, providing the formations could be followed with certainty on both sides. Their probable continuation as far as the next cross-section was marked in pencil. From all good vantage points along the route sketches were made showing the geological structure and also the probable geological arrangement. In the most unfavourable case this was limited merely to recording whether the rock was hard or soft. At the same time panoramic views were photographed from all the vantage points, primarily with colour film in interesting regions. The camera stations were fixed by compass measurements, and the heights determined barometrically. The films of the panoramic photographs were marked with the same number as the corresponding sketches in the field book. In regions where it was difficult to obtain a general view of the topographical conditions the panoramic photographs were taken at such close intervals that more distant ranges of mountains could be detected stereoscopically.

In the reconnaissance of the neighbouring cross-section the geological survey was confined to verifying the conditions assumed to exist by the previous route survey: the salient formations drawn in with pencil only from the opposite side of the valley could be confirmed or corrected. The geological formations were definitely drawn into the panoramic sketch prepared from the opposite side of the valley. At the same time the area already reconnoitred was again covered with panoramic sketches and photographs from the camera station. The sketches could be made fairly complete as far as geology was concerned, since the conditions were of course known from the reconnaissance. The whole region between the two cross-sections could now be interpolated with a reasonable degree of certainty. The same procedure was again followed, however, on the still unknown side. In this way each geological route survey became a corroboration of the conditions assumed to exist by the preceding survey, and at the same time a probable extrapolation into the still unexplored region. The network of roughly measured camera stations, together with the panoramic views, became progressively denser and every salient terrain point or peak was included in several panoramic views.

Often impressions of fairly large sections of terrain could also be obtained stereoscopically in this way. Of great advantage, too, was the fact that the high peaks of the Himalayas measured by the Survey of India were visible from almost all the ranges of hills in central Nepal and thus were included in the panoramic views. Finally, such a dense network of photographic lines of sight resulted so that rough topographical and geological maps of large regions could subsequently be made at home by graphical methods.

Similarly, the simple geological panoramic views in the field book, which, essentially, contained only the geological skeleton, could also be completed cartographically and graphically later with the aid of the photographs.

The geological specimens, too, were marked with the numbers corresponding to the entry in the field book. Furthermore, all geological detailed photographs of important indications were given identical numbers in the field book, as well as on the photograph and the specimen. Subsequent evaluation with the aid of the many thousands of negatives, sketches and specimens proved not too difficult as a result of the systematic bookkeeping.

# CHAPTER 1

# GEOGRAPHICAL POSITION AND NATURAL DIVISIONS OF NEPAL

## *1) Topography*

The Kingdom of Nepal covers an area of approx. 141 000 km² in the shape of a long rectangle. This rectangle is situated between the 80th and 88th meridional degree and the 27th and 30th geographical latitude. The long-side of the country measures about 870 km. The shortest north-south section, east of Kathmandu, is about 130 km, while the longest cross-section in western Nepal measures 255 km.

Due to the geographical situation, Nepal belongs to the tropical-subtropical climate zone. The high mountains however cause a considerable transposition of the climate, which ranges up to arctic type.

Nepal has in past years become well known as the home of the highest mountains of the world. Seven of the 14 mountains of the world with altitudes above 8000 meters are in Nepal. The eighth (Shisha Pangma) is quite close to the Nepal–Tibetan border.

The following are the highest mountains of Nepal:

| | *meters* | *feet* |
|---|---|---|
| 1) Mount Everest | 8 848 | 29 002 |
| 2) Kangchendzönga | 8 585 | 28 168 |
| 3) Lhotse | 8 501 | 27 890 |
| 4) Makalu | 8 470 | 27 790 |
| 5) Dhaulagiri | 8 172 | 26 810 |
| 6) Cho Oyu | 8 153 | 26 867 |
| 7) Manaslu | 8 125 | 26 658 |
| 8) Annapurna | 8 078 | 26 504 |
| 9) Shisha Pangma | 8 013 | 26 391 |

These peaks were all triangulated from the Ganges plain in the middle of the 19th century. New calculations, taking account of more recent knowledge of refraction and other influences on long-range vision are under way. Heights of most of the peaks will thus probably be slightly increased.

Fortunately there is an excellent map existing of Nepal. The Survey of India produced a Quarter-Inch Map (approx. 1:250 000) in the early decades of this century. This map has been critizised sometimes by the mountaineers. These critics however were rather narrow-minded. On the whole the existing map is a classic masterpiece of Survey work, with regard to the most difficult relief, the simple techniques (the whole country was surveyed with plane table, since the modern aerial photogrammetry was not available at that time) and the lack of mountain-trained surveyors. There are thus only some minor areas beyond the main range of the Himalayas which show gaps and errors; areas, which apparently have not been really surveyed, but sketched only. The survey of the populated area does not leave anything to be desired, and the more the author has travelled in Nepal, the more he had to admire the masterwork of the Survey of India. True, some photogrammetric new maps have been produced by mountaineers during the past years, but these cover very small areas only (for example the map of the Mt. Everest region, by Erwin Schneider).

The topographic quarter-inch map of Nepal gives abundant information for the geographer and the geologist, who really knows how to read maps. The map given in fig. 3 is abstracted from the map of the Survey of India.

Fig. 3 first of all shows that Nepal is a country of the greatest contrasts: the altitudes vary from the Ganges plain (200 m) up to nearly 9000 meters. The contour lines and level-planes in fig. 3 are to show the main natural physiographic divisions.

The areas above 7000 m above sea level are rather limited, compared with the size of the country (fig. 3). They do not form one single belt, but are divided into a number of mountain groups, which are alined dominantly in ESE-WNW direction. Thus we can speak of the *Great Himalaya Range* in spite of this division into different groups.

The distribution of the 7000 m level is not equal through the whole country; the areas above 7 000 m are concentrated in the eastern half of the country. There exists a considerable gap of altitudes above 7000 m between Dhaulagiri and Saipal in western Nepal.

It is quite common in other mountain ranges of the world too, that they are not built symmetrically, but with one side steeper than the other. The non-symmetric character of the Nepal Himalayas exeeds that of all other mountains of the world: The Tibetan highland is raised to an average of 4000–5000 meters above sea level, while the southern flank of the Himalayas drops to 200 meters only in the Ganges plain. Neither the northern flank of the great Himalaya range to the Tibetan plateau, nor the southern flank to the Ganges plain show an equalized gradient: west of the Thakkhola there is another mountain range further north, which strikes parallel to the main range (towards the west), but at a distance of about 30–40 km (Palchung Hamga-Ladak-Changla).

East of the Thakkhola, this northern range (Thorung) joins up in the Manaslu chain with the main range. East of the Manaslu the northern range is represented by small isolated elevations only (Sringi and Dzo Raptzang). In the far west, in the Gurlamandata range, the northern mountain chain exceeds the main range in altitude.

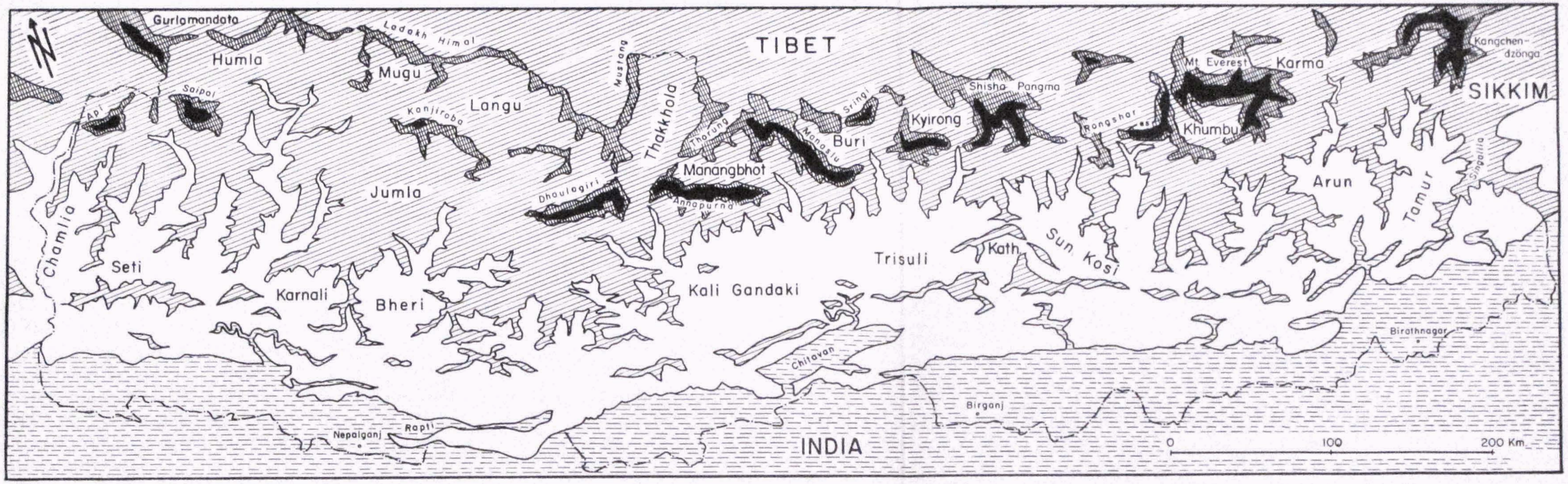
In three areas, the mountain ranges exceeding elevations of 6000 m are not aligned with the general ESE-WNW strike: On both sides of the Thakkhola (Mustang Himal, Thorung Himal), near Mugu (Humla Patan, Syanath), and between Everest and Kangchendzönga (Nyönno Ri). (Fig. 3 and 4).

In this way, big *natural compartments* are formed between the *Great Himalaya Range* and the northern *Tibetan Marginal Range*. These are from west to east: Purang, Humla, Mugu, Langu, (Dolpo), Thakkhola, Manang, Buri-Kutang, Kyirong, Nyanam, Rongshar, and Karma. These valleys are called the *Inner Himalayas*, since they are surrounded on all sides by high, snow-covered mountains.

There are two valleys in eastern Nepal, which show similar character to the Inner Himalayan valleys, surrounded by high mountains on all sides, but having the Great Himalaya range in the north, and less high mountains in the south. One of them is the *Khumbu*, between Everest and Kangtega Himal. The situation of the Khumbu is quite unique for Nepal. It is, with the Kathmandu valley, probably the best known area of Nepal since it is the home of the famous Sherpas. We shall see later on (chapter 3, paragraph 5) how these special configurations have been caused by the geological structure.

Of course the level planes in the map of fig. 3 have been chosen for the best illustration of the main physiographic features. With other levels the resulting picture would differ slightly from the present one. In the chosen level of 2000–6000 m, the whole Tibetan plateau is uniform. It does not show any mountains, nor do any valleys occur in this area.

The topographic pattern is entirely different on the southern flank of the great Himalaya range. The belt of altitudes between 2000 m and 6000 m varies considerably in width and it is also shaped quite irregularly, and is intersected by deep transverse valleys, reaching from the south far to the north. Surprisingly, a mountain range occurs in the south, separated by wide areas of lower altitudes. This is the *Mahabharat Lekh*, with maximum heights of about 3000 m. The Mahabharat Lekh thus

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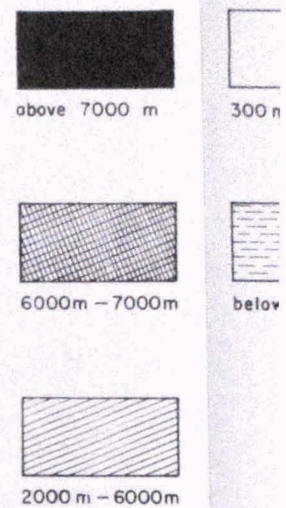


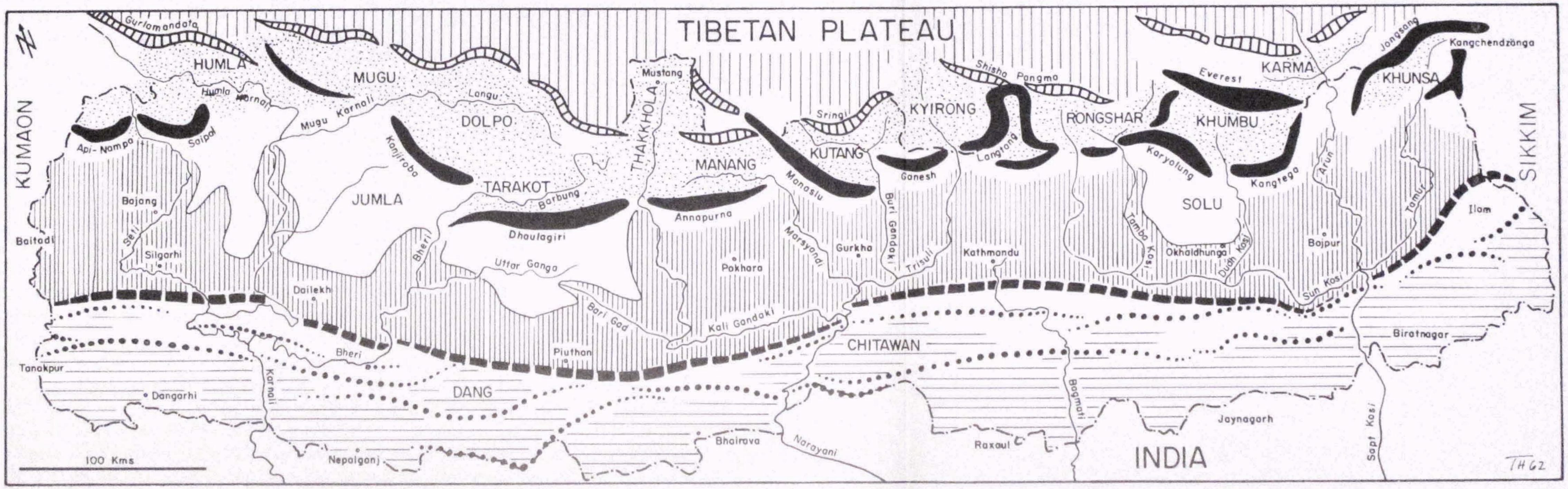


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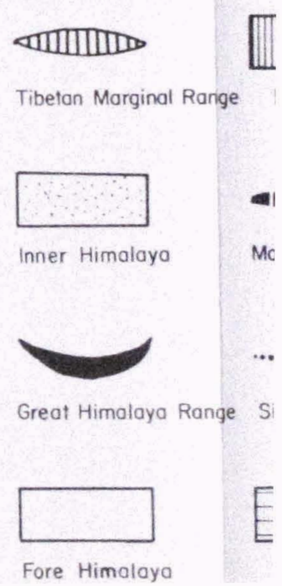


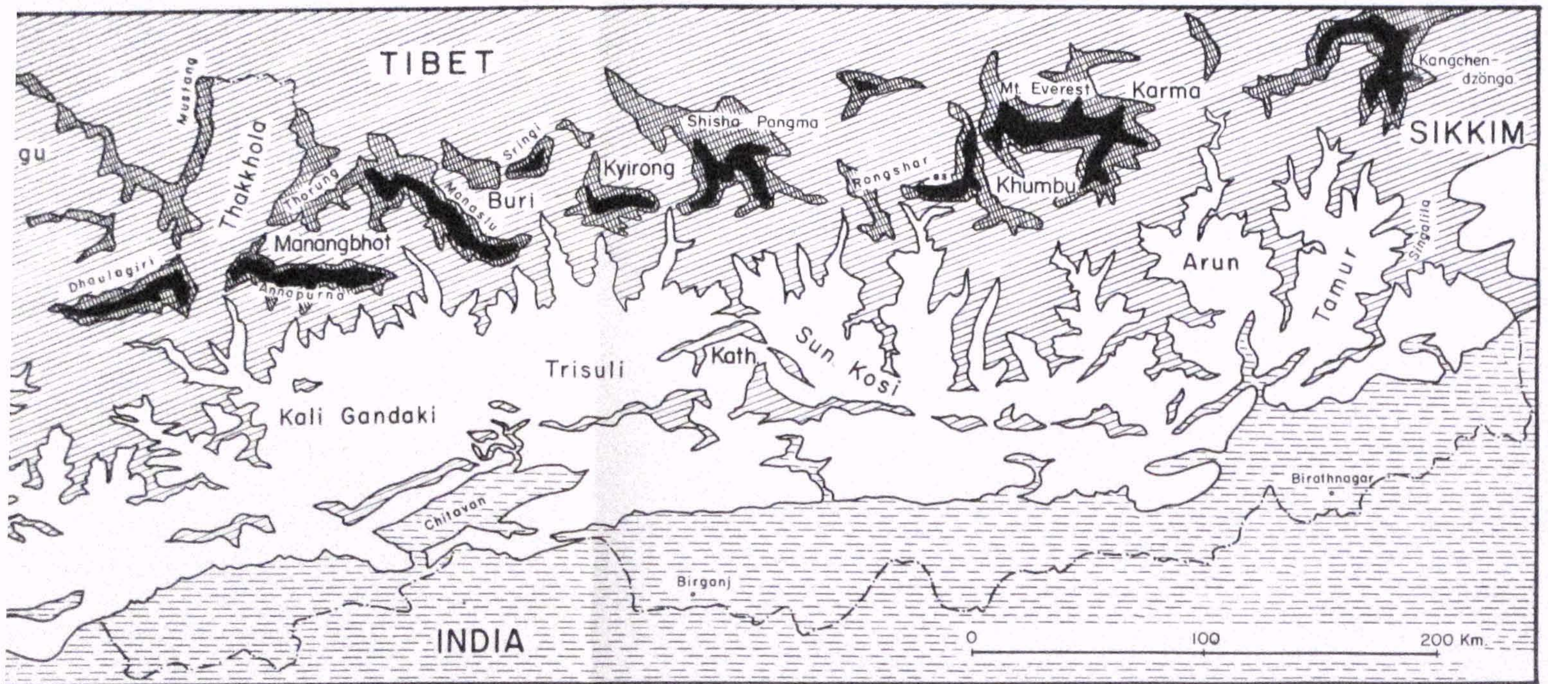
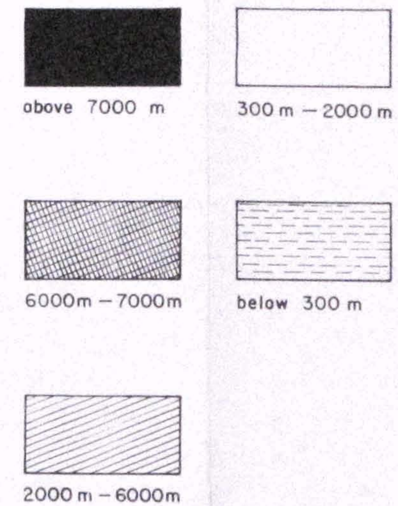



Fig. 3 Topographic sketchmap of Nepal

the very rough topographic sketch shows clear the natural divisions of the country. The altitudes above 7000 m form clearly separated mountain chains rather than large masses. The Tibetan marginal range, with altitudes between 6000 and 7000 m is separated from the Great Himalaya. The transverse Thakkhola graben interrupts both, the Great Himalaya as well as the Tibetan marginal range. The Midlands basins are best developed in central Nepal. West of the Kali Gandaki basin, the Fore Himalaya with its altitudes between 2000 and 6000 m reaches far to the south, and joins almost the Mahabharat Lekh. The latter, as natural barrier protecting the Midlands toward south, is well recognisable.



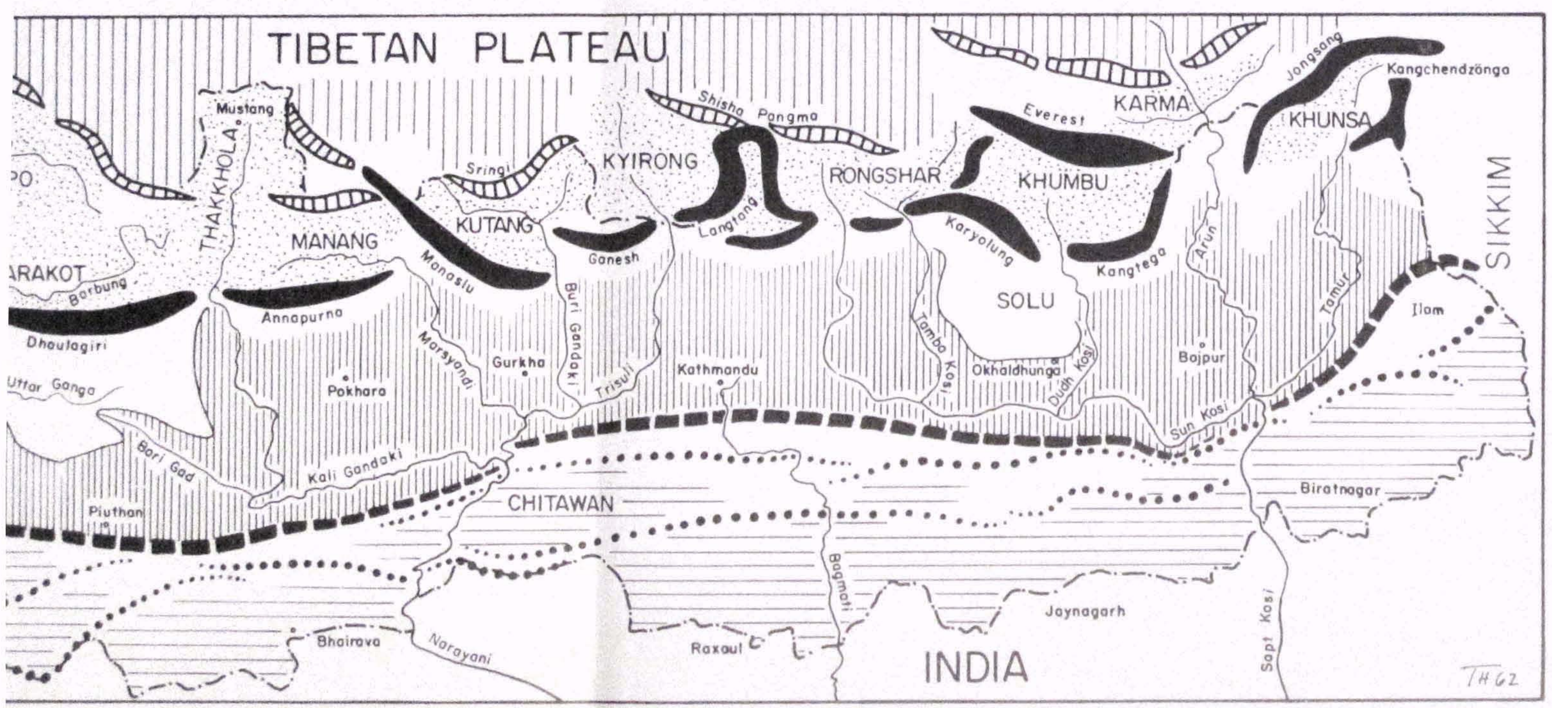
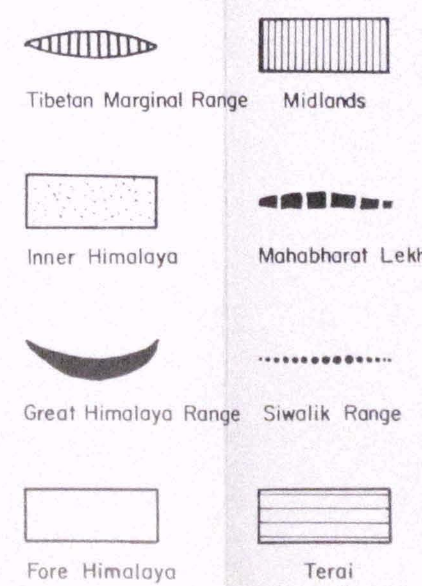




Fig. 4 Morpho-Tectonic sketchmap of Nepal, showing the natural divisions and the main drainage pattern

This map has been derived from the topographic map given in fig. 3. All the different natural compartments of the country show their characteristic topography, climate, natural vegetation, population and agriculture.



frames a zone of wide low-lands within the country. This part will be called the *Midlands*. Resulting from the general ESE-WNW strike the Midlands form a long belt in the same direction. However, it is not one single belt, but intersected by some minor transverse hills. The basins of the Midlands correspond to the main rivers which drain the Nepal Himalayas.

The Midland basins are best developed in central Nepal, where the areas of the Kali Gandaki river and the Trisuli river form 70 km wide and 100 km long compartments each (fig. 3). The other Midland basins show a much more complicated shape, since the valleys of the transverse rivers spread like fingers towards the north. The Sun Kosi basin in eastern Nepal for example has the shape of a recumbent "E", the main branch of the "E" being the west-east directed longitudinal valley of the Sun Kosi, from which the partial basins of the Indrawati-Kosi s. str., the Tamba-Bhote Kosi and the Dudh Kosi stretch towards the north. The Midland basins in western Nepal are likewise complicated, namely the Chamlia basin, the Seti basin, the Karnali baisn, and the Bheri basin (figs. 3 and 25).

In two areas, the Mahabharat Lekh is connected by a mountain range with the Himalayas, namely in the Singalila range in eastern Nepal and in the Dailekh range between the basins of Karnali and Bheri (fig. 3).

While in the Annapurna section the contour line of 2000 m approaches to not more than 15 km from the Great Himalaya the levels between 2000 m and 6000 m cover wide areas and fill almost the whole region between the main Himalaya range and the Mahabharat range west of the Kali Gandaki basin (Jumla area). The same occurs in eastern Nepal, between the Tamba basin and the Arun basin (Solu). Though it cannot be recognized in the much simplified map of fig. 3, it should be mentioned that the areas of Jumla and Solu have altitudes of 3000–4500 meters and show a physiography, climate and economy which is quite different from that of the Midlands. These elevated areas will be called the *Fore Himalaya*.

The map (fig. 3) shows the important role of the transverse rivers and valleys in Nepal. Quite a number of such valleys with levels less than 2000 m reach far to north, right into the belt of the great Himalaya range. A striking example is the Karnali valley between the Saipal and Kanjiroba Himal in western Nepal. The 2000 m contour line goes even beyond the main range of the Himalayas. It is evident, that such configuration must be expressed in nature by very deep gorges.

Between the Dhaulagiri Himal and the Annapurna Himal the 7000 m contour line is separated by only 15 km, and yet the bottom of the Kali Gandaki valley is on this line not more than 1200 m above sea level! Similar conditions are found in the valleys draining the Manang basin, the Kutang basin, the Kyirong basin und the Nyanam- and Rongshar basin to the south. Further, the Arun valley in eastern Nepal is excessively deep. It crosses the main range of the Himalaya between the highest mountains of the world.

The *Ganges plain* has an average altitude of 200 m, at the foot of the most southern hills. In some minor areas however it rises up to 300 m. In the map of fig. 3 therefore the 300 m contour line has been chosen to illustrate the real foot of the hills. This contour line is quite complicated; in several areas, valleys below 300 m altitude stretch from the Ganges plain towards the north-east and west into the Siwalik zone. These are the so-called *Dun valleys* or Duns; the largest is the Rapti valley in western Nepal (not to be confused with the Chitawan area south of Kathmandu, which is drained by another Rapti river). Further large Dun valleys are slightly elevated above the 300 m level. These cannot be recognized in fig. 3 (i. e. Dang, Surkhet).

Due to the large interval of height between 300 m and 2000 m given in the map (fig. 3), the Siwalik hills do not occur on the map, except in a very small strip south of the Mahabharat Lekh in the meridian of the Seti basin (western Nepal).

According to the map (fig. 3), the greatest contrasts in altitude are found at the southern flanks of the Dhaulagiri, Annapurna and Manaslu ranges. In these areas the contour level of less than 2000 m approaches to within 10–20 km only, the 7000 m and 8000 m level.

## 2) *The Natural Divisions of Nepal*

We have seen in the foregoing chapter, how a reading of the topographical map alone, gives the main natural divisions of Nepal. However, topography is not the only and should not be the only criterion for deriving the natural units of a country. It is true that the topography is the base of any geographical description as it not only gives the skeleton of a country but influences other important factors in forming the landscape, as for example the climate, and with this the natural vegetation.

So far there is some confusion in giving general names for the various parts of Nepal. One can find in publications "great Himalaya" side by side with "low Himalaya" or "lesser Himalaya". Hereby the meaning of "low Himalaya" varies according to the author, or the professional origin of the author. P. Bordet for example referred to a certain tectonic zone (Kathmandu nappes) as "low Himalaya", while the overlying tectonic units were called the "great Himalaya". In the existing topographical map of the Survey of India the expression "lesser Himalaya" is used partly for the Mahabharat range partly for those mountains which are named by the author "Fore Himalaya". Frequently the word "Mid-Terai" is used in the same sense as "Dun valley", etc.

It is evident, that in a basic description of a country, in which not too much has yet been published, the names for landscapes and natural units should not be chosen from a narrow-minded professional standpoint; the names should also make sense to the layman. Facts, visible for a layman should be regarded, as for example the vegetation and the topography; and the population as a result of the first two items.

In Nepal, with its enormous contrast in every respects, it is not too difficult to find adequate names for the different landscapes. Quite a number of them have been introduced in the foregoing chapter already.

The meaning of the "Great Himalaya Range" should be clear. "Hima", "Himal" means snow, "alaya" means place. Himalaya thus translated has the meaning of "place of snow". From the origin of the word it can be concluded, that the word "Himalaya" should be limited to real snow mountains, and not be extended or applied also to minor hills which are never covered by snow or, to geological units, which do not include snow mountains. From the two-word origin of the "Himalaya" it may also be concluded, that emphasis is on the first "a" (Himālaya) and not on the "ay" as is incorrectly heard most frequently.

In the whole north-south cross section of Nepal we can work out the following natural divisions (fig. 4):

1) Tibetan Plateau
2) Tibetan Marginal Range
3) Valleys of the Inner Himalaya
4) Great Himalaya
5) Fore-Himalaya
6) Midlands
7) Mahabharat Lekh (Lekh means range)
8) Dun valleys
9) Siwalik Range (or briefly Siwaliks)
10) Terai

This division can be applied through the whole country from Sikkim through to Kumaon. The importance of the role played by the units however varies in the different sections.

In longitudinal view, the country is also divided into different compartments by the main transverse rivers. These compartments however do not differ from each other, all of them containing the above mentioned natural divisions.

Generally, the drainage pattern plays a most important role in forming the natural units of a country, which is the case in Nepal too. However it must be mentioned, that the drainage pattern itself is the result of the geological structure. It is really the tectonics which have formed the present landscape of Nepal.

A most characteristic fact of the Nepal Himalaya has been pointed out in the foregoing chapter already, namely the non-symmetric lay-out of the Himalaya range. The fall and the gradient of the southern flank greatly exceeds those of the northern flank, toward the Tibetan Plateau. In addition, the non-symmetry of the Nepal Himalaya shows some additional features, which are quite unique in the world. The main range is not the main watershed, as the great rivers have their origin in another mountain range, the Tibetan Marginal Range, which lies much further north and which, surprisingly enough, does not reach the heights of the main range. There are only a few summits of 7000 m in the Tibetan Marginal Range, and average heights hardly exceed 6000 m.

How then can it happen, that rivers have their origin on a mountain range of 6000 m altitude only, and cross a much higher range, which exceeds 8000 m? This kind of drainage pattern seems to be quite unnatural and is unique in the world. We shall see in later chapters, that we can explain these features only by considering the Tibetan Marginal Range, and thus the drainage pattern too, as much more ancient than the Great Himalaya Range.

There are three main groups of rivers draining the Nepal Himalayas namely from west to east, the Karnali system, the Narayani system, and the Sapt Kosi system.

It has been mentioned above, that the geological structure has played the most important role in forming the Nepalese landscape. The structure of the Nepal Himalayas is characterized by huge nappes, which are thrust to the south over distances of almost 100 km. When describing the natural divisions to some extent in the following pages, the correlation with the structural units and zones will briefly be mentioned.

*The Terai*

The Nepalese portion of the alluvial plain of the Ganges at the southern foot of the hills is called Terai. To the hundred thousands of Nepali farmers who use to come down every year from the Midlands to the Terai and to the bazars on the Indian border, the word "Terai" has a rather bad reputation. It is a real malaria hell, and many Nepali, living on the healthy hills of the Midlands, catch a malaria and bring it up to their homes on the hills, where they never get rid of it, due to lack of medicines and treatments.

On the other hand, the Terai will undoubtedly one day play a most important role in the economic development of Nepal. The flat terrain does not present much difficulty in opening up for transport and the soil is in general excellent. So far, the yearly yield depends largely on the monsoon, but irrigation might render the Terai one day fairly independent of the monsoon, and may enable it to provide easily two harvests per year. The Terai is in an advantageous position, as it is crossed by the big rivers from the Himalayas; thus water is available in the area in abundant quantities. It only requires irrigation channels to divert the water from the rivers on to the fields.

There is no doubt at all of the existence of *ground water* in sufficient quantities in *any place* in the Terai. Local people already use simple holes to obtain the water for domestic use. With cheap electric power from the big rivers, water could be pumped for agricultural use also.

Furthermore, there are indications, that the level of underground water is very close to the surface in certain areas and at times is held by impervious strata even under pressure below the surface. The author observed after heavy rains east of Butwal, how the rice fields were covered with holes similar to those caused by shells. It seems that the water had opened the surface in an explosive manner creating *artesian fountains*.

So far, only the southern part of the Terai is populated, while the northern part is covered in dense jungle. The jungles themselves represent enormous wealth for the country; with adequate exploitation, tremendous benefit could be drawn from timber export and timber industries.

The Terai is mostly level land. At a few places only the plain rises towards the foot of the hills. This can be seen for example near Dharan in eastern Nepal. We shall give some details of these facts in later chapters, since these signs of recent crustal movement are most interesting.

The Terai forms a belt of an average width of 30–40 km and at an average altitude of 200 m only. East of the Narayani river the Indian-Nepal border follows the foot of the hills. In this section we also find the widest Dun valleys behind the most southern range (figs. 3 and 4).

*The Siwaliks*

This mountain range, the southern most in Nepal, rises abruptly from the Ganges plain. This aspect of the landscape is quite different from the Alps, where the Molasse (the equivalent of the Siwaliks) rises gradually from the Midlands to the "Voralpen" (Fore-Alps).

The name Siwaliks is probably derived from Shiwa-Lekh (Lekh means mountain range). The natural limits of the Siwaliks are the Ganges plain in the south and the so-called "Main Boundary Thrust" in the north.

The Siwalik zone is an extremely rough landscape, entirely devoid of population and covered with jungles. These however are not so dense as those in the Terai, since the soil is rather immature, with rough boulders from the upper Siwalik formations on the surface. The Siwalik soil therefore is rather dry as it does not hold the water. During heavy rains the water is drained immediately into the valleys and rivers, which otherwise during the dry season are dried out. The Siwaliks build mountain ranges with altitudes up to about 1000–1500 m. The greatest elevations are found in western Nepal (north of Tsamali) where the Siwaliks rise from the Ganges plain straight up to 2000 m (plates 2–5).

The Siwaliks form one single mountain range in western Nepal, west of the Karnali, near Butwal and in eastern Nepal east of Dharan (fig. 4). In all the other areas there are two Siwalik ranges. This configuration is caused by the tectonic structure.

Seen from an aircraft, the Siwaliks have quite a unique appearance, since the ranges are formed by isoclinal chains and isoclinal valleys with a general northerly dip. (Fig. 133.)

In the areas with two Siwalik ranges, they generally do not have a parallel strike, but converge and diverge. Thus, space is left for wide valleys between the two Siwalik ranges, which are called the *Duns*. The largest Duns are from west to east (fig. 4): Jogbura, Surkhet, Dang, Rapti (western Nepal, not to be taken for the Rapti south of Kathmandu), Nawalpur, Chitawan, Kamla Khonch, Trijuga, and Kankai. Most of these Dun valleys are more or less on the same level as the Ganges plain (200 m). Two of them however (Surkhet and Dang) are elevated to about 400 m. So far, only the Surkhet Dun and the Dang Dun are appreciably populated. All the Dun valleys suffer heavily from malaria of the same type as in the Terai. The Dun valleys might play an important role in the future development of Nepal, but the soil is in most parts immature, with little or no humus compared with the southern Terai. Areas, so far covered by the jungles, will have an extremely dry soil after clearing. Irrigation will require incomparably more water to render the land fertile. The soil in most areas should be improved by adequate afforestation (fast growing trees) to provide humus in the first place.

Only those Duns which are adjacent to the big rivers, are at present suited for agricultural development. This is especially the case with the Chitawan in the lower part of the Rapti valley, where the Narayani river has deposited fine material.

*The Mahabharat Lekh*

The Mahabharat Lekh takes its name from the world famous Indian Epic. This mountain range rises to higher altitudes than the Siwaliks, namely up to 3000 m. It extends through the whole country, a distance of about 800 km. It is intersected by very narrow, deep gorges, through which the big rivers reach the Siwalik zone and the Ganges plain (fig. 4).

The Mahabharat Lekh comprises a rather rough terrain, with steep slopes. The upper parts above 2400 m, are covered by extensive jungles with Rhododendron dominant. In spite of the rough terrain, the general impression of the Mahabharat Lekh is not so much of a wilderness, since it is populated. Even on extremely steep slopes the farmers have built their terraced ricefields. The change in landscape, when walking from the Siwaliks across the Main Boundary Thrust into the nappes in the Mahabharat Lekh, is really striking. After the wilderness of the Siwaliks the neatly built houses of the Nepali give the landscape a surprisingly friendly aspect.

In certain areas, where the altitude does not exceed 2000 m, the Mahabharat Lekh is even very densely populated, and carries big towns, like Tansing.

Geologically, the Mahabharat Lekh corresponds to the front parts of the great nappes. It shows in general a synclinal structure (plates 2–5).

The southern flank is rather complicated with folds and thrustfolds, as is also characteristic of the nappe fronts in the Swiss Alps (for example in the Säntis or Pilatus range).

Since not one single nappe or nappe group extends right through the southern part of country from east to west, the Mahabharat Lekh is not built of one and the same nappe. The variations of the rockformations in the different nappes, are reflected in the general aspect of landscape. The acid gneisses and granites of the Kathmandu nappes in central Nepal produce a rather acid soil, while the carbonaceous series of the Nawakot nappes (for example near Tansing) and of the Piuthan Zone have weathered to very fertile soils, which influences the density of the population (i.e. on the Malka Danda, Karnali bend).

The additional height of the Mahabharat Lekh (3000 m) over the average altitude of the Midlands (1500–2000 m) is not caused by the nappe structure, but rather by a general rise due to vertical crustal movements.

*The Midlands*

The outlook from the Mahabharat range provides a comprehensive view across the whole Midlands, the heart of Nepal. The Midlands are formed by the big rivers running down from the Himalayas and then collecting in longitudinal valleys before gaining the Ganges plain through the Mahabharat range.

Thus the Mahabharat range is a natural southern protective wall of the Midlands. Only this protection made possible the origin of a such a high culture and a nation with such a particular and independent character as Nepal.

The great Himälaya range is the northern natural barrier of the Midlands. It was pointed out in chapter 1 (1) when describing the topographic map of fig. 3, how abruptly the Himalayas rise out of the Midlands.

The Midlands cover altitudes between 600 m and 2000 m. The soils are very fertile, but of course vary with the subsoil rocks, from which they have been weathered and eroded. The climate varies between a tropical one in the valleys and a temperate climate on the hills. The snow limit in winter is at about 2000 m in western Nepal and at about 2600 m in eastern Nepal.

The most surprising feature of the Midlands is the poverty of the forests. The population crowded into the Midlands has cut at will, and cutting was uncontrolled by the old regime (and still is). More and more distant areas are providing the supply of fuel for the Kathmandu valley for example.

As a result of the progressing deforestation, increasing soil erosion can be observed throughout the whole country. Afforestation with fast growing trees (for example Eucalyptus) is one of the most urgent needs in Nepal.

It is true that the water conservation of the Midlands is greatly influenced by the intensive terracing, which covers all the slopes. During heavy rains, the terraces with the small surrounding earth walls, retain much water which would otherwise cause sudden floods and landslides.

The ethnologic pattern and the distribution of the different races and population groups is quite unique in the world. Differing from other countries, the boundaries between different population groups follow contour lines. Thus the Indo-Nepalese population group lives dominantly below 2000 m. The native Nepalese group (of the Birmo-Tibetan languages) covers the areas between 1200 and 2400 m, while the group of Tibetan origin lives above 2400 m (the Sherpas for example).

Following this ethnologic pattern (or rather in reverse) we find different agricultural levels. Each belt of a particular altitude grows the necessary and adequate products, for example rice up to 2000 m, maize and millet between 1500 and 2400, potatoes and barley above 2400 m.

The highest villages on the southern flank of the great Himalaya range are at about 2400 m, namely the Mangar-population at the foot of Dhaulagiri, Gurungs south of Annapurna, and Thamangs south of the Ganesh Himal. Above the populated areas, the southern flank of the great Himalaya range is covered by the most dense jungles of coniferous and Rhododendron trees and bushes.

Geologically, the Midlands correspond to the overthrust parts of the big nappes. The main valleys follow without exception the anticlinal structures (plates 2–5).

*The Fore Himalaya*

The Fore Himalaya has been defined as an area within the Midlands, in which the altitudes exceed the average of 3000 m. The Fore Himalaya is developed in two areas only, namely in the Karnali area in western Nepal and in the Solu area in eastern Nepal (figs. 3 and 4).

In both these areas, the Fore Himalaya, with altitudes up to 4000 m, has produced a special landscape, which differs in many respects from the rest of the Midlands.

The basin of Jumla in western Nepal for example is a highland with a solid snowcover in winter and bearing huge pastures and widespread coniferous forests on the higher hills. Nevertheless, rice is grown at Jumla at about 2000 m. The population belongs—as an exception in such altitudes—mostly to the Indo-Nepalese group (Kshyatrias).

The *Solu* is the other zone of the Fore Himalaya. It is highland too, and enabled the Sherpas to settle down even to the south of the main range of the Himalayas.

*The Great Himalaya Range*

This of course is the most impressive part of the country; the highest peaks have already been mentioned in chapter 1. The range is divided into different groups by the transverse rivers. The general impression is, that the different groups have been raised out of a softer shaped base, which lies between 4500 and 5000 m.

It was G. O. Dyhrenfurth, who first created the expression "Hebungsinsel", which could be translated as "lifted block". The high peaks indeed show extremely steep and even vertical walls on all sides from the summits down to the pedestal at 5000 m.

The great Himalaya range, though not the main watershed, separates two entirely different types of landscapes. The rainbringing monsoon winds from southeast loose all their water at the southern flank of the great Himalaya range. The area north of the high mountains has the character of a mountain desert. At some places, the change of climate (recognized in the vegetation) takes place in a distance of a few kilometers only (for example in the Kali Gandaki valley near Tukucha). Geologically, the Great Himalaya Range corresponds to the roots of the main crystalline nappes.

*The Inner Himalayas*

The valleys of the Inner Himalayas are an intermediate area: The rain bringing winds enter through the gorges between the mountain groups. We thus find in the lower part of the northern flanks of these valleys dense vegetation with bamboo and coniferous trees (for example in the Manang valley, in the Rongshar, or in the Karma (figs. 3 and 4).

*The Khumbu area* holds a unique position; it is an Inner Himalayan valley but still lies on the southern side of the highest range (Everest). The Khumbu is comparatively dry and, protected from the heavy monsoon rainfalls and monsoon storms it is more densely populated than any other area of this altitude (above 3900 m).

In general the level of the villages is much higher on the northern flank of the great Himalaya range than on the southern side. While the Nepalese population groups do not live above the 2400 m level (south of Annapurna) and the Sherpas of Solu not above 3000 m, we find north of the main-range villages at 4000 m and even above this altitude. The town of Manang is at 3900 m, Muktinath at 3700 m. The highest settlement in Nepal, Phopagaon, was found in Langu, north of the Dhaulagiri range, at 4300 m above sea level. In Phopagaon, even potatoes and barley are grown. The different valleys of the Inner Himalayas are denoted in figs. 3 and 4.

Geologically the Inner Himalayan valleys correspond to the complicated Tibetan Marginal Synclinorium, defined in chapter 3 (plates 2–5).

*The Tibetan Plateau*

The expression "Tibetan" Plateau is here applied in a physiographic and geographic sense. It has no political meaning. It does in some areas include Tibetan territory. On the other hand in some areas, Nepalese territory reaches far north onto the Tibetan Plateau in the physiographical sense. Political boundaries do not always correspond with physiographic boundaries. In this publication on the Geology of Nepal all expressions containing the word "Tibetan" are applied in a physiographic sense. The Tibetan Plateau means the highland plateau which lies north of the Himalayas. "Tibetan zone" means the sediment zone of the Plateau. The southern limit of the sediment zone does not coincide with any political boundary.

The Tibetan Plateau has been defined above. It is the area north of the Tibetan Marginal Range with the flat warped table land. It is a pure mountain desert with a very small population. Agriculture is possible only with irrigation. Farming however plays a minor role for the population because their main activities lie in the field of trade between Nepal and Tibet. The trade deals mainly with salt which is imported into Nepal, agricultural products which are exported in exchange from Nepal into Tibet. (While this publication was in the press in 1961, Chinese troops have closed the Tibetan-Nepalese border hermetically. Thus the trade between the two countries has temporarily stopped.)

Geologically, the Tibetan Plateau corresponds with the sedimentary tableland. The gentle structures of the plateau decrease in magnitude and in intensity northwards.

# CHAPTER 2
# NOTE ON THE HISTORY OF GEOLOGICAL RESEARCH IN THE CENTRAL HIMALAYAS

When speaking of the geological research of the central Himalayas, we cannot restrict on Nepal. Nepal, having been a "forbidden land" until 1950 has played a minor role in scientific research until recently.

The Great Himalayas as a whole are by no means investigated in a systematic way, compared with other mountain ranges in the world. Undoubtedly, the gap of geological knowledge of the Himalayas was caused by the total lack of transport systems in large parts, which forced the explorers to cover the itineraries on their own feet and thus made all investigations rather inefficient, compared with the time involved.

However, there are some outstanding examples of general pioneering and geological research in the central Himalayas, carried out by small expeditions or even by single scientists. But as mentioned above, those expeditions took place beyond Nepal.

Thus, also nappes were first found in areas beyond Nepal, especially in the Simla area and in the Garhwal Himalaya.

In the view of better understanding of creating the nappe theory in the Himalayas, we have to consider also areas beyond Nepal, where the major research work has been done until recently.

The first paper on Himalayan Geology was published in 1851 by Captain Richard Strachey. He made some traverses in the Himalaya in 1848–49. His section given, in fig. 5, although not expressing any conception of overthrusts, was an amazing achievement of his time. The data of his cross section allow easily the interpretation according to the modern nappe theory. Strachey distinguished already the main lithological and stratigraphic divisions of the Great Himalayas, all dipping north.

Thrusting in the Himalayas was first mentioned as early as 1893 by R. D. Oldham. However it concerned the thrusts of the most southern ranges over the subsiding Gangetic Plain.It was the Hungarian Professor L. v. Lòczy, who published already in 1907 a profile from the Kangchendzönga range (eastern Nepal) right through to the Gangetic Plain (fig. 7), which applied for the first times the nappe conception in the Himalayas. In his view, the huge crystalline mass of Kangchendzönga—Singalila range (8) formed a huge recumbent fold and reaches toward the south for about 150 km. The recumbent fold is lying on its reversed series (7), which corresponds to the Daling series (phyllites and schists). It seems, that v. Lòczy also considered the deeper underlying, less metamorphic series (5) to belong to the reverse series of the lying fold. This non-metamorphic series occurs in the Rangit valley, east of the Singalila range, and have later on been determined as carboniferous by Geologists of the Geological Survey of India.

It may be interesting to illustrate with the example of the Rangit valley, how history of geological research is sometimes repeated: A recent interpretation of the carboniferous Rangit series agreed to their being overthrust by the Kangchendzönga crystalline. However, according to that interpretation, overthrust had been directed from south as well as from north, forming a "double fold", under which the Rangit series occurs. A striking example of similarity with the famous "Glarner Doppelfalte" of Albert Heim!

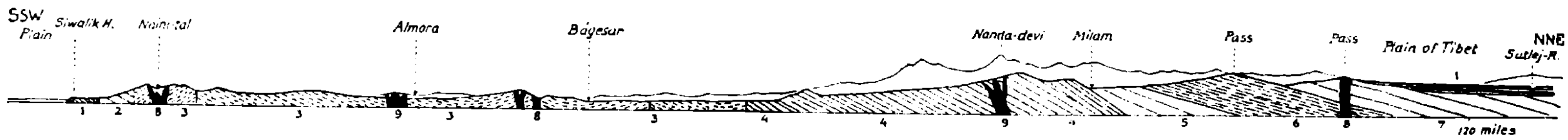



Fig. 5 The first geological profile across the Central Himalaya
by Captain Richard Strachey (1851).

1 Tertiary, 2 Secondary or Palaeozoic?, 3 metamorphic strata without fossils, 4 crystalline schists, 5 azoic slates, 6 Paleozoic, 7 Secondary, 8 greenstone, 9 granite.
The rock formations and the dips are in general correct. The cross-section as given above permits easily the tectonic interpretation created 85 years later by J. B. Auden and A. Heim and A. Gansser.

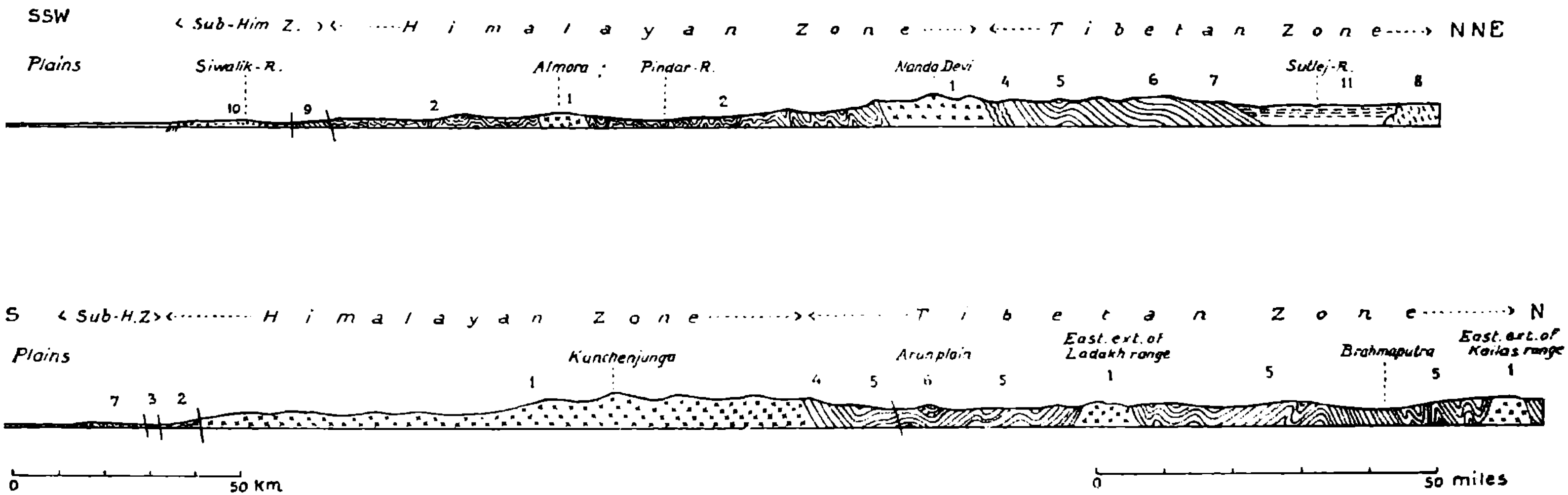



Fig. 6 Diagrammatic sections across the Himalaya
after Burrard and Hayden's "Geology of the Himalaya", revised edition 1934.

1 crystalline in general, "Central Gneiss", 2 Krol series (Carboniferous–Triassic).
The interpretation of Burrard and Hayden shows the crystalline series of the Nanda Devi and of Almora, and of the Kangchendzönga (right down to Darjeeling) as massifs. Compared with the profiles of v. Lóczy, with the huge recumbent fold this interpretation means rather a step backward. Also E. Argand (fig. 8) with his Himalayan nappes was far ahead of the publications of Burrard and Hayden.

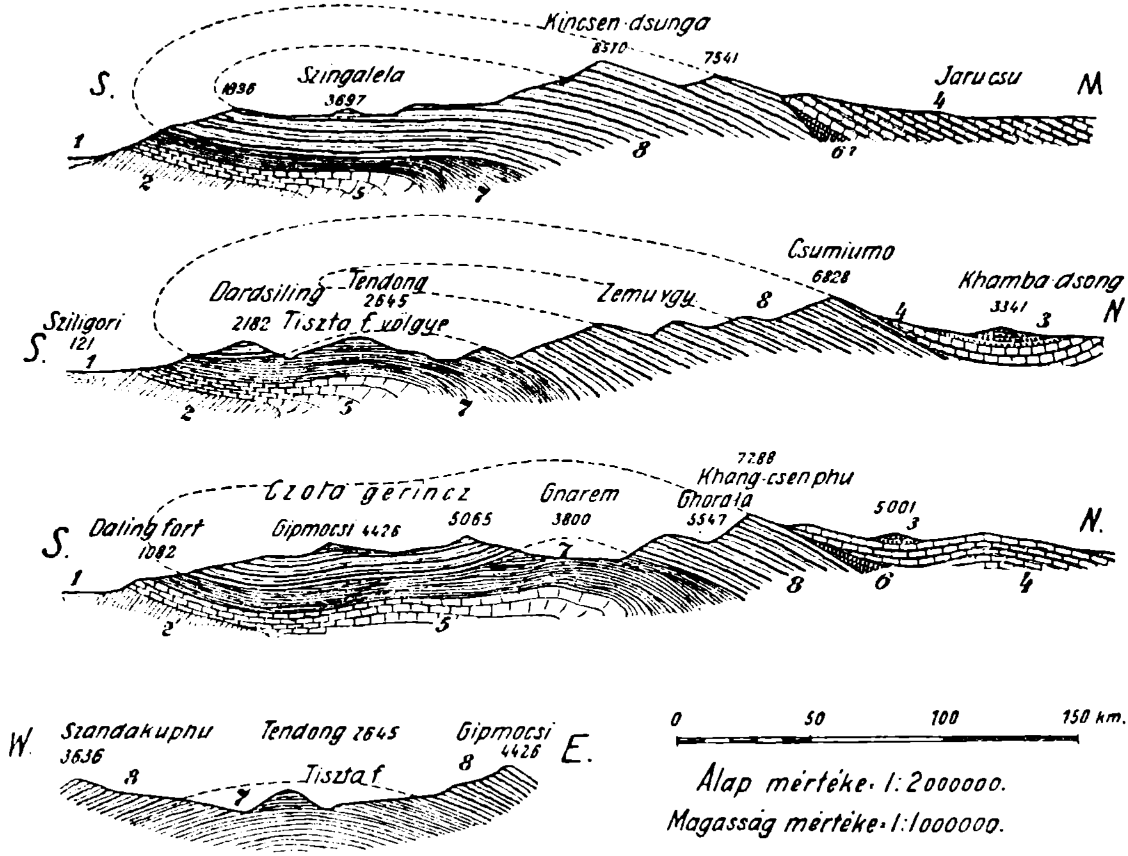



Fig. 7 Tectonic cross sections of Kangchendzönga–Darjeeling
by L. v. Lòczy (1907).

This Hungarian author, with his "recumbent folds" can be considered to be the founder of the nappe theory in the Himalayas. The type of Lòczy's profile with the soft shaped folds and reversed series at the bottom recall very much the profiles of the Alps in the early stage of the nappe theory, at the beginning of this century.

The cross sections show to an amazing degree all the tectonic features as found out by the author and given in this volume: The steeply northern dips of the "roots"; the flat syncline of the Marginal Synclinorium; the Himalayan fore-anticline and the Mahabharat syncline (section 2).

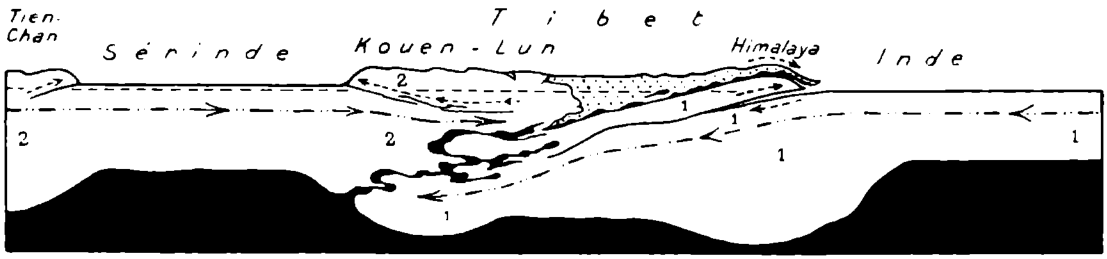



Fig. 8 Tectonic interpretations of the Himalaya (central Asia–India)
by E. Argand (1922).

1 ancient Gondwana continent, 2 Asian continental Block, dotted area: filling of the ancient geosyncline.

Like the whole publication of E. Argand, from which this section has been taken, the given profile has to be considered as genuine. We may read from the profile several features, which are still (or again) valid today. Thus, Argand for example correctly considered the Himalayan nappes originated from the northern margin of the Indian continental block.

Emile Argand, one of the founders of the nappe theory in the Alps, gave in his famous "Tectonique de l'Asie" a cross section through the Himalayas, which proved to be genuine (fig. 8). In his view, the main Asiatic continental block has converged with the Indian subcontinental block. The northern edge of the latter was at the same time supposed to have subsided, thus an overthrust of the area lying between (the geosyncline) toward south resulted. There are different views of the origin of the forces, which led to the rise of the Himalayas or mountain ranges at all. This does not matter too much in our discussion, since the main features of the tectonics of the Himalayas, especially the results as given by Argand proved to be correct in principle (see fig. 8).

The fundamental work of Burrard and Hayden, (revised edition 1934) gave a comprehensive description of the geological results obtained in the Himalayas so far. Hayden himself with his investigations in the Spiti area has laid the base for the stratigraphy of the sediment zone north of the crystalline of the Great Himalaya Range. While the Spiti area was very rich in fossils, the southern parts of the Himalayas have been named the "unfossiliferous zone". Only in 1954 paleozoic fossils were found in the Mahabharat Lekh south of Kathmandu.

However, the "Diagrammatic sections across the Himalayas" given in Burrard and Hayden's "Geology of the Himalaya" do not take too much regard to the tectonics (fig. 6). The profiles show the crystalline masses of the Great Himalaya Range as well as of the Almora area as massifs. The section through Kangchendzönga (fig. 6) means rather a step backward, compared with the same section given by Lòczy 28 years earlier in 1907 (fig. 7).

G. E. Pilgrim and W. D. West worked in the Simla area, and it is their merit to have established great overthrusts in that part of the Himalayas. Their results were published in 1928. Thus, this date has to be considered the birthday of the nappe conception, at last in the lower Himalaya.

It was then J. B. Auden, who has carried on the main geological research in the Himalaya. His publications, dealing with traverses in various areas of the Himalayas appeared in short intervals between 1934 and 1938. He established the "Garhwal nappes" in 1937 (fig. 11). Though covering only the southern part of the Garhwal Himalaya, he suggested that the overthrust parts must have their roots in the crystalline formations of the Great Himalaya Range.

Two years later, the fundamental work of A. Heim and A. Gansser appeared. The results of this very small two-men expedition, which lasted only 9 months, are an outstanding achievement. They covered the whole area from the Gangetic plain right up to the Tibetan Plateau near the holy mountain Kailas. They also visited the Tinkar valley in the northwestern corner of Nepal, which drains into the Kali Ganga in Kumaon (India). A grandeous nappe structure was unveiled in their publication and Gansser found a rich triassic fauna in the Tinkar valley. A. Heim made also a short excursion to Darjeeling and tried to design two "tentative" geological cross sections compiled from datas of earlier investigations of other geologists and from own "distant" observations (fig. 12).

He draw huge recumbent folds through Mount Everest and Kangchendzönga which have been thrust far to the south.

In the section through Kangchendzönga Heim established the "Sikkim Fenster" in the Rangit valley (which was described above). This view proved to be basically correct compared with the later interpretation as a "double fold". A. Gansser's beautiful collection of upper Triassic ammonites from the Tinkar valley should be mentioned, which have got a full description by A. Jeannet in 1959.

We have seen, that the major portion of geological research has been done so far outside Nepal. The first geologist to be found visiting Nepal itself was Hooker, who made in 1848 a trip into the Tamur valley in eastern Nepal. Medlicott made some observations in the Nepal valley and in the Trisuli valley northwest of Kathmandu. In 1933, two geologists of the Burmah Oil Company, Dr. Sali and Dr. S. Bowman were called by the Government with regard to possible Petroleum prospecting. S. Bowman determined some crinoids from the Chandragiri pass (Mahabharat Lekh, southwest of Kathmandu) to be of Ordovician age.

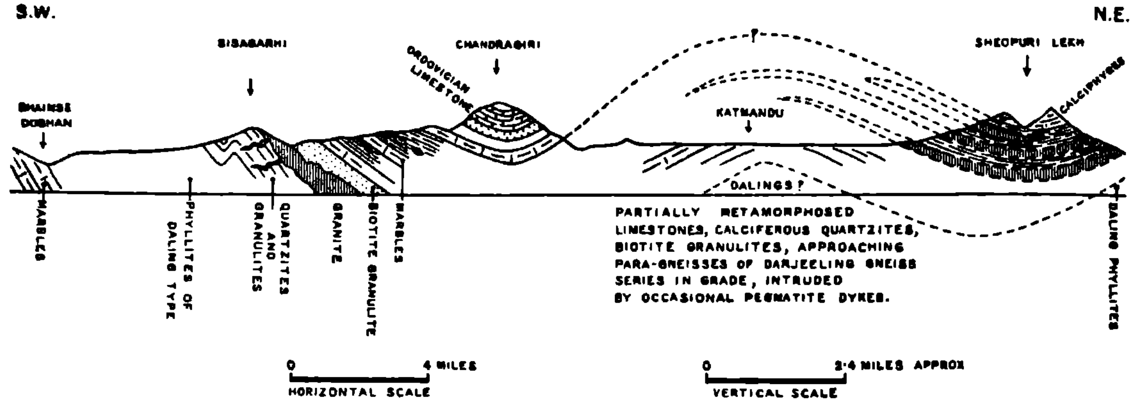



Fig. 9 Diagrammatic section across the Nepal valley in sheet 72 E
by J. B. Auden (1935)

Auden found the general syncline character of the crystalline in the Kathmandu area, with a local upwarp in the center. He also recognized the totally different series of Kathmandu (which he attributed to the Darjeeling gneiss) and of Suparitar (which he considered to be of Krol type).

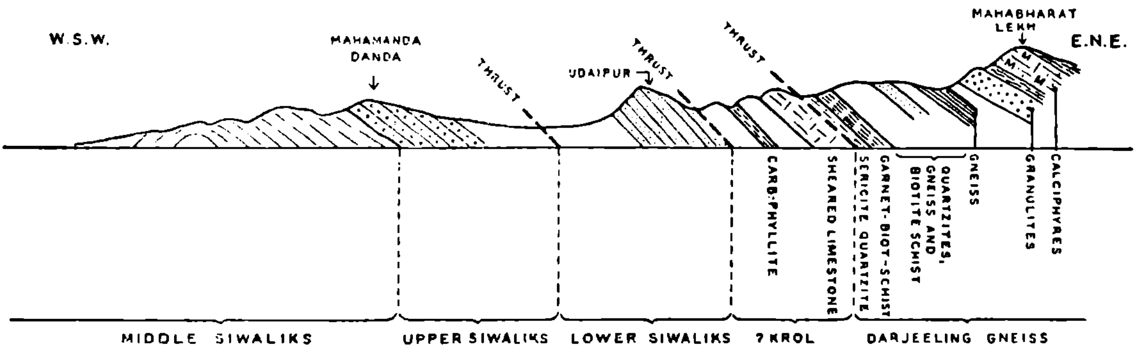



Fig. 10 Diagrammatic section through Udaipur Garhi in sheet 72 J
by J. B. Auden (1935).

Auden observed the two main thrusts between the Siwaliks and the Krol series, and between the Krol series and the Darjeeling gneiss of the Mahabharat Lekh.

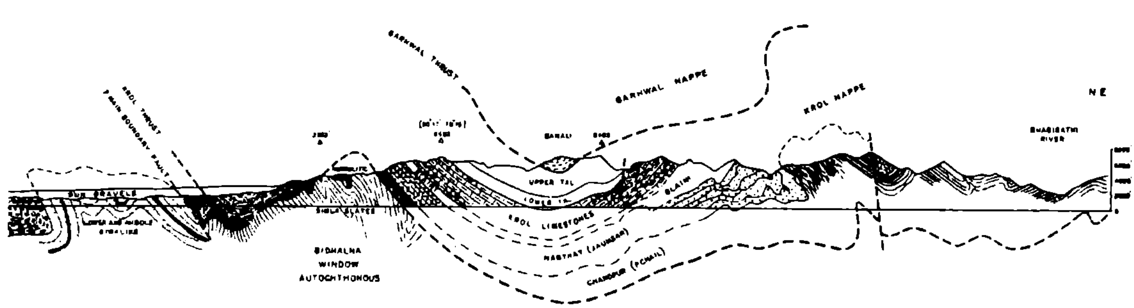



Fig. 11 Section across Siwalik range and Lower Himalaya
by J. B. Auden (1938).

Auden was the first geologist to give a modern tectonic interpretation of the central Himalayas. His divisions of the various tectonic units and the respective rock formations gave the base for the further investigations, and are in principle still today valid and adopted.

It was again J. B. Auden to carry out the first real geological traverses. He went to Nepal in connection with the disastrous Nepal-Bihar earthquake in 1934. In a preliminary account on that earthquake, Auden already mentioned thrustplanes in Nepal.

In the main paper, "Traverses in the Himalaya", three traverses are described, namely a trip to Kathmandu, to the Trisuli river near Nawakot, and to the Indrawati river near Dolalghat. The second trip was made from Jaynagarh on the Indian border up to Udaipur Garhi (eastern Nepal) and the third one from Jogbani to Dharan-Dhankuta, along the Arun river to Legua Ghat and Chainpur, over the Milke pass to the Tamar river and Taplejung, and finally up the Kabeli river to the Singalila range.

Auden recognized on his trip to Kathmandu the same threefold Siwalik formations (lower-middle upper Siwaliks) as found in India. The sedimentary series between Sanotar and Suparitar were attributed to the Krol series in Garhwal, (Carboniferous-Triassic). To quote him: "the rocks of Dhankuta-Chainpur, of the Mahabharat Lekh near Udaipur, and of the Sheopuri Lekh north of Kathmandu are unquestionably, in my opinion, Darjeeling gneiss. The underlying phyllites of Taplejung, Mulghat (on the Sun Kosi river) Deopur (in the Indrawati valley) and near Nagarkot may be regarded as Dalings."

The following three thrustplanes were found by Auden: One separating the Nahans (lower Siwaliks) from the overlying upper Siwalik conglomerates (fig. 10). It occurs near Hitaura (in the Kathmandu section). The Main Boundary Thrust, which separates the pre-Tertiaries from the underlying lower Siwaliks, was observed just north of Sanotar (north of Hitaura; fig. 9), and again on the first col eastnortheast of Udaipur Garhi (fig. 10). A third thrust was seen 2,5 km eastnortheast of Udaipur Garhi, and marks the boundary between the garnet schists of the Darjeeling gneiss and the underlying "possibly Krol rocks".

Thus, Auden recognized all the basic petrological and also tectonic elements. His cross sections, as given in figs. 9 and 10, may easily be interpreted according to the view of the author, Auden's Darjeeling series correspond to the Kathmandu nappes, while his Krol rocks are identical with the Nawakot nappes. He also mentions that the present disposition of the various formations and units is owed to large scale warping and folding (the Midlands structures of the author), the gneiss occurring in the cores of the synclines (the Mahabharat syncline of the author).

Basing on the establishing the nappe structure in the Garhwal Himalaya, Auden (Lit. 1937) also discusses the northern extension of the Garhwal nappes. To quote him: "it would seem possible therefore, that the main Garhwal nappe joins up with the rocks at the base of the main Himalayan range, and that the minimum distance of translation of this tectonic unit may be about 80 kilometers. It appears, that the granites were intruded principally into the Garhwal and overlying units and were thrust with them for miles towards the southwest, over rocks, which are free from granitic intrusions, but are in places considerably injected with basic magma. – Finally, comparison may be made with the eastern Himalaya. In eastern Nepal and north Bengal there are two main dislocations: 1) the thrust causing the Gondwana rocks (Krol) to lie upon the Siwaliks; 2) the thrust separating the Daling series (phyllitic and schistose base) from the underlying Gondwanas. These two thrusts may be analogous respectively to the Krol Thrust and one of the Garhwal Thrusts."

We may realize the far-seeing conclusion of Auden, when we mention that the Garhwal nappes correspond to the Kathmandu nappes and the Gondwanas are identical with the Nawakot nappes.

Two years later, Heim and Gansser also tried to extrapolate the result of their investigations in Kumaon toward east into the Nepal Himalaya. Utilizing the datas of former explorers, Heim concluded an interpretation of the Kangchendzönga and Mount Everest section, which was basically confirmed by the author. To quote him (Lit. 1939): "we must come to the conclusion, that the Darjeeling gneiss and its continuation in the Kangchendzönga massife belongs to a huge recumbent anticline thrust, from north to south, over a visible surface of more than 80 kilometers (fig. 12). While the Darjeeling gneiss is underlain and surrounded by younger sedimentaries, the huge Kangchendzönga massife represents the root zone of the great Darjeeling thrust fold (fig. 12). In principle we thus come to the same conclusion as L. v. Lòczy, who in 1907 reconsidered his observations of 1878 and whose conclusions were so long ignored. The highest mountains correspond to the back of the largest known thrust fold of our globe."

This conclusion is in principle correct. However, Kangchendzönga is just an exception, it lies rather south of the root of the main nappes. Nevertheless, all the other highest mountains of Nepal are today on the back of the roots. But the history of the highest mountains appears to be not so simple as it may seem (see pages 144–154).

The recumbent fold with a reverse series at the base needs some correction. As Auden and Heim considered, the Daling phyllites are not separated by a thrust from the overlying Darjeeling gneisses. Their difference is not a tectonic one, but rather a matter of degree of metamorphism. Nevertheless it appears not to be necessary to see in the Daling series (though less metamorphic) younger formations than the Darjeeling gneiss and thus to create a "reverse series" at the base of the huge recumbent fold. The imagination of huge recumbent folds with reversed series has been created in the early stages of the nappe theories in the Alps, when for example E. Argand considered the large nappes in the Wallis as "recumbent folds". Now, in the Alps, the ideas of most of the "recumbent folds" have been abandoned and have been replaced by the view of thrust sheets, with clear cuts at the base of the nappes. In the Nepal Himalayas too, the author has practically not found any reversed series at the base of the main nappes, which deserve that name.

When the author entered Nepal in 1950, nappe structure was thus evident in the Kangchendzönga section, while in the rest of the country just the three main thrusts were established by Auden, without proof for real nappes. During the first trip beyond the capital, to Nawakot in the Trisuli valley, the author found indications for nappe structure (see page 63 giving the history of the investigations in the Kathmandu area). The two main nappe groups in central Nepal—the Kathmandu nappes and the underlying Nawakot nappes—were introduced in a preliminary paper (Lit. 1951).

During the 9 years long field work, one stone after the other was joined to the mosaic, which forms the present pattern of the tectonics and of the Geology of Nepal (see figs. 13–14). Just a few marks may be mentioned: 1950 nappe structure found in central Nepal; tectonic window of Pokhara during a reconnaissance flight; 1952 Tibetan Marginal Synclinorium in the Thakkhola, with rich fossils; various nappes within the Nawakot nappe group; 1953 granite with irregular contact north of Manaslu; 1954 large Marginal Synclinorium in the Langu basin, evidence of a very young uplift of the main range due to dips of lacustre deposits north of Dhaulagiri; 1955 geology of the Everest group; overthrust of the Siwaliks over the topmost Gangetic alluvium near Muksar (eastern Nepal); 1956 Schuppen on Mount Everest and in its Kangshung flank, reverse dips north of Everest in the Karma valley; 1957 Mesozoic origin of the Tibetan Marginal Range, transverse graben of the Thakkhola; both ancient and post orogenetic origin of the huge Arun anticline; fault structure as origin of the Tibetan Marginal Synclinoria; conception of pre-orogenetic block tectonics in the southern edge of the later Tibetan Plateau.

The author has not been the only geologist working in Nepal since opening of the country in 1950. Auguste Lombard (Geneva) accompanied the Swiss Mount Everest Expedition in 1952 and carried through most important investigations in the Khumbu in eastern Nepal. The French Abbé P. Bordet was with the French Makalu expeditions two times in eastern Nepal. He and his compatriote M. Latreil studied especially petrological problems and laid the base in this field in eastern Nepal. We shall deal with the work of both, Lombard and Bordet later on, in the chapters on the Everest-Makalu group (see pages 120–128).

The Japanese petrologist Seiji Hashimoto (1956) described the petrological profile from Kathmandu to the Buri Gandaki valley. According to him the crystalline of the Sheopuri Lekh was supposed to be a massif with faultstructure (fig. 50). We may now begin with the physiographic and geological description of Nepal, as it results from the investigations by the author.

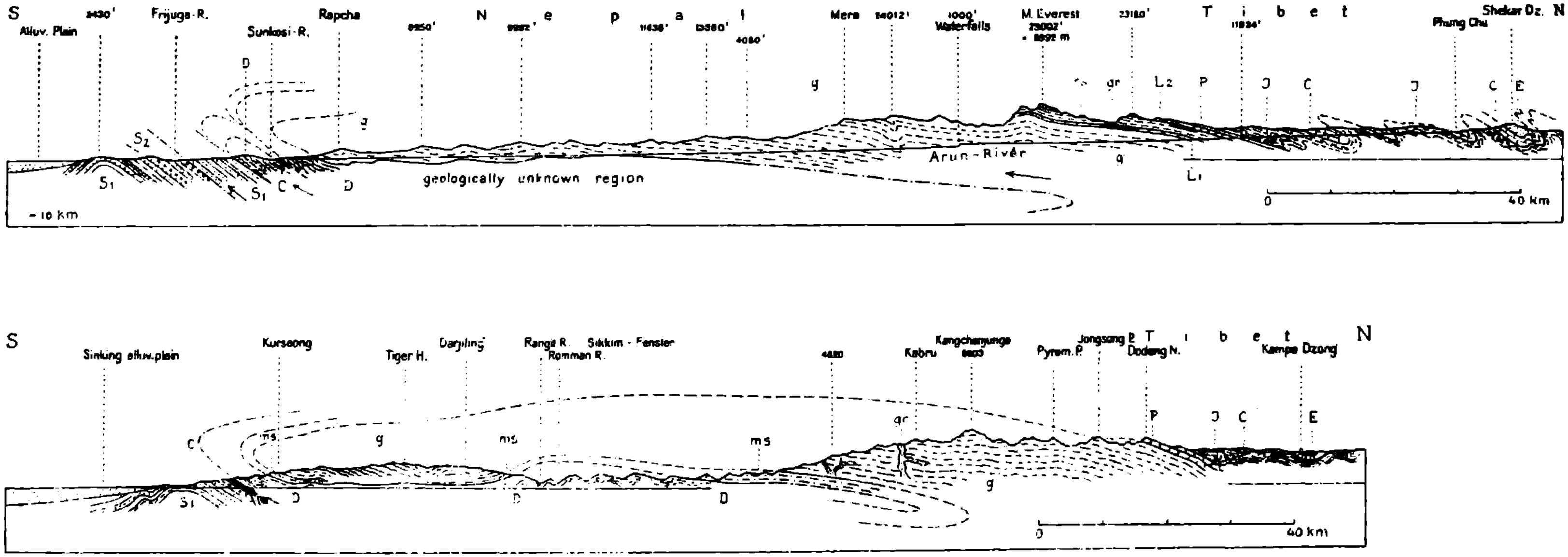



Fig. 12 '1 and 2 tentative tectonic sections of Darjeeling-Kangchenjunga and Nepal–Mount Everest' by A. Heim and A. Gansser (1939)

(compiled from the topographic maps; further after the investigations of Mallet, Garwood, Hayden, Heron, Dyhrenfurth, Wager, Auden and personal observations of Heim and Gansser).

From S to N: $S_1$ = lower Siwalik, $S_2$ = upper Siwalik (congl.), C = Gondwana, Carb., D = Dalings, ms = micaschists, g = gneiss, gr. = granite, $L_1$ = low. Everest limestone, $L_2$ = upper Everest ls., ss = sericitic schists, P = Permian, J = Jurassic, C = Cret., E = Eocene.

The profile shows a huge recumbent fold, similar to the interpretation of v. Lóczy (fig. 7).

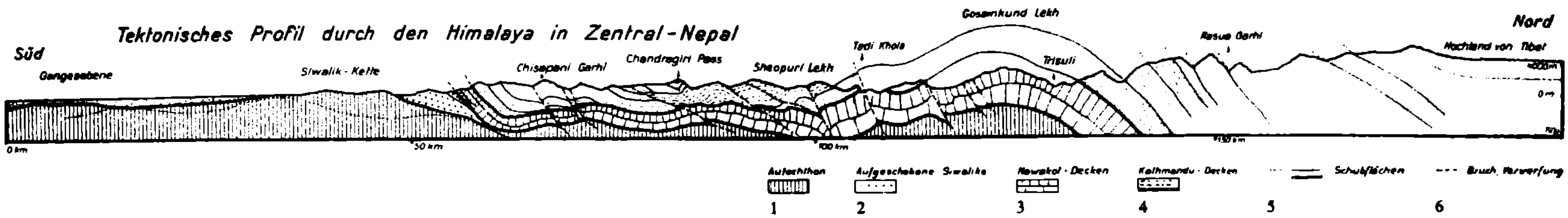



Fig. 13 Tectonic section of the Himalaya in Central Nepal
by Toni Hagen (1952).

1 autochthonous basement, including Siwaliks, 2 thrust Siwaliks, 3 Nawakot nappes, 4 Kathmandu nappes, 5 thrustplanes, 6 fracture, fault
This was the first profile of the Nepal Himalaya showing nappe structure and giving the two different main nappe groups in central Nepal.

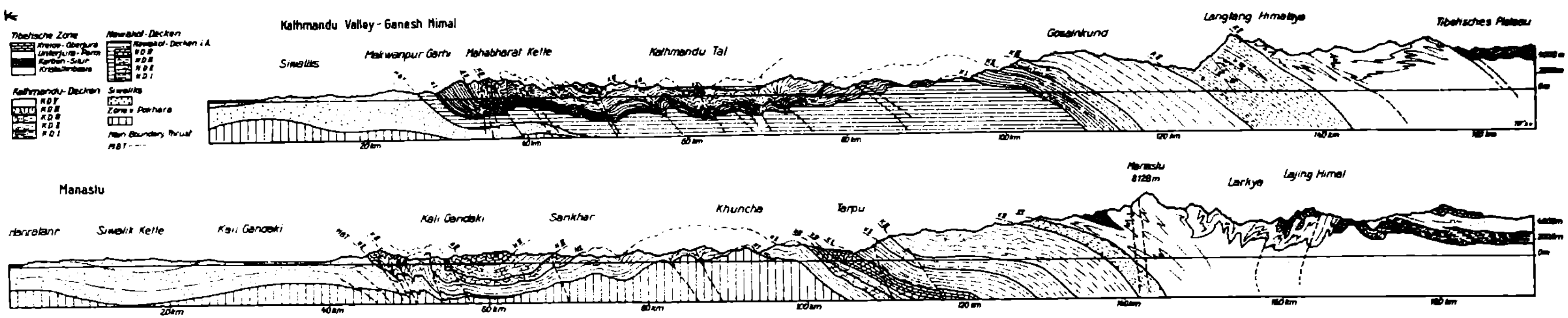



Fig. 14 Two tectonic sections across central Nepal
by Toni Hagen (1954).

These sections show the tectonic window of Pokhara as the lowest tectonic zone, and also the Manaslu granite with its irregular contact to the mesozoic series of the Tibetan sediment plateau. Also the reverse folds of the Tibetan Marginal Synclinorium are drawn.

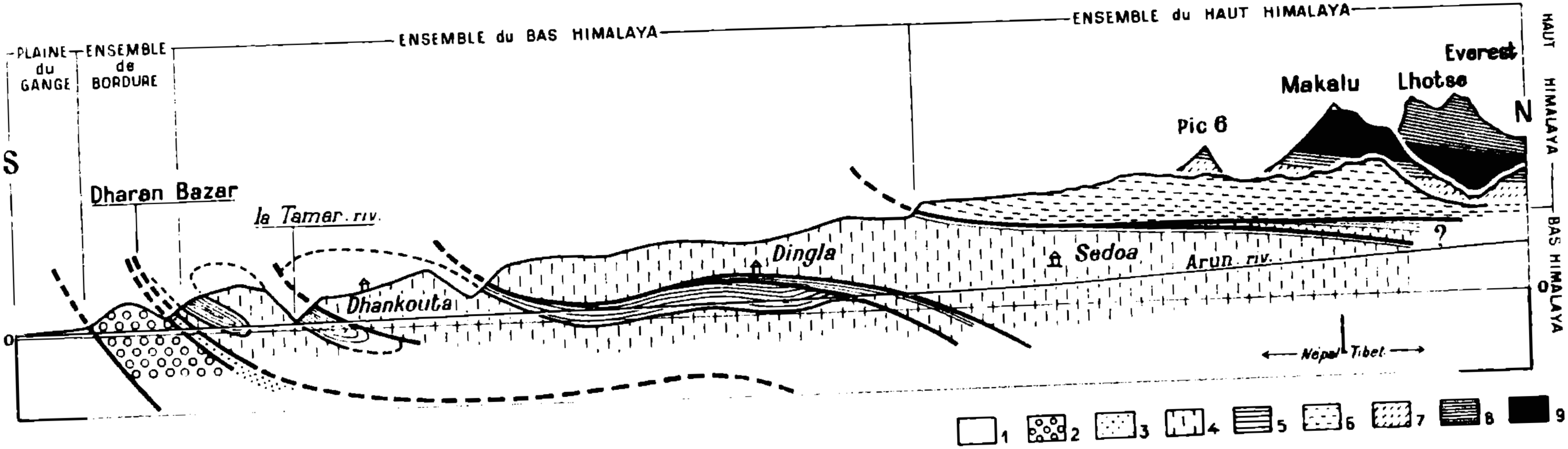



Fig. 15 Tectonic section of Everest–Ganges plain (heights two times exaggerated) by P. Bordet (1955).

1 Ganges plain, 2 Siwaliks, 3 Sanguri series (Nawakot nappes of T. Hagen), 4 migmatites of the "Lower Himalayas", 5 epimetamorphic cover of the migmatites of the "Lower Himalayas", 6 Barun gneiss, 7 Barun migmatite, 8 black Barun gneiss, including Everest series, 9 Makalu granite.

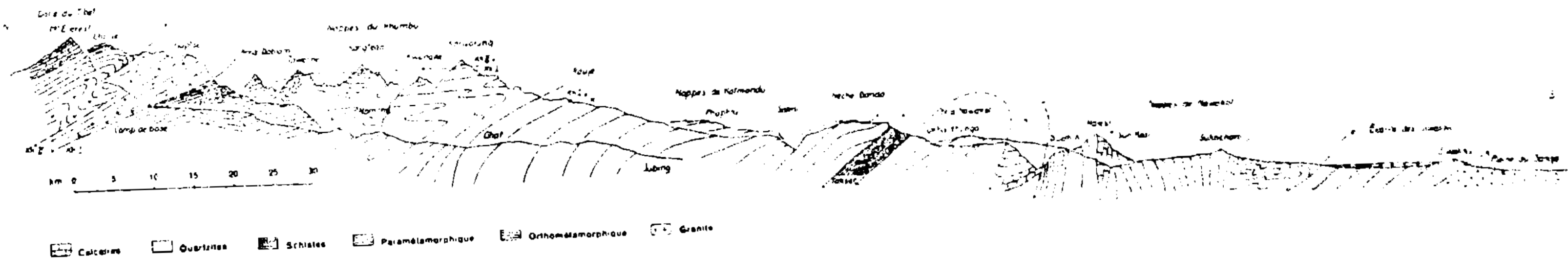



Fig. 16 Geological section from Mount Everest to the Ganges Plain by A. Lombard (1958).

Lombard gave for the first time the main tectonic divisions of the Khumbu area (Kathmandu nappes and Khumbu nappes) and also the tectonic Schuppen at the southern flank of the Everest group.

# CHAPTER 3
# TECTONIC STRUCTURE OF NEPAL

## *1) Basic features of the Tectonics, the Tectonic units and their distribution over the country*

In several minor preliminary papers the author has laid the foundation of the nappe structure in Nepal. The first note was published in 1951 after his first trip to Nepal, late in 1950. Below, on pages 62–66, a brief description is given, of the establishment of nappe structure in Nepal by the author.

The tectonic picture presented now, might seem rather complicated for those who are not familiar with the structure of the Alps or with nappe structure in general. A popularly written introduction has been published in the Mt. Everest-Monograph, an English edition of which came out by the Oxford University Press in 1963.

However, in general, the tectonics seem to be much simpler than those of the Alps, especially as the tectonic units seem to be more regular. Nevertheless the author is convinced, that further investigations will reveal a much more complicated tectonic picture of the Himalayas.

In the Alps, the general structure seemed to be fairly simple in the first stage of serious geological research, during the last century. After the creation of the nappe theory, early in this century, more and more tectonic units, nappes, blocks and slices, were found and the tectonic profiles showed gradually more complications. In addition, stratigraphic precision has allowed a more certain interpretation although many problems remain. How otherwise for example, could leading Swiss geologists come to discuss again the basic problem of the massif-structure or the nappe-structure of the Gotthard?

In Nepal of course, the geological problems are further from solution. A one-man-survey of a country four times larger than Switzerland, can of course never be compared with a century of geological research by hundreds of geologists, as it was undertaken in Switzerland.

The present tectonic lay-out will undoubtedly have to be modified and completed after further investigation. But the present volumes may serve as a basis for systematic geological mapping and studies in economic geology. There is one point however, in which Himalayan geology is more advanced than Alpine geology: in the Alps so far, no fossils have been found in the large metamorphic masses of the nappes; no fossils older than Carboniferous age are known. In the Himalayas too, so far, the overthrust masses of the big nappes have been described as an "unfossiliferous zone". In 1954 B. P. Malla, Mining Engineer of the Nepal Bureau of Mines found a number of fossils on the Phulchok, a few kilometers south of Kathmandu. This series was at that time considered to belong to the Kathmandu nappes and to be of Silurian age. Amongst serveral crinoids and an archecyathus, a *trilobite* was of most interest. This trilobite was later described by P. Bordet as of upper Cambrian-Silurian age.

As in the Alps, a number of nappe groups were found in Nepal, each of them consisting of several nappes of similar type of lithology and structure. Three of these nappe groups consist dominantly of crystalline formations, namely from top to bottom: the *Kangchendzönga-Lumbasumba nappes*, the *Khumbu nappes* and the *Kathmandu nappes*. Two of the nappe groups are dominantly formed of palaeozoic sediment-formations, with minor crystalline bodies *(Hiunchuli nappes, Jajarkot nappes)*. A further two nappe groups contain mostly carboniferous-mesozoic formations *(Bajang nappes, Nawakot nappes)*. The latter group however undergoes considerable changes in lithology and stratigraphy in the direction of the strike. They show a kind of transitional character, consisting in the south and in central Nepal dominantly of young formations (Permian-Triassic), while consisting in eastern Nepal almost entirely of palaeozoic formations. The Nawakot nappes thus show a gradual development to the type of the Kathmandu nappes.

There are two large zones of *Schuppen-structure (scaled structure): The Hiunchuli zone* and the *Dailekh zone*. Both of them consist of a great number of Schuppen of Palaeozoic formations. The *Piuthan zone* which is also *sliced*, differs from the others in its content of upper mesozoic-eocene formation. Finally there are several zones within the area of the nappes, which are to be considered as autochthonous and parautochthonous. They all occur in tectonic windows and half-windows: the crystalline mass of *Dandeldhura*, the *Galwa window*, the *Pokhara zone*, and the *Angbung zone*.

The most southerly hills are formed by the Tertiary *Siwaliks*. These are built from the detritus, brought down from the rising Himalaya by the big rivers. The Siwaliks show a great similarity to the Molasse of the Alps both in structure and lithology.

The lithology however seems to be rather monotonous compared with that of the Alpine Molasse. As in the Alps, there exists a thrust and a folded zone of the Siwaliks.

The *Tibetan Marginal Synclinorium* extends to the north of the big crystalline nappes. This zone corresponds geographically to the valleys of the *Inner Himalayas*. We have seen in chapter 1, paragraph 1 (page 23) that the *Tibetan Marginal Range* is the northern boundary of the Inner Himalayas. Consequently, this Tibetan Marginal Range forms the northern boundary of the Tibetan Marginal Synclinoria.

This synclinorium is a complicated system of folds and thrusts, which together form a syncline. The syncline is filled by a fairly complete series of sediments ranging from Palaeozoic to Upper Mesozoic age.

The Tibetan Marginal Range forms the separation between the complicated fold structures and the gentle warping structure of the Tibetan Plateau. The *Tibetan Plateau* consists of sedimentary formations similar to those of the marginal synclinorium, though the facies seems to be slightly different. The geology of the Marginal Synclinorium can be based on a firm stratigraphic scale, since a rich fauna ranging from Palaeozoic to Eocene has been found by the author in some places. The fauna is partly the equivalent of the world famous Spiti fauna further west.

Finally, some young *massif zones* of young granitic intrusions which occur at some places in the marginal synclinoria and in the Tibetan Plateau, should be mentioned.

The following table gives a summary of the nappes in Nepal and the numbers in each group:

| | | |
|---|---|---|
| *Crystalline nappes:* | Kangchendzönga nappe | (1) |
| | Lumbasumba nappe | (1) |
| | Khumbu nappes | (3) |
| | Kathmandu nappes | (5) |
| *Nappes of dominantly Palaeozoic sediments:* | Hiunchuli nappes | (2) |
| | Jajarkot nappes | (2) |
| *Nappes of dominantly Carboniferous-Mesozoic sediments:* | Bajang nappes | (4) |
| | Nawakot nappes | (4) |

The total of 22 nappes in the whole area of Nepal is surprisingly high. In comparison with the Swiss Alps however the number is not so unusual as the total figure is of about the same magnitude. We have nevertheless to bear in mind, that Nepal covers an area which is about 4 times the size of Switzerland. Thus the number of nappes calculated for the same area of earth surface will decrease considerably and as a percentage, in the Nepal Himalayas a smaller number of nappes has so far been observed than in the Swiss Alps.

The total figure of 22 nappes will certainly give a wrong impression of the real situation, as all 22 nappes cannot of course be found in one single cross-section of Nepal. The different nappe groups do not strike through the whole country from east to west; the Kathmandu nappes for example terminate east of the Arun river, while the Khumbu nappes do not occur further west than the meridian of Kathmandu. The Hiunchuli nappes and the Jajarkot nappes only occur west of the Kali Gandaki section (see fig. 17).

A remarkable difference between the Alpine nappes and the Himalayan nappes in Nepal may be seen from the profiles in plate 5. The nappes of the Swiss Alps are much more contorted and sliced into isolated masses, which often appear in the form of lenses or very small irregular slices, and which are also in some areas very strongly folded. The Nepal Himalayan nappes are much more regular in the north-south profile or the cross-section. The regularity mostly concerns the thicknesses of the individual nappes.

Fig. 17 (below) may give an idea of the geographical distribution and the pattern of the different nappe groups and their relative positions. The figures in brackets denote the number of nappes in the respective groups.

It may be seen that the cross section through Mt. Everest shows the maximum number of nappes, namely 11. In the section of Kangchendzönga there are only 5 nappes, while the sections of Kali Gandaki and Karnali show 9 nappes.

The Kathmandu nappes prove to be the real backbone of the Nepal Himalayas (plate 6). They extend through from eastern Nepal right to the western border of the country. They continue even far beyond Nepal into the Kumaon and Garhwal Himalayas, where they are identical to the "Garhwal nappes" of J. B. Auden and the "Central Gneiss" and the "Almora Thrust mass" of Heim and Gansser. The Bajang nappes, underlying the Kathmandu nappes also continue to the west beyond Nepal. They correspond to the Krol nappes and the Tejam zone of the authors mentioned above. Since the Nawakot nappes in central and eastern Nepal correspond to the Bajang nappes (lithologically and tectonically) they can also be considered as equivalent to the Krol nappes of Auden.

Fig. 17 gives a schematic sketch of the distribution of the various main tectonic units and their correlation with each other. Two tectonic zones strike through the whole country without interrup-

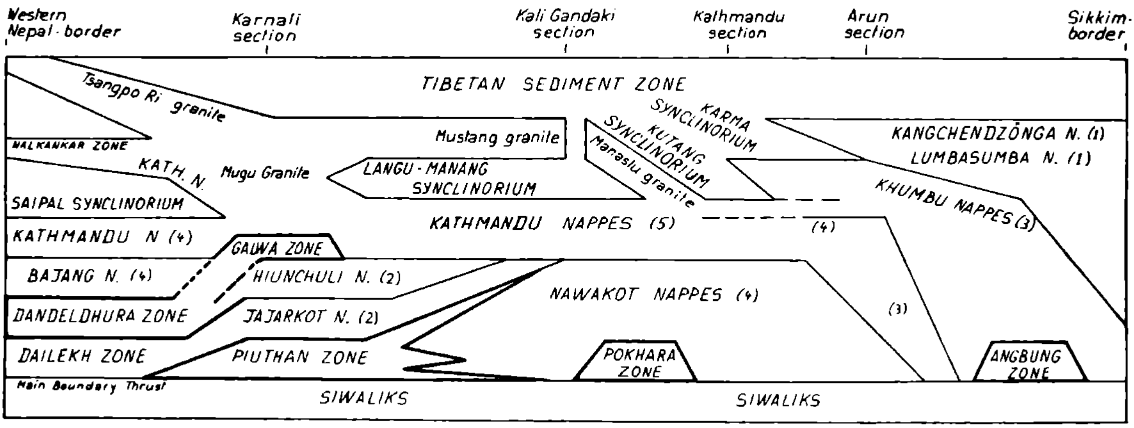



Fig. 17 Schematic and simplified sketch of the various tectonic units and their relative position

The autochthonous and parautochthonous zones are marked with heavy lines. The numbers in brackets denote the number of nappes in the particular nappe group.

The Pokhara zone is the lowest tectonic unit found in Nepal. The Nawakot nappes are the lowest nappes in the Nepal Himalaya. It may be seen, how from central Nepal toward east and west gradually various nappes have been thrust over the Nawakot nappes. Thus central Nepal takes a central position, from which thrusting has started, geographically and chronologically. The Kathmandu nappes show the longest east-west extension; they are the backbone of the nappes in Nepal.

tion: the Tibetan Sediment Zone in the north and the Siwalik Zone in the south. These zones extend to the east and the west beyond Nepal. Within the various nappe groups, the Kathmandu nappes strike almost through the whole country too. West of the Kathmandu section (fig. 17), the Kathmandu nappes are the uppermost nappes. They join the Tibetan Marginal Synclinorium and the Tibetan Sediment Zone. East of the meridian of Kathmandu, the Khumbu nappes overlie the Kathmandu nappes and east of the Arun section the Lumbasumba nappe and the Kangchendzönga nappe again overlie the Khumbu nappes (fig. 17 is drawn so that the higher tectonic units are at the top and the underlying ones at the bottom). Since the overthrust has been directed from north to south, the figure can be compared with a schematic sketch map; the upper nappes at the top of the plate being the northernmost ones, the lowest nappes being at the bottom and in the south). Thus, the Siwaliks are shown at the bottom, underlying all the nappes.

The irregular boundary of the northern edge of the Kathmandu nappes with the Tibetan Sediment Zone is most interesting (plate 6). In two areas, there are large intermediate marginal synclinoria. The Langu-Manang Synclinorium is almost entirely surrounded by granites, while the Saipal Synclinorium opens towards the west into the Tibetan Sediment Zone. Only a small belt of sediments connects the Langu-Manang Synclinorium with the sediment zone of Tibet. This is due to a Graben structure, the "Thakkhola Trench" which created the upper course of the Kali Gandaki valley (Mustang, plate 6).

Two branches of crystalline zones (mostly granites) stretch from the Mugu granite zone towards the northwest, namely the Nalkankar zone and the zone of the Tsangpo Ri granite (fig. 17). Both of them show axial pitching towards the northwest into the Tibetan Plateau. The *Nalkankar zone* is identical to the *Gurla Mandata crystalline anticline* found by Heim and Gansser in 1936. The Tsangpo Ri granite most probably continues into the granitic base of the holy mountain Kailas.

A glance at figs. 17 and plate 6 shows the repetition of similar features in eastern Nepal: the Khumbu nappes as well as the overlying Lumbasumba and Kangchendzönga nappes diverge from the main root zone of the Kathmandu nappes towards the northwest, into the Tibetan Sediment Zone. Their respective crystalline masses and anticlines show a pitch in the same direction, so that they end east of the Kathmandu section. From the distribution of the above mentioned nappes and their intersections with the Tibetan Sediment Zone, it can easily be concluded, that mountain building in this northern belt commenced in western Nepal, and gradually moved towards the east. The youngest, overlying nappes are found in the east. The number of overthrust nappes also increases towards eastern Nepal.

Regarding the nappes south of the crystalline roots, the picture is entirely different. There are also considerable changes in strike direction (east-west), but here, unlike the northern belt, the number of nappes increases towards western Nepal. In central Nepal, the Nawakot nappes are the only nappes underlying the Kathmandu nappes. The tectonic cross sections between the Arun meridian and the Kali Gandaki meridian are quite simple, containing two nappe groups only (see plates 2 and 3). West of the Kali Gandaki meridian, quite a number of additional nappes develop gradually out of the joint between the Kathmandu nappes and the Nawakot nappes. In the Karnali section, even an authochthonous zone (in the tectonic window of Galwa) occurs at the base of the Kathmandu nappes. This is only one of the three autochthonous and parautochthonous zones, which exist to the west of the Kali Gandaki section (fig. 17).

The *Dandeldhura zone* with its huge masses of augengneisses and granites, is considered to be a *massif* too. It is connected laterally and underneath the overthrust Bajang nappes, with the Galwa zone. The latter showing in the tectonic window the Triassic and Upper Palaeozoic sedimentary cover of the Dandelhura massif.

The third parautochthonous zone of western Nepal, the *Piuthan zone* however shows a different character in lithology and structure. It is a sliced zone of Upper Mesozoic-Eocene sediments containing also elements of the Nawakot (Krol) nappes. It covers a large area along the Main Boundary Thrust, and reaches far north into the Midlands and underneath the Jajarkot nappes. Most interesting is the eastern termination of the Piuthan zone, which sends wedges laterally between the different Nawakot nappes, and also between the Jajarkot nappes and the Nawakot nappes (fig. 17 and plate 6).

From the distribution of the lower nappe groups in western Nepal, with their divergence from the main crystalline roots (Kathmandu roots) towards the south-west, it can be concluded that mountain building started in the meridian of the Kali Gandaki, and has gradually moved towards the west. The section of the Kali Gandaki river thus holds a most important, central position. It is the pivot from which the main tectonic units have separated towards the east and the west.

From the very much simplified illustration in plate 6 it can already be seen, how important the main transverse river systems of Nepal (Karnali, Kali Gandaki and Arun), have been in the primary lay-out of the structure. The respective sections divide the country geologically into five different longitudinal areas:

a) The sector between the Kali Gandaki and Arun with the limited number of only two nappe groups;

b) the sector between Kali Gandaki and Karnali in western Nepal, with three nappe groups of dominantly low-metamorphic Palaeozoics;

c) the Mesozoic Piuthan zone;

d) the sector west of Karnali with two nappe groups and the Dandeldhura massif, and

e) the sector east of the Arun with three nappe groups of the crystalline type.

Let us now compare the distances of overthrust in the various nappe groups. The distance is measured from the root of the nappes to their front. It is evident, that the main nappe group, the Kathmandu nappes, developed the longest overthrusts.

The roots of the Kathmandu nappes also built the backbone of the Nepal Himalaya, the Great Himalaya Range.

The maximum overthrusts of the Kathmandu nappes are found in the Kathmandu section where they are almost 100 km. In the Meridian of Galwa-Jumla, the overthrust even exceeds 100 km (profile 80, plate 5). The Nawakot nappes have their maximum thrust of 90 km in the section of the Kali Gandaki river (plate 6). The remaining nappe groups in western Nepal do not exceed 50 km of overthrust. In general, the magnitude of the overthrust of the Himalayan nappes in Nepal can be compared with that of the Alpine nappes in Switzerland (compare the sections through Nepal and through the Swiss alps in plate 5).

After this general introduction to the main tectonic features of Nepal, we shall give a brief description of the more detailed structures.

### *2) Structures in the Midlands*

The Nepalese Midlands are built of the overthrust parts of the nappes. These nappes do not now lie horizontally, but they are warped, and intersected by a number of different structures.

The main structures in the Midlands naturally show an east-west strike, following the general alignment of the Himalayas.

The structures themselves are not confined to particular nappes; but all the nappes piled one above the other, are affected by the Midland structures. These structures thus necessarily have to be considered to be younger than the great overthrusts of the nappes from their roots southwards.

The roots of all the nappes of course show a steep northern dip. South of the roots, all the nappes bend over to the horizontal and even to give a southerly dip in the Himalayan *Fore-Anticline* (plate 6). This Anticline is not developed equally throughout the whole country, but is limited to certain areas.

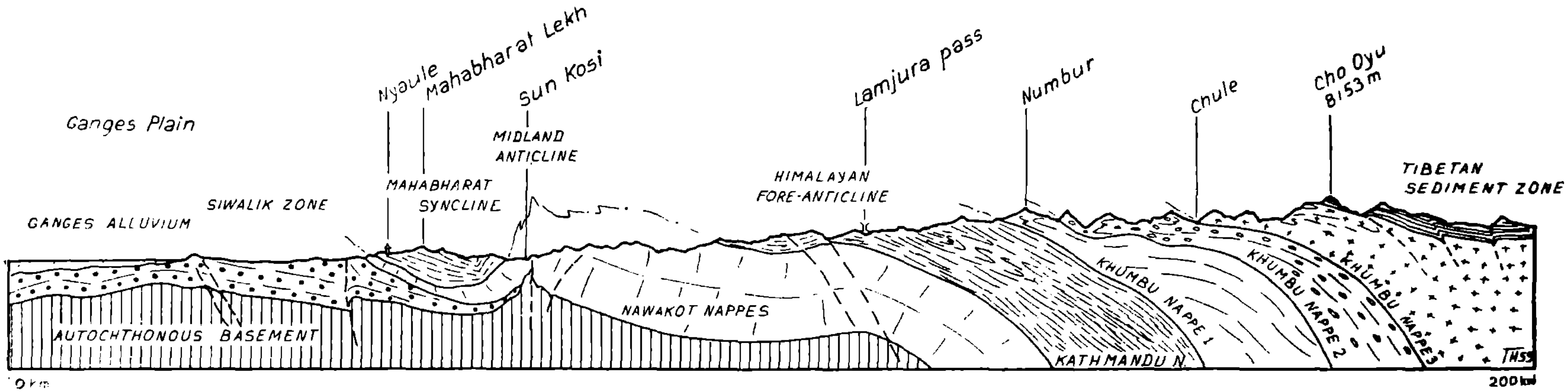



Fig. 18 Generalized tectonic cross section of eastern Nepal

The profile shows the main tectonic structures from the Tibetan Plateau right down to the Ganges plain.

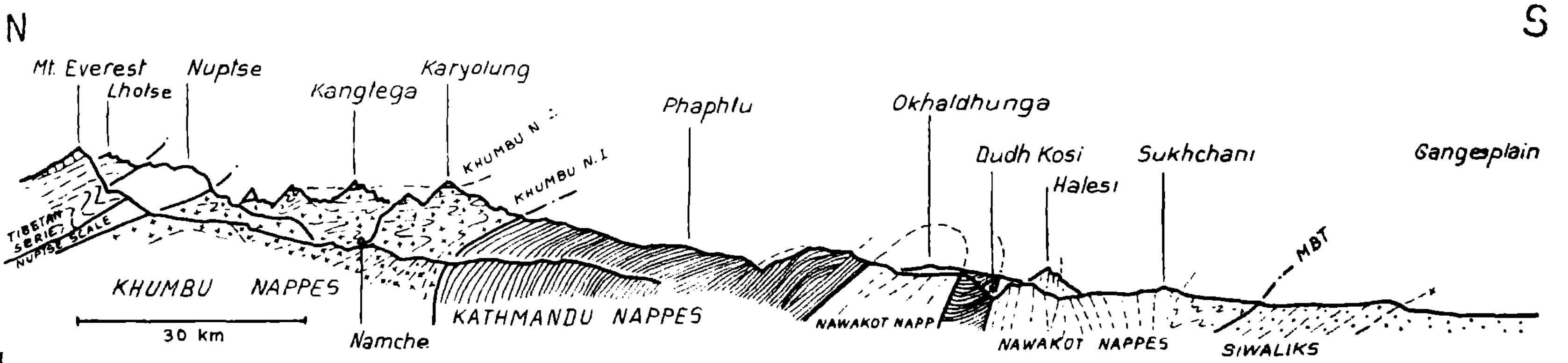



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Fig. 19 Tectonic interpretation of the Everest section by A. Lombard, 1958

The interpretation of the area north of Okhaldhunga is identical with that one by T. Hagen (fig. 20). The southern area however seems not to be quite clear. It has been mentioned in the texts (page 73) that it is rather difficult in eastern Nepal to distinguish between the Kathmandu nappes and the Nawakot nappes from a lithological standpoint. The difficulties of Lombard in interpreting might have been caused by this fact.

The profile has three times exaggerated heights, thus it may give partly a wrong impression. Especially the structures and the dips appear to be greatly too steep compared with the real configuration in nature.

This can be seen in the profiles and in the tectonic stereograms (figs.29–35). (In the tectonic map of plate 6, the Himalayan Fore-Anticline has not been drawn, since it is of much less importance than the other main structures). The fore-anticline may be seen clearly in the section of Everest (profile 11, plate 2) where the valley of the Irkhua Khola has cut the top of the anticline. In profile 14, the Hongu valley plays the same role. The said anticline is also well developed in the profiles 30 and 46. In the latter, the Khuncha anticline continues towards the west into the dome of Pokhara, where a parautochthonous zone occurs in a tectonic window.

Further west, the Bheri anticline takes over the role of the fore-anticline. The parautochthonous Piuthan zone occurs in that anticline in the form of a tectonic semi-window (plate 6). The Hiunchuli and Jajarkot nappes have been thrust over this anticline.

In the Karnali section, the Himalayan Fore-Anticline is transposed considerably towards the north. It forms the Galwa zone, which underlies the Kathmandu nappes and occurs in the double tectonic window.

In the Baitadi area, the Himalayan Fore-Anticline caused the appearance of the Dandeldhura zone in a tectonic semi-window underneath the Bajang nappes (plate 6 and fig. 35).

It has been mentioned above that the Himalayan Fore-Anticline is not the main structure of the Midlands. The main role is played by the *Midland Anticline* (fig. 18 and plate 6). This huge anticline occurs in two different areas, namely in the Sun Kosi basin in eastern Nepal, where it is called the *Sun Kosi* Anticline, and in the Kali-Trisuli basin in central Nepal, where it is called the *Kali-Trisuli-Anticline*. The latter structure continues to the west into the *Bheri Anticline*. It terminates finally near Jajarkot, after a total distance of nearly 500 km; this is probably one of the longest single anticline-structures in the world.

In western Nepal, beyond Jajarkot, the Midland anticline does not exist. There is no space for such a large structure, due to the *autochthonous massif* of *Dandeldhura*, which extends from a point near the Main Boundary Thrust in the south, right through and underneath the overthrust Kathmandu nappes to the windows of Galwa (plate 6 and fig. 34).

A look at the tectonic map given in plate 6, shows the extraordinary strike of the Midland anticline in eastern Nepal: the eastern part of the Kali-Trisuli anticline is bent round parallel to the upper course of the Trisuli valley and breaks up into partial anticlines. The same feature, but exaggerated, occurs in the Kosi anticline, the western end of which is bent to the north with branches even to the north-east. It is indeed a unique structure, with an axis forming almost a circle! The eastern termination of the Kosi anticline is also bent to the north and directed into the transverse anticline of the Arun (plate 6).

Both, the Kali-Trisuli and the Kosi anticlines are of an asymmetric type (fig. 18). The northern flanks are very mighty with a monotonous series of 7 kilometers thickness for example in the Nawakot nappe no. 2 alone, and with an extremely reduced southern flank (see plate 5 profile 17 Cho Oyu and profile 20 Gauri Sankar). In some places, the Midland anticline thus takes the character of an anticline-fault, with a broken top. It is evident, that this type of anticline-fault has weakened the rocks and has produced the primary lay-out of the river courses. Both the main river systems in central Nepal (Kali Gandaki) and eastern Nepal (Sun Kosi) follow the Midland anticline. The names of the anticlines have been taken from the river systems: Bheri anticline, Kali-Trisuli anticline and Kosi anticline.

In both of the Midland anticlines, erosion has eliminated the overlying Kathmandu nappes, so that the underlying Nawakot nappes occur in tectonic windows and semi-windows. At both ends, these Midland anticlines show a strong axial pitch. The pitching terminations will be discussed in the paragraph on the transverse structures.

The *Mahabharat syncline* is the southernmost main structure and as indicated by the name, it follows the Mahabharat Lekh (fig. 18 and plate 6). The longitudinal extension corresponds to that of the Kali-Trisuli anticline and the Kosi anticline. The Mahabharat syncline strikes without interrup-

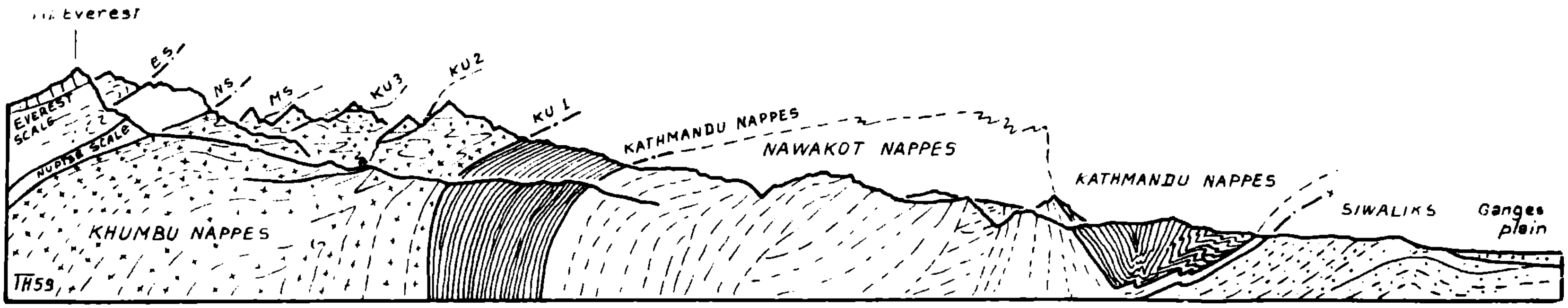



Fig. 20 Tectonic interpretation of the Everest section by Toni Hagen

| | | | |
|---|---|---|---|
| ES | Everest Schuppe ("scale") | Ku 3 | Khumbu nappe 3 |
| NS | Nuptse Schuppe ("scale") | Ku 2 | Khumbu nappe 2 |
| MS | Makalu Schuppe ("scale") | Ku 1 | Khumbu nappe 1 |

The same lithological features (as for example given in fig. 19) and especially the same dips and structures visible on the surface allow a different tectonic interpretation from that one given by A. Lombard.

The author considers the main portion of the series between Phaphlu and the Sun Kosi river to belong to the Nawakot nappes, while the series of Sukhchani (on the Mahabharat range) undoubtedly are part of the overthrust Kathmandu nappes. The particular structure and the dips on the Mahabharat range allow without any difficulties the interpretation of A. Lombard. However, when field investigations are extended toward east and west, the syncline character of the Mahabharat Lekh, built by the Kathmandu nappes, is evident. The itinerary of A. Lombard crossed the Mahabharat Lekh just by bad luck in that area, where the Mahabharat syncline (which else extends on a distance of 400 kilometers) is rather unclear.

The fact, that there are in eastern Nepal considerable lithological similarities between the Kathmandu nappes and the Nawakot nappes (see page 73) makes it understandable, that A. Lombard considered the series of Phaphlu series to belong to the Kathmandu nappes.

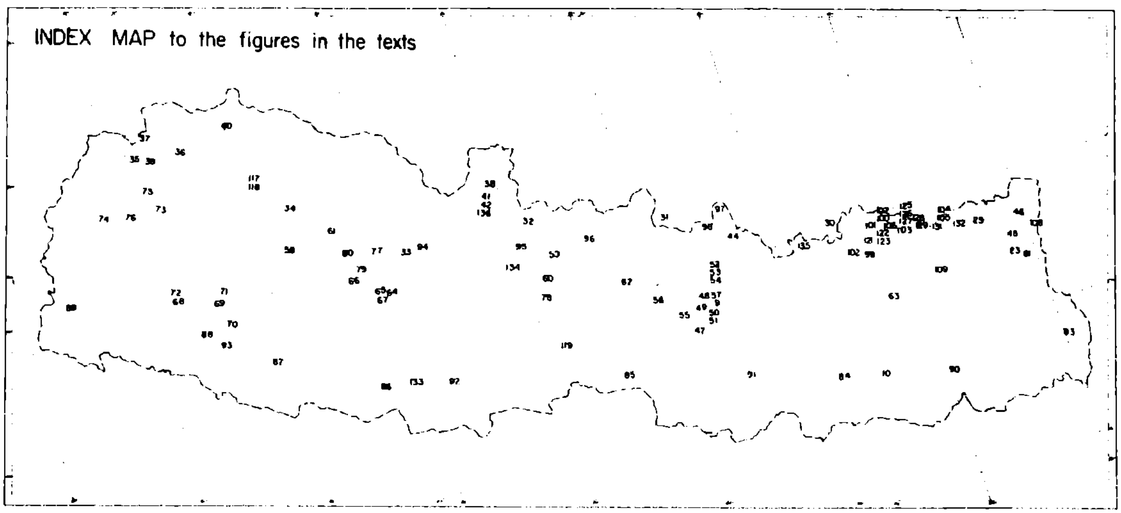



Fig. 21 Index map showing the location of the figures in the text and the photo plates

tion through from the sharp river bend of the Sun Kosi (20 km east of Udaipur Garhi) to Kanchikot, 50 km west of Tansing, which gives a total length of 400 km. The Mahabharat syncline is thus probably one of the longest single syncline structure of the world.

The structure of the Mahabharat syncline is not so simple as that of the Midland anticline. In some areas, for example near Kathmandu it is quite a complicated synclinorium with a number of secondary folds and thrust-folds (see profiles 27 and 30, plate 3). The Mahabharat syncline is also asymmetrical: the northern flank is in part rather reduced (tectonically), while the southern flank shows a great thickness (fig. 18 and profile 20, plate 3).

The asymmetric character of the Mahabharat syncline has sometimes confused geologists. In the section of Okhaldunga-Jaynagarh for example, the Midland anticline-fault has raised the beds to a vertical position, and this also includes the northern flank of the Mahabharat syncline. Based on this one cross section, it is quite possible to consider the Nawakot nappes as overlying the Kathmandu nappes and the latter as dipping towards the north underneath the Nawakot nappes (figs. 20 and 19), as was done by A. Lombard.

Taking just a single section in that area, it is difficult to recognize the general synclinal character of the Kathmandu nappes in the Mahabharat range. This shows again the difficulties and risks of interpretation of single cross-sections. The author has taken dozens of other cross-sections at other places in the Mahabharat range and they show all quite clearly the general synclinal character.

In eastern Nepal, in the area of the Arun, the Mahabharat syncline is interrupted for about 70 km. It only re-appears again northeast of Dharan (plate 6). From this place it strikes for about 30 km along the Mahabharat range, but then turns towards the north into the Singalila range and continues into the western part of the Kangchendzönga (plate 6 and fig. 24).

Thus, the Mahabharat syncline, in the same way as the Midland anticline turns into transverse structures. The syncline of Bhojpur with its north-east strike (plate 6) might also be considered as a deflected northern branch of the Mahabharat syncline, affected by the Arun transverse structure.

In the areas, in which the Mahabharat syncline is well developed, there are several axial culminations and depressions. As a whole, the overthrust Kathmandu nappes have mostly been protected from erosion in axial depressions. The Kathmandu nappes show the greatest north—south magnitude in the areas of axial depressions in the Mahabharat syncline. This is so in the meridian of Kathmandu and in the area of Bhojpur (plate 6).

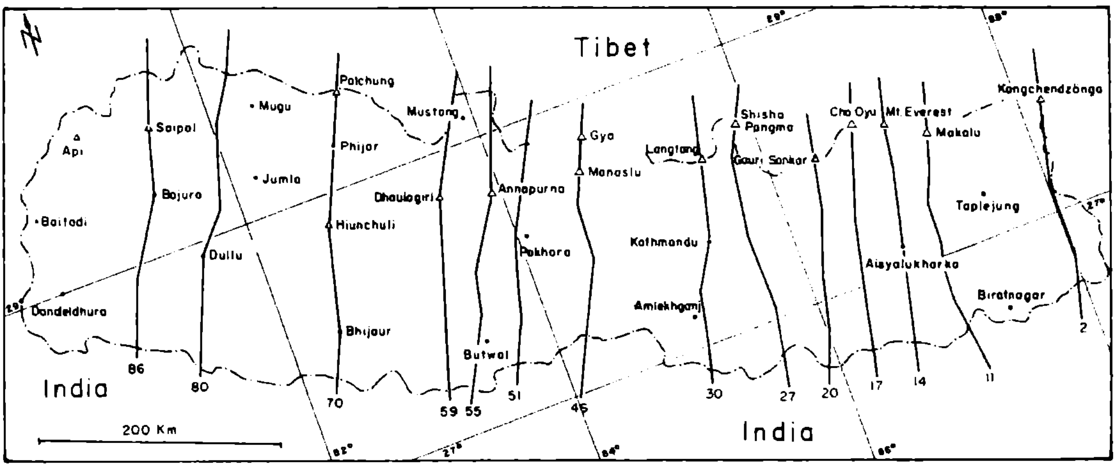



Fig. 22 Index map, showing the tectonic profiles given in plate 2

A selection of 14 profiles is given out of the total number of 96 cross sections, which are completed and will gradually be published in the further volumes.

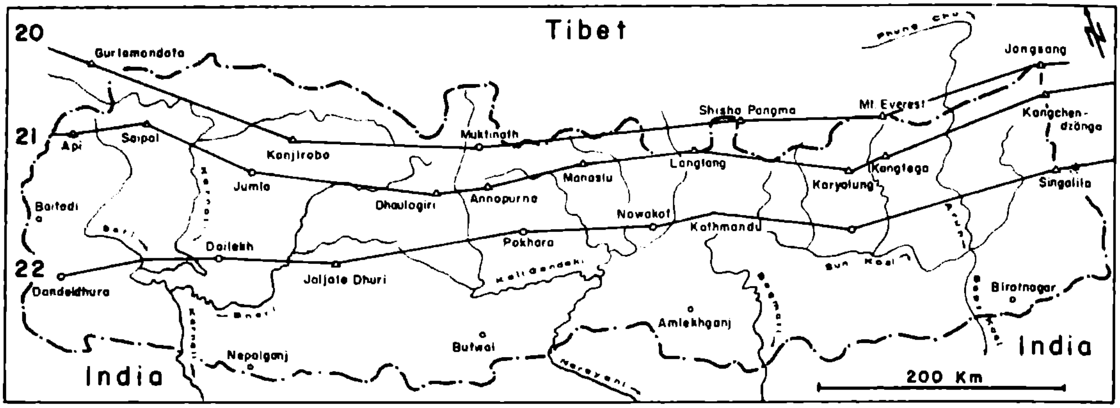



Fig. 23 Index map of the longitudinal profiles given in figs. 26–28

In western Nepal, beyond the Bheri river, no main skeleton of structures in the Midlands can be recognized, except the Himalayan Fore-Anticline of Galwa and Bajang. This is caused by an extensive autochthonous zone, which apparently proved rather resistant to upwarping, folding and faulting. In this area (plate 6) transverse structures dominate, compared with those of the normal east-west strike. The transverse structures also, do not show a clear pattern but are rather irregular. The best developed structure is the Tila syncline (near Jumla), which does not fit into the transverse system, nor into the normal strike direction. East-west structures develop again further west: the Bajang anticline and the Baitadi syncline. The latter is identical with the wide basin in which, further west beyond Nepal, the Almora thrust masses were found (Heim and Gansser).

The meridian of Dhaulagiri thus separates two quite different zones from the standpoint of structures in the Midlands. This will be dealt with in the following chapter on autochthonous and parautochthonous zones in the Midlands.

### *3) The roots of the main crystalline nappes and the transverse structures*

The root zones of the main crystalline nappes (Kathmandu nappes and Khumbu nappes) show some most interesting features. The respective areas, being in the main range of the Himalaya, are well exposed, in contrast to the Alps, where the roots are partly buried under the Po-Alluvium.

In the geological and tectonic maps of the Alps, the roots are drawn more or less as one single straight belt, without major interruptions and without major bends. It is thus understandable, that the major nappes in the eastern Alps have frequently been compared with those of the western Alps, and consequently quite a construction of parallelisation has been built up.

The root zone of the Kathmandu nappes (plate 6) does not form one single belt, but is interrupted and intersected and is shaped like garlands. Some of the root "garlands" are transposed and appear to turn, others change direction entirely. The unique picture of the root "garlands" is caused by a number of transverse structures. Some of them have already been mentioned in dealing with the structures in the Midlands, since the main Midland structures are connected with the transverse structures.

Let us point out the main transverse structures from east to west (plate 6):

*The Arun transverse anticline* is by far the largest transverse structure found in Nepal. It is astonishing that Wager, who has travelled through the whole Arun-Phung Chu valley, does not mention this huge anticline. In the main range of the Himalayas, between the Everest group and the Kangchendzönga group it is a normal anticline with northerly pitch. Considering the dip and thickness of the Kathmandu series on both flanks of the anticline, we must conclude that the upwarp amounts to at least 8 km. (P. Bordet even speaks of 15 km of crystalline formations which have been eroded in the axis of the Arun anticline in the Arun valley. This however is not proved, as we shall see later on.) Nevertheless, the Arun anticline is undoubtedly one of the greatest anticlines of the world.

The axial extension is no less impressive: in the south, transverse structures connected with the Arun are found right down to the Siwaliks and even into the Ganges trough. In the north, the pitching anticline extends at least for another 50 km beyond the great Himalaya range. (According to an oral information by Agocs, there is a huge transverse structure underneath the Gangetic Alluvium, in a straight continuation of the Arun structure).

Due to this anticline, the roots of the Kathmandu nappes interrupt their normal east-west strike. They bend sharply through nearly a right angle and strike towards the north for about 75 km. The root arcs which bend towards the north, build the Kangtega-Chamlang range on the western flank of the Arun anticline, but form no major mountain range east of the Arun. Here, the roots have a strike, which is directed towards the southeast, which means right into the Siwaliks. It shows the "dying out" of the Kathmandu nappes east of the Arun. The corresponding root zone, the Patek arc (following the Patek range) thus strikes due south and ends on the Main Boundary Thrust between Dharan and Ilam (plate 6 and fig. 24).

The whole area east of the Arun (fig. 29) must be considered as influenced by the Arun transverse structure. There exists in that area practically no structure in the normal east—west strike. The Mahabharat syncline is bent towards the north into the Singalila- and Kangchendzönga transverse syncline. Another syncline structure is recognized between the Angbung zone and the window of Dumlingtar (plate 6), directed and pitching to the north. The autochthonous *Angbung zone*, itsel occurs in a transverse anticline. The magnitude of the Arun transverse anticline may also be seen from the longitudinal profiles of figs. 26 and 27. The altitudes of these profiles are three times exaggerated, with regard to the very small horizontal scale. The small horizontal scale was necessary in sections covering the whole country from east to west (900 km).

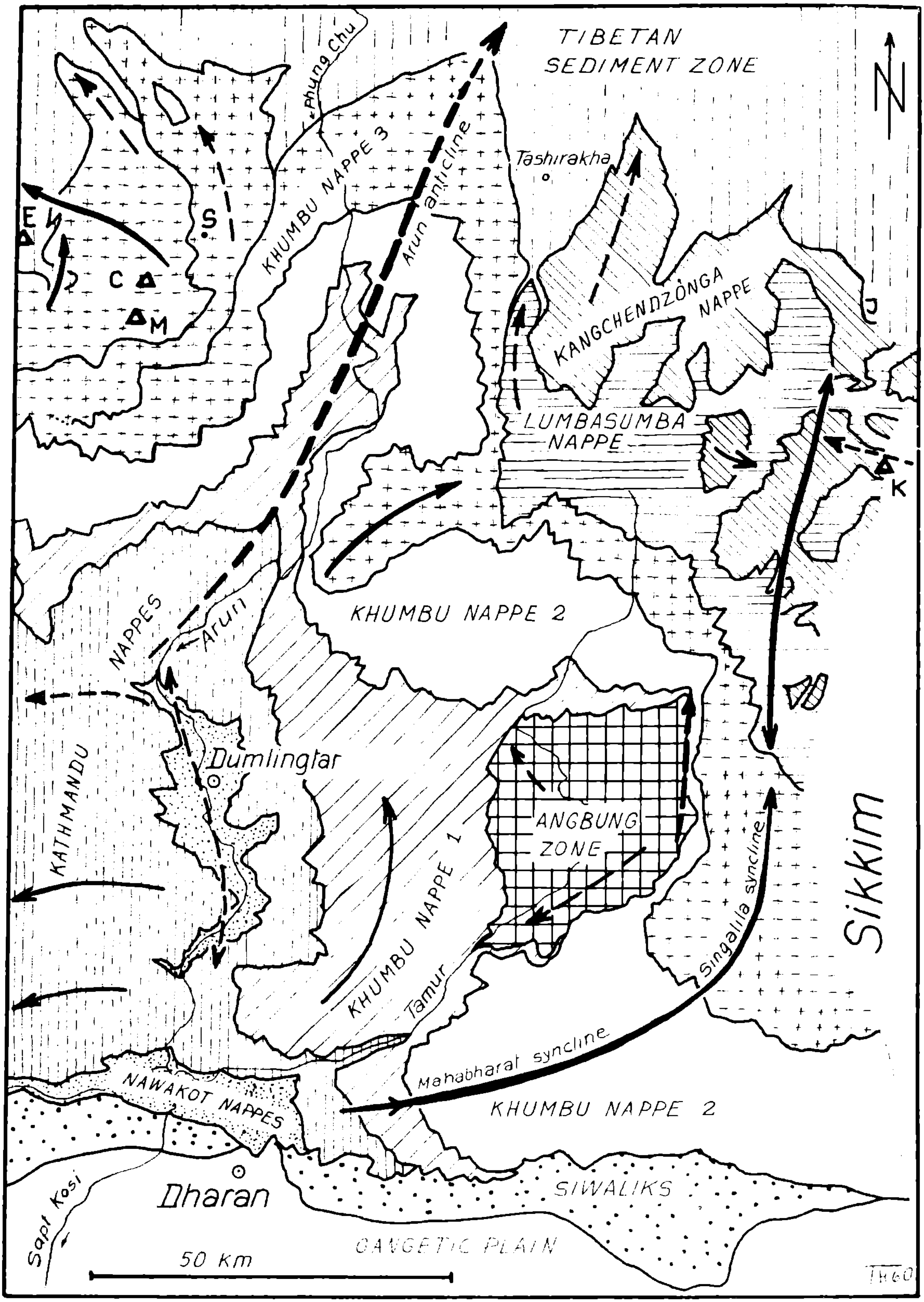
When moving from the Arun to the west, we find the next major transverse structure in the Sun Kosi, east of Kathmandu. It is the western termination of the Midland anticline, which, by turning towards the north, pitches north between the Jugal Himal and the Choba Bamare (fig. 4 and plate 6).

However there are other structures of less magnitude between the Arun anticline and the Sun Kosi anticline: an anticline strikes through the area of the Nangpa La towards the south. Considering the Everest-Makalu group between these two transverse anticlines, it appears, surprisingly enough, to be a syncline in the longitudinal profile (figs. 26, 27 and 104).

Between the Dudh Kosi and the Sun Kosi, the Kathmandu roots show a fairly straight strike towards the northwest (Gauri Sankar root-arc, plate 6).

The Langtang root arc, west of the Sun Kosi, is again considerably transposed to the south. Its shape is a real arc but the same cannot be said of the neighbouring root arc to the west of the Ganesh Himal (plate 6). The Trisuli-Gosainkund anticline separates the Ganesh from the Langtang arc (plate 6). The Gosainkund anticline shows an extremely steep pitch, which in places leads to a vertical dip. The extension to the north is of minor importance compared with the Arun anticline. It continues, transposed, as the Trisuli anticline, which is a part of the Midland anticline (plate 6). Not far to the west there is another pitching structure, the Chilime anticline (fig. 44). Both the Chilime and the Gosainkund structure form together one transverse structure, which pitches towards the north between the Langtang arc and the Ganesh arc (plate 6).

The next adjoining arc to the west, the Manaslu root arc (plate 6), is characterized by an extreme length of about 110 km and by its oblique position compared with the general strike (fig. 4 and plate 6). Its eastern termination is also transposed towards the south compared with the Ganesh arc. There is a minor anticline structure in the Buri Gandaki gorge, separating these two root arcs.


TIBETAN
SEDIMENT ZONE
N
Phung Chu
KHUMBU NAPPE 3
Arun anticline
Tashirakha
E
S
C
M
KANGCHENDZONGA
NAPPE
J
LUMBASUMBA
NAPPE
K
KHUMBU NAPPE 2
NAPPES
Arun
KATHMANDU
Dumlingtar
ANGBUNG
ZONE
KHUMBU NAPPE 1
Tamur
Singalila syncline
Sikkim
Mahabharat syncline
NAWAKOT NAPPES
KHUMBU NAPPE 2
Dharan
SIWALIKS
Sapt Kosi
GANGETIC PLAIN
50 km
TH60

*The Annapurna arc* joins nearly at a right angle to the Manaslu arc (plate 6).

The Marsyandi gorge between the Annapurna and Manaslu arcs corresponds to an anticlinal structure, containing faults and fractures on its axis. This anticline is especially well developed a little further north, in the overlying sediments of the Manang synclinorium. The eastern termination of the Manang basin is an abrupt, thrustfault-like rise of the sediments, representing a western pitch of the crystalline under the sediments (figs. 26 and 27).

The *Dhaulagiri arc* and the Annapurna arc are apparently the only roots, which are aligned more or less without a change of strike between them. Nevertheless they are separated by a considerable transverse structure, the Dangarjong thrustfault with the Thakkhola graben (figs. 41 and 42). This transverse structure is not well developed within the crystalline zone of the roots, but it becomes increasingly important towards the north (see paragraph 4).

*The Kanjiroba arc* is considerably transposed towards the north, compared with the Dhaulagiri arc (plate 6). The Bheri River crosses the main range at the junction between these arcs in a structure. The Kanjiroba arc is bent to the north and even to the northeast towards Mugu, it encroaches on the Langu basin.

The *Humla arc* develops out of the same area near Mugu and strikes towards the Gurla Mandata where it pitches as a simple gentle anticline into the Tibetan sediment zone (plate 6).

Fig. 24 Tectonic sketchmap of the Kangchendzönga group

Syncline with axial pitch
Anticline with axial pitch
Gangetic plain
Siwaliks
Tibetan sediment zone

E = Mt. Everest
M = Makalu
C = Chomo Lönzo
S = Sakyetang
K = Kangchendzönga

*West of Arun River*

Makalu and higher schuppen
Sakyetang schuppe
Khumbu nappe 3
Khumbu nappe 2
Khumbu nappe 1
Kathmandu nappes
Nawakot nappes
(incl. tectonic window of Dumlingtar)

*East of Arun River*

Kangchendzönga nappe
Lumbasumba nappe
Khumbu nappe 3
Khumbu nappe 2
Khumbu nappe 1
Kathmandu nappes
Angbung zone

The Humla arc is only one of the two or three Kathmandu arcs in western Nepal. The Changla arc is a northern branch of the Kathmandu roots. It diverges from the main roots in the area of the Tsangpo Ri towards the west-northwest (plate 6).

In the Saipal range a southern branch of root arcs occurs, in the shape of a complete bend, opened to the west. The particular configuration of these three root arcs is caused by an immense anticlinal structure between the Kanjiroba and the *Saipal arc* (figs. 26, 27). Further south, the underlying Bajang nappes are exposed in this culmination, in the Galwa window. The Saipal root arc on the other hand frames the Saipal synclinorium with its filling of Palaeozoic and Mesozoic sediments (fig. 36).

We have so far started our descriptions in the east and continued to west. In this direction, we have been speaking of "transposition" of the particular root arcs towards the south.

From a tectonic and a geologic-chronological standpoint however, the northern root arcs are the overlying ones and thus the younger ones. When considering the general pattern of the arcs in plate 6, it must be concluded that the two arcs of Dhaulagiri and Annapurna are the *primary* ones, which have been raised first. All the others have been joined on their northern flank, one after the other. Especially onwards to the east, the mountain building has gradually involved more northerly areas.

When we now try to construct longitudinal cross-sections, connecting all the highest peaks, we find them all lying in *axial depressions*, and not on axial culminations as might have been expected (figs. 26 and 27). The axial synclines are without exeption separated by transverse anticlines through which the main rivers cross the Great Himalaya Range. Finally, the division of the Great Himalaya range into several groups has been caused by transverse structures, which produced the primary lay-out of the transverse valleys.

It has been noted, that some of the root arcs (Humla, Gurla Mandata, Manaslu) end in the Tibetan plateau in the form of pitching anticlines and thrustfaults. This feature is still more clearly visible in the overlying Khumbu nappes and Khumbu root arcs. These nappes begin east of Shisha Pangma (fig. 17 and plate 6) and build, to the east of the Tamba Kosi, the main range of the Himalayas, with Cho Oyu (8153 m), Mt. Everest (8848 m) and Makalu (8470 m). The Khumbu root arcs are tremendously affected by the huge Arun anticline, showing a nearly semi-circular shape. They turn for about 70 km to the north, round the pitching Arun anticline (plate 6 and fig. 4).

Some interesting details of the Arun anticline will be described later on in chapter 4.

In the most westerly part of Nepal, the Changla root arc, which tectonically overlies the Kathmandu nappes in the Humla arc, can be compared with the Khumbu roots in eastern Nepal.

### *4) The Tibetan Marginal Synclinorium*

These areas have been defined in paragraph 1, as the syncline zones, which join north of the roots of the great crystalline nappes. The northern flank of the Tibetan Marginal Range can be considered as the northern limit of the synclinoria.

We find the synclinoria north of all the roots, but they do not show the same character throughout the whole country. For the geologist of course these synclinoria are most interesting, since they contain the most complete Palaeozoic and Mesozoic fillings. This is so in the Saipal synclinorium in western Nepal, the Langu-Manang synclinorium and the Kutang synclinorium in central Nepal (plate 6). In some areas, the crystalline basement was raised so high, that all the sedimentary infilling has been eroded.

The Saipal synclinorium lies partly beyond Nepal, in India (Kumaon) and this part has been studied in detail by Heim and Gansser. The latter found the famous Norian fauna on the northern border of the synclinorium. A geological profile sketch of the Nepal portion is given in fig. 37. Characteristic features of the synclinorium are the complicated structures with thrustfolds, thrustfaults, fractures and especially reversed folds. With the latter, we find a surprising correspondence with the Alps, which also show the reverse folds on the back of the roots, made clearly visible in the Mesozoic sediments.

The Saipal synclinorium shows a fairly complete succession up from the Garbyang series to the Upper Mesozoic. The Garbyang series are considered by Heim and Gansser as well as by the present author as Cambrian.

The southern part of the synclinorium is heavily sliced. This tectonic zone has, in the further description by the author, been called the *Himalayan Marginal Schuppen Zone*, for it is well developed on the back of the roots throughout the whole country, and plays an important role in building the highest peaks (figs. 94–103). The Schuppen in this marginal zone are partly built of crystalline rocks, which in some places occur at the surface. At other places, the crystalline remains below ground, and visible slicing only involves sediments.

The crystalline Schuppen in the Saipal synclinorium do not extend over the whole length in the strike direction, as can be seen in fig. 36. They are best developed in the section of the upper course of the Seti river, between Chaurpani and Saipal (fig. 41). There are altogether 4 crystalline slices, including the Schuppe corresponding to the Kathmandu nappe no. 5 in central Nepal. All the Schuppen die out from the section of the Seti onwards to the east and towards the Saipal peak (see map fig. 36). Even the crystallines of the Kathmandu nappe 4 disappear east of the Saipal Peak, in the upper course of the Kuwari valley, and reappear again north and east of the Sankha pass (fig. 36).

A. Heim considered the enourmous thickness of 30 km of the Garbyang series as primary and thus as a normal series. After having seen the complicated Schuppen in the Seti valley, there is but little doubt, that accumulation of this great thickness has been caused by tectonic piling.

A section through the Saipal Peak (7034 m) is given in profile 86: the filling of Cambrian schists, micaschists and Silurian-Devonian limestone shows rather complicated folding. The Karnali anticline, especially its northern flank, represents the dying out of the northern root branch of the Kathmandu nappes.

North of Simikot (fig. 36) one crystalline Schuppe after another (representing the western terminations of the roots) pitches into the Tibetan sediment plateau. Also the western continuation of the *Mugu granite*, namely the *Changla granite*, pitches and ends towards the northwest. To the north a further granite zone joins after a new sedimentary series. This is called the *Tsangpo Ri granite*, named after the peak Tsangpo Ri, (6574 m). According to Sven Hedin the Tsangpo has its origin on the glacier (Tsangpo glacier) east of this mountain. The Tsangpo Ri granite is probably identical with the granite found by A. Gansser, in the basement of Kailas.

*The synclinorium of Langu-Manang*

This sedimentary synclinorium is almost entirely surrounded by crystalline rocks, in contrast to the Saipal synclinorium, which is open to the west (plate 6 and fig. 36). A very small belt of sediments lap over to the north. They are probably connected with the sediments of the Tibetan Plateau in the Tsangpo valley north of Mustang. However it is not certain, how far the sediments extend in the Tsangpo valley north of Muktinath, since there is no doubt (as the author was able to recognize from high peaks on the Tibetan border) that the Trans-Himalaya Range beyond the Tsangpo also consists of granite. The Langu basin shows a natural frame, built by the main range on the southern flank and the Tibetan Marginal Range on the north. The latter also consists of granite, with peaks up to 7000 m. The contact between the granite and the sediments is irregular. In the western termination of the synclinorium, the granite does not seem to have intruded above the Cambrian formations. North of Langu there are Permian rocks lying on the granite.

The Langu-Manang synclinorium extends for about 230 km in an east-west direction. The width varies, since the shape is not that of a regular trough: in the Thakkhola-Mustang area, this synclinorium is probably the most interesting one of the whole Nepal Himalayas, since all the structural elements occur and are well exposed. Rich occurrences of fossils permit a fairly good stratigraphic analysis.

The synclinorium is situated at the crossing point of two main structures: the longitudinal complicated syncline and the transverse "Thakkhola graben".

The structure may be seen in the fig. 38, and the profiles 55 and 59 (of plate 4). According to the cross-section we may distinguish the following tectonic and geological zones, from south to north:

- The northerly dipping crystalline roots of the Kathmandu nappes.
- The normal sediment cover on the back of the Kathmandu root no. 5, with sediments from Cambrian-Devonian upwards.
- The zone of the complicated reverse folds and thrustfolds, in the adjacent area north of the main range.
- An anticlinal structure within the synclinorium with complicated folds and thrustfolds (between Thinitse and Muktinath).
- A zone of increasing folds and thrustfolds, directed towards the south (Muktinath-Thorungtse).
- A zone of generally flat synclinal structure; flat upwarps, which decrease towards the north (Thorungtse-Tehachang). The structures of course, are not quite the same in the various cross-sections, but the reverse folds in the southern area and the southerly directed folds in the northern area remain the same throughout the whole synclinorium.

Special interest must be given to the mountain range, which is built in the folded zone at the southern rim of the Tibetan Plateau. This is called, in figs. 38 and 39, the *Thorungtse range*. This mountain range was defined in chapter 1 as the *Tibetan Marginal Mountain Range*. It was the first main watershed between the Ganges drainage pattern and the Tsangpo system. Even today, it forms the main watershed over the main portion of the Nepal Himalayas. However, transverse structures have caused erosion of this watershed from the south, thus pushing the main watershed gradually back on to the Tibetan side.

Backward erosion is especially the case in the Thakkhola area. A system of transverse faults and thrustfaults has created a characteristic *"graben" structure*, a trench. The thrustfaults are especially clearly developed at the western edge of the trench, in the Dangarjong thrustfault, named from the village Dangarjong (fig. 39 and 40). This fault continues for a distance of more than 80 km. The western side of the fault has been raised to a maximum of about 2000 meters near Dangarjong: Devonian limestones are now situated side by side with the Upper Mesozoic series. Further to the north, near Thakmar and Kehami, the fault is split up into quite a number of thrustfaults. These single faults do not show such magnitude as in the south, but their cumulative effect is probably more than 2000 m.

The eastern rim of the trench is not characterized by a single thrustfault. A clear fault is to be seen only near Muktinath, and near Narsing La (fig. 39). The corresponding total rise of the Dangarjong fault is on the eastern edge effected by a considerable dip toward west (fig. 40).

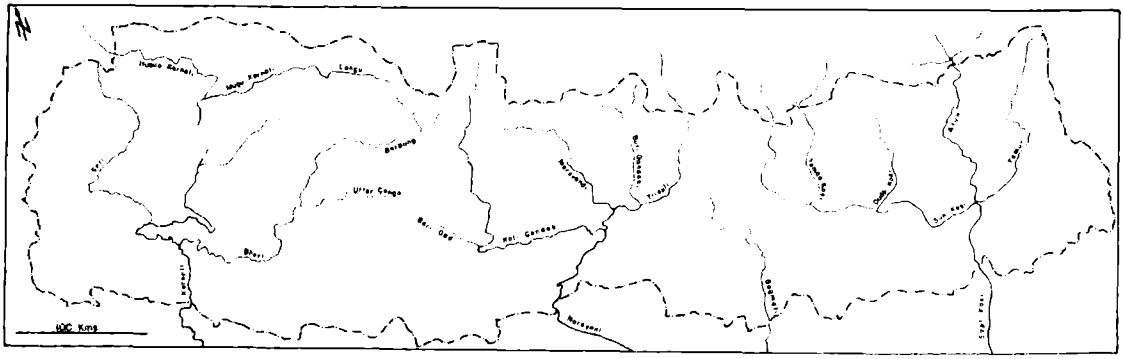
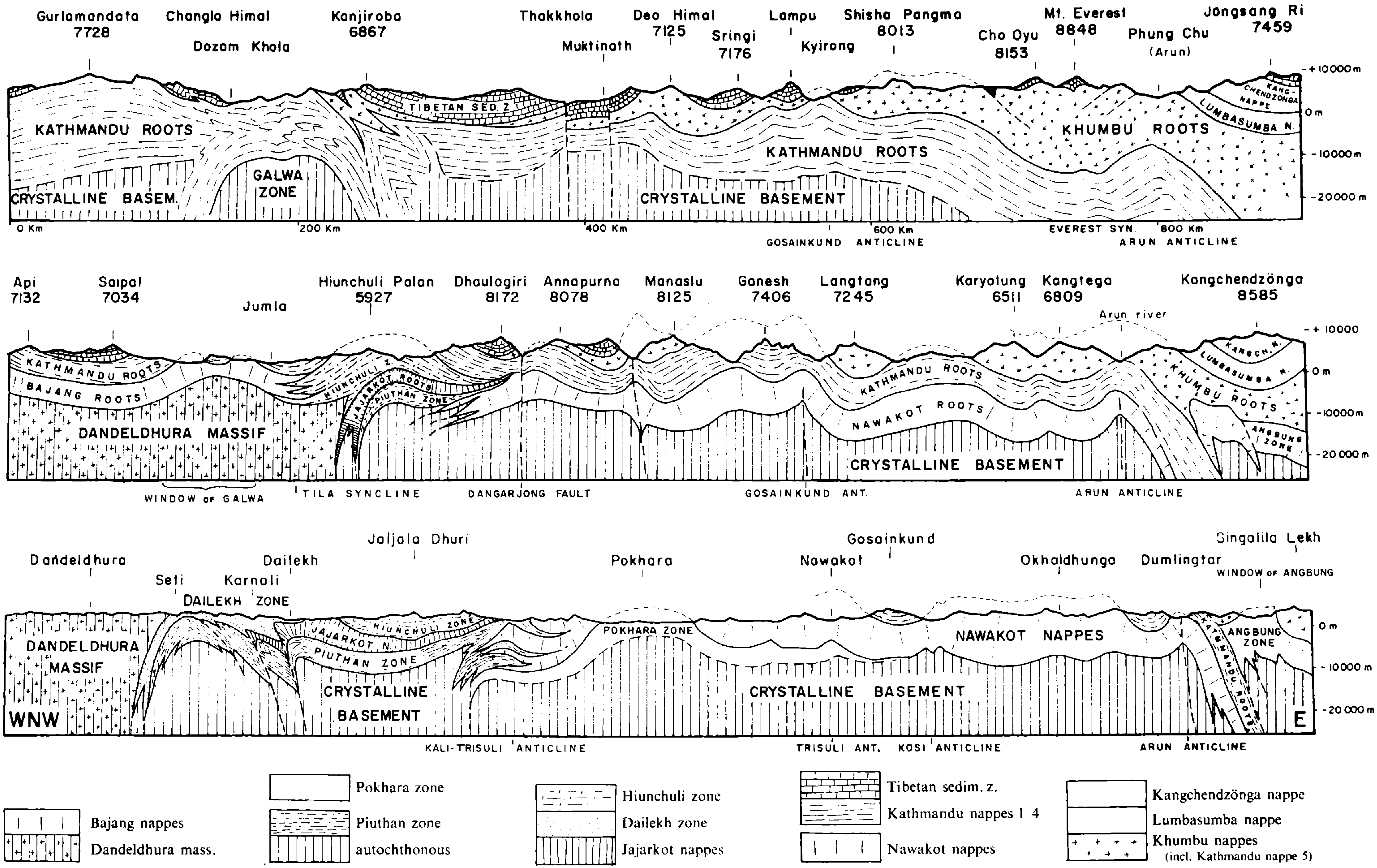


Fig. 25 Drainage pattern of Nepal




All the hights are three times exaggerated compared with the horizontal scale

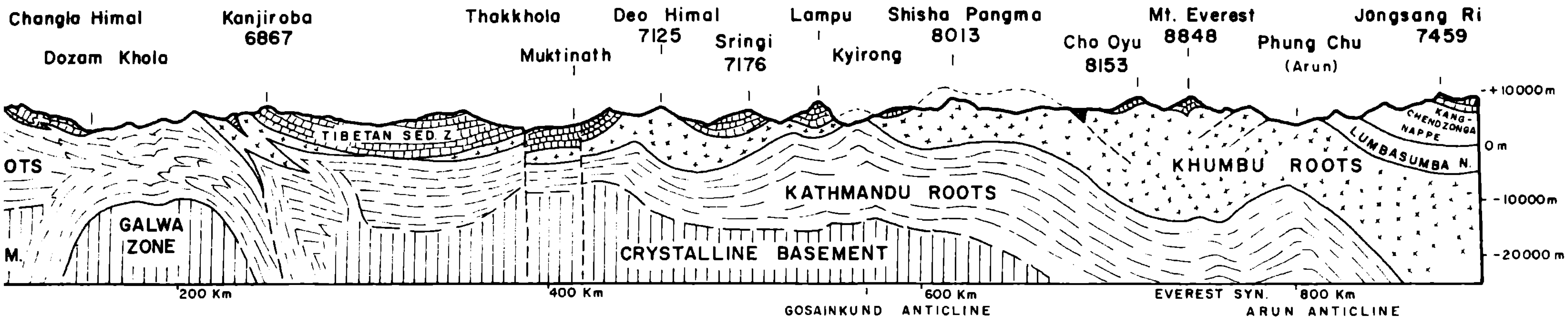



Fig. 26
Longitudinal profile
of the
Tibetan Marginal Range

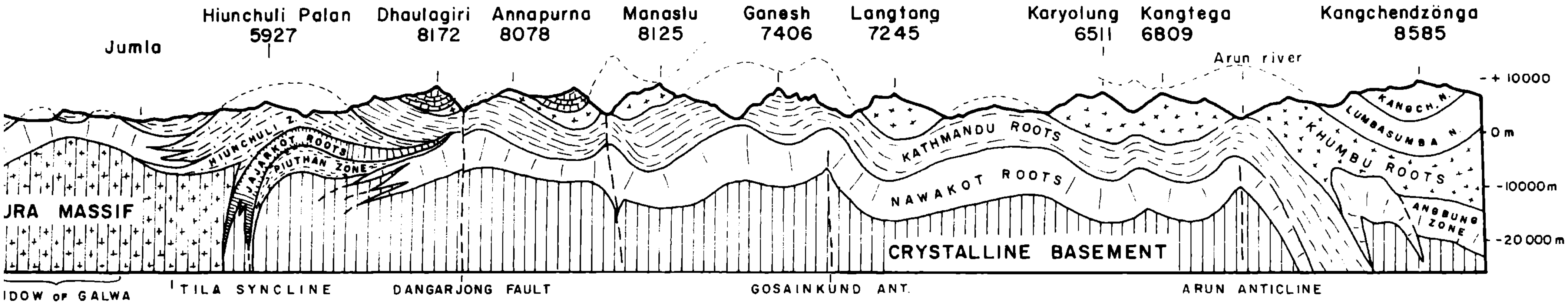



Fig. 27
Longitudinal profile
of the
Great Himalayan Range

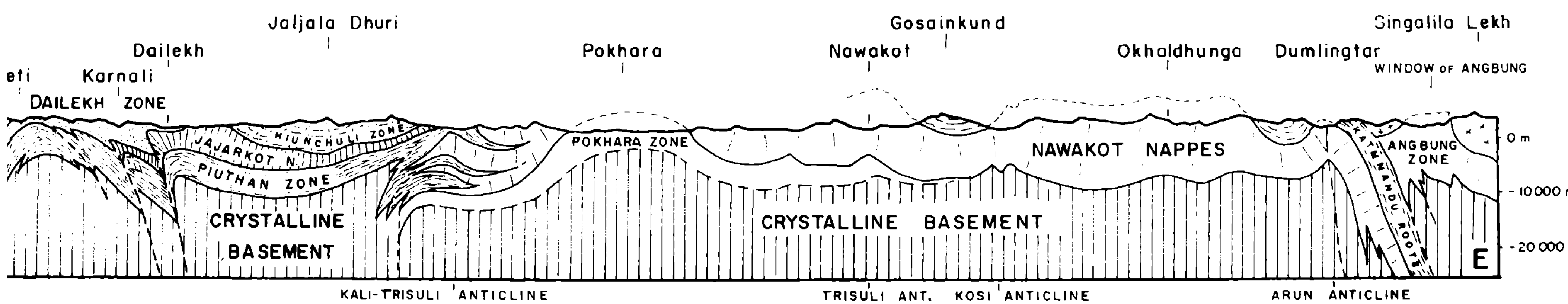
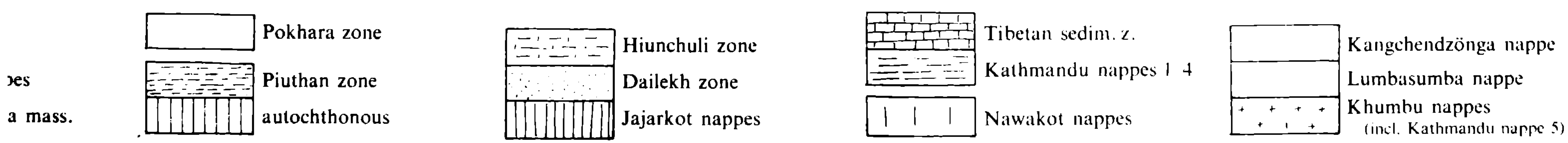



Fig. 28
Longitudinal profile
of the
Nepalese Midlands




All the hights are three times exaggerated compared with the horizontal scale

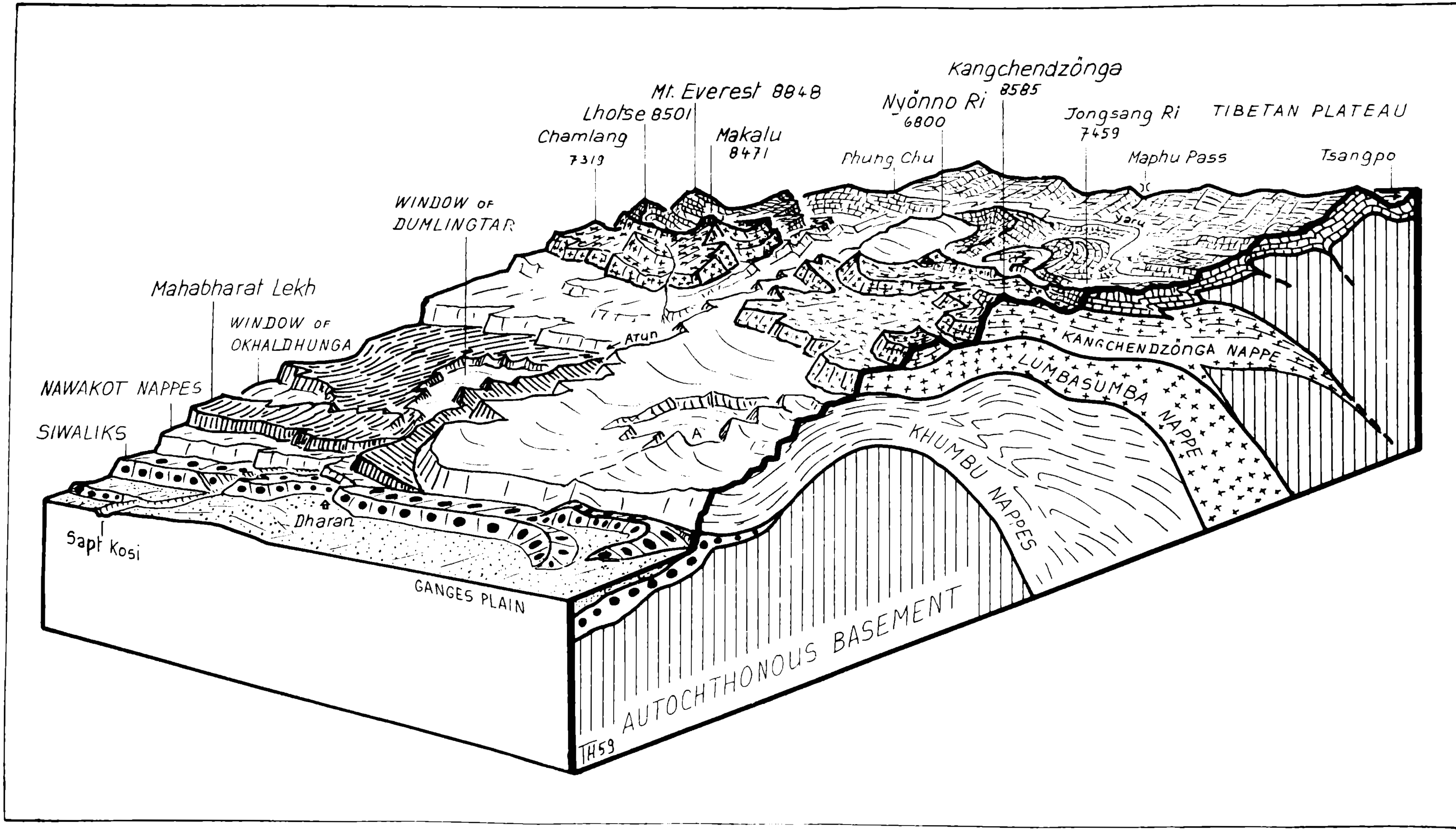



Fig. 29 Tectonic stereogram of eastern Nepal
(Kangchendzönga–Mount Everest)

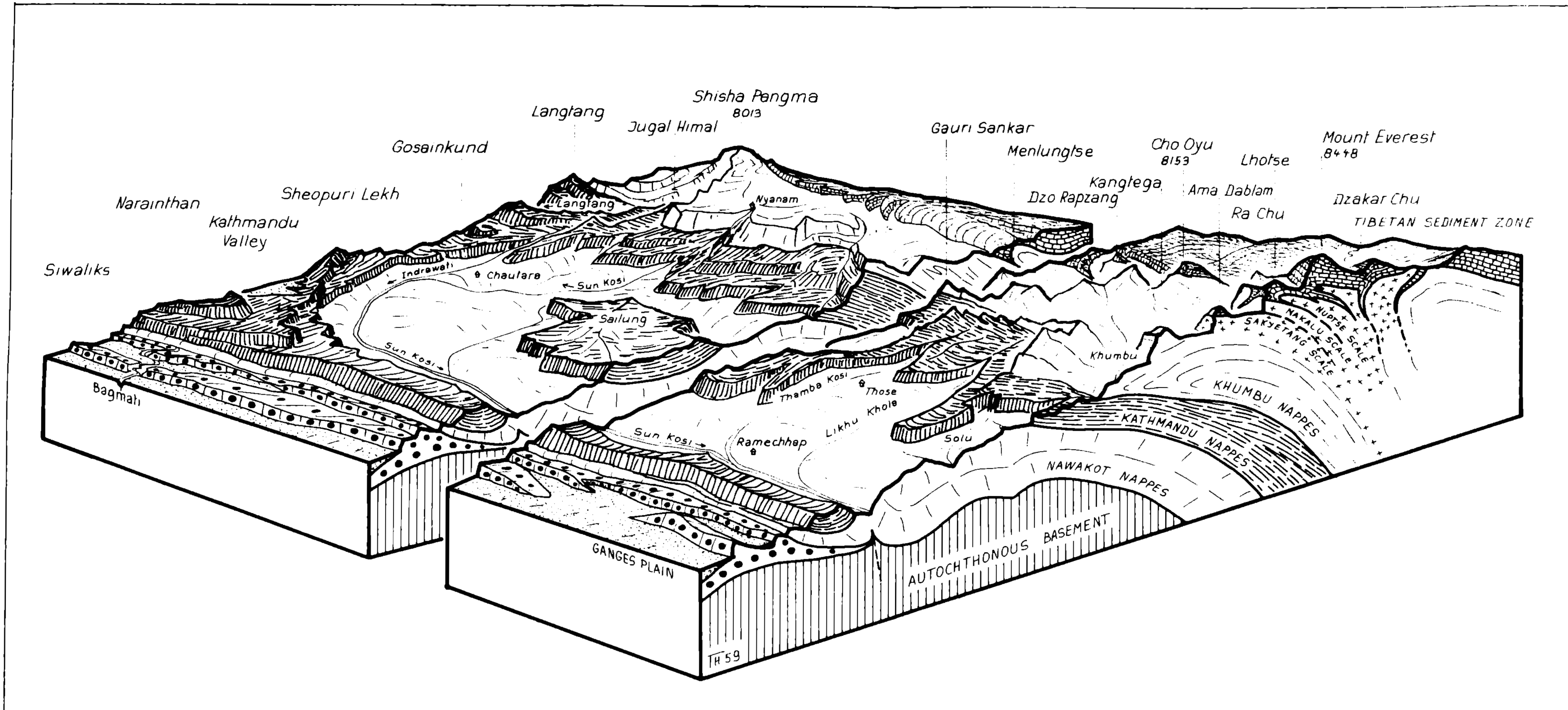



Fig. 30 Tectonic stereogram of eastern Nepal
(Mount Everest – Shisha Pangma)

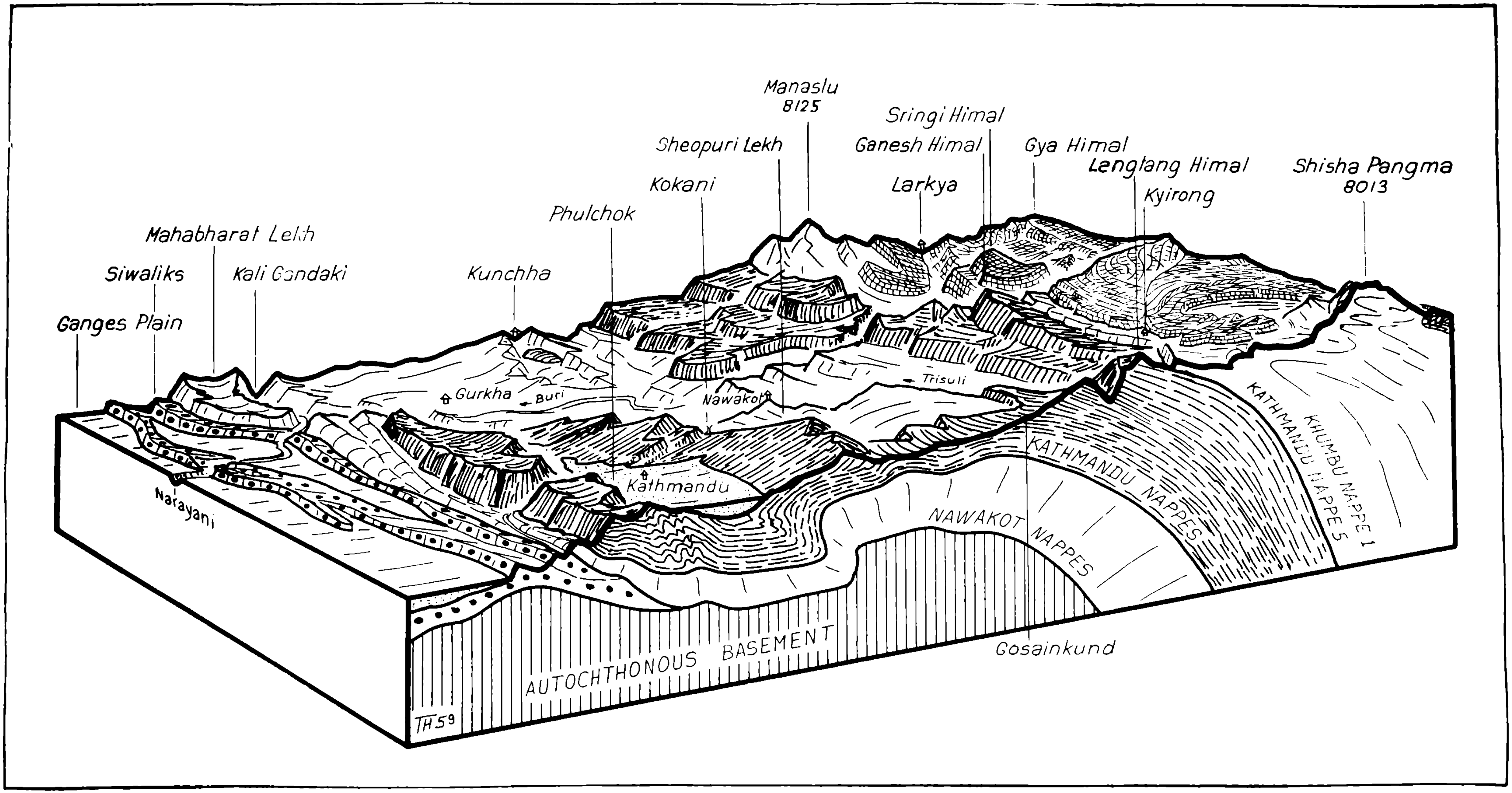



Fig. 31 Tectonic stereogramme of central Nepal
(Shisha Pangma – Manaslu)

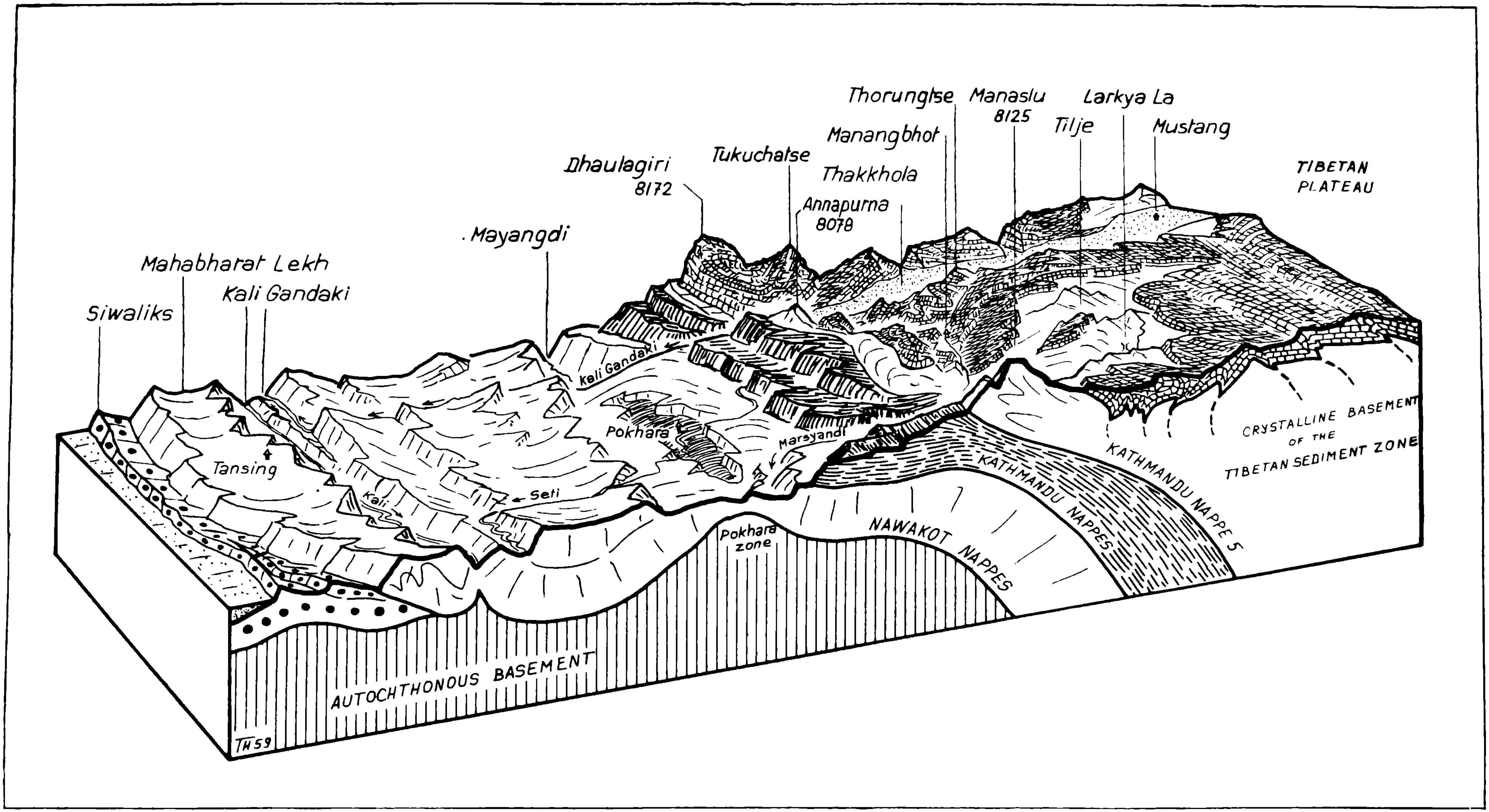



Fig. 32 Tectonic stereogram of central Nepal
(Manaslu-Dhaulagiri)

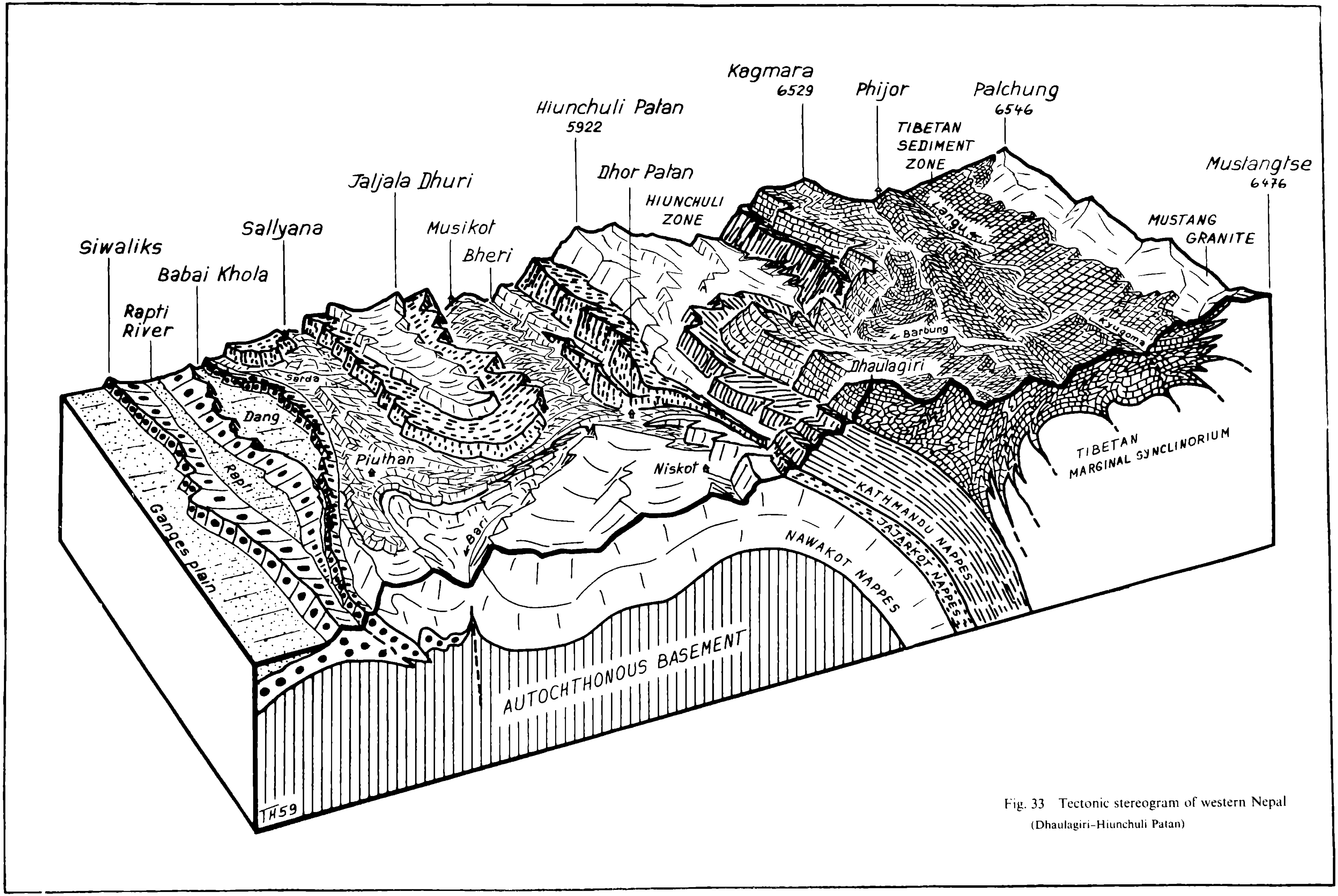



Fig. 33 Tectonic stereogram of western Nepal
(Dhaulagiri–Hiunchuli Patan)

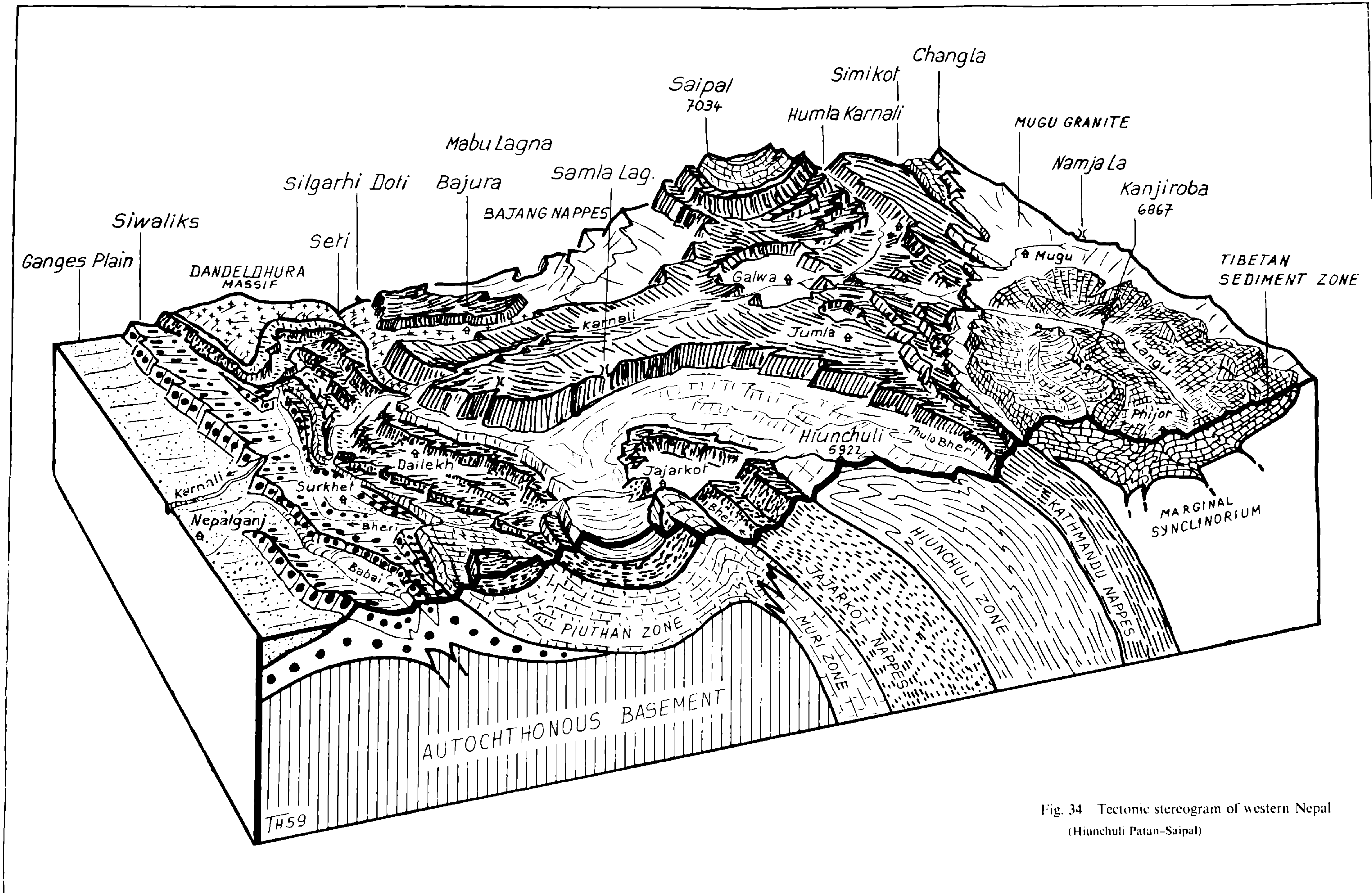



Fig. 34 Tectonic stereogram of western Nepal
(Hiunchuli Patan–Saipal)

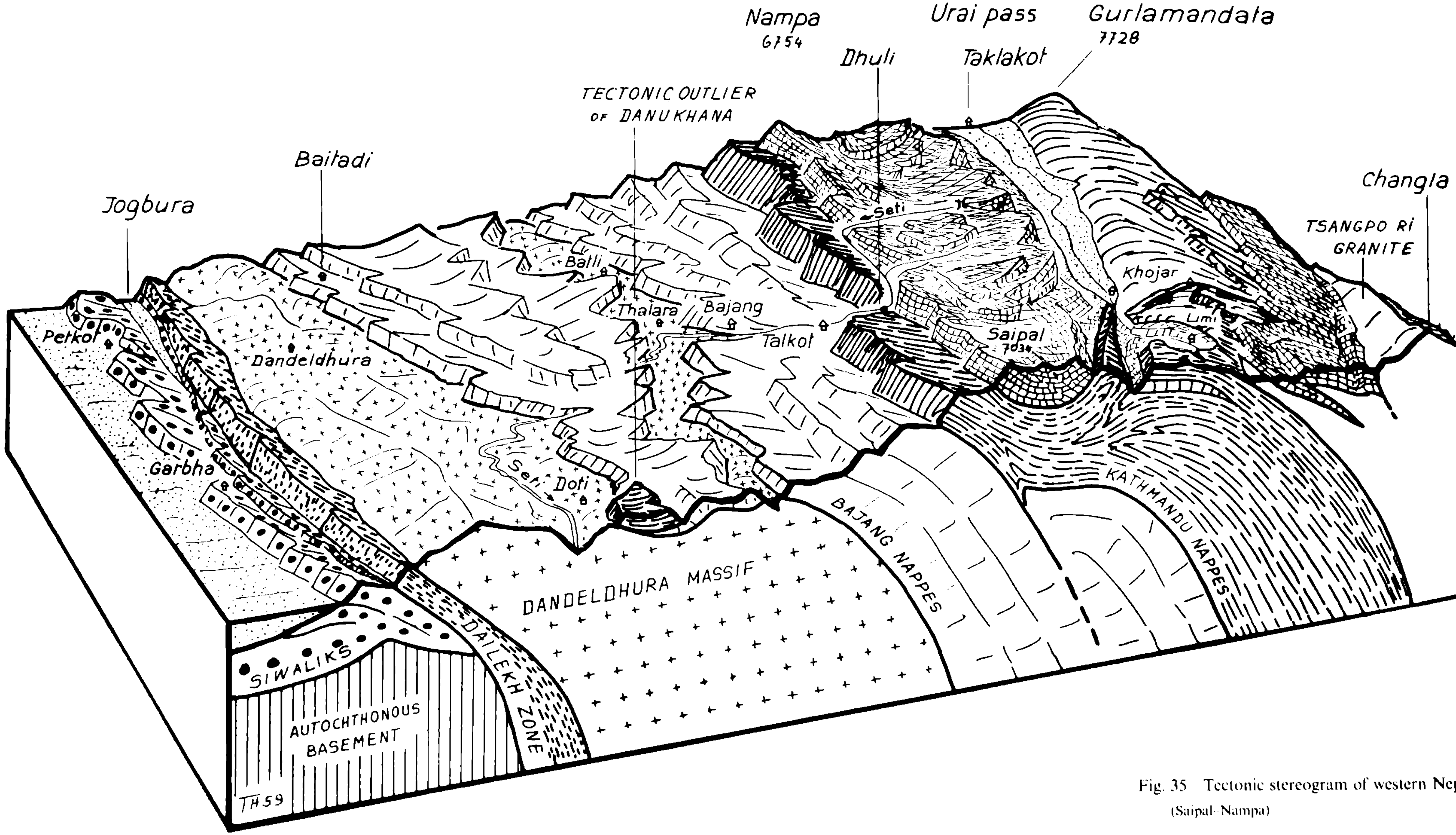



Fig. 35 Tectonic stereogram of western Nepal
(Saipal–Nampa)

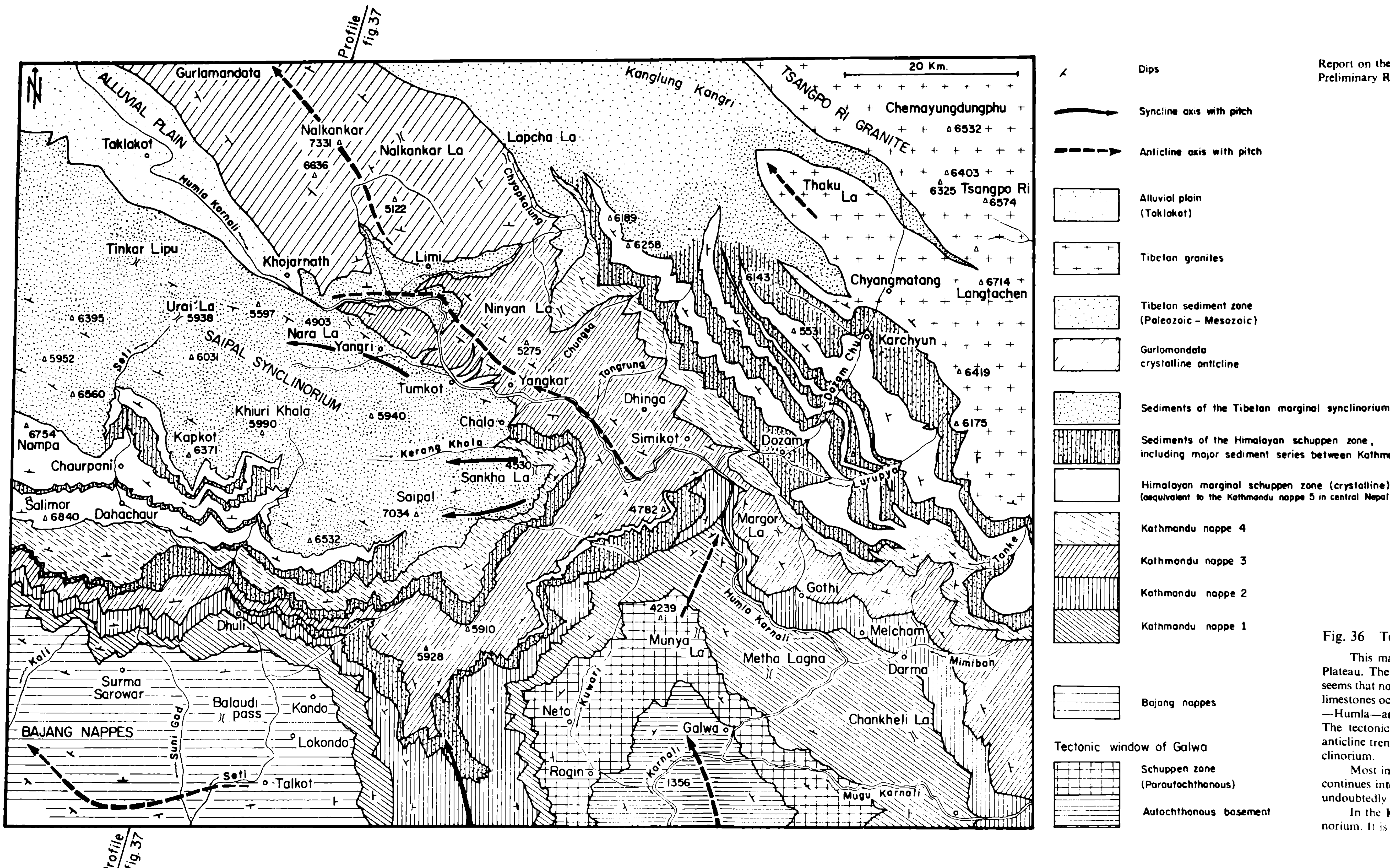



Fig. 36 Tec

This map
Plateau. The r
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limestones occ
—Humla—ant
The tectonic
anticline trend
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continues into
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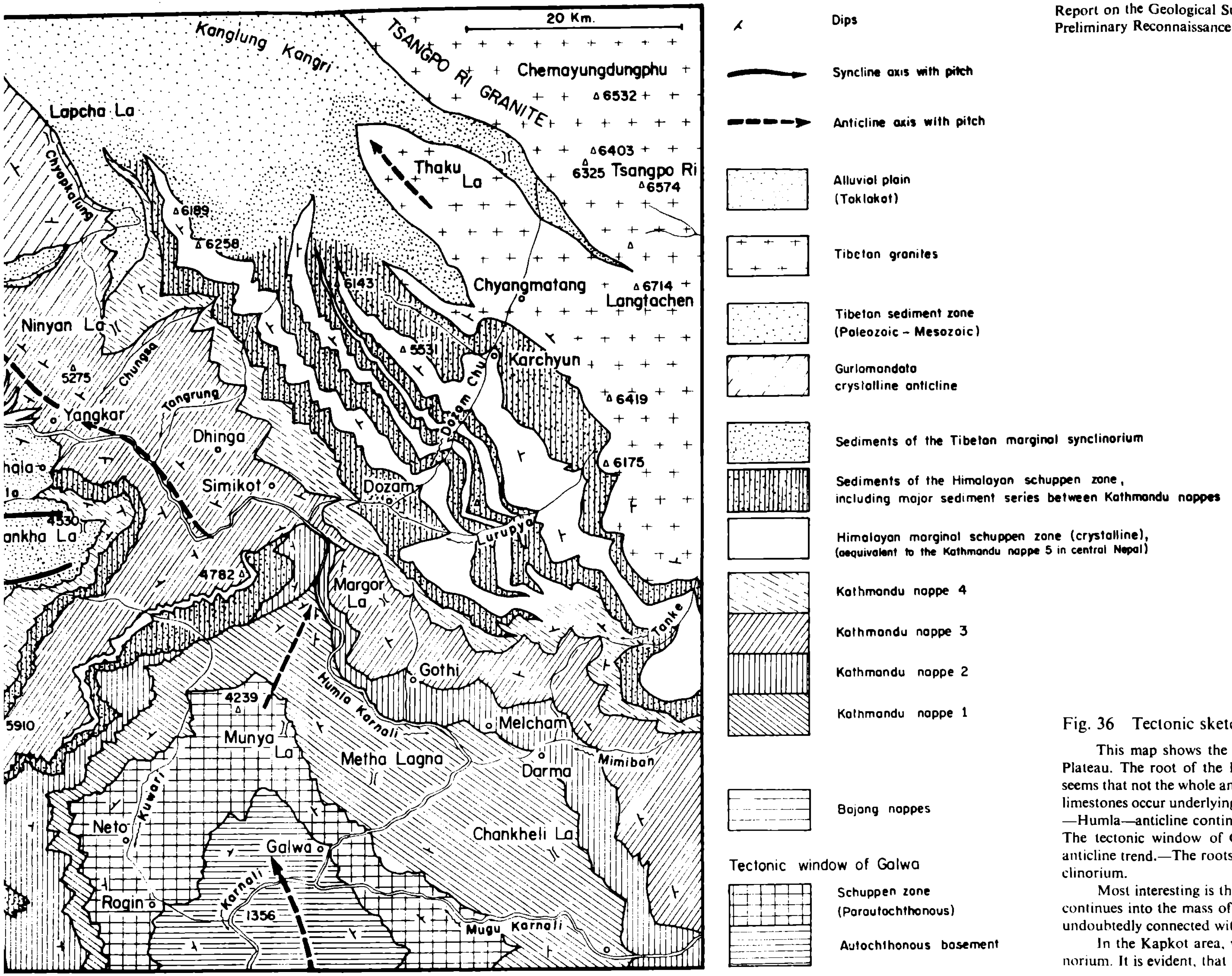



Fig. 36 Tectonic sketchmap of the Saipal–Humla–Dozam area.

This map shows the "dying out" of the roots of the Kathmandu nappes toward northwest, into the Tibetan Plateau. The root of the Kathmandu nappe 3 develops out of the Gurlamandata crystalline anticline. However it seems that not the whole anticline continues toward southeast, since in the Limi Valley thick series of upper Paleozoic limestones occur underlying the Nalkankar crystalline. Probably, the series are tectonically doubled. The Gurlamandata —Humla—anticline continues south of Simikot beyond the Kathmandu crystalline, and it's axis turns toward south. The tectonic window of Galwa with the underlying and autochthonous Dandeldhura zone is caused by the same anticline trend.—The roots of the Kathmandu nappes 3, 4, and 5 are bent around the western pitching Saipal syn. clinorium.

Most interesting is the "dying out" of the crystalline roots and scales in the Dozam Valley. The Mugu granite continues into the mass of Chyangmatang. The Tsangpo Ri granite is north of the Mugu granite. The Tsangpo Ri is undoubtedly connected with the granite in the base of the sacred mountain Kailas.

In the Kapkot area, west of Saipal, also some crystalline Schuppen occur in the sediments of the Saipal synclinorium. It is evident, that the thick Garbyang series are tectonically piled up.

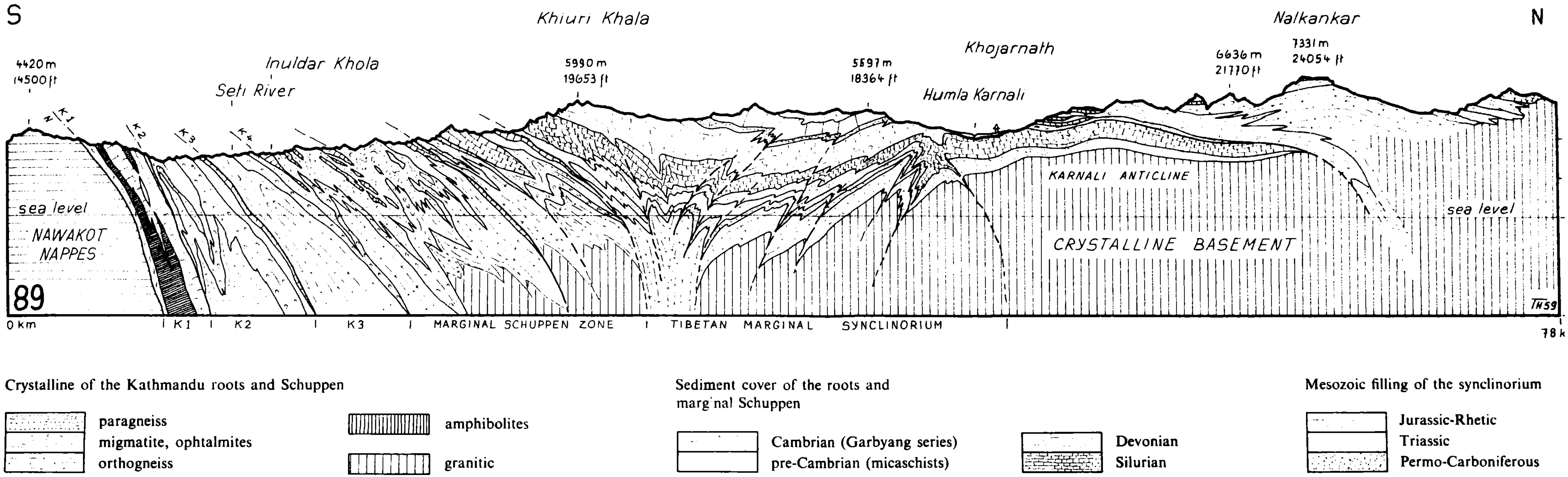
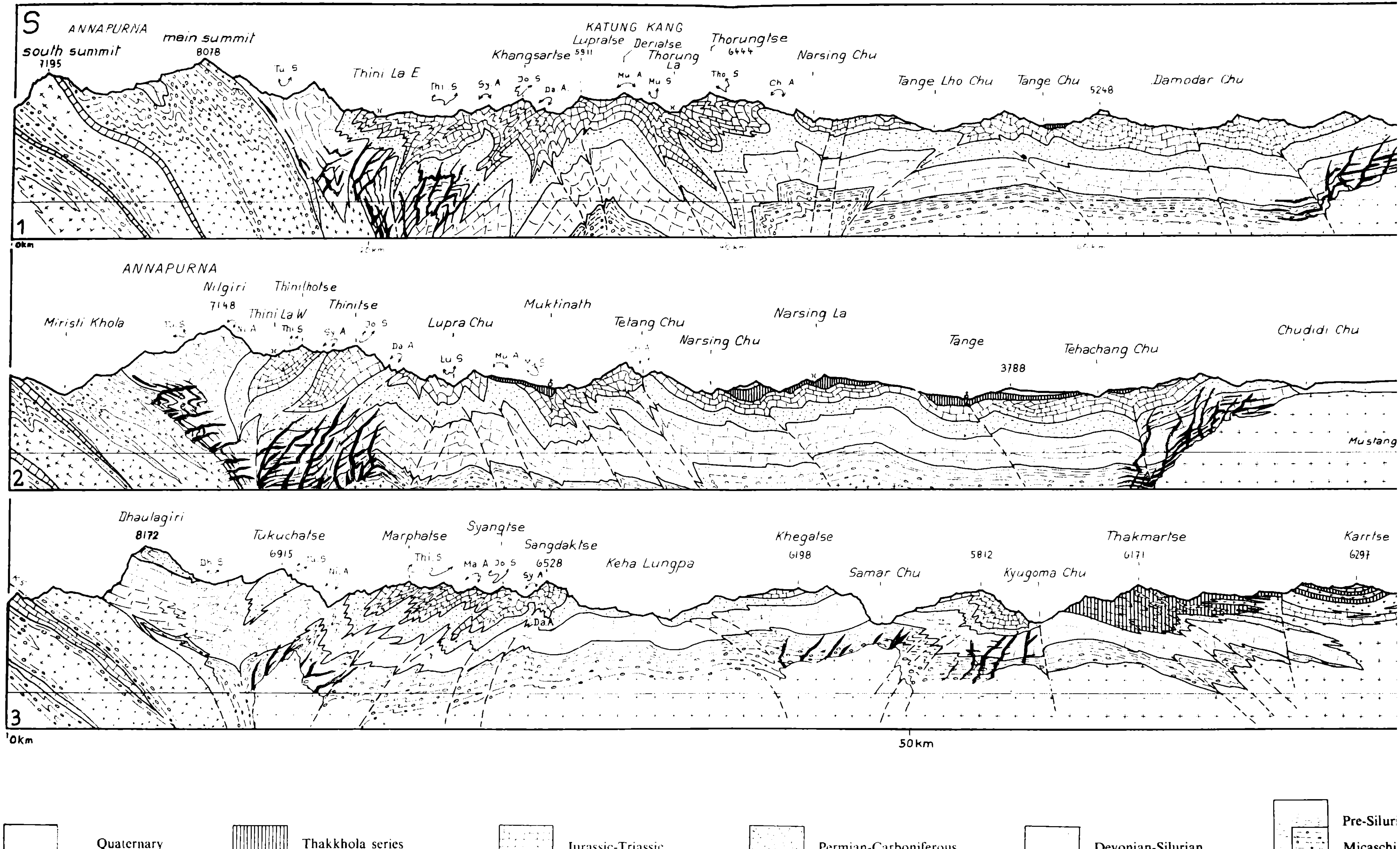
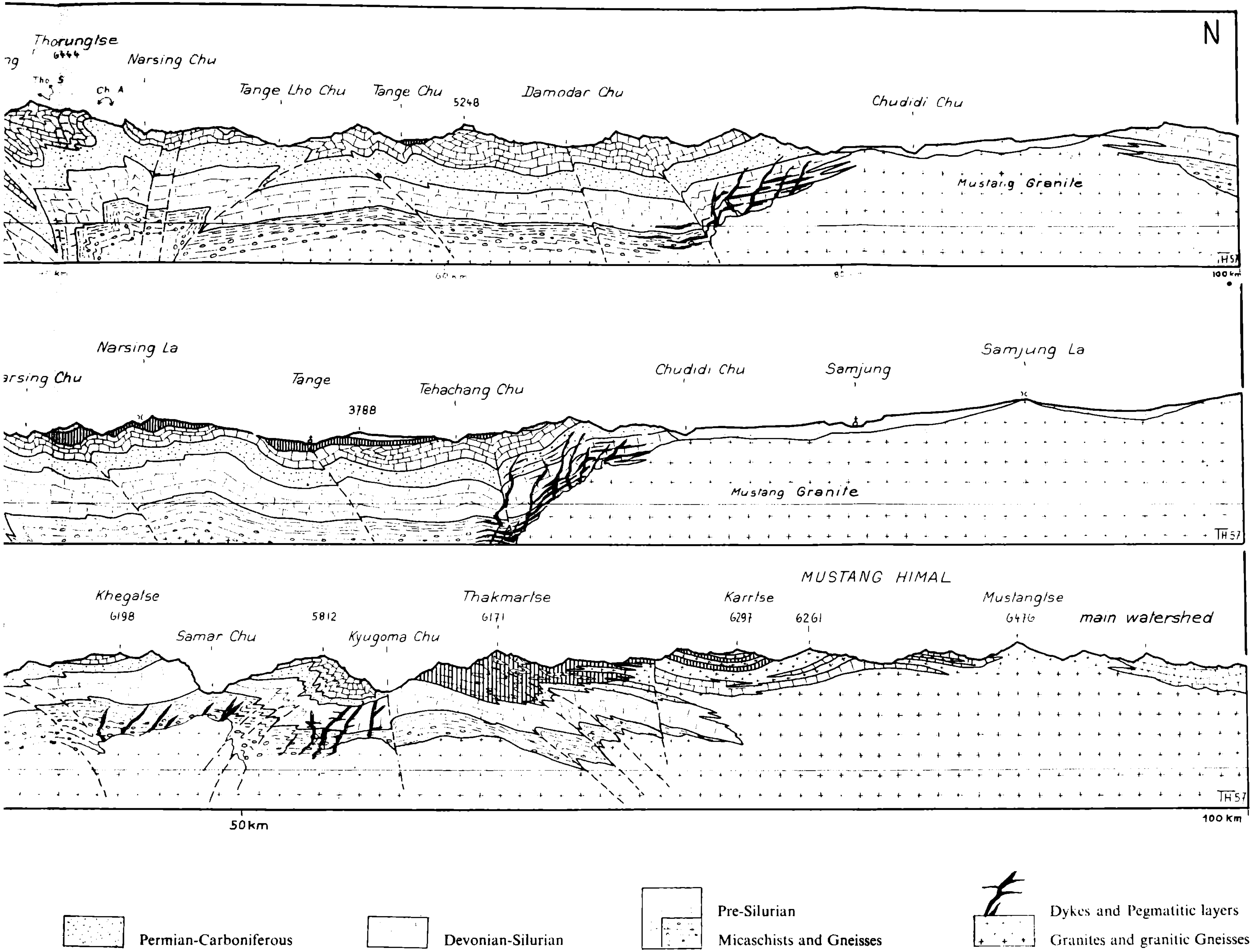



Fig. 37 Geological profile Khiuri Khala–Khojar–Nalkankar (northwestern Nepal), scale 1 : 150 000.


S
ANNAPURNA
south summit
7195
main summit
8078
Thini La E
KATUNG KANG
Lupratse
5911
Deriatse
Thorung La
Thorungtse
6444
Khangsartse
Narsing Chu
Tange Lho Chu
Tange Chu
5248
Damodar Chu
1
0km
ANNAPURNA
Nilgiri
7148
Thinilhotse
Thini La W
Thinitse
Miristi Khola
Lupra Chu
Muktinath
Tetang Chu
Narsing Chu
Narsing La
Tange
3788
Tehachang Chu
Chudidi Chu
Mustang
2
Dhaulagiri
8172
Tukuchatse
6915
Marphatse
Syangtse
Sangdaktse
6528
Keha Lungpa
Khegatse
6198
Samar Chu
5812
Kyugoma Chu
Thakmartse
6171
Karrtse
6297
3
0km
50km
Quaternary
Thakkhola series
Jurassic-Triassic
Permian-Carboniferous
Devonian-Silurian
Pre-Silur
Micaschi




| | |
|---|---|
| Tu. S | Tukucha syncline |
| Ni. A | Nilgiri anticline |
| Th. S | Tilicho syncline |
| Lu. S | Lupra syncline |
| Ma. S | Marpha syncline |
| Sy. A | Syang anticline |
| Jo. S | Jomosom syncline |
| Da. A | Dangarjong anticline |
| Mu. S | Muktinath syncline |
| Mu. A | Muktinath anticline |
| Ch. A | Cheheng anticline |
| Tho. S | Thorungtse syncline |

Fig. 38 3 geological profiles of the Thakkhola

The profile 2 is laid through the Thakkhola trench itself, showing the upper Mesozoic filling, which covers an old, eroded land surface. Profile 3 is taken on the western edge of the Thakkhola trench, where the Dangarjong thrustfault has rised the paleozoic formations to mountains of more than 6000 m altitude. This profile also shows the clear alinement of the peaks in a plane ("Gipfelflur"). While Dhaulagiri group, (including Tukuchatse), exceeds all the other mountains, the summits of the northern peaks form an almost horizontal plane of 6100–6400 m.

The complicated fold-structure in the Paleozoic and Mesozoic filling of the synclinorium has been caused by various systems of pre-orogenetic fractures and faults.

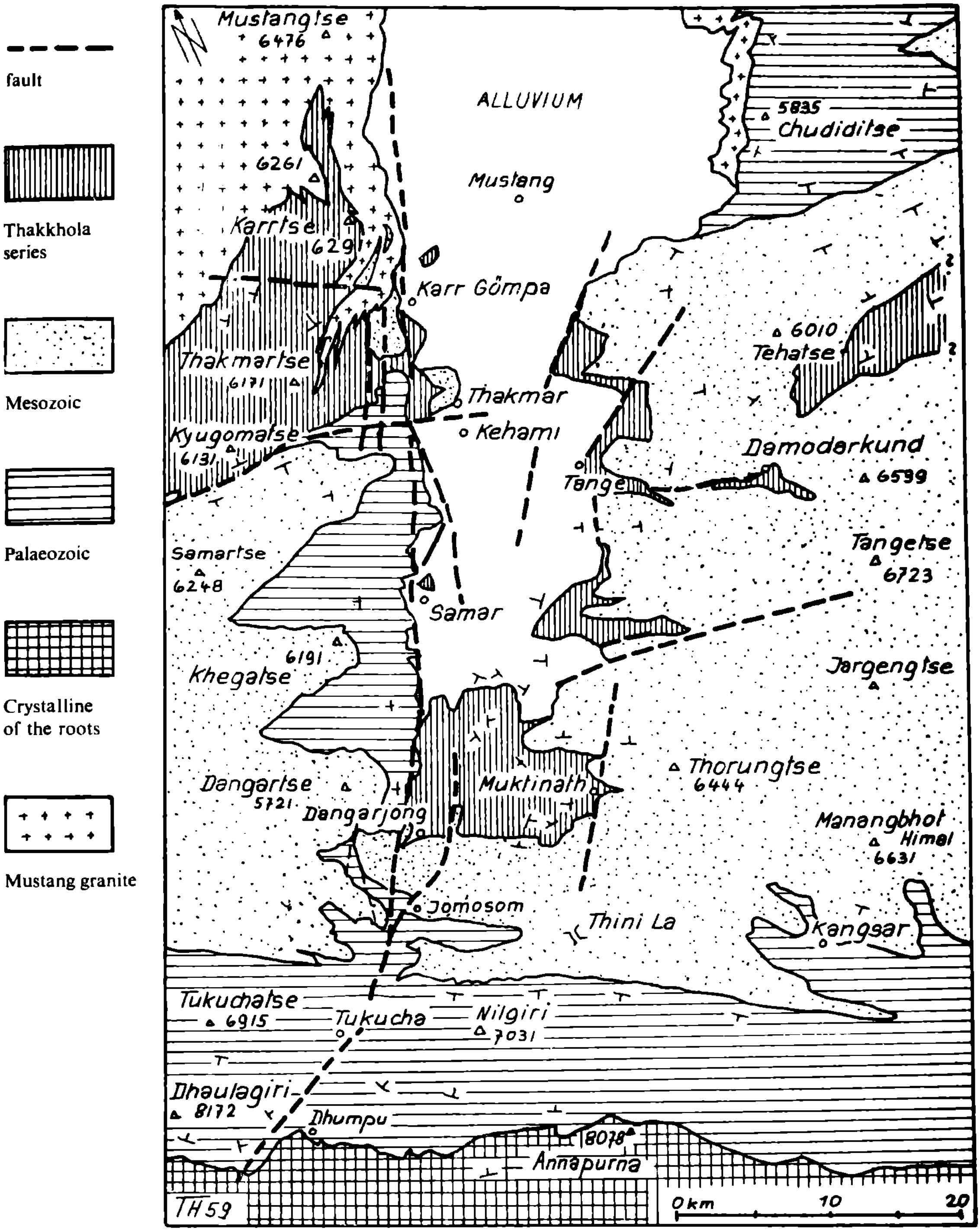



Fig. 39 Sketchmap of the Thakkhola,
showing the geology and the various systems of faults and fractures.

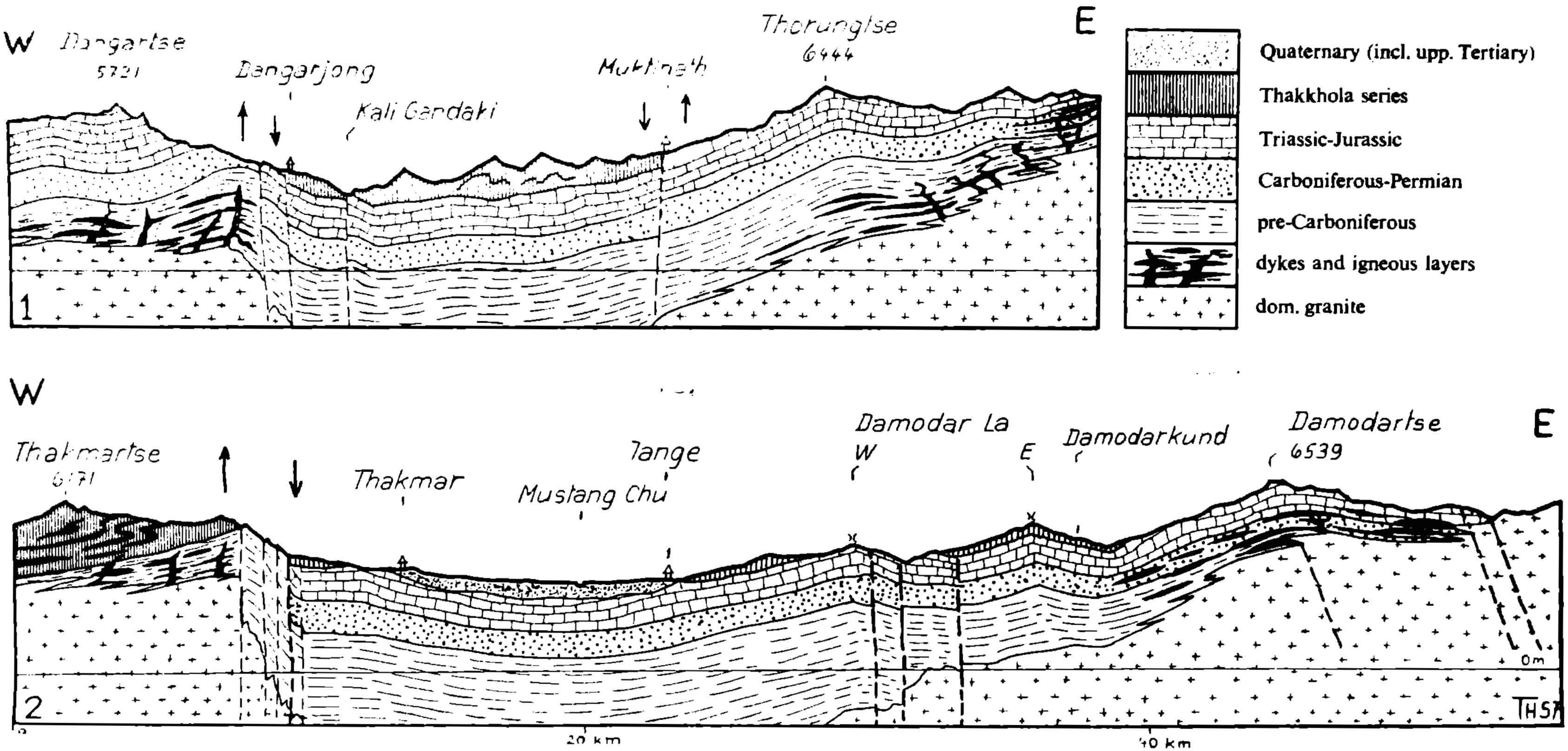



Fig. 40 2 geological profiles across the Thakkhola Graben
(along the geological strike).

The unsymmetric lay-out of the Thakkhola trench is clearly to be seen. The western edge is caused by the huge Dangarjong fault, while toward east, the beds gradually rise, interrupted by some minor faults.

Owing to the trench structure of the Thakkhola and the sinking of its bottom, an entirely different series has been deposited in the trough, the so-called *Thakkhola series*. It lies entirely unconformably on the underlying series and shows a structure and dips, which in no way correspond to those of the underlying series of Devonian-Mesozoic age. Through the finding of fossils it is possible to date the origin of the Thakkhola series as Upper Mesozoic-Tertiary (Eocene). Nummulitic limestones were found, besides conglomerates and a large series of greensands, sandstones and quartzites. One of the beds of the Thakkhola series has been called the *Saligramseries* due to the finding of abundant Saligrams (calcareous concretions with ammonites in the interior). Saligram is the native name for these boulder-like rocks, which in the beliefs of the hinduistic religion are considered to be sacred rocks.

Other formations of the Thakkhola series consist of reddish limestones, clays and sandstones. Large areas can be compared with the Flysch facies of the Alps (varied deposits of clays, sandstones and shales of Upper Mesozoic-Eocene age).

Concluding from the fossils, the Thakkhola Graben must be considered of Mesozoic age, which means that it was created a long time *before* the thrusting of the great nappes.

It is evident that the Thakkhola is not a mere trench, but that transverse movements have also been acting. In the southern part between Jomosom and Tukucha, the two flanks of the valley do not fit each other geologically. The normal (east—west) structures do not continue from the eastern side across the valley to the western side.

The Thakkhola series does not only fill the trench, but in the northern part laps over the Dangarjong fault into the high mountains west of Thakmar and Mustang. They build the Kyugomatse (6131 m), the Thakmartse (6171 m) and the Karrtse (6397 m), (see fig. 38). This series on these mountains shows a flysch-type lithology, with shales, slates and quartzites. They are transgressive onto Palaeozoic limestones (probably Ordovician), in which crinoids of the Chandragiri type have been found. We can thus conclude, that the origin of the Thakkhola trench has not been due to one single crustal movement. The western edge of the central part, between Jomosom and Kehami has been lifted first. The Thakkhola series does not exist on the top of this mountain range (Syangtse-Samartse). North of the Kyugoma valley, which is a tributary of the main valley near Kehami, the Thakkhola series covers large areas on the top of the mountains. These thus lay originally at the same level as the primary Thakkhola trench near Jomosom-Samar. The mountain range of Kyugomatse-Mustangtse has thus been raised not only by the transverse Dangarjong thrust, but at the same time by a normal east—west striking fault.

The Thakkhola series has transgressed over Mesozoic formations (Triassic-Rhaetic and Jurassic containing Spiti fauna) in the bottom of the Thakkhola trench, while north of the Kyugoma fault the flysch-like series transgresses undoubtedly on to Palaeozoic rocks, of Silurian-Devonian age. We can thus also conclude, that this area northwest of Kyugoma has not been covered by sea during the main portion of the Mesozoic age, nor during the late part of the Palaeozoic-Mesozoic. Triassic formations occur again further north, near Karr Gömpa, apparently transgressing on to the Devonian limestones. Rhaetic and Triassic fossils were found on those limestones, besides a few Jurassic ammonites, while for example Permiam and Carboniferous rocks could not be identified.

North of the Thakmartse (6177 m) granitic layers and dykes occur in the Thakkhola series. They increase considerably towards the north. In the Karrtse (6297 m) the granitic layers and dykes form more than 50% of the rocks and the Mustangtse (6476) is entirely built of the *Mustang granite*. This is an acid turmaline granite.

Some of the layers are cut by east—west striking faults (for example through Karr Gömpa, profile 59).

No Thakkhola series occurs north of Mustang. This does not mean, that it does not exist, since the whole valley is filled with huge masses of Upper Tertiary-Pleistocene formations, under which all other rocks are buried. Only east of the Chudidi Chu, the Mustang granite occurs again (on the eastern flank). It forms a gentle transverse anticline, the axis of which strikes through the Chudidi valley. The eastern mountain range thus shows a dip towards the east. Owing to this dip, the sediment covers on the granite occur south and east of the Chudiditse (5835 m), (fig. 39). Apparently these are Silurian-Devonian limestones. Due to an anticlinal structure with a normal east—west strike in the area of the Chudiditse, the beds show a dip towards the south, so that the overlying series appear one after the other towards the south. The Tehatse (6010 m) is built of Jurassic limestones and shales, which cover a large area to the south as far as the Narsingtse. In the Damodartse (6539 m) and the Tangetse (6723 m) the last layers and dykes of granitic pegmatites occur. A connection with the Mustang granite of the Chudidi area could not be recognized. The granites of Damodartse apparently belong to the large granite area of Deo-Himal-Manaslu, which occurs further east.

The geological situation mentioned here may be sufficient for an understanding of the importance of the Thakkhola in the geology of the whole Nepal Himalayas. A detailed description will be given in Volume two of the series of these publications.

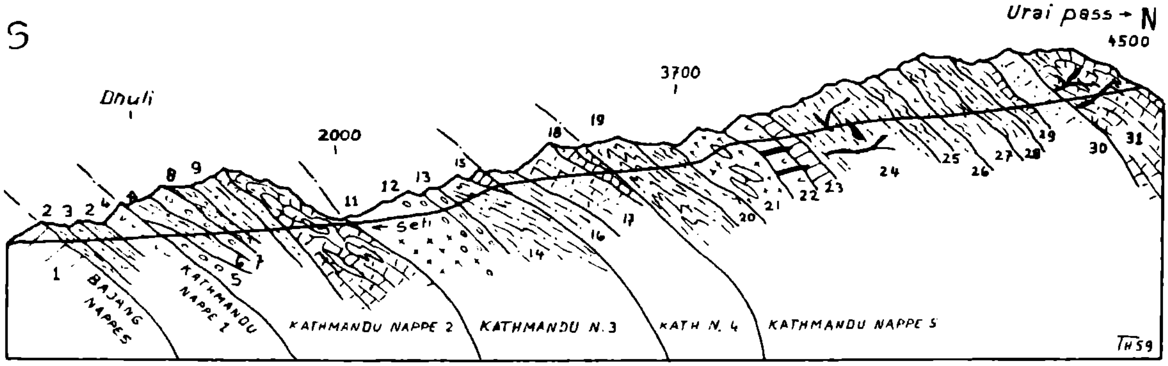



Fig. 41 Profile sketch in the upper course of the Seti Valley (northwestern Nepal)
(dying out zone of the Kathmandu nappes).

1 dolomite, calcareous slates, 2 graphitic schists, 3 quartzite, 4 quartzite; there is a considerable change in strike between 4) and 5), namely 25° E in 4) and 150° E in 5), 5 augengneiss (few, large feldspars) much garnet, 6 mainly well bedded fine grained biotite gneiss, 7 augengneiss, rich in muscowite, 8 garnet—micaschists, mixed with augengneiss, 9 fine grained paragneiss, with quartzites, 10 calcsilicate limestone, with granitic pegmatites, highly tectonized, 11 large series of orthogneiss and granites, 12 gradual change to banded augengneiss, increasingly tectonized, 13 augengneisses, 14 gradually out of 13: fine grained and banded biotite gneiss, increasing calcareous and calcsilicate rocks, layers of aplite granites, fine grained gneiss with biotite, garnets, amphibols, pyroxene, slightly calcareous; large grained pegmatite, idiomorph pyroxene crystals of the adjacent rock directed parallel to the dykes. This whole series forms the characteristic gorge between the Inuldar and the Seti rivers, 15 marble and calcsilicate rocks, 16 well banded fine grained paragneiss and mixed gneiss with limestone and marble, 17 thick clear-coloured series of massif gneiss, type 14 (Barun gneiss) with amphibol, garnets, pyroxene, limestone. Swarms of pegmatites with turmaline. Pegmatites are up to 20 m thick, they rise toward north relative to the beds, 18 out of 17), increasing content of carbonates, well banded (1 km SE of Nayaodyar), 19 toward Dahachaur again fine grained "Barun gneiss", extremely folded; turmaline granite dykes and layers up to 70 m thickness, 20 gradually out of 19); fine grained micaschists, hornblende "Garbenschiefer", 21 gorge of Dahachaur mainly turmaline granites with inclusions of fine grained micaschists and biotitegneiss within the granite, 22 mainly red and green quarzites, pelitic series, containing numerous pegmatites, quartzite is doubled, with change of strike between the two series (strike 115° East), 23 limestone, 24 mainly paragneiss (approx. 1000 m), fine grained biotitegneiss, sand-grained; decrease of metamorphism toward north; slaty, fine grained clear-coloured gneisses mixed in the lower part with amphibolites, amphibol "Garbenschiefer" and layers of coarse grained marble, 24 mixed in general with granite-pegmatites and banded mixed gneiss, 25 micaschists with biotite, muscowite and garnets, 26 greenish quartzite, with pegmatites, 27 fine grained micaschists without garnets, 28 fine grained biotite-paragneiss, 29 micaschists, changing to calcschists, 30 pelitic series (Chitlang series), 31 limestone, marble, top most pegmatites further north, up to the Urai pass there are only pelitic series and sliced calcareous series. The series between 23) and 32) appear to correspond to the Budhi series and Garbyang series of Heim and Gansser.

We shall now try to put the whole Thakkhola structure in the frame work of a larger area. For this purpose we have to consider once more the normal east—west striking structures. The northern rim of the synclinorium is found on the Thorung mountain range on the eastern flank of Thakkhola, while on the western flank, the range of Dangartse (5721 m)—Sangdaktse (6528 m) has to be considered as the northern limit of the synclinorium. These two mountain ranges are identical with the *Tibetan Marginal Range*. This mountain system is interrupted and intersected by the transverse Thakkhola trench. Normally, the Tibetan marginal mountain range forms the main watershed between the Ganges system and the Tsangpo system. In the Thakkhola trench, due to the transverse structure, a transverse valley has been created, which drains a large portion of the former (now sunken) Tibetan Plateau. The main watershed is certainly older than the main range of the Himalayas and the overthrust of the great nappes. Otherwise, the transverse valleys and the drainage pattern crossing the main range cannot be explained reasonably. Apparently not only the Tibetan Marginal Range, but also the whole synclinorium between the Marginal Range and the Great Himalaya Range has been created by a system of east—west faults. This was another "graben" structure, with complicated faults, differentiated uplifts, sunken zones, and overlap and folding of the sediment fillings onto the edges, along the faults.

The mountains of the synclinorium and the Tibetan Marginal Range are the oldest mountain ranges of the present Himalayas, built in Middle and Upper Mesozoic times, long before the rise of the main range and overthrust of the great nappes took place. This phase will from now on be called the *Thorung Phase*, named from the Thorungtse range east of Muktinath, where it is best developed.

The occurrence of old trench structures on the back of the roots has also been cited in the Alps recently by R. Staub. However in the Alps, this is rather the result of theoretical studies, since most of the relevant areas are buried under the Po-alluvium. The Thakkhola with its fairly safe stratigraphic base and extreme exposure has thus an importance which goes far beyond the Himalayas.

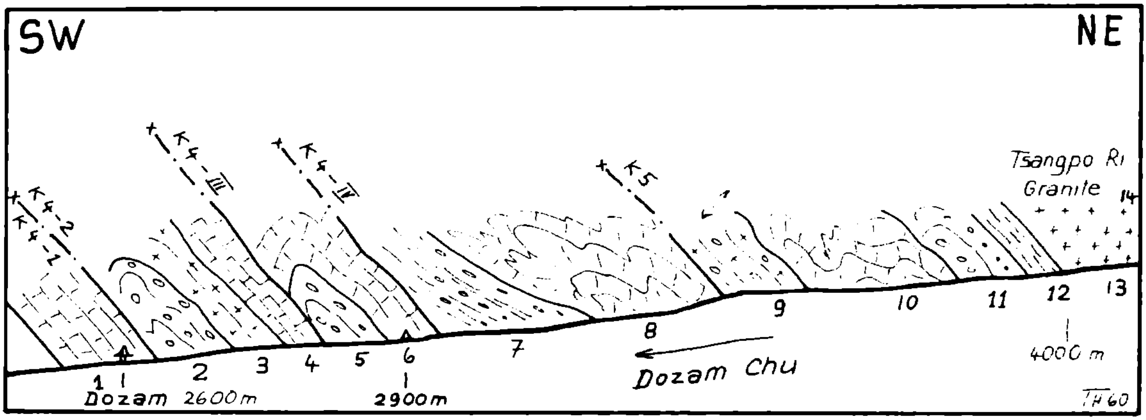



Fig. 42 Profile sketch in the upper part of the Dozam Valley (northwestern Nepal)

1 silicious limestone, banded, with few pegmatitic layers (400 m), 2 augengneisses (300 m), 3 granitic gneiss, banded gneiss in the upper part (300 m), 4 limestone, large grained (400 m), 5 augengneiss, felspar porphyroblast up to 10 cm diameter (200 m), 6 greenish silicious limestone with pegmatites (600 m), 7 thick crystalline series, various types of gneisses, dominantly banded orthogneisses and augengneisses, 8 limestone series, partly marble, with pegmatite layers, reverse folds, 9 crystalline series of mainly orthogneisses and granitic gneisses, 10 in the upper part of 9 limestones and marble as inclusions, 11 augengneisses, 12 beds of fine grained biotite-paragneisses in massif granite (Tsangpo Ri granite), 13 massif granite (Tsangpo Ri granite), 14 toward north gradual increase of limestone and calcsilicate rocks within the granites; also beds of fine grained pelitic series.

*The Manang Valley*

In the Manang valley behind the Annapurna range, the synclinorium is very complicated too, with many reverse faults. Walking from the town Manang down-valley along the Marsyandi river, one observes, due to a strong axial rise toward east, gradually lower formations: at Manang itself, Rhaetic formations are found. Opposite Pisang, on the southern flank of the valley, Carboniferous rocks are folded in, while east of Pisang the Devonian limestones rise very steeply towards the east. The limestones form one single bed, from 3000 m up to 5500 m, the greatest dip-slope ever seen, possibly the greatest in the whole world. Like a gigantic dish the polished-like even surface of the limestone turns round the valley in a half-circle, and the Marsyandi river leaves this "dish" through a gorge and drops onto the underlying crystalline series.

Nevertheless, the eastern termination of the Manang synclinorium is by no means a mere axial rise of the crystalline basement. It is really the huge granite of the Manaslu group, which joins the Annapurna crystalline at a considerable angle. The *Manaslu granite* shows a strike which is directed towards the north-northwest and due north (fig. 32 and plate 6). The contact of the granite with the over-lying limestones of probably Silurian age is tectonically undisturbed in the "dish" of Pisang. Towards the north and northeast increasing structures can be observed in those limestones. They apparently have been thrust and folded independently from the underlying crystalline basement (in the Tilje range). Towards the north, in the valleys of Naurgaon and Phugaon, the contact between the Manaslu granite and the Mesozoic filling of the synclinorium gradually becomes a tectonic one, with thrustfaults and thrusts towards the south. Unfortunately the northwestern border of the Manaslu granite mass could not be studied, since this area belongs to Tibet, but there is little doubt that the Manaslu granite strikes toward the Mustang granite in the Chudidi area on the erstern flank of the Mustang basin. It is uncertain whether the Manaslu granite connects on the surface directly with the Mustang granite. Possibly some sediments lie in the synclinal zone, but there is no doubt that the granitic layers and dykes in the Damodartse (6539 m) and in the Tangetse (6723 m) are the marginal traces of the granite body of the Manaslu granite (plate 6).

Regarding the age of the Mustang granite, the author regards it as Tertiary in the Mustang area. However, there are severe discrepancies: the granite of Mustang is directly connected with that of Mugu through the Tibetan Marginal Range north of Langu. This Mugu granite again is linked towards the south with the crystalline base of the synclinorium, which rises axially towards the west and is thus the same as the crystallines of the Kathmandu nappe no. 5, into which it gradually passes (plate 6).

Similarily, the Manaslu granite, which is connected with the crystalline of the Kathmandu nappe no. 5, also forms the crystalline basement of the Manang synclinorium. It is most probably in direct connection with the Mustang granite in the Chudidi area. While the Mustang granite near Mustang itself is undoubtedly of young, most probably Late Tertiary age, the intrusions in the Kathmandu nappes are undoubtedly of older age. They have intruded before the rise of the Himalayas, probably in the Upper Palaeozoic.

We shall see in the next chapter on the Khumbu nappes a similar feature, whereby the undoubtedly young granites in the Everest area strike into the nappes and thus far south, where they must be considered as much older.

*The Kutang Basin (Nubri)*

While on the south-western flank of the Manaslu granite the granite is intruded into series not younger than Devonian, on the eastern side, this igneous body is in unconformable contact with Triassic and Jurassic formations. This can be especially well seen north of the Larkya pass and on the Lajing pass, north of Larkya. The folded series of Mesozoic age strikes due east-west and ends at an irregular contact with the Manaslu granite, the surface of which strikes due northwest. On the Manaslu peak itself, apparently the granite intruded older formations. The top of the Manaslu peak just contains the lowest beds of limestones and silicate-limestones of probably Silurian-Devonian age, embedded in the granite. However, the contact of the granite on the north-eastern flank of Manaslu, near Sama, also seems to be an irregular one. The strike of the thick limestones seem to be directed into the granite of the Manaslu massif and not onto its top.

The Kutang basin is framed by the Manaslu-Himalchuli range and the Sama Himal-Sringi Himal. The marginal synclinorium is filled with sediments, which extend from Cambrian to Mesozoic age. The structure is complicated, with many folds and faults, as is characteristic of the synclinoria. The sediment basin is open towards the north into the Tibetan Plateau: no granite occurs further north as far as I was able to see from high peaks on the border.

In the Kutang area the Tibetan Marginal mountain range is from the geological standpoint not so clearly developed as in the Thakkhola and in the Langu area.

It is the Sringi Himal with its complicated structures, which separates the complicated folds of the synclinorium from the flat upwarps of the Tibetan Plateau. The structures on the plateau decrease towards the north. On the other hand, in the section north of the Ganesh Himal the gentle structures reach far onto the Plateau namely, as far as visibility extended (approx. 70 km). This is much further than in other areas.

*The Chokhang Basin (Tsum)*

The Chokhang basin is the eastern continuation of the Kutang valley. Geographically, it is not separated from the latter. It is drained by the Shar Khola, an eastern tributary of the Buri Gandaki. This valley does not show particularly interesting features; the Schuppen and fold structure just continues from the Kutang valley to the east. This valley is the easternmost valley in Nepal, in which the Tibetan sediments occur. Unfortunately, further to the east, the crystalline roots are situated further north respectively, as the Nepal-Tibet boundary is identical with the main range of the Himalayas. Consequently the sedimentary area was not within the possible field of investigations of the author

*The Marginal Synclinorium east of the Trisuli river*

The Trisuli river follows a geological feature with regard to the east-west geological structure, as we shall see in the next chapter. East of this section, the Khumbu nappes appear. Further, the Tibetan marginal synclinoria are east of the above mentioned transverse valleys (Trisuli) not filled with sediments, but instead due to axial lifts in the crystalline base, the latter appears on the surface (plate 6). This is the proof that the structures so well developed in the Langu-Manang synclinorium, do not just involve the sediments but reach to the crystalline basement at a very great depth.

The structures in the crystallines which correspond to the Tibetan Marginal Synclinorium are exposed in the crystalline zone of the upper course of the Langtang valley between the Langtang Himal and the Shisha Pangma (fig. 97). Further east, the synclinorium structure is especially well visible in the eastern flank of the Everest-Chomolönzo-Makalu group (fig. 100). Due to the strong axial pitch of these series towards the west (on the western flank of the Arun transverse anticline), the mountain flanks show the crystalline structures like a textbook. The overlying sedimentary filling appears only on the peaks of Everest-Lhotse. Due to the further strong axial pitch of the syncline west of Everest, the sediment zone gradually widens in this direction. (More details of the geology of Everest will be given in the chapter 4).

The map of fig. 43, shows the various Tibetan marginal synclinoria throughout the whole country, and their relative positions. It is evident, that the synclinoria do not extend in one single line,

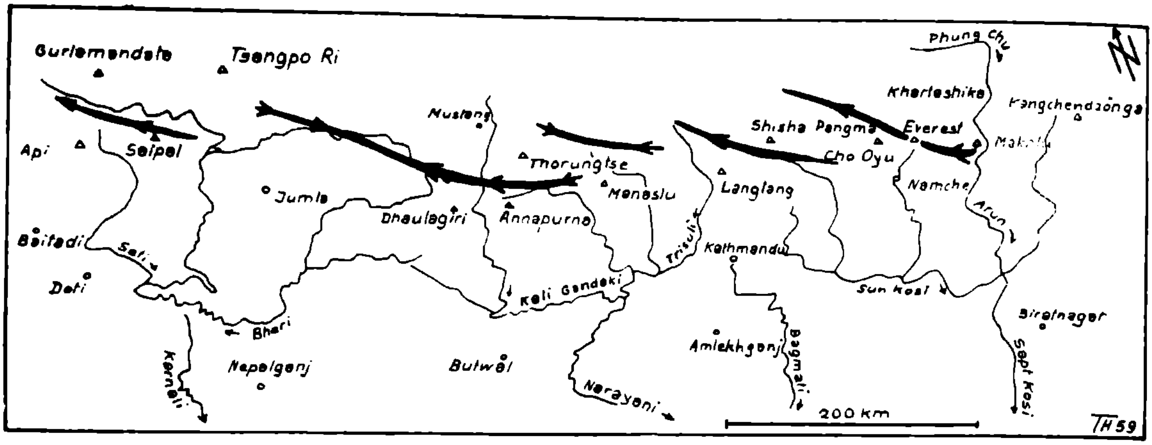



Fig. 43 Sketchmap, showing the Tibetan marginal synclinoria and their relative positions to each other

but are dissected into different parts, which on the other hand are transposed to each other. The transposition is effected in such a way, that each of the eastern joining synclinoria begins more to the north (fig. 43). Tectonically each synclinorium is higher, compared with the foregoing one. This means, that the synclinoria have generally been built from west to east, those in western Nepal being the oldest ones, the Everest synclinorium the youngest.

The pre-orogenic age of the marginal synclinoria has been suggested above. It has also been said that the marginal synclinoria apparently have been caused by graben structures in the old Himalayan geosyncline. The pattern of the various synclinoria, as given in the map of fig. 43, shows, that those graben structures have right from the beginning not been aligned in one single belt, but have originally already been transposed to each other. A chronological succession however of the graben structures cannot be given, since the most southerly situated graben (for example the Saipal graben) has not necessarily been created first. Nevertheless we may say, that the original pattern of the synclinoria in the former Himalayan geosyncline has directed the consequent pattern of the later uplift of the Himalayas and the geographical distribution of the great overthrusts.

### *5) The Khumbu nappes*

The crystalline nappes overlying the Kathmandu nappes were called the Khumbu nappes by the Swiss Geologist A. Lombard, after the Khumbu area, the home of the Sherpas on the southern flank of Mt. Everest. The author has accepted this name, though possibly the divisions within the nappes might not prove to be exactly the same as those of Lombard. Nevertheless, the overthrust of the Khumbu nappes over the Kathmandu nappes near Ghat, in the Dudh Kosi Valley south of Khumbu is evident. It has been found by both authors independently.

In course of the investigations, the Khumbu nappe no. 1 has proved to be identical with the Kathmandu nappe no. 5, as indicated in fig. 17 and plate 6. It develops out of the topmost Kathmandu nappe (no. 5). It is just a matter of convention, from which area onwards to the east the Kathmandu nappe no. 5 may be called Khumbu nappe no. 1. It is suggested here by the author, to consider the Trisuli Valley, the basin of Kyirong Dzong as the separating section. For, from Kyirong Dzong onwards to the east the Khumbu nappe 2 rises out of the sediments of the Tibetan Plateau in form of an anticline, which on the other hand pitches westward into the sediments (plate 6 and fig. 44). This area was forbidden to the author, since it lies in Tibet. However, from some peaks on the boundary itself, north of Ganesh Himal and on the Salbu pass, the layout of the geological structure could be seen very well. There is no doubt, that east of Kyirong Dzong new structural elements join north of the main Himalayan range. The Phuriphu Himal and the Shisha Pangma group (figs. 44 and 97) being entirely built of crystalline formations, show a complicated structure which otherwise used to occur in the sediments of the Tibetan marginal synclinoria (Profiles plate 4; further figs. 97 and 44, tectonic sketchmap of Shisha Pangma-Kathmandu). There is no doubt, that the synclinorium is, in the section of the Trisuli valley, transposed step-wise towards the north (fig. 43). A new range occurs onwards from this section to the east, which is identical with the Tibetan Marginal Range.

The Shisha Pangma—belonging to that range—is the first eight-thousander from Manaslu towards the east. We have said earlier that the highest mountains are built by the roots of the crystalline nappes, but the Shisha Pangma is an exception. It is situated on an *axial culmination* of the Tibetan Marginal Range. The axial culmination is in connection with the transverse anticline of the Goasinkund (plate 6 and fig. 44, tectonic map). We thus see, how important the effect of the transverse structures has been for the physiography of the Himalayas.

In the same way as the Khumbu nappe 2 rises out of the Tibetan sediment plateau, the Khumbu nappe 3 occurs east of the Pö Chu (Pö Chu is the upper course of the Sun Kosi). This area was also beyond the range of the field studies of the author, but from high peaks on the Nepal border in the area north of the Chhoba Bamare (5959 m, 19,550 ft.) the sediment cover of the Khumbu nappe 2 was clearly recognized in the area north of Lapche Gömpa and in the bottom of the southern flank of Dzo Rapzang (7038 m, 23,092 ft.). It was also recognized, that the upper part of this southern flank is built of crystalline rocks, dominantly granite, with a gradual dying out towards the top in the form of pegmatitic layers and dykes. The peak of Dzo Rapzang again consists of sediments.

The crystalline of Dzo Rapzang develops further to the east to the Khumbu nappe 3. Onwards to the east of Nangpa La the Khumbu nappe 3 builds the main range of the Himalaya, beginning with Cho Oyu (8153 m). Simultaneously the Kathmandu roots diverge towards the south, building lesser ranges not exceeding 7000 m in height. By this divergence of the roots, space was created for overthrust nappes in the Khumbu area (figs. 99 and 100).

East of Everest, quite new tectonic elements are involved in the Khumbu nappes, and make them turn northward and bend round the pitching transverse Arun anticline. Upper schuppen on the back of the Khumbu nappe 3 develop from Everest onward to the east and build the highest mountains of the world (Everest 8848 m and Makalu 8471 m). Four tectonic slices (Schuppen) were recognized, namely the Sakyetang slice, the Makalu slice, the Nuptse-Chomolönzo slice and the Everest slice (figs. 103 and 104). While the Khumbu nappe 3 continues beyond the Arun anticline, these Schuppen disappear again in the Tibetan sediments still on the western side of the Arun anticline (plate 6 and fig. 24, tectonic sketchmap of eastern Nepal). The Khumbu nappe 3 in the Arun anticline is bent about 50 km towards the north before turning to the south again at its eastern flank.

East of the Arun river, the Khumbu nappes strike due south and join thus the Main Boundary Thrust some kilometer east of Dharan (plate 6 and figs. 17 and 24). This means that, east of the Arun the Khumbu nappes take over the main role in mountain building, while the underlying Kathmandu nappes die out (fig. 29, stereogram).

In the Angbung zone, the underlying formations, underneath the Khumbu nappes occur in a tectonic window (plate 6).

The Khumbu nappes consist of various gneisses, migmatites and granites. Large areas show rather monotonous augengneisses. In general their rock formations are similar to those of the Kathmandu nappes. The rocks will be dealt with later in the chapter on regional descriptions.

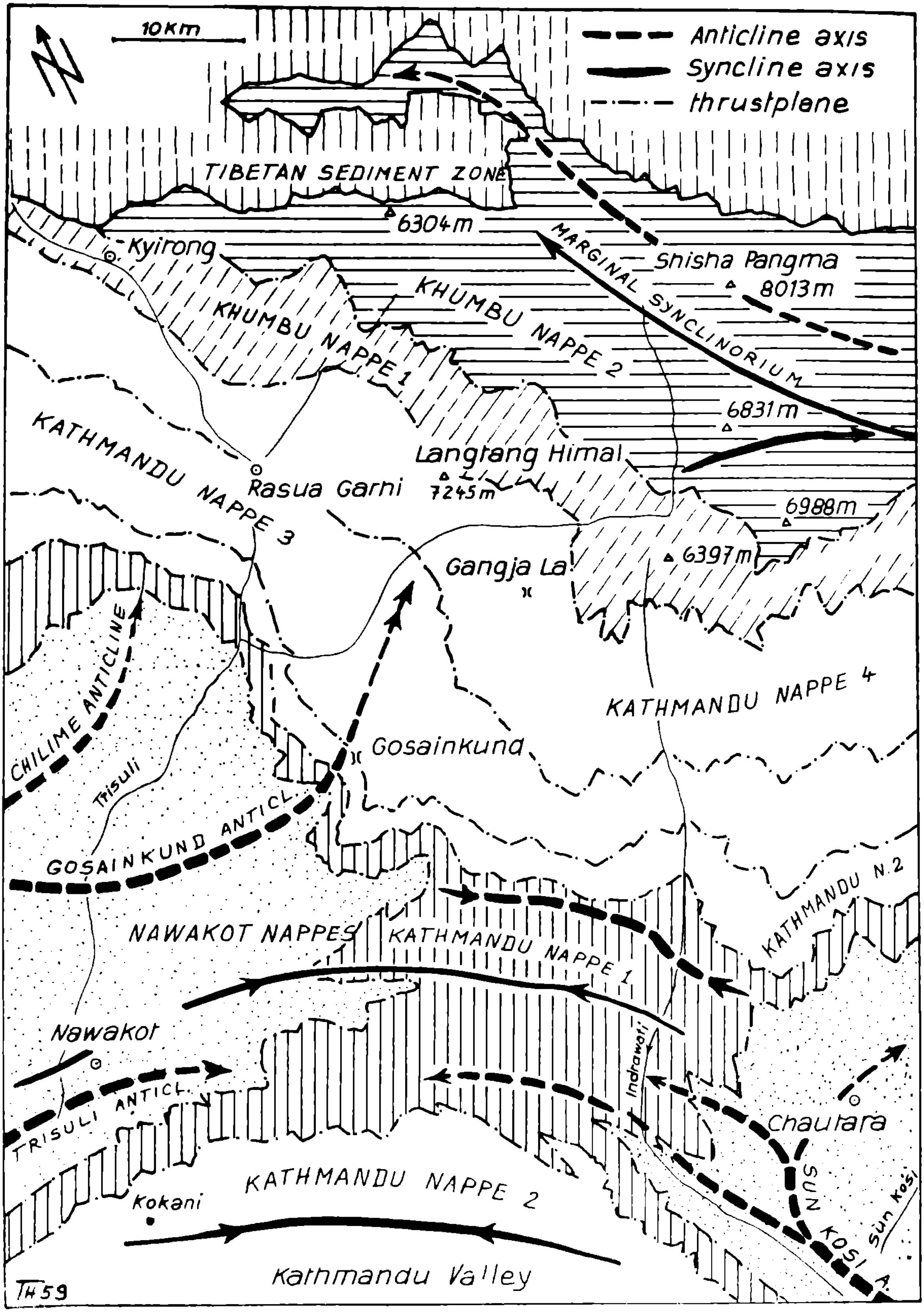

10 Km
Anticline axis
Syncline axis
thrustplane
TIBETAN SEDIMENT ZONE
6304 m
Kyirong
MARGINAL SYNCLINORIUM
Shisha Pangma
8013 m
KHUMBU NAPPE 2
KHUMBU NAPPE 1
6831 m
KATHMANDU NAPPE 3
Langtang Himal
Rasua Garhi
7245 m
6988 m
6397 m
Gangja La
CHILIME ANTICLINE
KATHMANDU NAPPE 4
Trisuli
Gosainkund
GOSAINKUND ANTICL.
KATHMANDU N. 2
NAWAKOT NAPPES
KATHMANDU NAPPE 1
Nawakot
Indrawati
TRISULI ANTICL.
Chautara
SUN KOSI A.
Sun Kosi
KATHMANDU NAPPE 2
Kokani
Kathmandu Valley
TH 59

Fig. 44 Tectonic sketchmap of central Nepal (opposite) (Kathmandu valley–Shisha Pangma)

### 6) *The Lumbasumba and Kangchendzönga Nappes*

The Lumbasumba Himal is the mountain range east of the Arun river, between the valleys of Walungchung and the valley of Thudam-Topke Gola. It is a minor mountain range, hardly reaching the 6000 m level. The range strikes north–south, which is quite an exception in the Nepal Himalayas. However, this abnormal strike reflects the structure of this area, which is caused by the Arun transverse anticline. The Lumbasumba range is built by the tectonic unit overlying the Kathmandu nappe 3 (fig. 17 and plate 6). The nappe develops as a crystalline anticline out of the Tibetan sediment zone south of Tashirakha. The corresponding sediments were found very far south near the Tag La (the pass between Topke Gola and Thudam) as calcareous wedges, overlying and underlying the crystalline anticline, which at this place is lying horizontally and directed towards the west. Onwards to the east from Lumbasumba Himal, the Lumbasumba crystallines develop into a real nappe, which forms with its horizontally bedded formations the base of the whole Kangchendzönga group. (Fig. 24, tectonic profile 2, Kangchendzönga, and fig. 105, geological profiles.)

*The Kangchendzönga nappe* develops also out of the Tibetan sedimentary plateau north of Tashirakha (fig. 24 and plate 6), as a huge crystalline anticline. East of the Umbhak Himal, the corresponding crystalline masses are overthrust to the south, forming the upper part of the Kangchendzönga group (plate 6, figs. 24 and 105 geol. profiles, further tectonic profile 2). Kangchendzönga itself is situated on a large but flat anticline, with its axis in the west-east strike direction.The flat bedded formations and the thrustplane cause an intersection with the mountains which takes more or less the shape of a contour line. We thus find a number of tectonic outliers in the Kangchendzönga group, built of isolated masses of the Kangchendzönga nappe on the underlying Lumbasumba nappe (fig. 24).

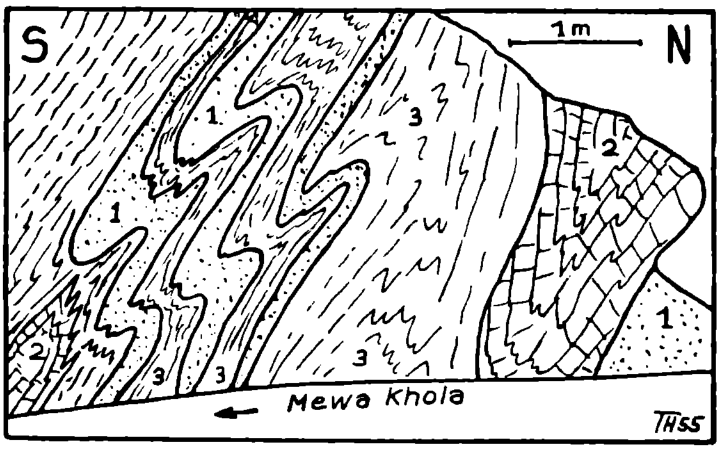



Fig. 45 Profile sketch in the Mewa valley, south of Topke Gola (eastern Nepal).

1 fine grained biotite gneiss, 2 calcsilicate limestone, 3 banded crystalline limestone, with small layers of fine grained intrusions (aplites).

The whole series is greatly tectonized.

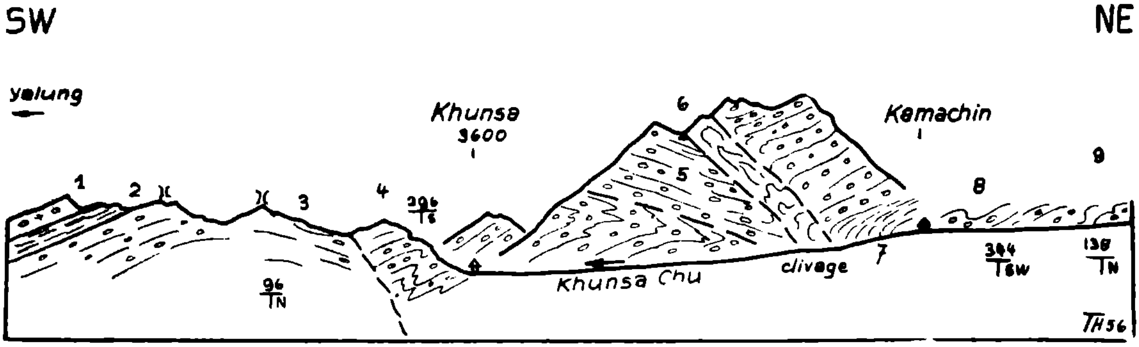



Fig. 46 Profile sketch in the Khunsa valley (Kangchendzönga group), total length of profile approx. 15 km.

1 thick series of ophtalmite (augengneiss) of mainly ortho character, 2 thrustplane with paragneiss, rich in biotite and muscowite, 3 well bedded gneiss, with small layers of micaschist and iron ore, porphyric augengneiss, 4 tectonized augengneiss; at the opposite flank of the valley (western flank) strong clivage with northern dip, 5 well bedded gneiss series, overlying a thrust with unconformity, 6 upper thrustfault with unconformity, 7 increasing portion of paragneiss and chloriteschists, 8 augengneiss, overlying fine grained granitic dykes and layers, aplites, on the western flank rosty augengneiss with various dips, 9 nodular augengneiss.

Both, the Lumbasumba nappe and the Kangchendzönga nappe consist of huge granite masses with various transitions to gneisses of all kinds, intercalated with micaschists. On the Jongsang Ri (7459 m) Dyrenfurth found the normal sediment cover of the Kangchendzönga nappe.

We have seen that the Lumbasumba nappe as well as the Kangchendzönga nappe are not in direct connection with the nappes west of the Arun—Phung Chu valley. Nevertheless, it is not too difficult, to make out to which Schuppen (slices) they correspond on the opposite (western side) of the Arun transverse anticline (figs. 17, 24, 104, and 105, longitudinal profiles of Everest-Kangchendzönga and plate 6). The Lumbasumba nappe corresponds to the Sakyetang schuppe, while the Kangchendzönga nappe is identical with the Makalu schuppe. More details will be given in the chapter on regional descriptions.

### *7) The Kathmandu nappes*

The Kathmandu nappes form the backbone of the Nepal Himalaya. Not only do they show far the greatest extent in longitudinal direction (east-west), namely 800 km almost throughout the whole country, but their roots build the Great Himalaya Range (plate 6), and most of the highest peaks of Nepal are situated in the roots of these nappes or in the adjacent marginal schuppen on the backside of the roots (Api, Saipal, Kanjiroba, Dhaulagiri, Annapurna, Manaslu, Ganesh Himal, Langtang Himal, Gauri Sankar, Karyolung, Kangtega).

The Kathmandu nappes were first recognized and stated in the Kathmandu valley in central Nepal, during the first geological excursion in the surroundings of the capital Kathmandu in 1950. The capital provided the name for this nappe group, and the choice proved later on to be a happy one; no better name could have been found for the tectonic units building the highest mountains of the world.

Strictly speaking, their roots form the highest mountains of the Nepal Himalayas from the western border of Nepal right across to the meridian of Kathmandu. East of this meridian, their strike

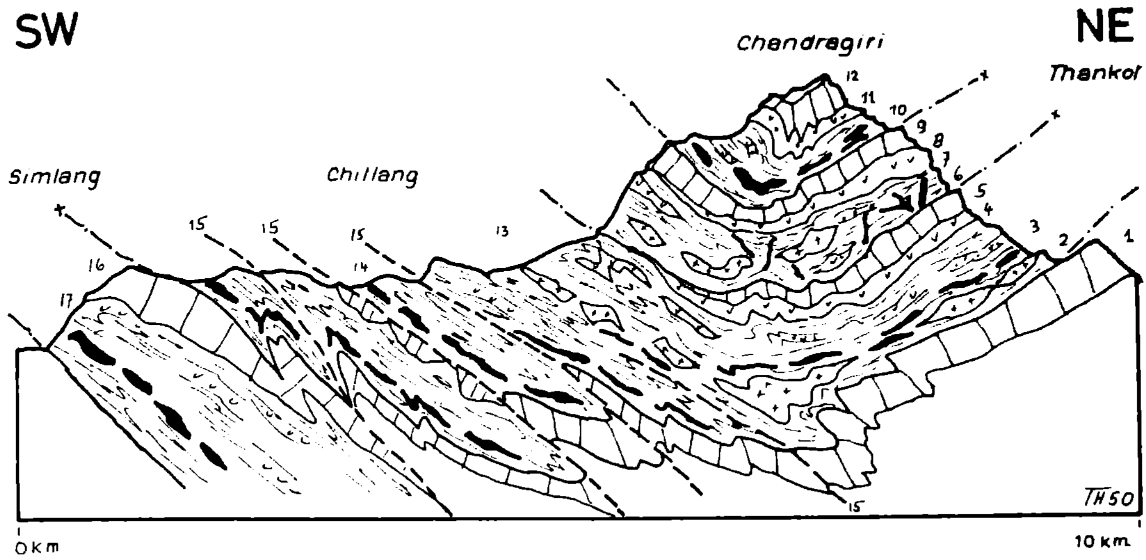



Fig. 47 Simplified profile sketch of the Chandragiri range
(10 km southwest of Kathmandu, central Nepal).

1 coarse grained limestone, 2 stratified quartzite, interbedded with sandstone, marls, shales; pegmatite dykes, 3 slates, slightly sericitic, red and green Chitlang slates, red marl slates, 4 quartzite, red and white, 5 coarse grained limestone, silicious limestone, 6 thrustplane, phyllites, interbedded with coloured quartzites, with quartz veins and small pegmatitic layers and dykes, 7 red and violet shales, 8 quartzite, 9 coarse grained limestone, crinoid limestone, 10 thrustplane, violet shales and slates, interbedded with quartzite layers (Chitlang slates), marly slates, quartz veins, 11 quartzite, interbedded with limestones and shales, 12 limestone, coarse grained and light coloured, also dark blue layers, hematitic layers, crinoid limestone, 13 rocks similar as no. 2), plus granulites with biotite but containing applitic bodies and pegmatites with turmaline, 14 thrustplane, with quartz veins, pegmatite layers, 15 thrustfaults, 16 thick limestone series (same as 1), 17 Chitlang slates, with small layers of quartzite, pegmatites.

The profile is much simplified, since there are a number of further tectonic disturbances expecially at the southwestern flank of the Chandragiri range. The eastern flank shows a four-fold repetition. The lithological repetitions allow easily an interpretation in form of a normal succession. However the occurrence of pegmatites and even applitic granite bodies always within the same lithological formations render some difficulties for the mentioned interpretation. Why, may we ask, have the granitic and pegmatitic intrusions always preferred the same rocks?—In addition, there are clear thrustplanes between the various repetitions. Thus the interpretation of various tectonic sheets (nappes) thrust and piled up on each other appears to meet more the facts.

This section also shows, how the overthrust nappes as a whole have been cut by thrustfaults of a very late phase. (Phase of the Midland structures, see page 149.)

turns gradually to the southeast and south, so that they end a few kilometer east of Dharan on the Main Boundary Thrust (plate 6 and fig. 24).

In this area east of Kathmandu, the overlying Khumbu nappes take over the rôle of building the highest mountains, including Mount Everest.

Fig. 47 shows the first field profile taken in the Kathmandu nappes, the cross section along the old "land route" from Bimphedi to Tankot. The author travelled by this route several times, before the air service and the Tribhuvan Raj Road were opened. The Chandragiri pass is interesting for geologists, because of the findings by Bowman of crinoids which he considered to be of Silurian-Ordovician age. The profile of fig. 47 was at first somewhat difficult to interpret; nappe structure could not necessarily be concluded from that area. Overthrust of the various gneisses, micaschists and migmatites of the areas surrounding Kathmandu was first suggested after having taken the trip via Kokani to Nawakot. In the Tadi Khola, underneath the southerly dipping crystalline formations, some entirely

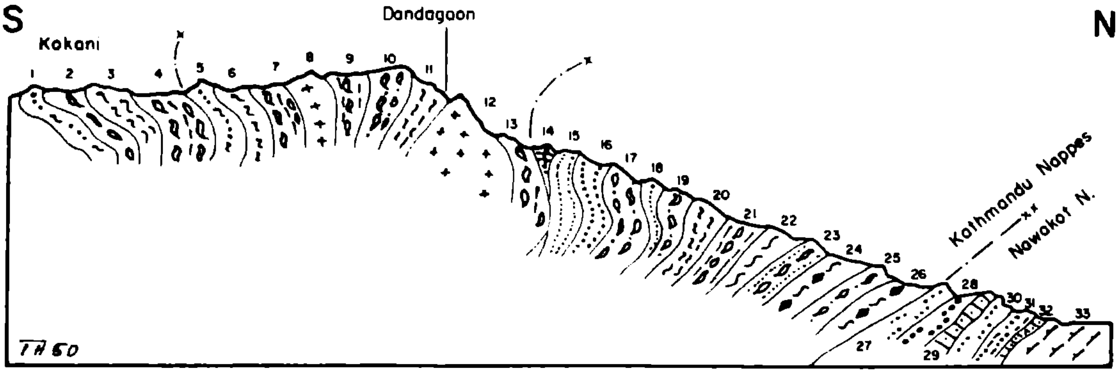



Fig. 48 Profile sketch Kokani–Dandagaon–Kaulia (Sheopuri Lekh, 15 km northwest of Kathmandu), total length of profile 16 km.

1 banded micaceous quartzite, hard, 2 banded gneiss, 3 micaschist with a few intrusions, 4 migmatite, 5 micaceous quartzite, hard, 6 micaschist, biotite granulite, with migmatitic layers, 7 migmatite, 8 granite, 9 gneiss with migmatite and pegmatitic layers, also lamprophyr dyke, 10 granulite and gneiss with biotite and intrusive layers, 11 micaschist, with migmatites, metamorphism decreasing toward north, 12 epidot granite, 13 migmatite, thrustplane, 14 calcareous slice, 15 sandstone, low metamorphism, hard, 16 sandstone similar as above, but coarse grain, multicoloured, folded, 17 granulite with intrusions, very soft, mixed with layers of large grained biotite gneiss, 18 grey soft sandstone, 19 granulite and gneiss, with pegmatitic layers, 20 micaschist, 21 migmatite, 22 micaschist, rich in coarse grained muskowite, 23 sandstone and gneiss with biotite, decrease in metamorphism toward north, 24 micaschist, with biotite, muscowite and garnet, 25 granulite with few intrusions, 26 garnet micaschist, 27 quartzite (Hornstein), 28 conglomeratic and slaty quartzite, 29 blue sandy limestone, 30 well bedded quartzite and sandstone with some sericite, very hard, yellowish, 31 banded quartzite, with layers of clay in the joints, 32 blue calcareous sandstone, 33 coloured clay, partly schistose, similar to the "Quartenschiefer" of the Alpine Trias.

non-metamorphosed dolomites and quartzites suddenly appeared (fig. 48). The interpretation however with regard to the cross section of Kathmandu—Nawakot alone does not prove nappe structure. The Japanese petrologist Seiji Hashimoto who accompanied the Manaslu Expedition in 1956 considered the crystalline mass of Sheopuri Lekh (north of Kathmandu) as autochthonous, with simple marginal fan-shaped overlap on the adjacent non-metamorphic Nawakot series (figs. 51 and 52). In these figures this problem is studied in some detail, since it shows characteristically how it is possible to interpret one and the same geological profile in quite different ways. It also shows how interpretation, based on a single traverse is always risky. The section Kathmandu–Kokani–Nawakot considered alone, certainly allows the two different interpretations, namely as an autochthonous fan and as overthrust nappes (outlier) (see figs. 50 and 51).

The author has had the chance to carry out not merely a few single traverses, but to cover the whole area, and to visit certain key-points of that area several times. Thus, he followed the border of the crystallines from Tadi Khola towards the west and found the final outcrop of the Kathmandu crystalline to be about 50 km in the west, near Kandrang Garhi (plate 6 and fig. 55). From there, he was able to follow the outcrop of the crystalline, which turned south and east and proved to be identical with the overthrust of the crystalline series onto the non-metamorphic sediments near Suparitar. Still at this stage one could consider the western outcrop, particularly the eastern dip of the Kathmandu series near Kandrang Garhi, as an autochthonous fan structure.

For the author however—after finding that outcrop near Kandrang Garhi—there was no doubt that the Kathmandu mass is a part of a nappe, which has been protected from erosion and is lying in a syncline with axial depression near Kathmandu.

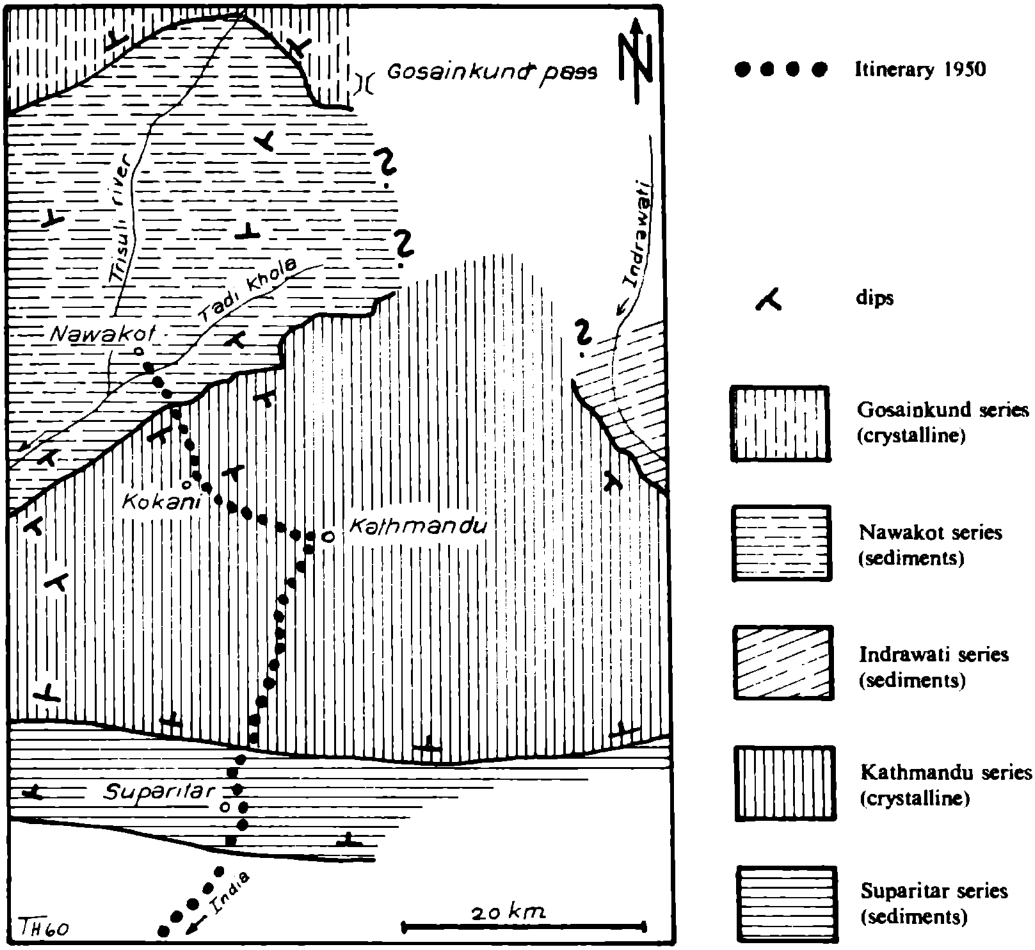



Fig. 49 Sketchmap of the Kathmandu area

This map shows the three main series (Suparitar series, Kathmandu series and Nawakot series) and their respective dips, as observed by the author during his first field trips in 1950–51. It appeared that the Suparitar series and the Nawakot series were probably identical, and that the Kathmandu series, lying in the Kathmandu syncline thrust on the two former series. However, no proof was found in 1951, and consequently a number of different interpretations were possible at that time (see figs. 50–55 below).

A further, final proof of nappe structure was found in the north. The crystalline series of Kathmandu on the Gosainkund ridge connects without interruption with the extremely thick, northerly dipping crystalline series in the Langtang- and Ganesh-Himal of the Great Himalaya Range. This "tectonic bridge of Gosainkund", however small it may be (it is really only a few kilometers across) simply does not allow one to consider the crystallines of the Langtang Himal and of Kathmandu to belong to two different autochthonous massifs with marginal fan structure (figs. 52–54). Thus the tectonic connection of the overthrust crystalline masses with their roots in the Great Himalaya Range was found for the very first times in the Himalayas. In the areas studied by Heim und Gansser as well as by J. B. Auden, such tectonic bridges have been eroded; they do not exist today. Those explorers only inferred the former connection of the overthrust (Almora) masses with the roots in the main range.

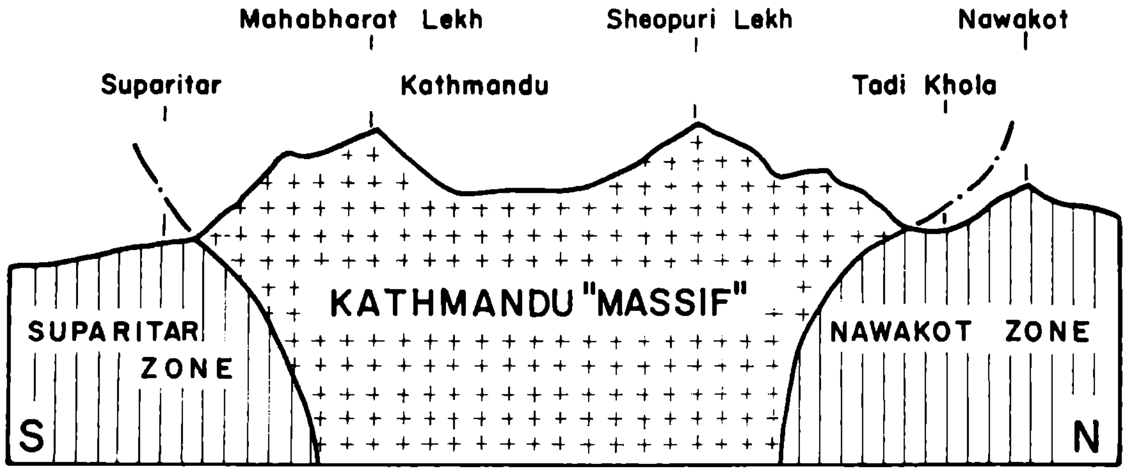



Fig. 50 Interpretation of the Kathmandu crystalline series as a massif
(adopted by the Japanese petrologist Seiji Hashimoto).

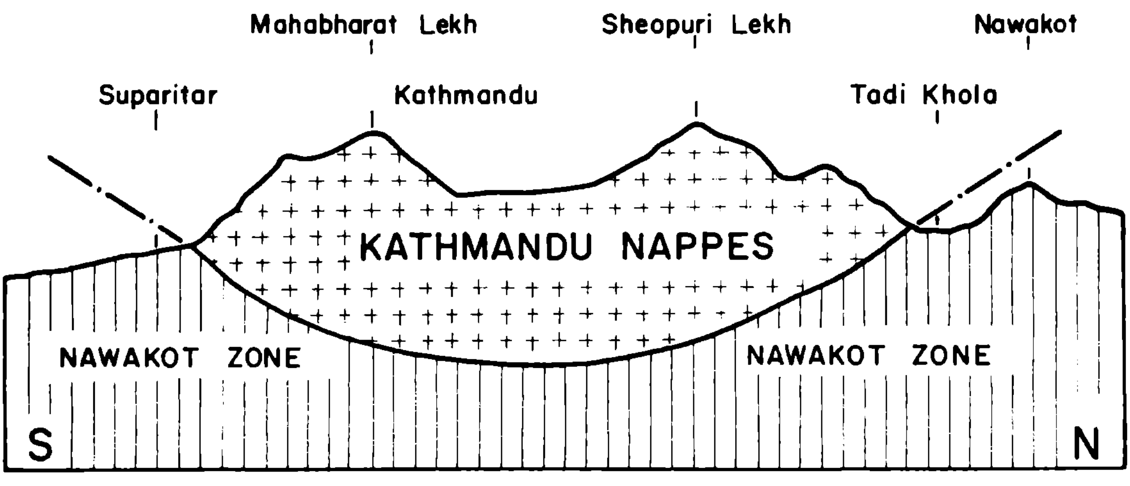



Fig. 51 Interpretation of the Kathmandu crystalline series as a nappe, lying in the Kathmandu syncline
(adopted by the author).
The Suparitar zone and the Nawakot zone are considered to be identical.

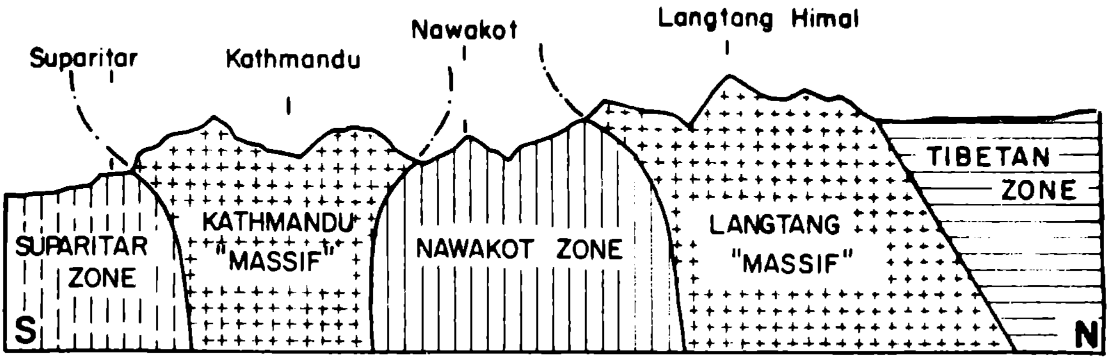



Fig. 52 Interpretation of the Kathmandu crystalline series and the Langtang crystalline series as separate massifs

In the section through Nawakot, these two crystalline series are separated by the entirely different (sedimentary) Nawakot series.

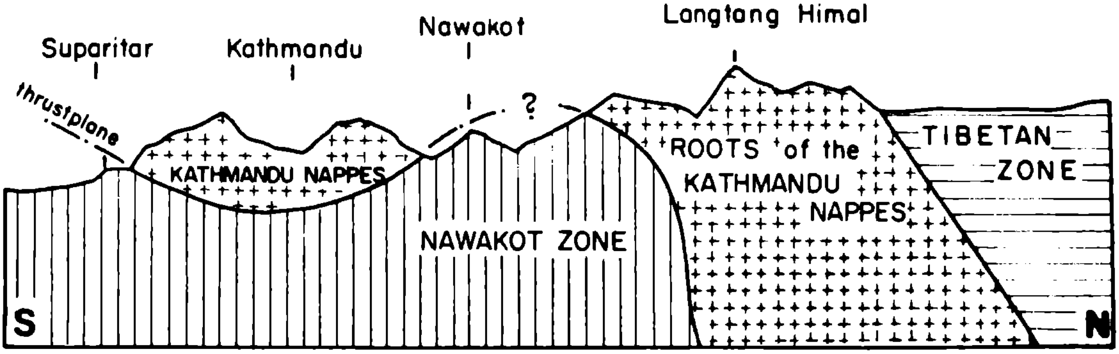



Fig. 53 Interpretation of the Kathmandu crystalline series as a nappe, and the Langtang crystalline the corresponding root zone

Both interpretations, as given in figs. 52 and 53 are possible, when considering only the Nawakot section. A strong axial pitch of the Nawakot series towards the east made it fairly probable, that on the Gosainkund ridge the two crystalline zones were connected (as shown in fig. 54).

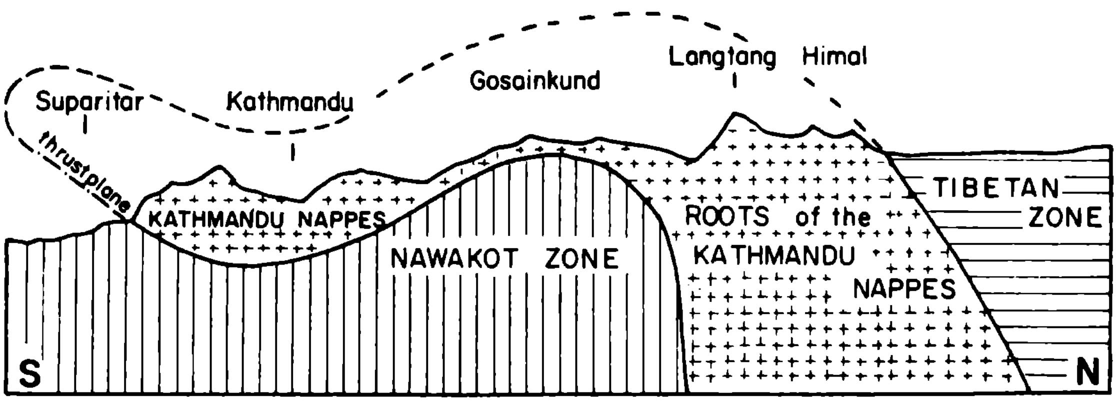



Fig. 54 Nappe structure on the Gosainkund ridge

This section is taken just a few kilometers east of the one given in fig. 53. It provides proof of the nappe structure of the Kathmandu crystalline series, and the Langtang crystalline series being the roots of the Kathmandu nappes.

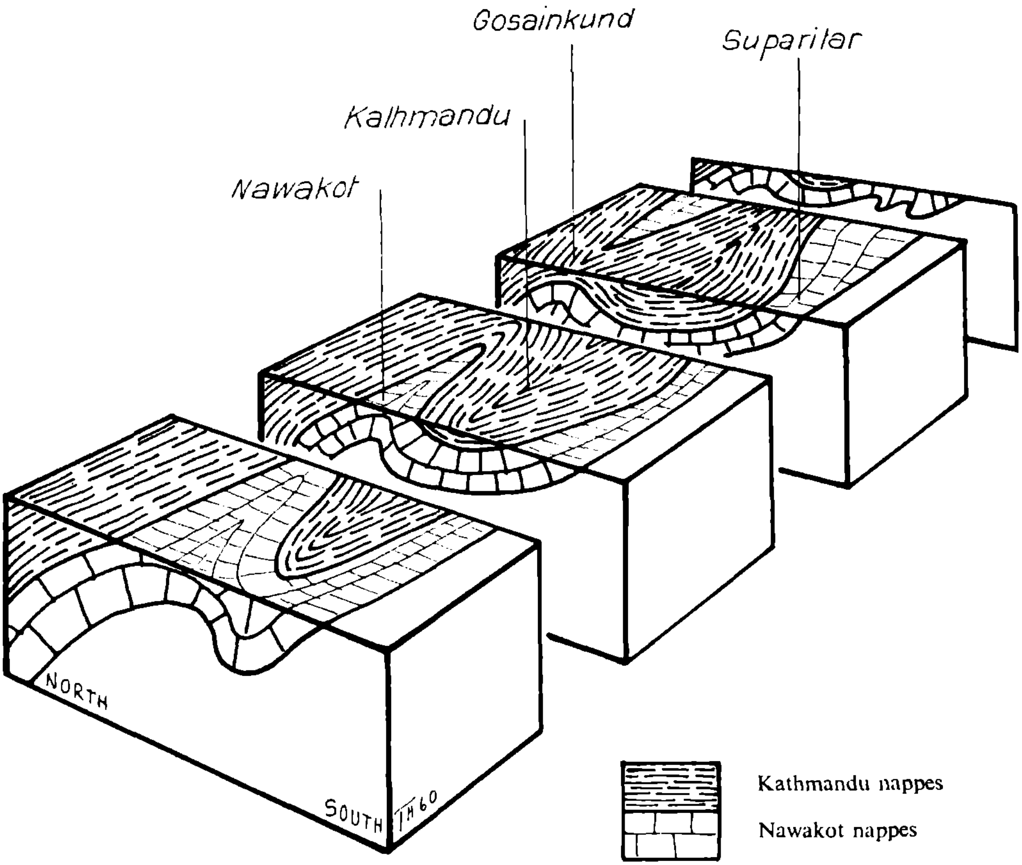



Fig. 55 Tectonic stereogram of central Nepal

This much simplified stereogram shows the "Halbklippe" of the Kathmandu nappes upon the underlying Nawakot nappes. The Kathmandu nappes have been protected from erosion in the longitudinal Mahabharat syncline and in its axial depression in this section.

The tectonic bridge of Gosainkund is not only small with regard to its thickness, but with a width of only 24 km is also extremely narrow (fig. 44). A geological traverse, taken beyond the line of this bridge will miss the Kathmandu crystalline altogether and thus shows quite a different tectonic layout.

The choice of geological traverses is of the utmost importance. This can be shown in the same area where some geologists have at times considered the underlying Nawakot series as a reversed, non-metamorphic cover to the Kathmandu nappes. The idea, that even in the nappes, the underlying series are considered to be the reversed limb of the nappe-fold (recumbent fold) is quite common. The whole history of geological research in the Alps show the gradual development from folds, via recumbent folds, thrust folds to nappe-folds, and finally to nappes.

Thus, the so-called reversed limb of the nappe-folds played a very important rôle in the early stages of nappe theory. In the Alps however almost all the "reversed limbs" and the "reversed series" underlying the great nappes proved to be a matter of imagination. More and more, the great Alpine nappes proved to be thrust sheets which have the oldest formations at the base, and which are overthrust over the youngest series of the underlying tectonic unit. This is the so-called "Gleitbrett-Tektonik". But still there are many geologists, who are not free of the belief, that all the great nappes have been developed out of folds. Theer are geologists who have frequently considered in Nepal the less metamorphic series at the base of the nappes as "reversed limbs". For example S. Hashimoto (Lit. 1957) considered the Nawakot series in the Tadi Khola (phyllites, slates and quartzites) with their only slight epimetamorphism to be the reversed limb of the Kathmandu crystalline, that is of the Kathmandu nappes of the Sheopuri Lekh.

These petrologists followed the section from Kokani to the Tadi Khola and the Trisuli river; a part of the relevant profile, taken by the author is given in fig. 48. Studying this profile alone one cannot exclude the possibility that the Nawakot series is a reversed sedimentary cover of the Sheopuri crystalline because there exists a kind of intermediate series between the various gneisses and the quartzites and conglomerates in the form of micaschists and slightly metamorphosed slates.

The existence of the very different Nawakot series underneath the Kathmandu crystallines was concluded from dolomites of only a few decimeters thickness and of a boulderbed. The latter however was detected rather incidentally by stepping through the water of the Tadi Khola (fig. 57).

When we study neighbouring sections to the Kokani-Tadi route, the situation looks quite different; the dolomite has developed to a thickness of about 1000 m (near Simpani), and has also been folded (fig. 56). The whole profile is undoubtedly of Triassic formations with quartzites, shales and dolomites. Resting on the entirely non-metamorphic dolomites are micaschists with garnet, biotite and muskovite.

The whole contact shows a clear thrust, which separates entirely different formations. There are no traces at all of a reversed limb, a reversed series or even of intermediate strata.

A few kilometer east of the Kokani-Tadi route near Cheharé (fig. 57) the situation is once more quite different; the dolomite, elsewhere more than 1000 m thick, is here entirely reduced and squeezed out. Only coaly slates and black and white quartzites represent the thick Triassic formations of the Simpani section (fig. 56). A geologist, taking the Ganykhar—Sheopuri traverse only, would by no means realize that he has crossed a most important tectonic contact at Cheharé. He would naturally consider the Nawakot series as the reversed sedimentary cover of the Kathmandu nappes.

There is yet another point, which might cause discussion. Within the Kathmandu nappe group, at least 4 sheets or single nappes could be recognized. Since the stratigraphy of the Kathmandu nappes is not yet on too strong a basis, lithological comparison had necessarily to be accepted to support the theory of several nappes. Although lithological repetitions need not necessarily lead to tectonic divisions, there is a kind of repetition within the Kathmandu nappes, which exceeds the importance of mere lithological repetitions and that is the distribution of the granitic, aplitic and pegmatitic intrusions. When within several characteristic lithological repetitions, granites and pegmatites always appear in the same formations and on the same level of the particular repetition, we have a good argument for considering the repetitions to be of tectonic origin. Otherwise, intrusive granite would have no reason at all, to prefer and select only one and the same rockformations at several levels.

I want to mention J. B. Auden, the very capable geologist, who had made some short traverses in Nepal in the early 1930s. He remarked then that the reversed series of the Darjeeling-gneisses disappeared towards the west into Nepal. At Udaipur Garhi and near Ilam he could not observe the reversed series underlying the Darjeeling gneiss.

The main divisions of the crystalline series go back to Middlemiss. He divided the crystalline masses into the "Darjeeling gneiss" and the Dalings. In general, these two main divisions can still be applied today.

The lower formations of the Kathmandu nappes consist of various gneisses and micaschists which have to be considered as pre-Cambrian. No fossils have so far been found in these series. The gneisses are to a great extent of former sedimentary origin; quartzites and sandstones were intruded by granitic material in various ways. In some areas, huge granite bodies are found in the Kathmandu nappes even in their front parts, for example on Narainthan in the Mahabhart Lekh; near Kulikhani,

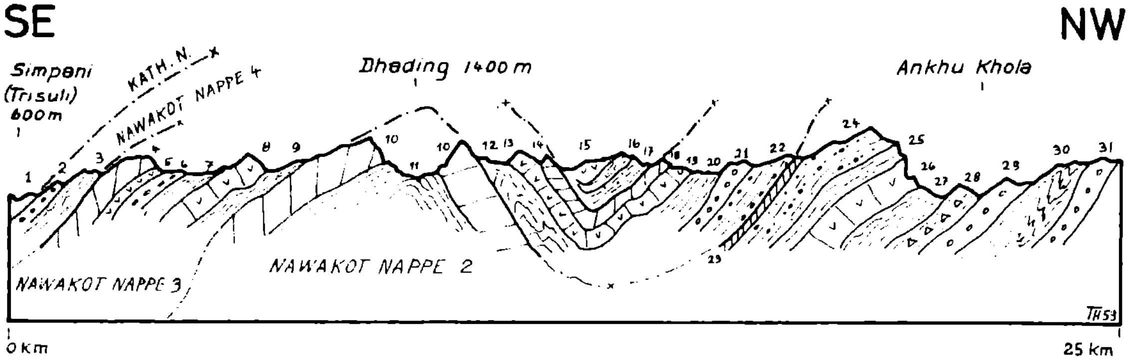



Fig. 56 Profile sketch Simpani–Dhading (central Nepal)

1 garnet micaschists of the Kathmandu nappes, 2 Rauhwacke, (cellular dolomite) with polygenetic breccias, 3 red shales and slates, 4 dolomite, 5 quartzite, white, dense, well-bedded (Triassic ?), 6 layer of conglomerate (Verrukano ?), 7 coloured (mainly light blue) slates, 8 quartzite (sand-grains visible), 9 red and light blue slates, 10 dolomite, some limestone, calcareous slates, 11 coloured dolomitic slates of Dhading, 12/13 Nawakot slates (quartzitic), 14 dolomite, coarse grained and partly fine grained, conglomeratic, 15, 16 quartzitic, banded, dolomitic, 17 fine grained conglomerate, sandstone, 18 calcareous dolomite, 19 quartzite, nodular, 20 Nawakot slates, 21 conglomerate (Verrukano), 22 conglomerates, fine and coarse grained, quartzite, 23 quartzitic dolomite (thin layer), 24 well-bedded fine grained conglomerate, sandy quartzite, 25 quartzitic sandstone, 26 sandy quartzite, 27 Nawakot slates, 28 Nawakot slates with brecciated pegmatitic intrusions, 29 conglomerates (Verrukano), 30 Nawakot slates, 31 red conglomerates and fine grained conglomerates (Verrukano).

This profile shows the overthrust of the Kathmandu nappes over various thrust sheets of the Nawakot nappes near Simpani on the Trisuli river (west of Kathmandu). The series within the Nawakot nappes shows a gradual change from the calcareous sediments to the conglomeratic type. This change indicates the domination of the older series in the north, while the upper series have been thrust furthest to the south.

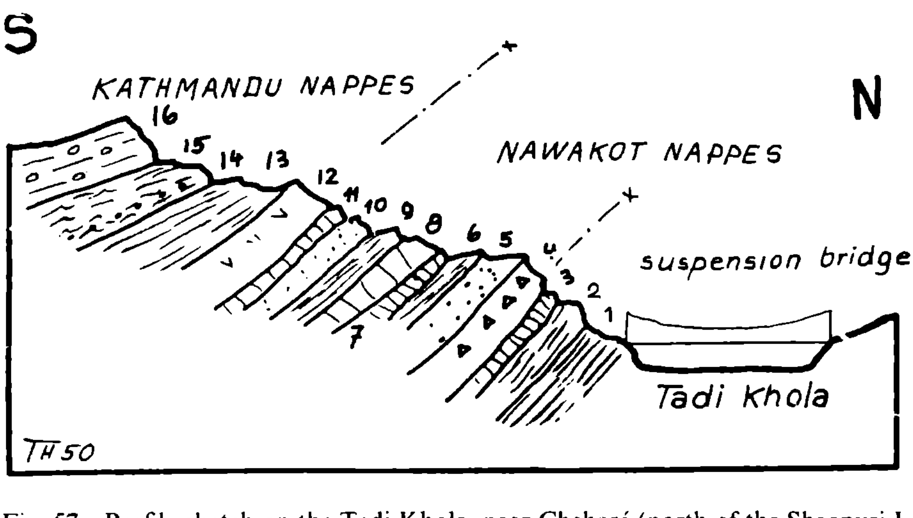



Fig. 57 Profile sketch on the Tadi Khola, near Cheharé (north of the Sheopuri Lekh)

1 graphitic phyllites, black, 2 phyllites of various colours, with lenses and veins of quartz, 3 black limestone (20 cm), 4 fine grained and conglomeratic breccia, clear quartz concretions (30 m), 5 yellow marl, 6 black phyllites, 7 well-bedded black dolomite (2 m), 8 blue limestone, non-metamorphic, well-bedded (30 cm), 9 gradual change to phyllites, well-bedded, 10 yellow chloritic-quartzitic sandstone, 11 yellowish silicious limestone, 12 micaceous quartzite, partly gneissic, extremely hard series, 13 phyllites, sericite phyllites (Daling type), weathering to red soil, 14 garnet micaschist, with muscovite (300 m), 15 micaschists, highly folded, 16 thick fine-grained biotite gneiss, paragneiss and mixed type; augengneiss.

Somewhere between 8) and 14) must be the overthrust of the Kathmandu nappes over the Nawakot nappes.

and near Runche Bhanjyang. Macroscopic examination of the Kulikhani granite shows the following contents and texture: While the granite bodies show at some places a sharp well-defined boundary with the neighbouring rock formations, "lit par lit" intrusions are also widespread. Such intrusions produced banded gneisses of many varieties and gradual changes into ophtalmites (augengneisses). The migmatites, with manyfold lateral changes and many varieties are especially common. It is not the intention in this volume to deal with petrological details, as we only mean to give a general survey, to help understanding of the following volumes which contain full descriptions of the traverses.

Regarding the less metamorphosed and non-metamorphic series overlying the crystallines, a firm base has been created by the finding of fossils on Phulchok, especially the trilobite of Silurian age. The youngest series in the Kathmandu nappes are the crystalline limestones, dolomites and quartzites of Silurian age. These are underlain by the *Chitlang series*, which consists of violet slates with thin beds of quartzites and clayey partings (named from Chitlang village on the southern flank of the Chandragiri range on the old "land route"); these are considered to belong to the basal Silurian.

Underlying the Chitlang series we find thick formations of phyllites, quartzites, boulder beds, chlorite-quartzites and graphite-phyllites. These are considered to be of Cambrian age. Their equivalent has been described by Heim and Gansser in the *Garbyang* series. The underlying series show increasing metamorphism. Sericite occurs in connection with amphibole porphyroblasts ("Knotenschiefer" and "Stäbchenschiefer"). The sericite phyllites gradually pass over to sericite schists with widespread garnets, and further to micaschists and paragneisses rich in biotite (figs. 47 and 48). The increasing metamorphism is the result of the proximity of the magmatic intrusions. Towards the top dykes, pegmatitic and aplitic layers are found in this series, here described as underlying the supposed Cambrian formations. However, the upper limit of the intrusions (migmatites, gneisses and granites) is not at a constant level through the whole zone of the Kathmandu nappes in Nepal. In general, the intrusions (gneisses and granites) increase towards the north to the roots of the nappes. Parallel to this feature, the non-metamorphic Cambrian and Silurian sediments in general decrease towards the north in the lower nappes.

The highest nappe (nr. 5) is an exception; its sedimentary cover differs considerably towards the north from that of the other nappes, since it passes over to the huge sediment zone of the Tibetan marginal synclinorium. Thus, younger sediments increase towards the north (from Devonian upwards).

Similarily as the upper limit of the granitic intrusions varies, the dykes die out towards the top at quite different levels. Normally they terminate in the Cambrian formations, but for example north of the Nilgiri range (Annapurna), the uppermost granitic dykes were found in Carboniferous series (fig. 38).

In the following pages, a few field profiles will be given of some selected areas from various sections of Nepal.

It was pointed out above, how the occurrence of the sedimentary cover differs in the direction of the cross-section (north-south). The variations in the longitudinal direction (east-west) are of no less magnitude. In eastern Nepal, near the eastern termination of the Kathmandu nappes on the Main Boundary Thrust east of Dharan, the Cambrian phyllites are best developed. The Silurian and calcareous series are missing in this area. In the Thakurji Lekh in western Nepal (fig. 58), the Silurian marmorised limestones are most fully developed, while the non-metamorphic Cambrian series is replaced by the crystallines, which reach right up to the limestones. Pegmatitic layers and dykes penetrate throughout the whole mass of the limestones (fig. 58).

In the area of Hurikot-Ila, 25 km north of the Hiunchuli (fig. 60) the Kathmandu nappe 1 contains huge masses of amphibolites, and no normal acid crystallines at all. Extremely thick and monotonous quartzites are the main sediments in this nappe (fig. 81) while the Silurian limestones are apparently also missing. The quartzite shows slight metamorphism to a very acid gneiss, containing some sericite. The hard quartzite has caused the Jagdula river to form a vast river bend to the west,

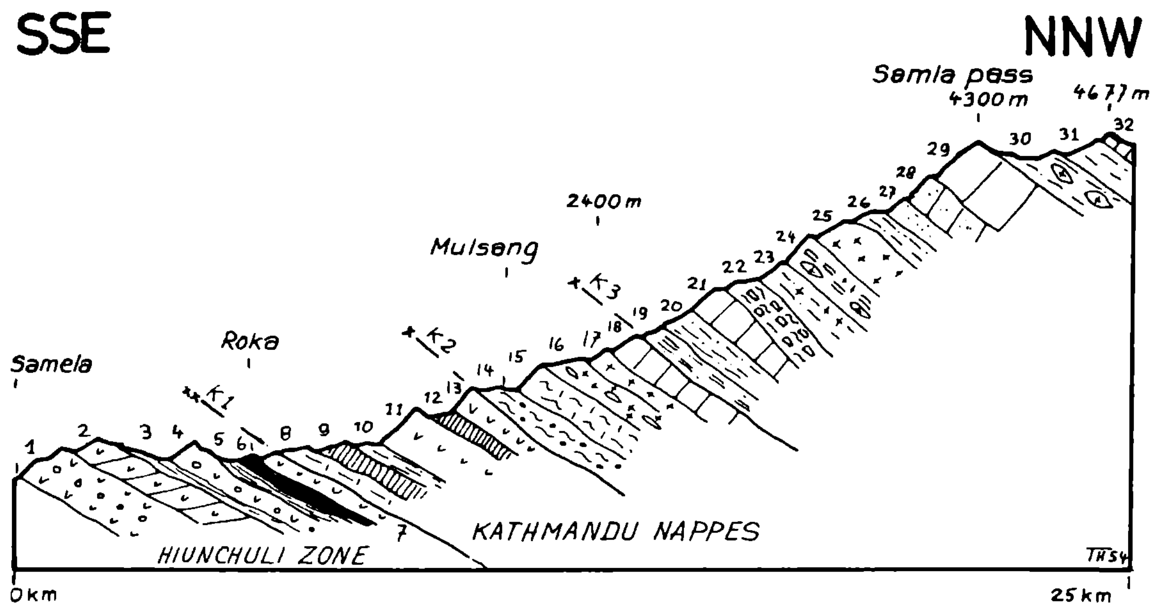



Fig. 58 Profile sketsch Samela-Samla pass
(Thakurji Lekh, western Nepal)

1 sericitic quartzite, 2 conglomerate gneiss, 3 talkschists, sercite schists, 4 conglomeratic quartzite, 5 iron shales, carbonaceous phyllites, 6 iron ore of Barikot, 7 quartzite, greenish banded, 8 hornblende gneiss, 9 gabbros and amphibolites, 10 hornblende—garnet micaschists, 11 thick quartzite, 12 layers of amphibolites and hornblende gneisses, 13 quartzite, 14 garnet—muscovite schists, 15 muscovite gneiss, 16 migmatite, with granitic layers, 17 mainly granite, 18 silicious limestone, partly coarse-grained, partly marmorized, 19 migmatites, containing granitic bodies, 20 biotite gneiss, fine grained, 21 silicious limestones and marbles, partly with garnets and muscovite, and also containing turmaline pegmatite layers, 22 kyanite micaschists (diameter of crystals 3 cm), 23 biotite gneiss, with granitic layers, 24 migmatites, with granites, 25 increasing granites, 26 biotite gneiss, fine sand-grained, 27 biotite sandstone, 28 calcareous biotite granulite, 29 limestone, sand-grained, 30 fine grained biotite—muscovite gneiss, with layers of turmaline pegmatites, 31 biotite—muscovite gneiss, with calcareous layers, 32 silicious limestone.

The series above 26) shows great similarities with the sediment formations on the back of the main roots of the Kathmandu nappes and in the Himalayan Schuppen zone. As characteristic for the back of the top roots, also here, west of the Samla pass, the topmost pegmatitic dykes are oblique to the beds; they rise toward the back (north).

around the quartzite. Incidentally this would be an extremely advantageous site for a hydroelectric plant, since the difference of fall amounts to 600 meters, in a horizontal distance of only 6 km.

The distribution of the Kathmandu nappes throughout the country is not even (fig. 17 and plate 6). When the Kathmandu nappes were called the "backbone" of the Great Himalaya Range in Nepal, it was with regard to the roots of the nappes, forming the main range of the Himalayas in the major portion of the country. When considering the overthrust parts of the Kathmandu nappes, we have to say that these nappes cover relatively small parts of the country (plate 6). In two different zones only, crystalline masses of the Kathmandu nappes are thrust from the roots towards the south. The larger area is found in eastern Nepal, between the meridians of Kathmandu and the Arun valley (fig. 17 and plate 6). The whole central area of the country lacks the thrust nappes. They occur again in western Nepal, only in the area of Jumla-Dailekh (plate 6 and fig. 34). In both of these areas, the Kathmandu nappes have been preserved from erosion in large synclines with axial depressions.

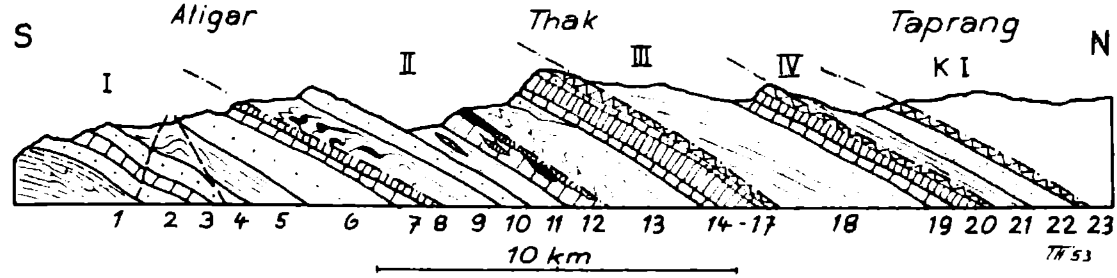



Fig. 59 Profile sketch Atigar–Taprang
(10 km north of Pokhara, central Nepal)

1 Nawakot slates and phyllites, with quartz veins and lenses (of probably pegmatitic origin), 2 conglomerate, (diameter of components 1,5 cm), coarse sandstone at the top, 3 white quartzite, containing pegmatite layers with idiomorph hornblende crystals up to 4 mm; tectonized, 4 conglomerates and sandstones, 5 quartzites and "Tüpfelschiefer", with layers of pegmatites, partly mylonitic, 6 sandstone, soft and sericitic (below), with fine grained conglomerates and sandstones (top), 7 white quartzite, stratified, dense, greenish and reddish laminated (top), 8 dolomite, partly sliced and squeezed, 9 Nawakot slates and phyllites, containing pegmatite breccias, 10 quartzitic sandstone with biotite, 11 sericite phyllite with layers and lenses of turmaline pegmatite, 12 light coloured quartzite, well bedded, at the top slices of calcareous breccias and granites ("calcgranites"), 13 sericite phyllite, with layers of conglomerates, 14 quartzite, 15 dolomite, partly quartzitic, 16 "Rauhwacke", 17 stratified sand-grained limestone with calcbreccias, 18 black shales with abundant quartz veins and lenses, sericite phyllites with "Tüpfelschiefer" at the top, 19 quartzite, 20 dolomite with sand-grained limestone and calcbreccias, 21 sericite phyllites, 22 biotite granulite, 23 stratified limestones and calcbreccias.

I = Nawakot nappe 1; II = Nawakot nappe 2; III = Nawakot nappe 3; IV = Nawakot nappe 4; K I = Kathmandu nappe 1.

This section represents the roots of the Nawakot nappes in central Nepal. The rocks are considered to be of Palaeozoic to Triassic age.

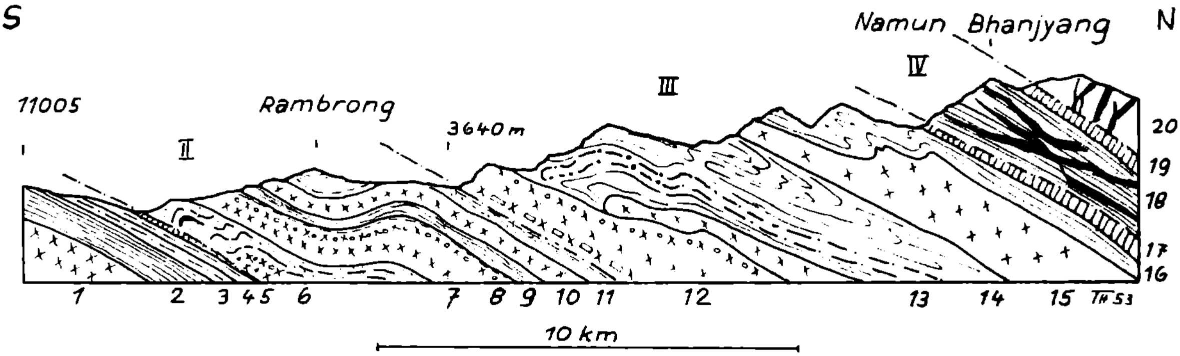



Fig. 60 The root zone of the Kathmandu nappes between Rambrong and Namun Bhanjyang
(southern flank of Annapurna, 12 km northeast of Pokhara, central Nepal)

1 granite, 2 gneiss, 3 garnet micaschists, 4 micaschists, partly sand-grained, 5 sand-grained limestone, 6 sandstone and granulite, with migmatitic layers, biotite at the top, 7 muscovite granite, porphyric-migmatitic, 8 granite with garnets, 9 sand-grained gneiss, 10 granite, partly porphyric, partly granite gneiss, 11 granulite, rich in biotite and muscovite, 12 granite, coarse grained, plenty of kyanite (idiomorphic crystals up to 10 cm length); in the upper part idiomorph garnet crystals up to 1,5 cm diameter, further porphyric-migmatitic granite gneiss, 13 gneiss, stratified, with migmatitic layers, augengneiss, 14 laminated gneiss, 15 mainly granitic intrusions, 16 stratified gneiss, with migmatitic layers, 17 sand-grained limestone, tectonized and sliced, 18 stratified gneiss with migmatitic layers; layers and lenses of granites and turmaline pegmatites, partly oblique to the beds, in the top part granite taking approx. half of the rocks, 19 limestone, sand-grained, partly migmatitic interbedded, 20 laminated gneiss, with dykes up to several meters thickness.

II = Kathmandu nappe 2; III = Kathmandu nappe 3; IV = Kathmandu nappe 4.

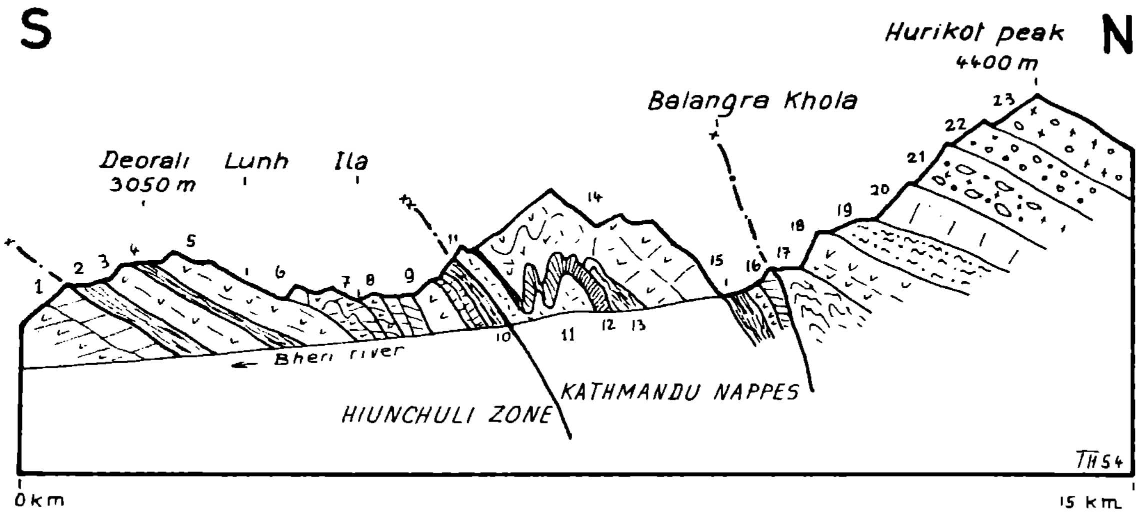



Fig. 61 Profile sketch in the Bheri valley from Lunh to Kai pass

1 quartzitic and calcareous dolomite, 2 shales, dark blue, 3 quartzitic gneiss, 4 dark shales, 5 mainly quartzite, interbedded with shales, 6 thick quartzitic dolomite, interbedded with sericitic quartzite and small layers of shales, 7 white dolomite, 8 quartzitic dolomite, dolomitic quartzite ("pseudo dolomite"), calcareous dolomite, with layers of pure dolomite, 9 quartzite, with small calcareous layers, 10 dark slates, interbedded in the quartzite, 11 hornblende gneiss, 12 hornblende rocks, gabbro, layers of amphibolites, 13 schistose sericite quartzite, 14 thick white quartzite (2000 m), same type as near Tarakot (Kathmandu nappes) interbedded with chlorite-sericite quartzite, 15 sericite phylliltes, graphite phyllites, 16 quartzite and dolomite, 17 black carbonaceous phyllites, interbedded with quartz veins, 18 white quartzite, laminated, partly "fluidal" character, typical for the base of the Kathmandu nappes, 19 muscovite-biotite schists, 20 granulitic biotite gneiss, 21 porphyric orthogneiss, augengneiss, partly granitic, with garnets and kyanite, 22 augengneiss with garnets, 23 porphyric orthogneiss, partly granitic.

Probably, the Kathmandu nappes formerly also existed between the sections of Kathmandu and Dhaulagiri, but have since been eroded. The same situation appears to exist in western Nepal, west of the meridian of Saipal (fig. 35). Further west, beyond Nepal, the overthrust masses occur again in the form of the "Garhwal nappes" of J. B. Auden or the "Almora Thrust" of Heim and Gansser. The synclinal structure, in which the "Almora Thrust" is lying, continues towards the east into Nepal as the Baitadi syncline (plate 6 and fig. 35). This syncline shows an axial rise towards the east, and the overthrust crystalline masses have been eroded in the upper and eastern part of this syncline.

In eastern Nepal, between the Kathmandu section and the Arun, the *underlying Nawakot nappes* occur in the huge *tectonic window of Okhaldunga* (figs. 17, 30 and plate 6). This window measures 160 km in the east-west direction and is 60 km across and is probably one of the largest tectonic windows of the world.

In the western overthrust zone there is a further tectonic window in *the zone of Galwa.* Triassic formations occur in the top of this doubled window. They belong to the facies of the Bajang nappes, which are found further southwest (plate 6 and fig. 34). The Triassic series of the Galwa window has to be considered as parautochthonous; there is apparently a normal succession from Devonian dolomite, Carboniferous shales and quartzites, Permian quartzites and phyllites to Triassic quartzites and dolomites. However, the topmost repetitions seem to correspond to tectonic slices. It is in general the same sedimentary cover which was found further south on the Dandeldhura massif (plate 6 and fig. 73; tectonic profile 86). Some dolomites at the top are doubled, thus indicating the eastern termination of the Bajang nappes.

East of the Arun river valley, after a turn far to north, round the pitching Arun anticline, the Kathmandu nappes change their strike towards the southeast and south. They end under a considerable angular unconformity on the Main Boundary Thrust 20 km east of Dharan (see plate 6 and fig. 24).

The number of the particular nappe sheets within the group of the Kathmandu nappes totals 5. However, not all five nappes are developed through the whole length of the country. The Kathmandu nappe 5 especially continues in some areas gradually into the crystalline base of the Tibetan Marginal Synclinorium and the Tibetan zone.

In the most westerly part of the country, the Kathmandu nappes 4 and 5 form various Schuppen only, which die out towards the Saipal group. The respective Schuppen begin again however transposed to the north, in the Thak Himal (fig. 36 and plate 6) and end in the Kanjiroba group. They then occur once more in the Dhaulagiri group and develop to the greatest thickness in the Manaslu group. Towards the east, they are identical with the Khumbu nappe 1, which name is applied east of the Trisuli Valley (plate 6, figs. 44 and 98).

The Kathmandu nappe nr. 4 is developed in the west only. It ends in the Gauri Sankar group. Further the Kathmandu nappe 4 seems to be overthrust in the section of Kathmandu only (figs. 44 and 98, tectonic profile 30). In western Nepal, in the overthrust area of Jumla-Dailekh, only the Kathmandu nappes 1–4 are present.

Some most interesting features in the roots of the Kathmandu nappes will be described later on.

### *8) The Nawakot nappes*

This nappe group has been named after the little town Nawakot in the Trisuli valley, 30 km northwest of Kathmandu.

The nappe character of the formations concerned was not so clear from the beginning of the author's field investigations, since nowhere were entirely different series found underlying the Nawakot series, on which the latter were overthrust, as had been the case with the overlying Kathmandu nappes. On the other hand, the Nawakot series in central Nepal produced fewer difficulties in their stratigraphic interpretation, since mainly Permo-Carboniferous and Triassic rocks were found in the areas investigated first. Correlations with the Krol series of J. B. Auden were evident right from the beginning. Repetitions in those rocks rendered it certain, that the Nawakot series formed a group of nappes piled and thrust one upon the other. The boundaries between the single sheets all showed features of tectonic contact with the usual disturbances, like disharmonic foldcontacts and thrustplanes.

During the author's first flight over central Nepal in 1950, a large tectonic window was recognized in the area of Pokhara (Lit b, 1952). In a dome-like shape, lower series seem to occur below the overlying formations dipping out from the dome in all directions. Thus the idea of a tectonic window of Pokhara was already established in 1950. However field investigations proved later on that the series of the Pokhara zone do not differ very much from those of the overlying (and overthrust) Nawakot nappes.

The idea of the *Pokhara zone* being autochthonous or at least parautochthonous arose when numerous considerable transverse structures were found in that anticline. None of these continue up to and into the Nawakot nappes; they are entirely different from the main strike and respective structures in the overlying nappes.

However, the rock formations of the Nawakot nappes soon proved to be far less uniform than those of the Kathmandu nappes as was expected at the beginning. The Krol type occurs only in central and southern Nepal. Towards the north in the roots as well as to the east, the rocks change entirely; the Permo-Carboniferous and Triassic formations are underlain and partly even replaced by undoubtedly older rocks, which show great similarity to the overlying Kathmandu nappes. Most probably,

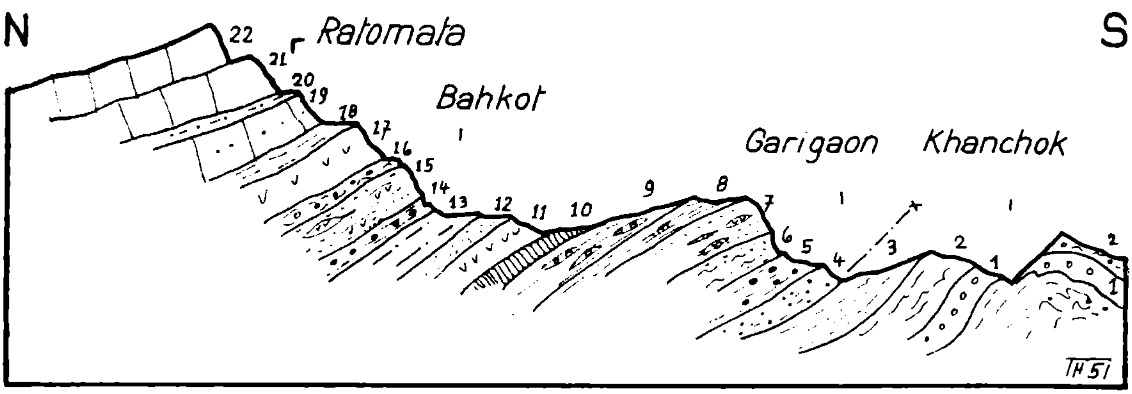



Fig. 62 Profile sketch Khanchok–Ratomata
(8 km northeast of Gurkha, central Nepal)

1 conglomerates, interbedded with phyllites (diameter 4 mm), 2 fine grained conglomerates with phyllites, 3 chlorite phyllites, 4 biotite-sericite granulite, 5 garnet phyllites, 6 schistose granulite, quartz grains up to 2 mm diameter, 7 granulite with quartz veins (up to 30 cm diameter), 8 phyllites, carbonaceous, black and white laminated, 9 schistose phyllites, with layers of migmatites, 10 basic intrusiva, amphibolites, 11 quartzite, white, sugar-grained, well bedded, 12 light blue sandstone and granulites, 13 transition to granulite and biotite gneiss, 14 gneiss with garnets, quartz veins and pegmatitic intrusions, copper ore, 15 schistose granulites, interbedded with small layers of white quartzites and phyllites, copper mine, 16 schistose conglomerates (diameter 5 mm), 17 quartzite, white, fine grained, 18 light blue slates, 19 white calcareous biotite quartzite sandstone, 20 granulite, 21 reddish sand-grained limestone, 22 crystalline limestone with crinoid breccias.

This section shows the root zone of the Nawakot nappes. The rocks are similar to those of the Kathmandu nappes and may be considered as Paleozoic. The front parts of the same nappes (fig. 116) are undoubtedly of lower Mesozoic age (corresponding to the Krol series). It appears, that the younger formations only have been thrust to the south, while the underlying older rocks within the nappes have remained back in the root zone.—This feature of bed-wise thrusting (Gleitbrett-Tektonik) is well known in the Alps too, where for example in the Helvetic nappes the Permian Verrukano formations have remained close to the root zone, while the overlying Jurassic and Cretacious rocks have traveled far to the north, right to the front parts of the nappes (fig. 116).

they are of the same age as the Kathmandu series, namely Palaeozoic and pre-Palaeozoic. They also contain in those areas large masses of crystalline rocks, ophtalmites and migmatites, as well as amphibolites.

It is thus not possible to give a general description of the Nawakot nappes covering the whole country, with regard to their rock formations. The latter vary considerably in the strike directions as well as across the strike.

Of all the nappe groups in Nepal, the Nawakot nappes form the second longest east-west extension, namely 550 km from the upper course of the Uttar Ganga river in western Nepal to a few kilometers beyond the Arun river, near Dumlingtar. The greatest single occurrence is found in central Nepal, where they cover the whole area from the root zone at the southern flank of the Great Himalaya, right down to the Main Boundary Thrust onto the Siwaliks. In eastern Nepal, the Nawakot nappes occur in the tectonic windows of Okhaldhunga and of Dumlingtar (plate 6 and fig. 24).

With a surprising steadiness, the front of the Nawakot nappes strikes through in a narrow belt between the Kathmandu nappes and the Main Boundary Thrust (plate 6). The front parts of the Nawakot nappes show a clear Krol type development, since only Carboniferous, Permian and Triassic rocks are represented.

The structure of the Nawakot nappes as a whole is different from that of the Kathmandu nappes. The Nawakot nappes show extensive fold structure, compared with the mass-like, rigid picture of the

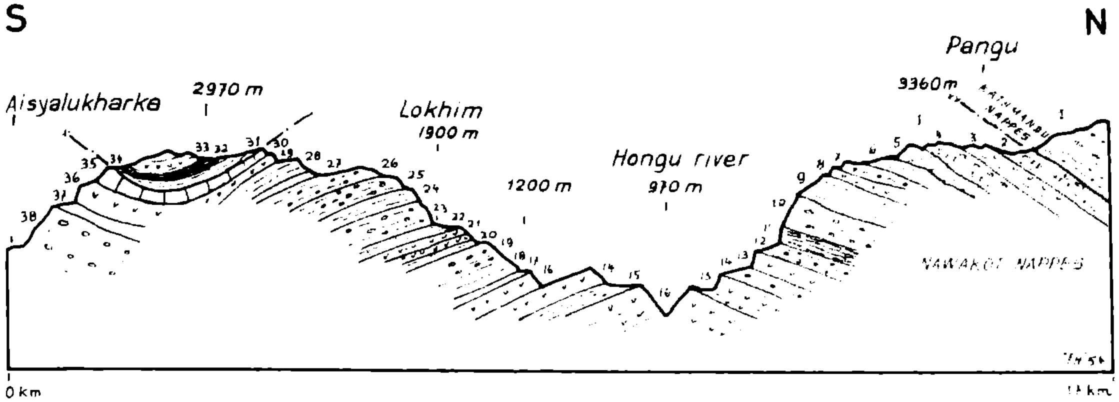



Fig. 63 Profile sketch through the roots of the Nawakot nappes between Pangu and Asyalukharka
(22 km northeast of Okhaldhunga, eastern Nepal)

1 garnet micaschists and gneisses of the Kathmandu nappes, 2 talkschists with dolomite and limestone slices, 3 schists, interbedded with paragneisses and quartzites, 4 nodular talkschists, with layers of chlorite schists, slices of dolomite and limestone, 5 dolomite, tectonized, 6 non metamorphic shales, blue shales, 7 garnet micaschists (diameter 1 cm), hornblende Garbenschiefer, 8 dense quartzite, 9 well bedded sericite biotite gneiss, interbedded with micaschists, 10 thick augengneiss, migmatites, interbedded with Nawakot shales with garnets, 11 talkschists, chlorite schists, 12 slates with garnets and sericite, 13 chlorite quartzite (Ramche type), 14 slates, phyllites, chlorite sericite phyllites, "Tüpfelschiefer," few garnets, 15 stratified chlorite quartzite (Ramche type), quartz veins, transition into gneiss, 16 sericite chlorite quartzite, 17 sericite phyllites, 18 gneiss, 19 augengneiss, 20 sericitic slates, 21 quartzite, partly gneissic, 22 sericite chlorite phyllites, 23 augengneiss, 24 well bedded paragneiss, 25 augengneiss, 26 slates with garnets, 27 blue shales, slightly sericitic, decrease of metamorphism, 28 well bedded paragneiss, 29 dense white quartzite, 30 slice of dolomitic limestone, 31 chlorite sericite phyllites, 32 graphitic phyllites, 33 series of slates and shales, with small quartzite beds, 34 carbonaceous shales, deep red quartzites and shales, 35 limestone and dolomite (100 m) soft, mylonitic, 36 quartzite, dense, white, 37 sericitic slates, clear coloured, light blue, partly sand-grained, 38 augengneiss.

Kathmandu nappes. The folds within the Nawakot nappes are especially well developed (fig. 56) in their central Nepal area. The structures in their front parts recall the folds of the front of the Helvetic nappes in the Swiss Alps (Säntis) to a surprising extent (figs. 119 and 120).

In the Midlands too, the Nawakot nappes show many folds, especially where they consist of dominantly Mesozoic calcareous formations.

When crossing the Midlands from south to north, the decrease of the calcareous formations within the Nawakot nappes is surprising. In the section of Gurkha for example (fig. 62) there are no dolomites or limestones north of Mankamna. Gradually, large areas are covered by phyllites and conglomerates. East of Gurkha, slight metamorphism begins with sericite and porphyroblasts ("Stäbchenschiefer", "Knotenschiefer"); further north, garnet appears and finally biotite (fig. 62). Finally, last quartz veins and pegmatitic layers in paragneisses indicate that the crystalline intrusives are not far from here. In the section mentioned however, crystallines were not found, but granite occurs only a few kilometers further northwest near Khuncha Bhanjyang. The thick limestones are undoubtedly of Silurian-Devonian age, and can be compared with the Phulchok series south of Kathmandu.

When considering the whole cross-section, from the front of the nappes to their roots north of Gurkha, it is evident, that the youngest series have been overthrust farthest to the south, namely right to the front, while in the back zones the older series (Palaeozoic) remained. We have thus a sheet-wise thrusting, within the boundaries of the different beds. This feature is well known in the Alps too, in the Helvetic nappes. In the Helvetic nappes of the Glaris district for example, the Cretaceous formations have been thrust right to the front of the nappes in the Säntis range. The Jurassic portions end in the

Churfirsten range, while near the roots in the back zones and in the roots, the "Verrukano" (Permian boulderbeds) plays the main role in the Helvetic nappes.

In eastern Nepal, in the tectonic window of Okhaldhunga, the Nawakot nappes show entirely different characters (fig. 63). They build the Midland anticline with the exaggerated northern flank and the tectonically reduced southern flank. Huge masses of quartzites of the Kathmandu Cambrian type cover large areas. A thick series of augengneiss indicates metamorphism due to near igneous rocks. The presence of Triassic formations is doubtful within this section.

Further west, north of Pokhara, the profile of the roots of the Nawakot nappes is again different (fig. 60, Thak). Apparently Mesozoic sediments as well as much older formations are represented. Granite occurs too, and has caused slight metamorphism with sericite and garnets. Amphibolites occur a few kilometers further west, in the Seti valley, and in the Modi valley, on the trail to the Ulleri pass on the main route to Thakkhola.

Unsolved geological problems were found in the western termination of the Nawakot nappes, west of the Kali Gandaki river (fig. 17 and plate 6). In the Tarakhola valley, thick masses of a reddish dolomite and limestones, with violet and dark red shales occur. Their thickness increases towards the west, while at the same time the formations of the Nawakot nappes decrease. It was later on found, that the reddish series belong to the Piuthan series, which is considered to be—at least partially—of upper Mesozoic (probably Cretaceous) - Eocene age. Further repeated field investigations proved that the Piuthan series lie in the form of wedges directed from the west into the joints and thrustplanes of the Nawakot nappes. The Piuthan zone thus has to be considered from the tectonic standpoint as a lateral continuation of the Nawakot nappes, with the restriction, that crustal movements were too weak to form thrust nappes; they produced Schuppen only.

In the west, the Nawakot nappes terminate on the Main Boundary Thrust with a considerable angular discordance (plate 6 and fig. 92). The eastern end of the Nawakot nappes on the Siwaliks, near Dharan is also an angular discordance (fig. 90).

The roots of the Nawakot nappes are formed without exception within the southern flank of the Great Himalaya Range. Nowhere do the Nawakot roots build high mountains; their contribution to mountain building can thus not be compared with that one of the Kathmandu nappes.

There are some areas, in which the roots of the Nawakot nappes extend to the north between the main mountain groups, as far as the main range. This is caused by the transverse structures in the valleys, round which the Nawakot roots are bent towards the north (plate 6).

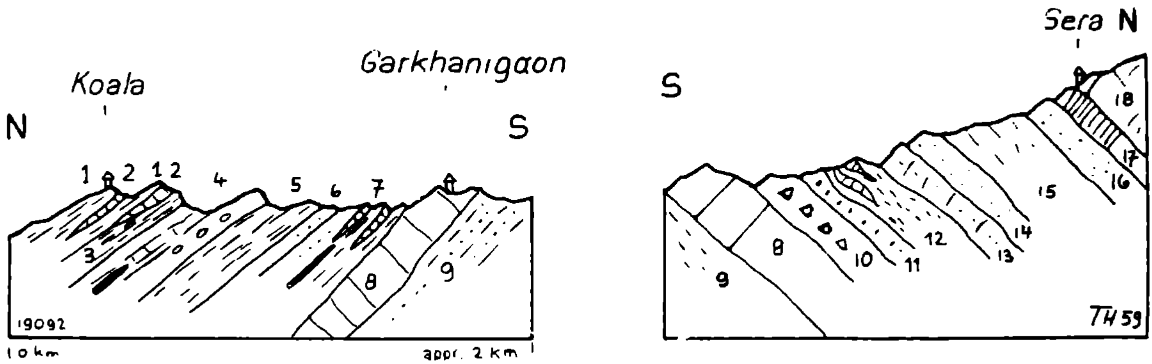
From the standpoint of facies, the Bajang nappes in western Nepal have to be considered as equivalent to the Nawakot nappes.

In conclusion, there remain many problems in the geology of the Nawakot nappes. Much further field investigation is necessary, since they seem to be much more complicated than the Kathmandu nappes in every respect. The separation by the author of 4 single nappes within the Nawakot nappe group, was due to the fact that the investigations started in the area with the simplest structure and the clearest lithological and stratigraphic conditions. In eastern Nepal it was possible to separate the Nawakot nappes from the Kathmandu nappes only by using knowledge of the geology in central Nepal. Otherwise in certain areas it would be extremely difficult to see clear differences between the two nappe groups. This is the reason, why A. Lombard has considered in the Okhaldhungha section parts of the Kathmandu nappes to be Nawakot nappes and vice versa (compare figs. 19 and 20). Also P. Bordet found difficulties in the Arun valley regarding the classification of the Kathmandu nappes and the Nawakot nappes (see fig. 15).

*9) The Piuthan zone*

The Piuthan zone joins the Nawakot nappes west of the Kali Gandaki valley (fig. 17 and plate 6); it really develops laterally from the Nawakot nappes. The Piuthan zone is exposed in two belts (fig. 67), namely in the Bheri anticline in the Midlands, and in the southern part along the Main Boundary Thrust. The latter belt is about 40 km wide in the Piuthan section, becoming narrower in the west. West of the Bheri River the Piuthan zone belt is only about 3–4 km wide and it ends west of the Karnali, where the river enters the Siwaliks. The two main areas of the Piuthan zone are connected with each other by a narrow belt in the Bari Gad valley (plate 6). Sub-surface, the Piuthan zone apparently covers a much wider area, and the two exposures of the Bheri anticline and the southern belt along the Main Boundary Thrust are certainly connected underneath the overthrust Jajarkot and Hiunchuli nappes; they belong to one and the same zone. The Jajarkot nappes and the Hiunchuli nappes are thrust over the Piuthan zone; they consist of quite different formations and remain protected from erosion in the Jaljala syncline.

Lithologically, the two belts of the Piuthan zone are identical. They include thick masses of reddish dolomite, limestone, quartzitic dolomite, black and deep red shales, quartzites and in some areas iron ore; boulderbeds with components up to 20 cm diameter occur at several places. Finally, nummulitic limestones were found at several places; firstly north of the Dang area by geologists of the Geological Survey of India, and later by the author at neighboured places near the Main Boundary Thrust. Near Dhading, nummulitic limestone occurs far into the interior of the Midlands. Stratigraphically, much work has still to be done, but it seems to be beyond doubt, that the main portion of the Piuthan formations is of Upper Mesozoic-Eocene age. The reddish limestones and dolomites recall surprisingly the Neocomian series in the Swiss Alps (lower Cretaceous). However, there are very thick formations in the Piuthan zone, which correspond to the Nawakot nappes and to the Krol series.




Figs. 64 and 65 Profile sketch Koala–Seragaon
(upper Bheri—Uttar Ganga valley)

1 series of blue, black and violet shales, 2 dolomite slices, 3 green schists, 4 gneiss, quartzitic-greenschists, pegmatites, layers of ophtalmites, 5 violet slates, mixed with green slates, 6 sand-grained quartzites with ripple marks, 7 clear and green sand-grained quartzites, with quartz veins, containing reddish-banded pegmatitic intrusions and slices of dolomite, quartzite-dolomite and reddish dolomite, 8 dolomite, with quartzitic layers, 9 violet and green fine slates, clear and wine-red fine grain conglomerates, 10 conglomerates with layers of iron ore, coarse grain, 11 conglomerates, deep red and blue, 12 violet slates with iron ore, slices of dolomite, 13 clear quartzitic sandstones, with inclusions of violet shales, 14 green sandstone, gradually from (13), with salt (on surface), 15 repetition of (11)–(14), 16 brownish-greenish sand-grained quartzites, similar to those of the Thakkhola series, several layers of iron ore, 17 hematite ore deposit of Seragaon, 18 dolomite, well-bedded, layers of quartzite, dolomite with calcareous nummulitic layers, with layers of very high grade hematite, and fine-grained conglomerates, dolomite itself reddish-banded, with subaquatic sliding, dolomite conglomerates (monomikt) similar to those of the Nigalchula. The whole series recalls the Neocomian rocks of the Mythen in the Alps.

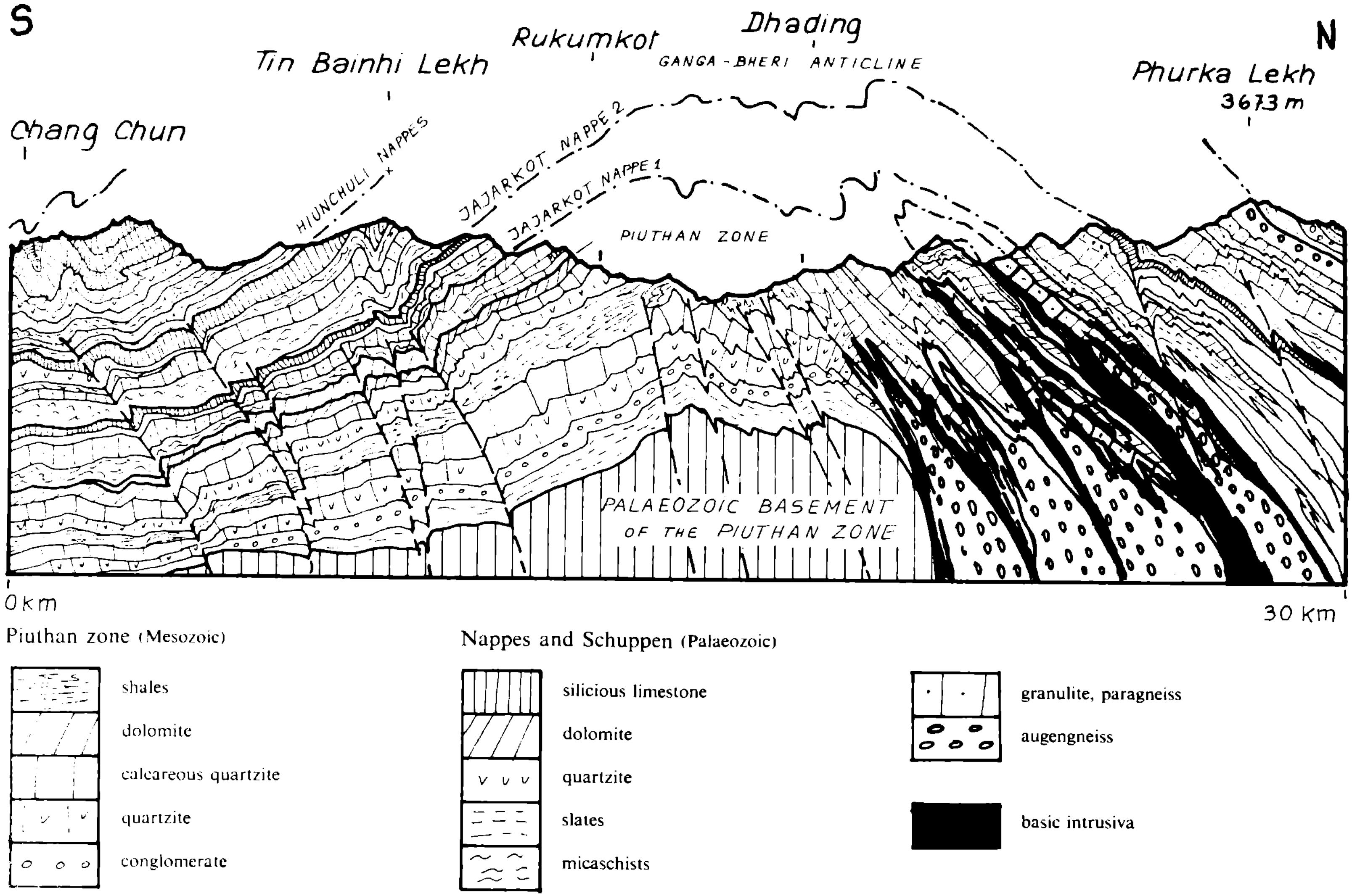



Fig. 66 Profile sketch of the Piuthan zone in the Bheri anticline
(Jajarkot district, western Nepal)

The Piuthan zone is exposed in the tectonic semi-window of the Bheri anticline. At the northern flank of the Bheri anticline, the Mesozoic Piuthan formations are heavily sliced and tectonized. In the roots of the various Schuppen, Palaeozoic formations occur. The Palaeozoic basement may be compared with the Simla slates in Garhwal, while the overlying Piuthan series also contain nummulitic limestones in some places.

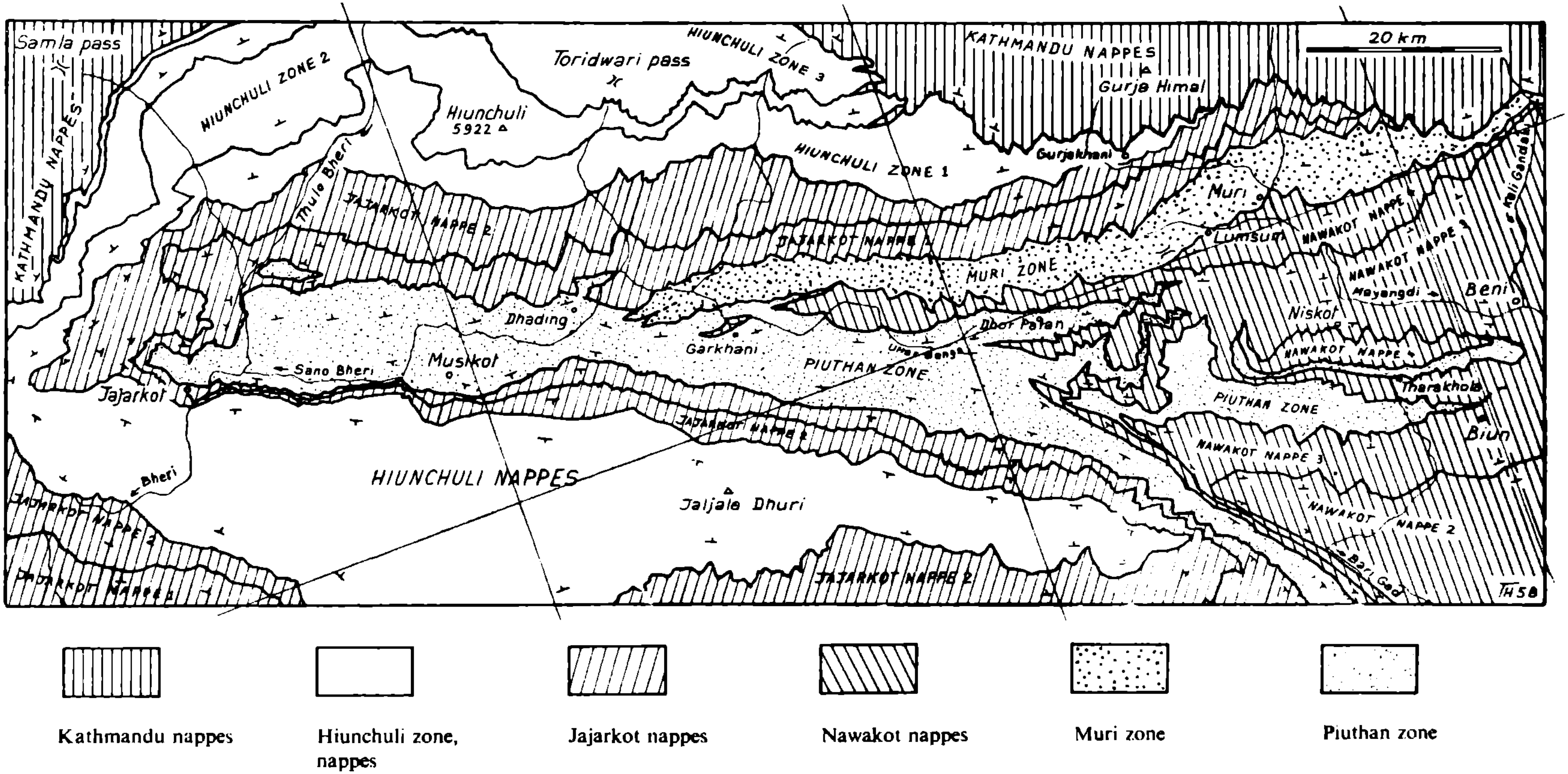



Fig. 67 Tectonic sketch map Bheri valley–Dhor Patan
(western Nepal)

The map shows the pitching of the Bari Gad—Bheri anticline towards west underneath the overthrust Jajarkot and Hiunchuli nappes. In the said anticline, the Piuthan zone is exposed. The underlying Nawakot nappes, and the Muri zone send lateral wedges from the east into the Piuthan zone. (Compare fig. 66.)

In structure, the Bheri area differs from the southern area. In the Bheri anticline, the overlying Jajarkot and Hiunchuli nappes have been eroded (fig. 66), and the calcareous series form the cover of the anticline, which is sliced, especially on the northern flank. There is no normal succession from the Piuthan dolomites and limestones downwards, but with intermediate iron ore layers, they undoubtedly repose at some places on much older formations. This basal series consists of slates, quartzites, gneisses, greenschists and amphibolites. When we compare these underlying formations, we may conclude that they are at least of Palaeozoic age, most probably Cambrian. Anyhow, they are much older than the Piuthan series and the latter have transgressed onto them. Fig. 66 gives the profile sketch taken near Takhbachi, in the Bheri anticline.

The Palaeozoic basement of the Piuthan zone has been called *Muri Zone*, after the big village Muri in the Mayangdi valley, south of Dhaulagiri. Muri has been the last village and base for some of the Dhaulagiri expeditions (see map fig. 67).

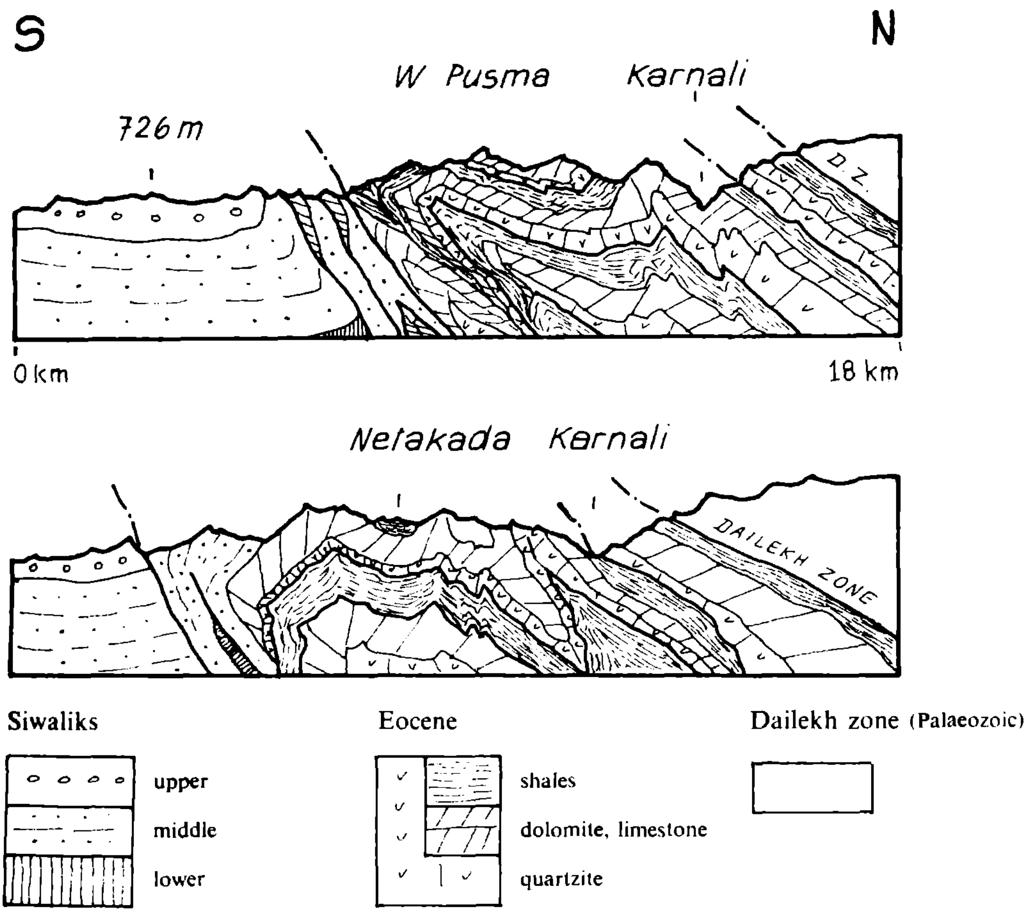



Fig. 68 Profile sketch of the Piuthan zone in the Malka Danda
(Karnali bend, Achham district, western Nepal)

The front parts of the Piuthan Schuppen show a similar structure as the Nawakot nappes in central Nepal, and thus with the front of the Helvetic nappes in the Swiss Alps (see figs. 119 and 120).

The Muri zone is generally regarded as the Palaeozoic basement of the upper Mesozoic and Tertiary Piuthan zone. However, the contact is not normal; not only has the Piuthan series transgressed onto the Muri series but the latter are greatly sliced and contorted. The Bheri anticline itself seems to be rather regular, but its northern flank has undergone considerable slicing, so that the schuppen (slices) of the Palaeozoic Muri zone have also been thrust; they are now exposed by erosion. The Piuthan formations penetrate like fingers or wedges into the Nawakot nappes and inbetween the Muri schuppen (profile sketch fig. 66).

The Muri zone extends to the east as far as the Kali Gandaki river, where it develops out of the junction between the Kathmandu nappes and the Nawakot nappes. The first indications of such new series (in passing from east to west) are found south of Annapurna.

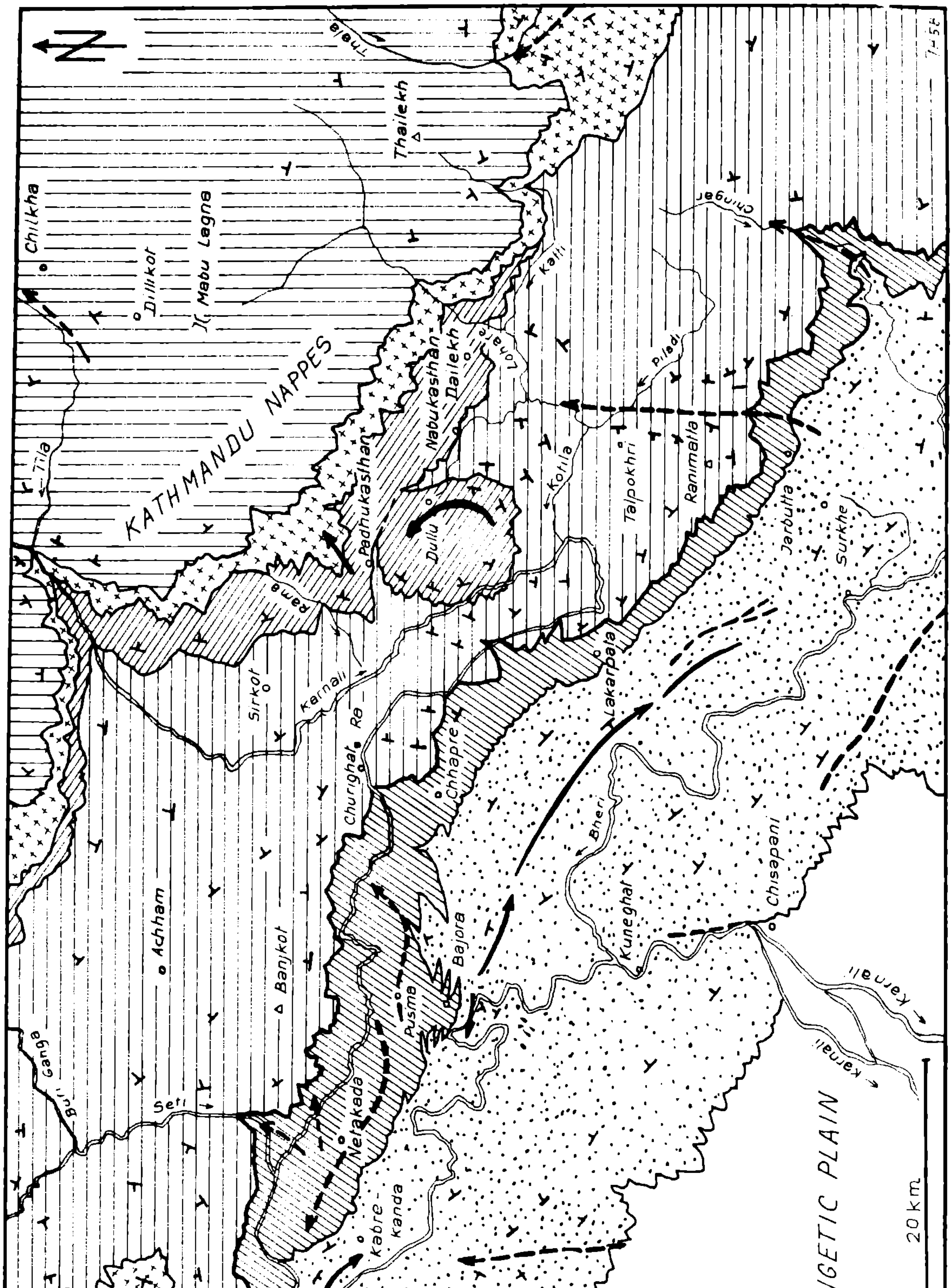
The transgression of Cretacious-Tertiary series onto Palaeozoic so far back in the Midlands might be surprising. However we have to mention that similar facts have been known for a long time from other parts of the Himalayas: Auden found the nummulitic Dagshais transgressing onto the Simla slates. The Dagshai series corresponds to our Piuthan zone, while the Simla slates are identical with the Muri zone.

The southern area of the Piuthan zone is different from the Bheri valley. There are a great number of schuppen, which are not merely thrust but also folded. In the west, where the Piuthan belt is only a few kilometers wide, the folding is especially intensive. On the Malka Danda, the great river bend of the Karnali (fig. 68), we find a structure similar to that of the front of the Nawakot nappes (fig. 119).

The area between Dailekh and Dullu-Karnali is most interesting, since there are a number of places with natural gas; the respective places are all on one structural line. Undoubtedly the natural gas originates from the Piuthan zone, though on the surface no trace of the Piuthan series can be seen. The gas has nothing to do with the Palaeozoic and sterile series of the overlying Dailekh zone, which zone we shall deal with in the next paragraph. We only want to point out that the present outcrop of the Piuthan zone on the Malka Danda and on the southern flank of the Ranimatta range does not coincide with its northern limit. There is no doubt, that the Piuthan zone continues underneath the overlying Dailekh zone far to the north, about to the line which connects Ra on the Karnali river with Dailekh (figs. 69 and 71).

We should like to make it clear, that we consider the overthrust of the Piuthan zone over the Siwaliks as the Main Boundary Thrust, and not the overthrust of the Palaeozoic formations of the Dailekh zone over the Piuthan zone. The Main Boundary Thrust in our sense is most interesting in the area of Rekcha. For the Piuthan series are overthrust over the Siwalik formations, the latter occurring further north again underneath the Piuthan series.

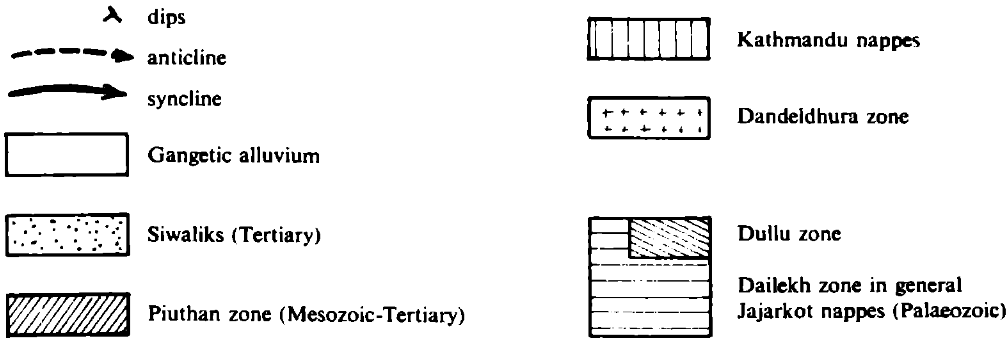
Other interesting aspects of the southern area of the Piuthan zone are the several minor transverse structures which have affected the Piuthan zone, including the overlying Dailekh zone. For example, we find anticlines with northern strike in the Chingar valley and in the Jubra valley; the latter transverse anticline extends due north as far as Dailekh. South of Dullu there is a syncline structure with northern strike and pitch. The western part of the Malka Danda (in the Karnali bend) shows a number of structures which are directed towards the eastnortheast, and which pitch with angular disconformity underneath the Palaeozoic formations. On the other hand, strike direction of the overthrust Palaeozoic series on the Dailekh zone and the Jajarkot nappes is practically nowhere parallel to the outcrop of the Piuthan zone and to the Main Boundary Thrust. We shall deal with this phenomenon in the following paragraph (fig. 93).

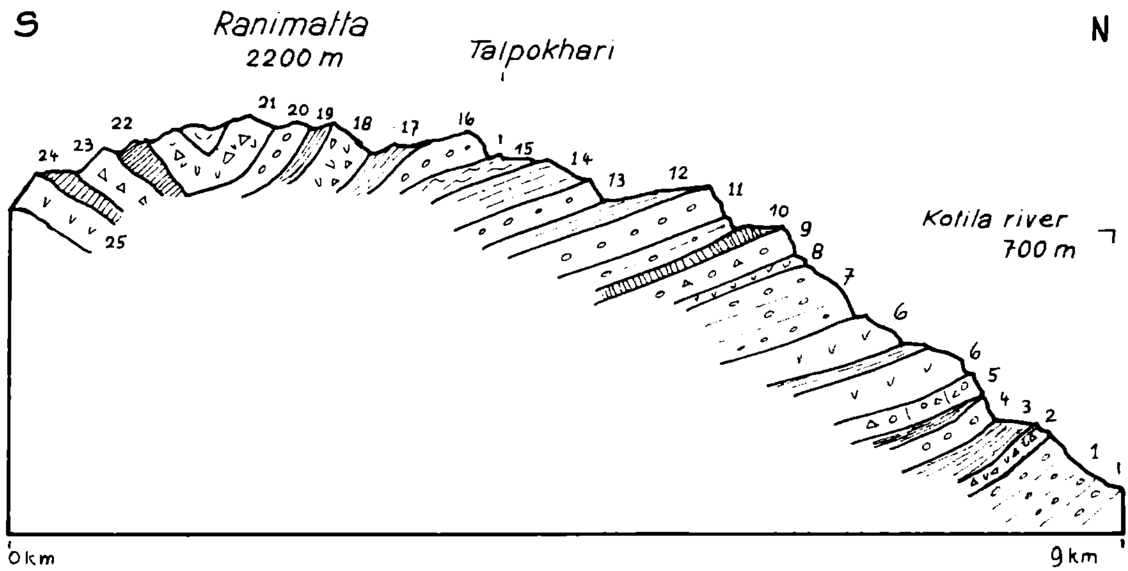


KATHMANDU NAPPES
Chilkha
Dillikot
Mabu Lagna
Thailekh
Tila
Thala
Kalli
Lohare
Nabukasthan
Dailekh
Padhukasthan
Dullu
Rama
Sirkot
Karnali
Kotila
Talpokhri
Ranimatla
Piladi
Chinger
Jarbutta
Surkhet
Lakarpata
Churighat
Chhapre
Achham
Banjkot
Budi Ganga
Seti
Bajora
Pusma
Netakada
Kabre-kanda
Bheri
Kuneghat
Chisapani
GANGETIC PLAIN
20 km

## Fig. 69 Tectonic sketch map of the Dullu-Dailekh area
(western Nepal)—opposite

This area is most interesting from various standpoints of view. The natural gas of Padhukasthan and of Nabukasthan occurs out of the Palaeozoic Dailekh series. The shortest distance to the nearest exposure of the Piuthan zone which is liable for that gas is 15 kilometers. There is no doubt, that the Mesozoic series of the Piuthan zone reach far toward the north underneath the overthrust and sliced Palaeozoic formations of the Dailekh zone. (Compare the profiles of the fig. 71).




## Fig. 70 Profile sketch Kotila Khola-Ranimatta
(Dailekh district, western Nepal)

1 augengneiss, decreasing felspars toward the top ("Baitadi gneiss"); transition toward conglomerate gneiss, 2 transition into conglomeratic quartzite, 3 graphite phyllites, talkschists, 4 augengneiss, diorite, 5 transition into conglomerate gneiss, 6 quartzite, interbedded with slates, 7 augengneiss, with layer of diorite, 8 quartzite, reddish, with sericite, 9 augengneiss (Baitadi type), 10 schists with amphibolites, 11 well bedded augengneiss, 12 green slates, with sericite, 13 augengneiss (Baitadi type), 14 banded fine-grained sericite gneiss, 15 biotite schists, 16 augengneiss, 17 chlorite schists (no sericite), 18 thick quartzite, partly conglomeratic, 19 slates, 20 augengneiss, layers of gabbrodiorite, 21 conglomeratic quartzite, 22 amphibolites, 23 quartzite, conglomerate quartzite, 24 amphibolites, 25 quartzite.

Toward south, the amphibolites and quartzites are repeated three times, and the lowest quartzite is thrust directly upon the Siwaliks near Ranimatta village (Main Boundary Thrust).—The whole series show a syncline structure, the axis of which is directed and pitching north-west. Undoubtedly, the Siwaliks, and especially the underlying upper Mesozoic formations of the Piuthan zone are reaching far toward north underneath the rocks shown in this profile, since natural gas occurs 25 km north of this locality (see tectonic map fig. 69 and profiles fig. 71).

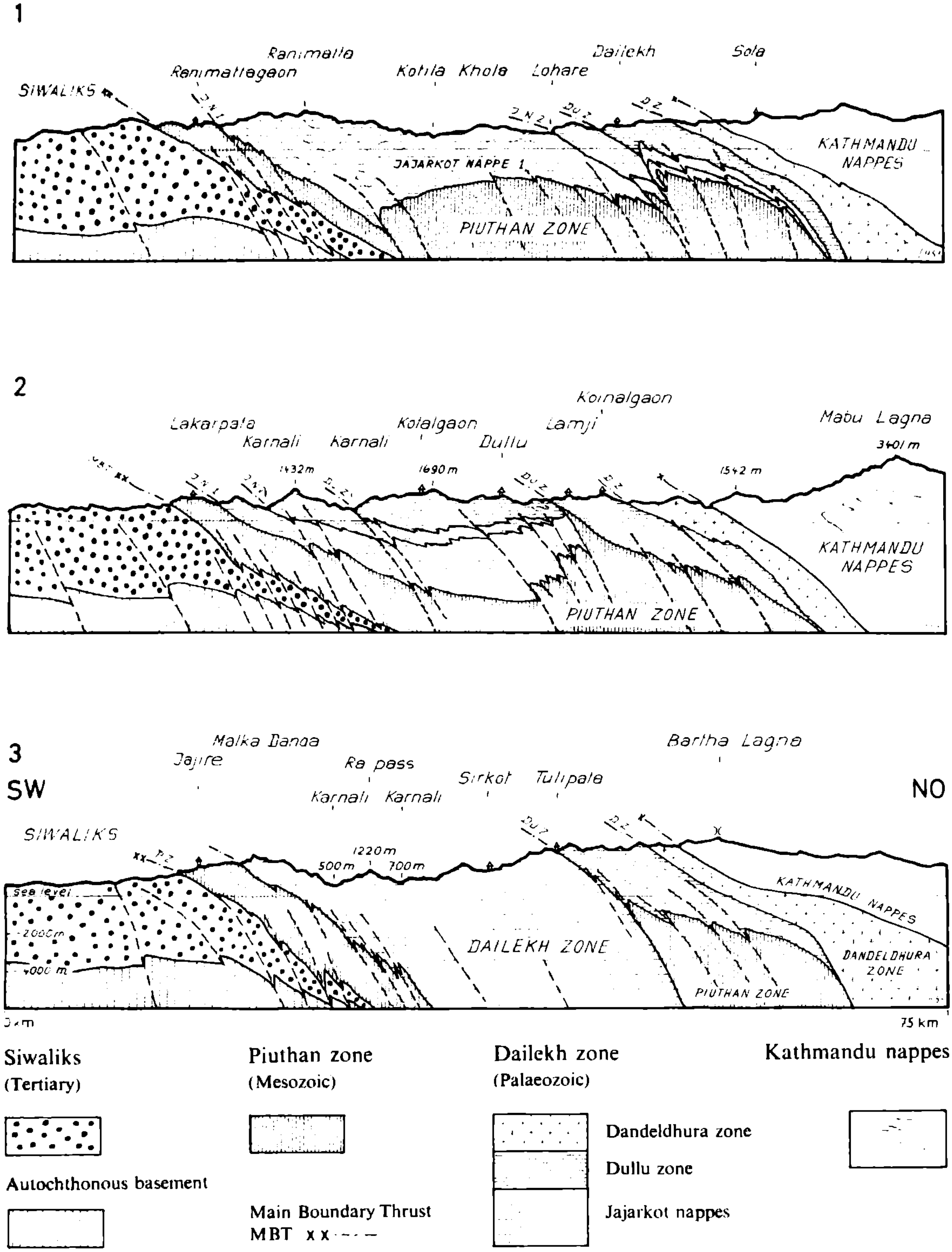



Fig. 71 Tectonic profiles of the Dullu–Dailekh area

The sections show the overthrust of the various Schuppen of the Dailekh zone over the Mesozoic Piuthan zone. The natural gas occurs in the thrust between Dullu and Lamji (section 2).

## *10) The Jajarkot nappes and the Dailekh zone*

The Jajarkot nappes overlie the Piuthan zone and they have been named after the little town Jajarkot on the Bheri river in the western Midlands. Jajarkot is a district center where a Maharaja rules.

Lithologically, the Jajarkot nappes consist of the same series as the Muri zone, namely slates, quartzites, sericiteschists, phyllites, and graphitic phyllites. They are considered to be of Cambrian and pre-Cambrian age. Their roots lie north of the Muri zone, adjacent to the Muri series. A clear separation from the underlying Muri zone is found west of Naktagaon, where wedges of the calcareous Piuthan formations dip into the junction (figs. 66, 67, 79). As with the underlying Muri zone, the roots of the base of the Jajarkot nappes are sliced (into schuppen). These die out towards the west into the Bheri anticline of the Piuthan zone. Thus the zones joining north of the Piuthan zone show a considerable angular disconformity to the strike of the Piuthan zone (fig. 67). In addition to the different strike, the structures show a considerable axial pitch towards the west. For this reason the Piuthan zone pitches north of Jajarkot finally underneath the Jajarkot nappes (plate 6).

The Jajarkot nappes are thrust in the section of Sallyana towards the south for about 60 km. The overthrust parts have been left as a large mass in the Jaljala syncline, and in altogether two large and two small outliers in the area of Sallyana (plate 6 and fig. 93). There seem to be two single sheets within the Jajarkot nappes (profile 70, plate 5).

The lower of the nappes, Jajarkot nappe 1, directly overlies the Piuthan zone along the whole length, from the Mayangdi (south of Dhaulagiri) to Jajarkot, and further round the Jaljala syncline in a vast bend towards the east, and on the southern front of the nappes to the west until its end on the great Karnali river bend (plate 6). The nappe 1 is interrupted northeast of Sallyana only where it disappears below the Jajarkot nappe nr. 2. The contact of the Piuthan zone in that area with the overthrust Jajarkot nappes is quite extraordinary: The nappe 2 has been pushed into an axial depression to the south and has thus covered the Jajarkot nappe nr. 1. The strike of the Piuthan zone as well as of the Jajarkot nappes is directed east-west, while the overthrust Jajarkot nappe 2 shows a strike of south-south-east (a few kilometers northeast of Sallyana). The southern limit of the Jajarkot nappe 1, towards the Piuthan zone, is also abnormal; it is a thrust fault, which separates the Palaeozoic Jajarkot series from the Piuthan zone, through which the northern part has sunk for about 1000 m, or equally the southern part of the Piuthan zone may have been lifted by the same amount. This thrust fault strikes through the Bheri valley, where the river leaves the Piuthan zone and enters the Siwaliks. Towards the west, the thrust fault gradually changes into an anticline. In the east, the thrust fault disappears underneath the overthrust Jajarkot nappe nr. 1.; continuation of the thrust fault (called the Sangi fault, after the Sangi river, an eastern tributary of the Bheri river) towards the east could not be recognized.

The Jajarkot nappes end in the west between Dailekh and the Karnali. Owing to transverse structures, they turn between Dailekh and Dullu abruptly to the south and join the Piuthan zone at nearly a right angle (fig. 69 tectonic sketch map of Dullu). A transverse anticline with northern pitch strikes through the Jubra valley from the Siwaliks due north as far as Dailekh. On its western flank, the series of the Jajarkot nappe 1 turn south to the Karnali (fig. 69). The Jajarkot nappes consist in this area of gneisses (ophtalmite), which are especially well developed in the Kotila valley; large sheets of amphibolites were found in the south, interbedded with thick quartzites. The detailed profile sketch of Ranimatta (fig. 70) gives an idea of the formations. The Jajarkot nappe 2 (fig. 69) decreases in the area of Dailekh and ends 2 km southwest of that town. The corresponding series appears again near Dullu (fig. 69), but with a strike due south. It strikes round the Kotal syncline to the south as far as the Piuthan zone in the Karnali and then strikes north and northwest under the newly named *Sirkot zone*. The Sirkot zone is characterized by huge masses of amphibolites, ophtalmites and thick quartzites.

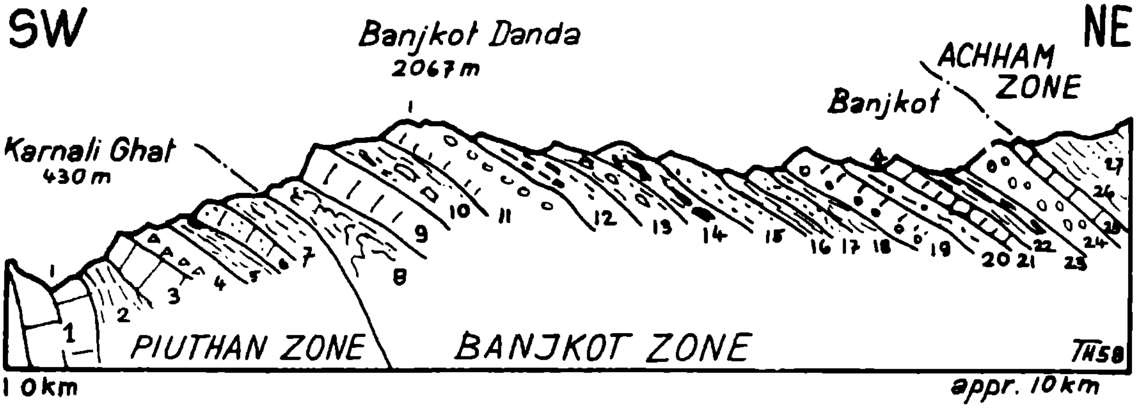



Fig. 72 Profile sketch of the Piuthan zone—Banjkot zone on the Karnali river (western Nepal)

1 pinked dolomite with slates in the joints, 2 red and green shales, 3 dolomite, white, very fine-grained, partly breccious (300 m), 4 quartzitic-breccias, 5 shales, dark green and bleach-green, 6 green, sand-grained quartzite, with quartz veins, glaucophan coloured quartzite and slates, chlorite quartzite (Ramche type), 7 green, violet and deep-red slates, radiolarite-like deep-red quartzite (Thakbachi series), 8 series of bleach-green and brick-red soft, sand-grained slates, with quartzite layers, tectonized, 9 quartzite, partly weathered to quartzitic grit ("Grus"), chlorite quartzite, 10 sericite phyllites, reddish-yellow, numerous quartz veins (dying out pegmatites), 11 quartzitic gneiss, gradually changing to ophtalmite (augengneiss), banded gneiss and mixed gneiss, 12 pinked sericite micaschists, phyllites, 13 in 12) layers of augengneiss, abundant small quartz veins and pegmatites, 14 red and green slates, some pegmatites, 15 sand-grained slates and fine-grained conglomerates, with some pegmatites, 16 sericite-chlorite schists, phyllites, 17 red sand-grained slates, 18 red and green slates, low metamorphic, 19 ophtalmite and quartzitic gneiss (500 m) (Banjkot-gneiss), 20 micaschists, sericite schists, slates, 21 quartzitic gneiss (Banjkot gneiss), 22 bleach-brownish and greenish, violet slates, slightly sand-grained, 23 slates with some layers of gneiss, pegmatites and quartz veins, 24 augengneiss (ophtalmite), 25 fine-grained banded quartzite, 26 sericite phyllite, clayey slates, 27 bleach-green and brown slates, slightly sand-grained (Chitlang slates).

The profile of the Banjkot zone is characteristic for the rocks in the whole Dailekh zone. (The Banjkot zone is one schuppe within the 5 slices of the Dailekh zone.) The sediments have to be considered dominantly of cambrian and pre-cambrian age. Silurian might be involved too, possibly in a reverse series (8 and 9).

Overlying the Sirkot zone we find a new series composed dominantly of slates and phyllites, called the *Dullu zone*. It develops out of the junction between the Jajarkot nappe 2 and the Dandeldhura zone, some kilometers east of Dailekh and increases to a considerable thickness in the area of Dullu. The Dullu zone is a northeasterly dipping slice (schuppe), which however in the syncline of Kotal has been thrust to the south. The Dullu zone has been preserved from erosion in this syncline. The connection of the overthrust masses of the Dullu zone in the Kotal syncline and the rooting slice (schuppe) in the north is disturbed by a considerable thrust fault, *the Padukasthan fault*. In this fault, natural gas occurs at various places, namely at *Padukasthan, Nabhisthan* and *Sirasthan*. These are all Holy places, and temples have been erected at the places, where the natural gas is nourishing permanent flames. There is no doubt, that the Jajarkot nappe 1, south of Dailekh (fig. 69) is really *overthrust* over the Piuthan zone, and that the latter reaches north even underneath the Jajarkot nappe 2 and the Dullu zone (see fig. 71).

The Jajarkot nappes however are the most westerly nappes in southern Nepal. From Dullu westward, no nappes were recognized. Crustal movements produced only "schuppen." A group of schuppen of similar lithological character has been summarized in *the Dailekh zone* (plate 6). The topmost schuppen of the Dailekh zone have already been mentioned as the Dullu zone and the Sirkot zone. The Dullu zone does not join the Piuthan zone (see fig. 69); the Sirkot zone does so in the great Karnali river bend. From there however, the Sirkot zone diverges from the Piuthan zone, since new, underlying (southern) schuppen develop out of the boundary north of the Piuthan zone. These are (from top to bottom) the *Muli zone*, the *Achham zone*, the *Banjkot zone*, and *the Khitkeshwar zone*. All these different zones which are similar lithologically, belong to the group of the Dailekh zone. They consist of quartzites, phyllites, graphite phyllites, slates, amphibolites, schists, mica-schists and ophtalmites. Details may be seen in the profile sketch fig. 72.

All the different series of the Dailekh zone dip north and northeast. All of them are schuppen rooting in place, which is quite extraordinary. Roots which reach right to the Main Boundary Thrust are rather rare in Nepal and even in the Himalayas in general. So far, only at one place can a similar feature be recognized, namely in eastern Nepal, where east of Dharan the Kathmandu nappes end at a wide angle on the Main Boundary Thrust (plate 6).

The various schuppen of the Dailekh zone also join the Piuthan zone near the Main Boundary Thrust at a wide angle (fig. 69). Their strike on the boundary with the Piuthan zone is directed due south; the various schuppen thus end laterally on the Piuthan zone.

There is no doubt that the extraordinary course of the Karnali river, forming two large riverbends to the east and west instead running straight south to the Siwaliks, is correlated with the position of the roots of the Dailekh schuppen. It may be concluded that these roots and schuppen have been raised rather late, after the Karnali had formed its primary course. The primary river course was probably directed due south from Porapalni, and by the late uprising of the schuppen the river was first deflected east for about 25 km. Subsequently by a still later uplift of the Piuthan zone on the Main Boundary Thrust the Karnali river was directed westward for about 60 km (plate 6).

The Dailekh zone widens from Dullu towards the north-west (see plate 6), reaching about 25 km maximum width in the section of the Seti and the Buri Ganga. The widening is caused by a very flat transverse anticline structure in the Buri Ganga and a large anticline in the Seti river, which pitches northwest in the direction to Silgarhi Doti. West of the Seti river, the Dailekh zone sharply decreases (plate 6) owing to the presence of the crystalline Dandeldhura massif. Only the Sirkot-, Banjkot-, and Khitkeshwar zones represent the Dailekh zone west of the Seti, in the form of a belt not more than 8 km wide. The Dailekh zone seems to continue westward beyond the Nepal border.

### *11) The Dandeldhura Massif*

In the first stage of fieldwork in the area of the Dandeldhura in western Nepal, the massive crystalline rocks of the Mahabharat range south of Dandeldhura were considered to be a "zone". This term does not describe the structure, which might have been a nappe or a slice (schuppe), or even an autochthonous belt.

In the neighbouring area in the west in India, there is the large crystalline mass of the "Almora thrust" with some layers south of the main mass, which were considered to be "slices" at the base of the thrust mass (A. Heim and A. Gansser). It seemed to be logical to bring the Dandeldhura crystalline into connection with these slices.

It was therefore rather surprising to find that, as more field data became available for that zone, it became more evident that these crystalline masses belonged to an *autochthonous massif*.

We may interpret the field profiles in two different ways, as has been done with the crystalline mass of the Sheopuri Lekh in the area of Kathmandu. While in the Kathmandu area the field data obliged us to adopt nappe structure, in the Dandeldhura zone, there is undoubtedly a massif. Admittedly there are certain sections, in which the crystalline mass shows a marginal fan-like shape, in which it might seem possible to consider the crystalline mass as overthrust. However, the northwestern flanks of the massif show a normal dip outwards. In addition the crystallines consist of granite, with only a marginal zone of ophtalmites, this may be seen from the profile sketch given in fig. 73.

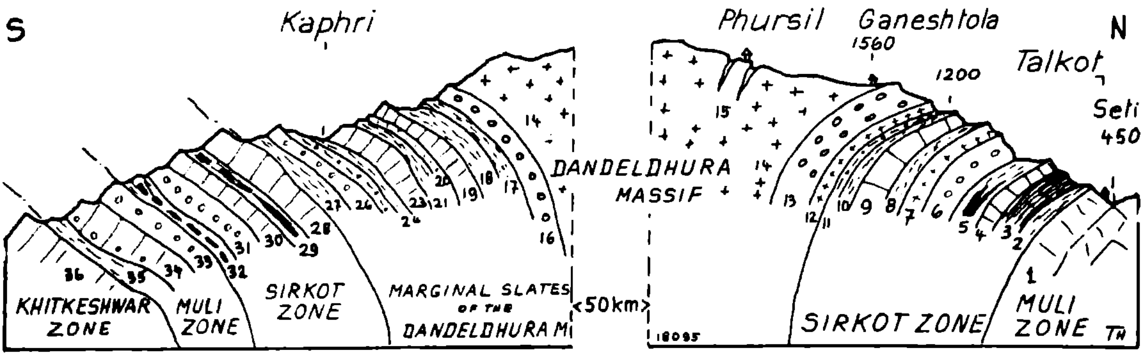



Fig. 73 Detailed profile of the Dandeldhura massif
(western Nepal)

1 thick quartzite series in the bottom of the Seti valley, 2 blue clayey sericite phyllites, 3 thick amphibolite series (300 m), with glaucophan schists and talkschists, 4 quartzite, fine-grained and conglomeratic-schistose rocks, 5 slates and schists, blue clayey phyllites, chlorite schists, with layers of 4), 6 Baitadi gneiss (ophtalmite) large felspar porphyroblasts, thick bedded, 7 granitic layers in the upper part of 6), 8 slates and schists as 5), 9 quartzite, well-bedded, platey, 10 sericite phyllites, 11 micaschists, pegmatites in the upper part, 12 pegmatitic granite (marginal rocks of the igneous massif), 13 gradually out of 12) granitic gneiss, nodular augengneiss, greatly weathered in the upper part, similar as in the Kathmandu nappes near Kokani (chorosmite after P. Niggli), 14 thick mass of porphyric granite, 15 inclusions of fine grain biotite paragneiss within the granite, 16 gradually from 14): decrease of felspar porphyroblasts, Baitadi gneiss, (few felspars in dark chloritic ground mass), 17 graphitic sericite schists, with fine garnets, 18 blue clayey sericite phyllite, 19 quartzite (minor layer), 20 quartzite beds in slates and sericitic phyllites, pegmatites, thin bedded quartzites (Chitlang type), 21 clear soft slaty series, similar as 20), 22 fine-grained biotite micaschists, 23 mainly quartzite, sand-grained with slates, 24 fine-grained micaschists, sericite schists, quartz lenses, 25 micaschists with pegmatites and quartz veins, 26 augengneiss, type Baitadi gneiss, quartz veins, 27 quartzitic slates, phyllites, 28 thick quartzite series, 29 slates and amphibolites, 30 white well-bedded quartzite, 31 Baitadi gneiss, large felspar crystalls, (directed at right angle to the beds), 32 Baitadi gneiss with slates and amphibolites, 33 Baitadi gneiss, 34 quartzite, upper part gneissic with felspars, 35 slates, 36 quartzite.

This section has been taken near the eastern termination of the Dandeldhura massif. Studying this profile alone, it might seem to be possible to interpret the crystalline mass as a nappe. We may apply the same thought as shown in figs. 49-55 regarding the Kathmandu crystalline north of Kathmandu. In the Dandeldhura zone however the lines separating the Dandeldhura massif from the underlying Sirkot zone are not connected underneath the granite. They dip very steep towards west, due to axial pitching in this direction. Besides the tectonic configuration, the huge mass of entirely homogenous granite of 40 km width, with no texture at all does not allow to see a nappe structure in the Dandeldhura zone.

In the given section the massif appears to have a syncline structure. The crystalline seems to dip towards the interior of the massif, due to the pitching Seti anticline. Further to the west, in the great main mass of the granite, the massif shows an anticline structure, which however is non-symmetric: The whole granite body is slightly turned towards the south (profile 86, plate 5).

The Dandeldhura massif covers in Nepal an area of about 3000 km$^2$, in the shape of a rectangle of about 80 km length and 40 km width. This however, is not the whole area of the Dandeldhura massif, since it extends westward beyond the Nepal border.

The southern flank of the massif shows a fan-like overlap, while the north-western flank has a normal northerly dip. The massif can thus be considered as an anticline, which has been pushed and slightly overturned towards the south. On the southeastern flank, the massif is intersected by the Seti anticline, which pitches in the Seti valley near Silgarhi Doti to the northwest below the crystallines of the Dandeldhura massif.

The crystallines of the massif continue far to the northeast. Huge masses of more or less horizontally bedded gneisses (ophtalmites) and granites were found in the bottom of the Buri Ganga valley, near Bajura (profile 80, plate 5) and to the north as far as Manu.

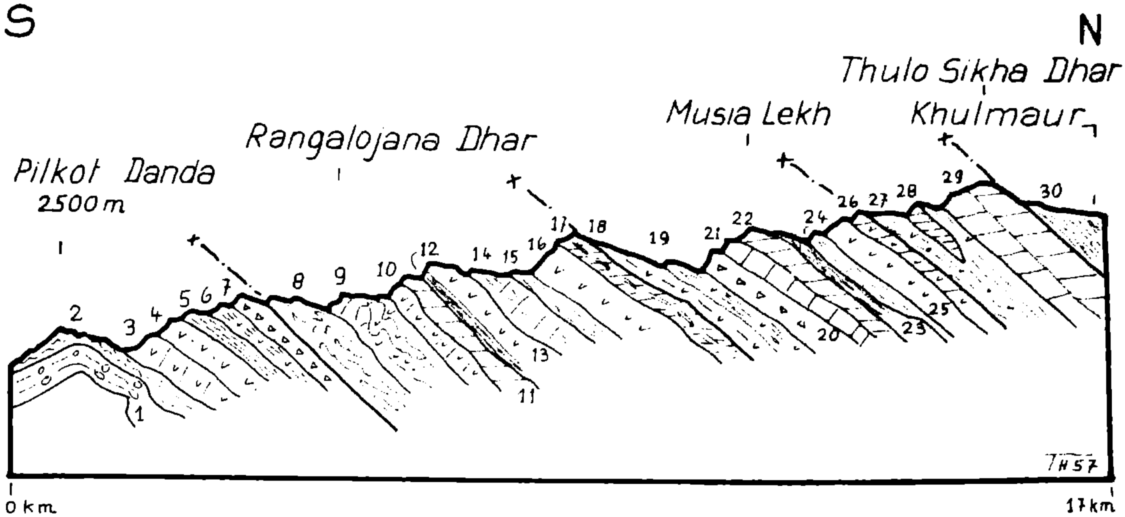



Fig. 74 Profile sketch of the Rangalojana Dhar to the north as far as Khulmaur
(12 km north of Dandeldhura, western Nepal)

1 migmatite, augengneiss, 2 micaschists, 3 red iron quartzite and iron shales, violet shales, 4 sand-grained quartzite, well bedded, interbedded with clayey layers (similar as the Chitlang series), 5 pelitic series, well bedded, greenish, brown and red, with layers of hematite, 6 quartzitic slates, 7 breccias with dolomites and limestones, thrustplane, 8 shales of the Banepatype, tectonized zone, with ancient small-scale folds, directed and pitching toward north; quartz veins and pegmatitic layers, 9 shales, red quartzites and radiolarite type, well banded, containing layers of conglomerates and breccias, slates of a net pattern, 10 quartzite, well bedded, reddish coloured (similar as the silurian quartzite on the Phulchok range), 11 small layer of dolomite, fluidal texture, 12 blue phyllites, 13 deep red quartzites, radiolarite type, with layers of hematite, quartz veins (in the neighbourhood of pegmatites), 14 red, greenish and yellow pelitic slates, 15 red slates, Chitlang series, 16 red quartzites, banded, partly conglomeratic, 17 traces of dolomite, (type of the "Seewerkalk" with interbedded shales), Devonian? 18 red and black carbonaceous shales, interbedded with quartzites, partly slightly sericitic, tectonized and folded, 19 violet, green and red phyllites, red quartzites (radiolarite type) interbedded with quartzites and breccias, 20 polygenetic calcareous breccias, 21 limestone, well bedded, with layers of shales and clays, 22 dolomite, 23 dark carbonaceous shales (Carboniferous?), 24 light coloured phyllites, 25 quartzite, 26 dolomite and quartzitic dolomite, 27 black, bleach shales, green phyllites with quartzitic intercalations (Krol?), 28 dolomite slice, 29 thick dolomite series, partly shaley, 30 series of dark shales.

The series given in this section in spite of containing 4 overthrusts show the most complete and non metamorphic normal lithological succession found in Nepal, reaching from the crystalline up to probably Triassic formations. It is the base of the Bajang nappes, however rather sliced.

East of the Buri Ganga valley (east of Ririkot) the Dandeldhura massif decreases and extends in a narrow belt along the front of the Kathmandu nappes toward Dailekh. It is connected east of Dailekh with the Hiunchuli zone nr. 2 and the corresponding great crystalline nappes.

The southern flank of the massif is overturned, the Palaeozoic sedimentary covers (quartzites, slates, phyllites and amphibolites) dipping towards the north underneath the crystallines. The crystallines decrease towards the west, while the Palaeozoic sediments increase. Along the border on Kali Ganga, the crystallines form only the minor portion. This explains why further west in India, no equivalent of the Dandeldhura massif has been found. The crystalline slices at the base and front of the "Almora thrust" are the last remnants.

The northern portion of the Dandeldhura massif is sliced (into schuppen) and folded. The sedimentary cover of the massif (Palaeozoic) passes as wedges and folds into the crystallines. Formation of schuppen continues in the Palaeozoic series to the north. Nevertheless, the section from Dainsli to Khulmaur shows the most complete succession of the whole country so far found south of the crystalline roots. There is undoubtedly a complete formation, reaching from Palaeozoic right up to the Triassic (fig. 74). The normal sedimentary cover of the Dandeldhura massif thus gradually develops to the north joining the *Bajang nappes*. These are really nothing but large schuppen on the back of the Dandeldhura massif. The latter is exposed once more further north, in the Chamlia anticline. Erosion has removed the overlying Bajang nappes over this anticline, so that the normal cover of the Dandeldhura zone appears on the surface (Profile 86). The exposure of the Dandeldhura massif in the Chamlia anticline extends from the western border more than 85 km to the east (plate 6).

The Chamlia anticline pitches towards the east near Pujarigaon. The anticline continues even to the east beyond Pujarigaon, but it is visible only in the overlying Bajang nappes. The anticline itself narrows with a faultlike southern flank.

East of Jilli, the Kathmandu nappes are found overthrust over the Bajang nappes. They form a tectonic bridge to the large overthrust masses of the Kathmandu nappe 2 in the Fore Himalaya of Raskot (plate 6). This bridge is only a few kilometers wide on the Porakhya Lagna. In the valley of Kanrkabara-Kolti, the Bajang series occurs again.

From Kolti to the east, an enormous thrust fault strikes through the valley, by which the northern parts are lifted for several hundred meters, while the southern parts seem to have sunk. This is the *Partol thrust*, which strikes through the Paorakya Lagna and into the southern flank of the Chamlia anticline near Pujarigaon (plate 6).

Owing to the Partol fault, the Kathmandu nappes now lie at the same level alongside the Bajang series. The latter occur in the large double *tectonic window of Galwa* (plate 6 and fig. 35).

Lithologically, the series exposed on the top are identical with those of the Bajang nappes. They consist of very thick dolomites, quartzites, and slates of Triassic age, underlain by Permian phyllites and conglomerates, Carboniferous shales and phyllites, and a thick lower dolomite probably of Devonian age.

In addition, the topmost series are sliced into schuppen being recognizable by repetitions of the Triassic series. The Devonian dolomite recalls the dolomite on the back of the Dandeldhura massif near Rangalojana Dhar. The geographic position as well as the structures leave no doubt at all that the tectonic window of Galwa is a northern exposure of the Dandeldhura massif. It is undoubtedly connected with the massif underneath the overthrust Kathmandu nappes.

*12) The Bajang nappes*

The Bajang nappes, named after the district center Bajang in western Nepal cover the area in the west, from the Buri Ganga right through to the western border of Nepal. Four different nappes can be recognized. Their top roots joins the roots of the Kathmandu nappes in the Api-Saipal group. Main structures within the Bajang nappes are the Chamlia anticline (plate 6), which corresponds to the Himalayan Fore-Anticline, and a syncline, the Baitadi syncline. The underlying autochthonous basement—the Dandeldhura massif—is exposed in the Chamlia anticline. In the Baitadi syncline, the Bajang nappes 1–3 occur as tectonic outliers. The Baitadi syncline pitches towards the west, and apparently further west the Almora Thrust Mass of Heim and Gansser is lying in the same syncline structure.

The main portion of the Bajang nappes consists of Carboniferous-Triassic formations, with very thick dolomites, limestones, quartzites, shales, slates and phyllites. The nappe nr. 3 however seems to be an exception. Large masses of gneisses (ophtalmites) were found, with thick layers of amphibolite; fig. 75 may give an idea of the formations of the Bajang nappe 3.

The calcareous series are especially thick and well developed in the northern part of the Bajang nappes, for example in the upper course of the Chamlia river. These series are intensively folded, and recall very much certain types of the Helvetic Nappes in the Swiss Alps (fig. 120).

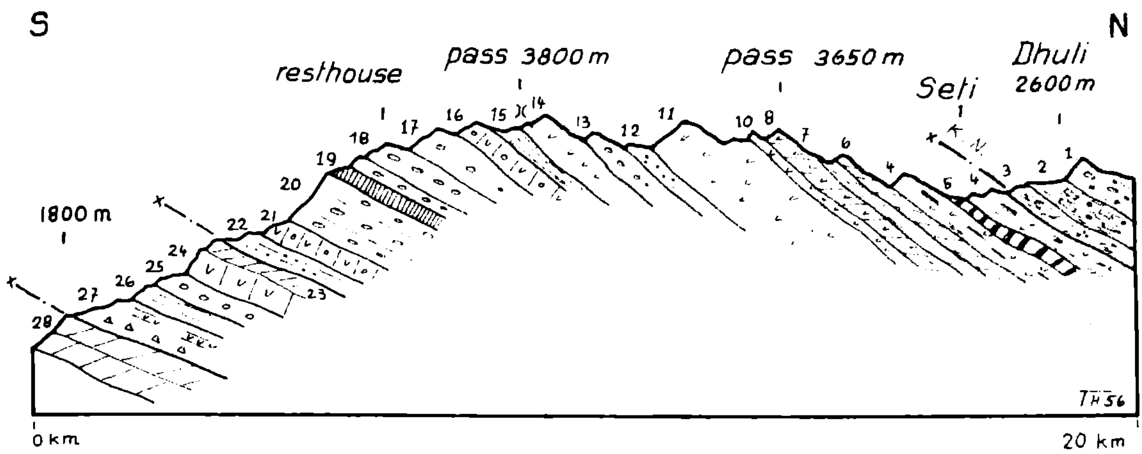



Fig. 75 Profile sketch of the Bajang nappes between Talkot and Dhuli
(20 km east of Bajang, northwestern Nepal)

1 augengneiss, with garnets and kyanite, 2 micaschists with biotite, garnets and kyanite, 3 phyllites, with some quartz veins and felspar porphyroblasts, slightly graphitic, 4 quartzite, interbedded with graphite phyllites, 5 gabbros, interbedded in the quartzite, 6 dolomite slice, 7 slates, carbonaceous, 8 quartzitic dolomite (100 m), 9 quartzite, 10 black and deep red quartzite ("Narebang quartzite"), iron oolites, 11 thick quartzite, 12 in 11) layers of coarse grained quartzitic sandstone, 13 conglomerates (diameter 12 mm), 14 chlorite quartzite (Ramche type), 15 talk slates, chlorite slates, 16 quartzite, with conglomerates, 17 conglomerates and boulderbeds, as layers in the quartzite, 18 augengneiss, 19 gabbros and amphibolites, 20 augengneiss, felspar porphyroblasts up to 5 cm diameter (total thickness of gneiss approx. 2 km), 21 conglomerate gneiss, conglomerates and quartzites, 22 series of greenish and yellow slates, interbedded with chlorite quartzites, also layers of sandstone and red shales, 23 dolomite slice, 24 quartzite, 25 conglomerates (Verrukano), 26 slates, greenish, talkose, 27 series of clear quartzite, deep blue-green shales, conglomerates and breccias, (diameter 4 mm); yellow sandstones with biotite, hornblende porphyroblasts, ("Stäbchenschiefer" and "Knotenschiefer"), 28 dolomite, approx. 400 m.

In general, the Bajang nappes may be compared with the Tejam zone in Kumaon, the Krol nappes in Garhwal, and thus also with the Nawakot nappes in central Nepal. They consist of formations of undoubtedly Carboniferous-Triassic age. However, similar as the Nawakot nappes in eastern Nepal, also the Bajang nappes are partly built of much older formations, which reach down to the Paleozoic. Especially the Bajang nappe no. 3, of which a section is given here, contains large masses of gneiss and basic intrusiva. Those crystalline rocks form large bodies of great thickness. The thickness varies considerably in the geological strike direction and may even on distances of a few kilometers entirely disappear.

The Bajang nappes continue to the west beyond Nepal. They have been described as "Tejam zone" by Heim and Gansser, and have been attributed also to the Krol nappes of J. B. Auden. This comparison seems to be reasonable, since in the nappes 1, 2 and 4 the respective series are undoubtedly of Carboniferous–Triassic age. Some boulderbeds with extraordinarily large components occur in this zone; the age of some of them is still uncertain. (Possibly Tillites?)

The overthrust of the Kathmandu nappes over the Bajang nappes in the upper course of the Chamlia is not very clear, since the Kathmandu nappe 1 contains little intrusive crystalline, but principally low-metamorphosed quartzites and phyllites, which are not very different from certain series of the Bajang nappes.

In general, the Bajang nappes may be compared lithologically with the Nawakot nappes of those areas, in which the latter are built dominantly out of Triassic formations.

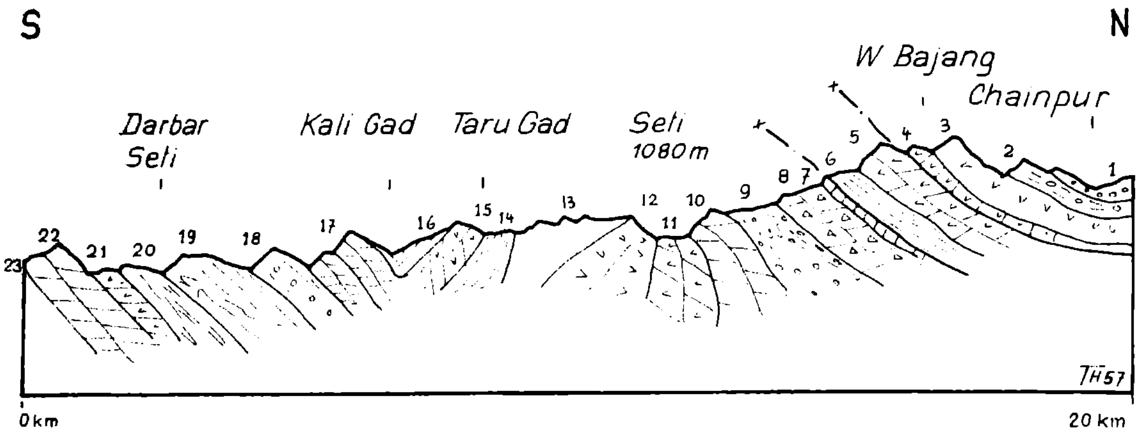



Fig. 76 Profile sketch of the Bajang nappes near Bajang and of the sediment cover of the Dandeldhura massif
(Bajang, western Nepal)

1 conglomerates and shales, 2 mainly shales, laminated; phyllites, with layers of conglomerates, 3 quartzite, 4 red and green Narebang quartzites, 5 dolomite (600 m) laminated, well bedded, 6 Narebang shales (red and green), 7 calcareous dolomite, 8 dolomite, polygenetic breccias (Triassic?); quartzitic dolomite (900 m), 9 green shales and conglomerates, 10 dolomite, well bedded, 11 quartzitic dolomite (cuspate structure), 12 white quartzite, 13 dolomite, 14 black carbonaceous shales, red shales, 15 dolomitic quartzite, 16 carbonaceous shales, 17 thick dolomite series (1500 m), 18 shales with layers of conglomerates, 19 carbonaceous shales, red and green shales, graphite phyllites, breccias 2000 m, (Carboniferous, Krol—infra Krol?), 20 blueish-grey slates, slightly sericitic (similar to the series in the Angbung zone in eastern Nepal (lower carboniferous?), 21 blue quartzites, well bedded, with layers of dolomite, 22 limestone, with net pattern, interbedded with shales and clays (type of the "Seewerkalk"), also dark coloured lens-shaped intercalations; dark red quartzites, well bedded red sandstones, the whole series highly tectonized (Devonian?), 23 blue quartzites (Silurian?).

All the series are tectonized. A number of Schuppen with lithological repetitions pass by increase of the intrusions gradually over to the crystalline of the Dandeldhura massif further south.

In spite of the Schuppen tectonics, a normal succession can be observed from the granites up to the Triassic formations of the Bajang facies.

### *13) The Hiunchuli nappes and the Hiunchuli zone*

The Hiunchuli zone is situated, geographically and tectonically, between the Kathmandu nappes and the Jajarkot nappes; it has been named after the mountain Hiunchuli Patan, 5922 m. In the east the Hiunchuli zone ends at the southern flank of the Dhaulagiri range, while in the west it is connected with the Dandeldhura massif (fig. 17 and plate 6).

The area covered by the Hiunchuli zone has the shape of a lens, which is convex to the north. The maximum width is found in the section of the Hiunchuli range with more than 30 km. From here to the east and west, the width decreases rapidly.

Tectonically, the Hiunchuli zone corresponds to the Dandeldhura massif. We have already seen in paragraph 11), how the Dandeldhura massif develops towards the east from the massif into a slice (schuppe) with a northerly dip. In the area of Khurpa, 15 km north of Jajarkot, the Hiunchuli zone develops rapidly from the slice into real nappes. There are 4 main schuppen in the root zone (Hiunchuli zone), while in the overthrust parts in the Jaljala syncline only 2 great nappes were recognized with certainty. The overthrust portions consist principally of crystalline schists, mica-schists with garnets, silicate limestone, marmorized limestones, gneisses of various characters (intrusives are lacking) quartzites, phyllites and slates. There is no doubt that these formations are not younger than Silurian age, and reach with certainty far into the Palaeozoic and pre-Palaeozoic. There are many lithological repetitions ; undoubtedly detailed studies will eventually enable us to separate more than one nappe in this large overthrust mass (see figs. 79 and 80).

The rocks in the root zone north of the Bheri river, are different especially in the northern schuppen. In the lower schuppen, quartzites with phyllites are dominant; graphite phyllites and graphite schists are also present. There is slight metamorphism, the quartzite showing some similarity with a very acid gneiss, and containing sericite and further north some garnets too. The metamorphism increases northwards (figs. 79 and 80).

There is a considerable change in the contents of the various schuppen towards the north. In the schuppe nr. 2, which builds the peak of the Hiunchuli Patan (5922 m), limestones increase and take a dominant position in the upper part of the mountain. On the Toridwari pass (4600 m) also, slightly metamorphosed limestones occur; they cover the whole northern flank, nearly down to Duragon (fig. 77). The limestone is well bedded with thin layers of reddish clay, partly sandy, partly slightly marmorized. Quartz veins as last remnants of pegmatites reach up as far as this limestone. The limestone itself recalls the Devonian formations as they have been found along the whole northern flank of the main roots (for example on Dhaulagiri).

One could really seem to be on the northern side of the roots in the Kali Gandaki valley, or in the Saipal synclinorium. The structures of the Hiunchuli Patan range are quite different from the

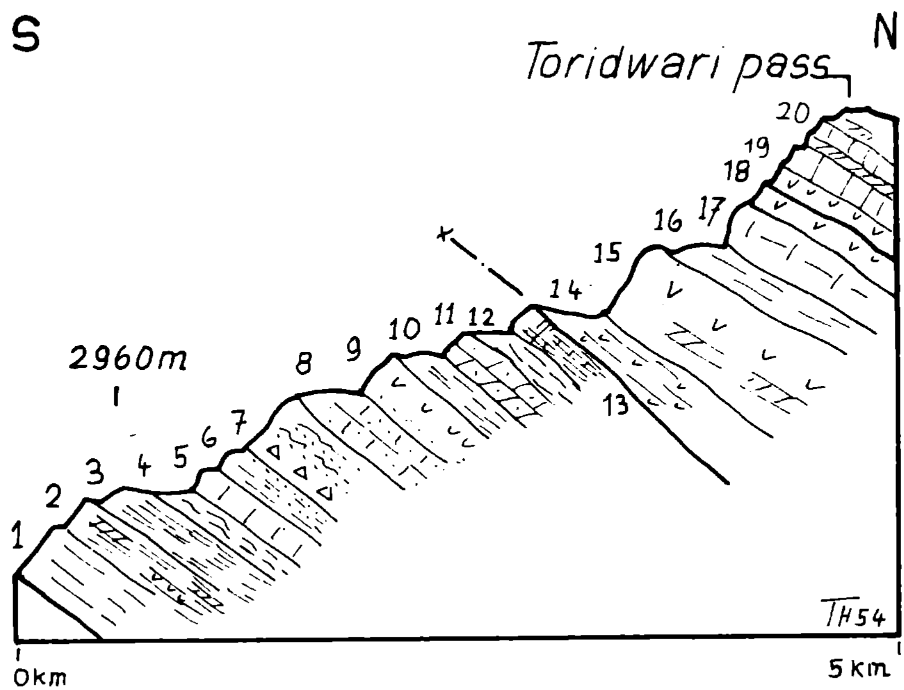



Fig. 77 Profile sketch of the Toridwari pass
(10 km east of the Hiunchuli Patan, western Nepal)

1 light blue slates, with quartz veins, 2 calcschists, with quartzitic and dolomitic layers, 3 talkschists, 4 silver coloured and blue sericite schists, 5 pelitic series, 6 slates, blue phyllites, slates with sandstone layers, 7 breccias, blue pelitic series, schistose sandstones, 8 sandstones, 9 quartzite, gradually out of 8), 10 slates, 11 yellow grained dolomite, 12 slates, 13 calcareous slates, 14 quartzitic slates, 15 quartzite, light coloured, pseudo dolomitic weathering, 16 slates, 17 fine grained gneiss, 18 clear coloured quartzite, slightly sericitic, slaty and pseudo dolomitic, 19 similar as above, but yellow coloured, 20 series of the pass, silicious limestone, sand-grained, dolomitic layers.

ordinary ones in the nappes or schuppen. Intensive folding can be recognized in the well bedded limestones which have a thickness of nearly 2000 meters. The profiles of fig. 79 give some idea of the geology of that mountain range.

Special interest must be given to the eastern termination of the Hiunchuli Schuppen. All of them develop (without exception) out of the base of the Kathmandu nappes. The Hiunchuli zone is thus not a new isolated zone, occurring between the underlying Jajarkot nappes and the overlying Kathmandu nappes (fig. 17). The Kathmandu nappes at their base west of the Chalike Pahar (5120 m, 16799 ft.) send quite a number of wedges and slices westward at an angle which is different from the general strike of the Kathmandu nappes. These Kathmandu nappes (particularly their roots) build the whole southern flank of the Dhaulagiri range, where they strike in an eastsoutheast–westnorthwest direction between the Mayangdi Khola and the most westerly high summit, the Churen Himal (7363 m, 24 150 ft.) From this section the strike of the Kathmandu roots turns abruptly north and crosses the Barbung Khola (upper course of the Bheri). The wedges at the base of the Kathmandu roots continue with the former strike, that is westnorthwest or even due west. Thus, the basal wedge and the main roots show a considerable divergence. The wedges themselves consist of the same crystallines as the Kathmandu nappes, namely various gneisses, with migmatites, mica-schists, and layers of pegmatites. Towards the west however the crystallines decrease rapidly within the basal wedges, and more and more sediments take their place: quartzites, phyllites, graphite-phyllites, schists and carbonaceous rocks. The latter form the top of each series and extend as wedges eastward between the basal crystalline slices of the Kathmandu nappes. We have thus to consider the huge limestone-schuppen as part of the Kathmandu nappes, which have changed their rock content westwards and became very thick along the strike further west (fig. 67).

When considering the strike of the Hiunchuli schuppen, it is further surprising that they turn southwest and even south in the west of the Hiunchuli range. The mountain range itself makes the turn too. It is really the western continuation of the Dhaulagiri range (topographically), in spite of the fact that this one single range (Dhaulagiri plus Hiunchuli range) does not coincide with the geological strike. Due to the divergence of the strike between the Kathmandu roots and the Hiunchuli schuppen, this one single range is not built from one tectonic unit, but traverses at an angle the Kathmandu roots and the Hiunchuli schuppen. This extraordinary fact must be considered when trying to explain the uplift of the mountains in this area. When studying the tectonic map of this area (plate 6), it is surprising how narrow the belt of the Kathmandu roots becomes in the sections of Tarakot. On the other hand, the Silurian and Devonian limestones are extremely thick in this same section (in the Dhaulagiri and in the Kanjiroba). We may conclude that before mountain building, the Dhaulagiri-Kanjiroba limestone and the Hiunchuli limestone have been formed in one single basin. Then, first the Hiunchuli schuppen rose, and only afterwards, possibly due to old underground structures, the Kathmandu nappes were overthrust. Thus their roots were created at an angle to the above mentioned calcareous basin. In a final stage, the roots and schuppen were lifted high up, and again the ancient, original strike was preferred, involving the Kathmandu nappes in the east and the Hiunchuli schuppen in the west. Another indication of a late uplift of the Hiunchuli–Dhaulagiri range is found further west; the overthrust Kathmandu nappes of the Thakurji Lekh and the Chakkhure Lekh build a mountain range, which strikes parallel to the Hiunchuli arc, and reaches excessive heights for overthrust masses. These mountain ranges are above 4000 m and at some places they reach 4500 m. It would be quite an exception, for the Kathmandu nappes to have been thrust to that altitude. It is more likely that this area has been lifted as a whole after the overthrust of the Kathmandu nappes. Proof of this uplift, especially in the southern part, have been found (plate 6, Partol fault and page 142).

We do not know, whether underneath the overthrust Kathmandu nappes, there are further schuppen of the Hiunchuli type, which join northwest of the Hiunchuli zone. It would be quite possible for the Kathmandu nappes in the Thakurji Lekh to have overthrust a number of such schuppen, in a kind of a relief-overthrust. The junction between the Hiunchuli arc and the Dori zone (eastern part of the double tectonic window of Galwa) seems to be not far from Jumla; the Jumla area is marked by superposition of a complicated system of structures with quite different strikes.

We shall deal with crustal movements of this area in the next chapter (14) on the autochthonous zones and roots.

*14) Autochthonous zone in the Midlands.*

The Dandeldhura massif, which is the largest autochthonous zone in the Midlands, has been dealt with in a special chapter (11).

The Piuthan zone has also to be considered as autochthonous, at least its basement below the top part which has been sliced into schuppen. There are two further autochthonous zones in the Midlands, which do not show any schuppen structure, but consist of visible anticlines, from which the overthrust nappes have been eroded.

Both of these, the autochthonous Pokhara zone and the Angbung zone, are exposed in tectonic windows (fig. 17 and plate 6). We may also consider the tectonic window of Dumlingtar, though showing Nawakot facies, as parautochthonous.

*The Pokhara zone*

*The Pokhara zone* is lithologically not very easy to separate from the overthrust Nawakot nappes, since its rock formations are quite similar to those of the Nawakot nappes.

Principally phyllites, and quartzites with layers of boulderbeds within the phyllites occur in the Pokhara window. The boulderbeds are especially well seen in the streets of the beautiful town of Pokhara.

The window of Pokhara measures 65 km in the longest east-west diameter, while the maximum width is 11 km in the section of Deorali. The Pokhara zone forms a long anticline with rather regular northern flank, and a folded southern side. In the valley 2 km east of Khuncha, the Pokhara zone occurs again in a separate small tectonic window (not indicated in the tectonic map).

The indications, which led the author to the adoption of an autochthonous zone in the window of Pokhara, were tectonic. The Pokhara series show quite a number of small transverse structures like folds, anticlines and synclines. All these structures are directed north-south and do *not* continue above the Pokhara series into the overthrust nappes. Evidently, the transverse structures are ancient, and have been created before the building of the Himalayas and the thrusting of the nappes (fig. 78).

The overthrust Nawakot nappes also show normal structures (east-west) in which the underlying Pokhara zone is not involved; the basal thrust plane is thus partly an unconformity.

The western termination of the Pokhara zone in the Modi Khola is abruptly bent to the south, toward Kusma (plate 6).

The Pokhara zone is by far the lowest tectonic unit found in Nepal so far. Surprisingly enough, it lies relatively close to the Tibetan zone in the synclinorium of Manang, only 40 km from the Mesozoic formations (fig. 17 and plate 6). Topographically, the Pokhara zone forms the lowest area in the Nepalese Midlands, Pokhara itself being only 800 m above sea level, and the plain falling to 700 m in the southern part. The section of Pokhara shows the greatest contrast in altitudes, since the Annapurna range of 8000 m is not more than 25 km north of the lowlands of Pokhara (figs. 3 and 4).

These contrasts have been caused by extreme narrowing of the former root-belt between the autochthonous Pokhara zone and the Tibetan marginal synclinorium of Manang. The roots have been strongly squeezed between the two autochthonous zones. The Nawakot roots of the Nawakot

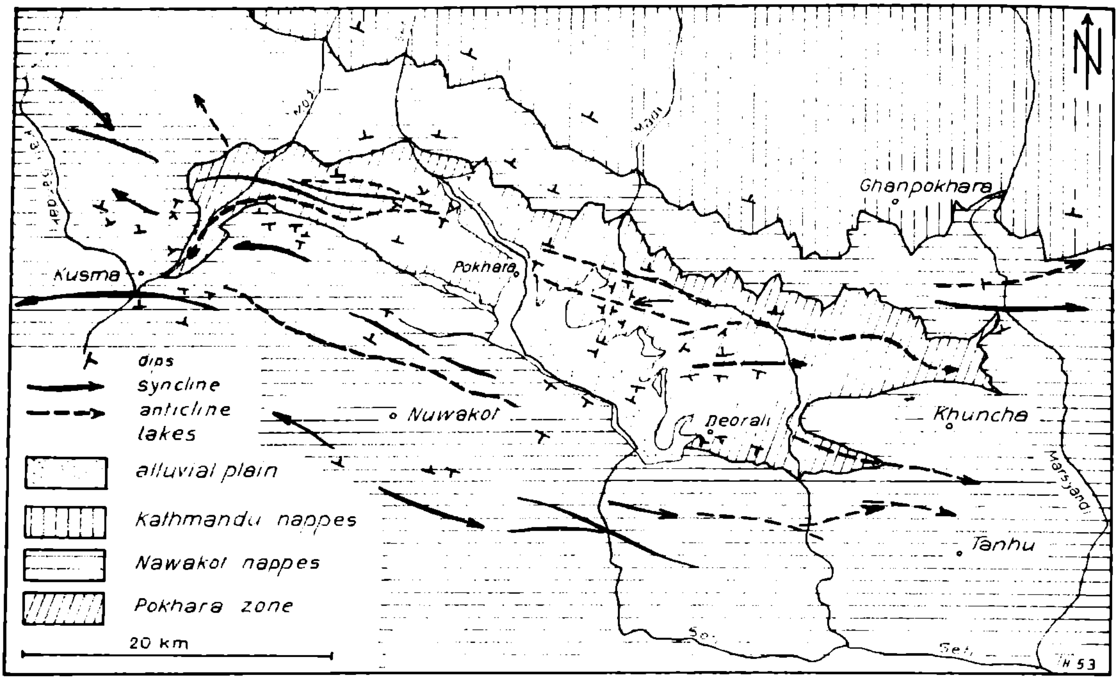



Fig. 78 Tectonic sketch map of the Pokhara zone
(the transverse structures do not show up well due to the small scale).

nappes north of Pokhara are only 5 km wide, compared with an average of 20 km in other areas. The crystalline roots of the Kathmandu nappes have been squeezed to a width of only 15 km.

This special tectonic situation thus causes the Pokhara area to show the greatest contrasts in landscapes. Nowhere else in the world, can the highest mountains reaching the 8000 m level be admired from such a short distance and from the tropical lowland without any intermediate mountain ranges. Pokhara is certainly one of the most extraordinary and most beautiful places in the whole world.

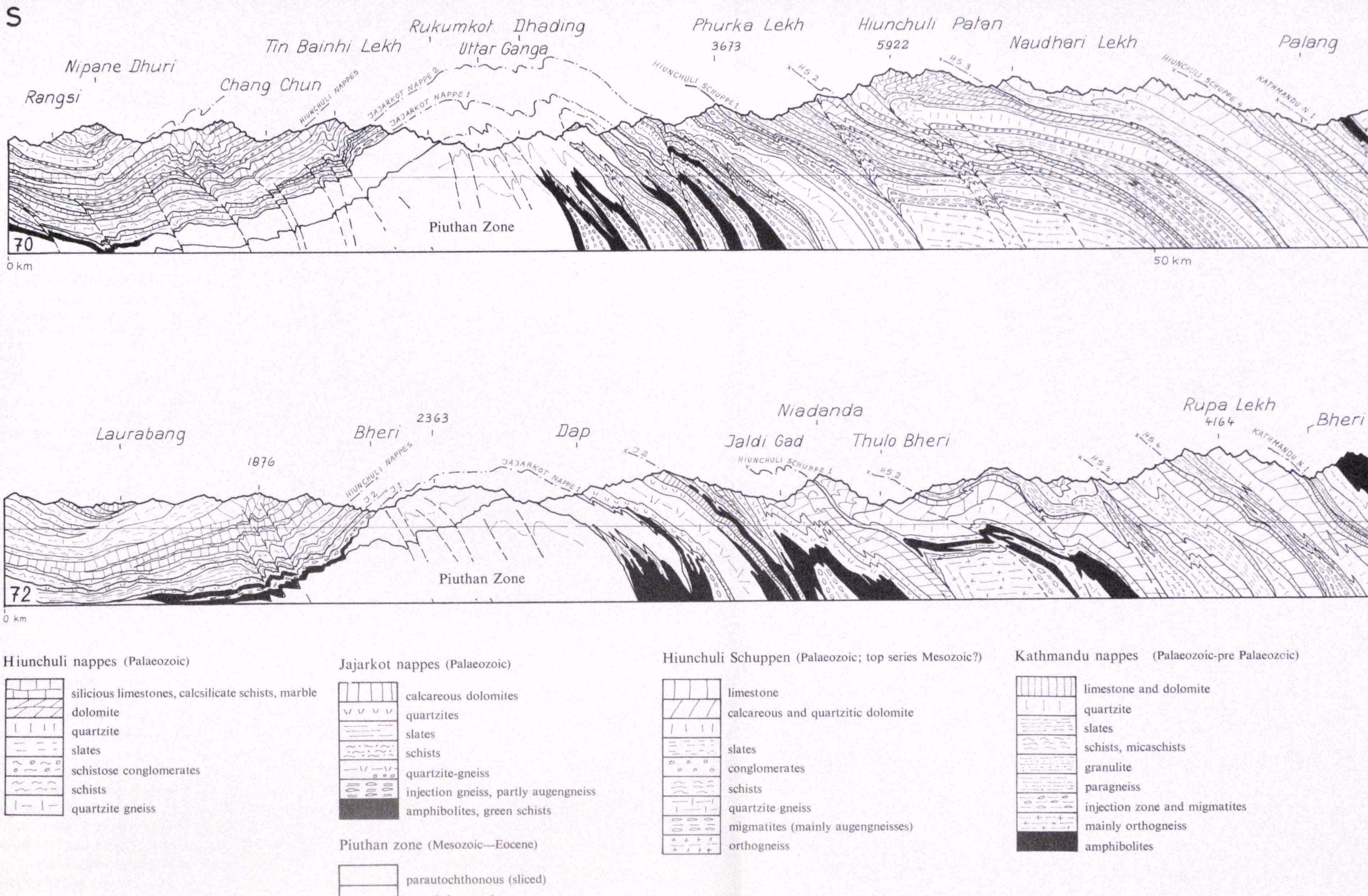
*The Angbung zone*

The Angbung zone is exposed in a tectonic window in eastern Nepal (fig. 17 and plate 6). It forms an irregular dome, over which the Khumbu nappes have been eroded (fig. 24). Three anticlines build the dome of Angbung; one follows the Tamur river in its south-western course, another strikes north-west in the Tamur river, and the third lies on the eastern edge of the tectonic window. The last one is asymmetrical with a faultlike flank on the eastern side.

All the anticlines pitch away from the center of the dome. The transverse anticline (north–south) dominates, thus the dome of Angbung has the long diameter in the transverse direction.

The thrust fault on the eastern flank of the dome has considerable magnitude: not only is the Angbung zone abruptly cut off, but the Khumbu nappe nr. 1 is entirely squeezed out on the eastern flank. Also the overlying Khumbu nappe nr. 2 is narrowed to only 1 km (fig. 81).

The rock formations of the Angbung zone are quite different from those of the overlying Khumbu nappes. The latter consist principally of crystalline rocks, mostly various gneisses, especially ophtalmites and also of mica-schists. The Angbung zone consists of quartzites, chlorite quartzites, phyllites, porphyroblastics (Tüpfelschiefer, Knotenschiefer), glaucophan rocks, and graphitic schists; boulderbeds are also present.


S
Rangsi
Nipane Dhuri
Chang Chun
Tin Bainhi Lekh
Rukumkot
Dhading
Uttar Ganga
Phurka Lekh
3673
Hiunchuli
Patan
5922
Naudhari Lekh
Palang
HIUNCHULI NAPPES
JAJARKOT NAPPE 2
JAJARKOT NAPPE 1
HIUNCHULI SCHUPPE 1
HS 2
HS 3
HIUNCHULI SCHUPPE 4
KATHMANDU N 1
Piuthan Zone
70
0 km
50 km
Laurabang
1876
Bheri
2363
Dap
Niadanda
Jaldi Gad
Thulo Bheri
Rupa Lekh
4164
Bheri
HIUNCHULI NAPPES
J 2
J 1
JAJARKOT NAPPE 1
J 2
HIUNCHULI SCHUPPE 1
HS 2
HS 3
HS 4
KATHMANDU N 1
Piuthan Zone
72
0 km
Hiunchuli nappes (Palaeozoic)
silicious limestones, calcsilicate schists, marble
dolomite
quartzite
slates
schistose conglomerates
schists
quartzite gneiss
Jajarkot nappes (Palaeozoic)
calcareous dolomites
quartzites
slates
schists
quartzite-gneiss
injection gneiss, partly augengneiss
amphibolites, green schists
Piuthan zone (Mesozoic—Eocene)
parautochthonous (sliced)
autochthonous basement
Hiunchuli Schuppen (Palaeozoic; top series Mesozoic?)
limestone
calcareous and quartzitic dolomite
slates
conglomerates
schists
quartzite gneiss
migmatites (mainly augengneisses)
orthogneiss
Kathmandu nappes (Palaeozoic-pre Palaeozoic)
limestone and dolomite
quartzite
slates
schists, micaschists
granulite
paragneiss
injection zone and migmatites
mainly orthogneiss
amphibolites

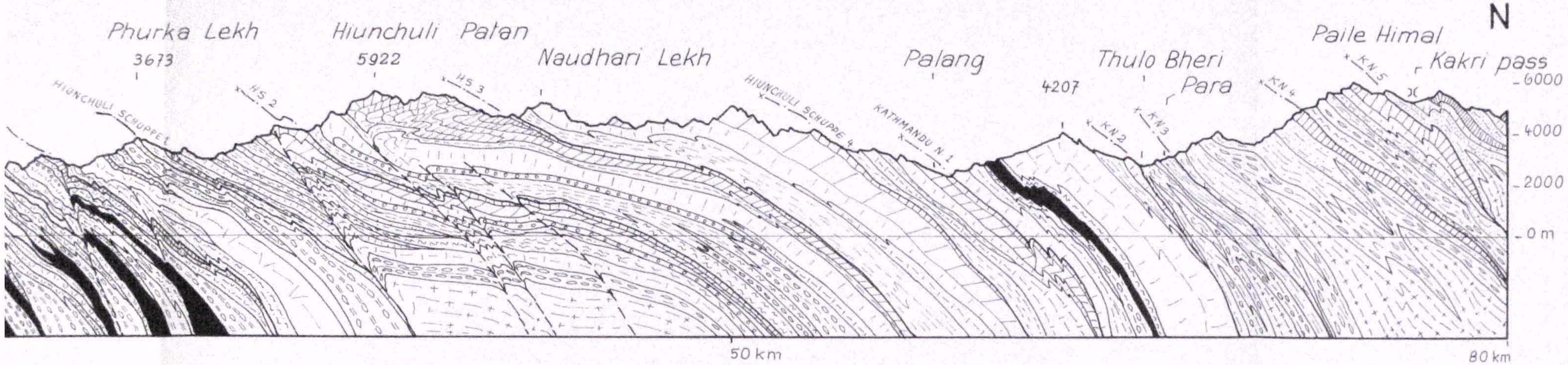



Fig. 79 Geological profile through the Hiunchuli Patan
(Jajarkot district, western Nepal)

Both sections (79 and 80) show the various Schuppen of the Hiunchuli zone and the southerly adjoining, underlying Jajarkot nappes. The latter are eroded above the Bheri anticline, thus exposing the underlying Piuthan series.

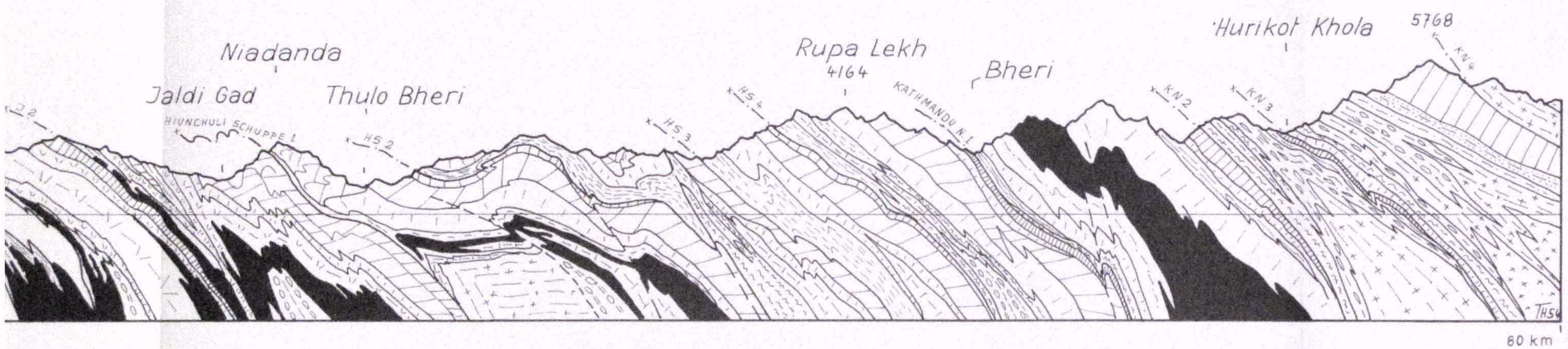



Fig. 80 Geological profile through the Mundkala Danda
(Jajarkot district, western Nepal)

Hiunchuli Schuppen (Palaeozoic; top series Mesozoic?)

- limestone
- calcareous and quartzitic dolomite
- slates
- conglomerates
- schists
- quartzite gneiss
- migmatites (mainly augengneisses)
- orthogneiss

Kathmandu nappes (Palaeozoic-pre Palaeozoic)

- limestone and dolomite
- quartzite
- slates
- schists, micaschists
- granulite
- paragneiss
- injection zone and migmatites
- mainly orthogneiss
- amphibolites

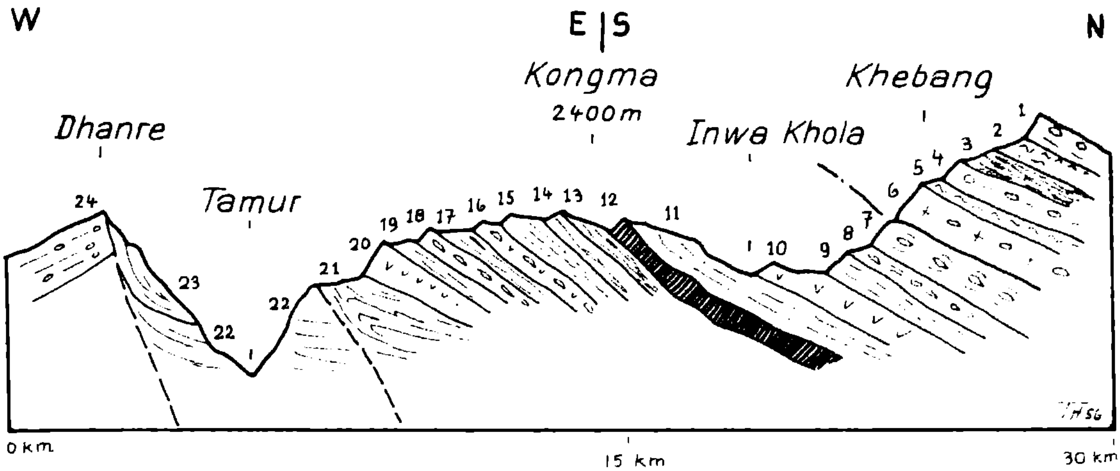



Fig. 81 Profile sketch of the eastern area of the Angbung zone

1 gneiss, mixed, thickly-bedded, 2 micaschists, 3 graphite schists, similar as those of Yamphodin, 4 injection mixed gneiss, augengneiss, 5 micaschists, rich in muscovite, 6 granite gneiss of Khebang, well and thickly-bedded, 7 nodular injection mixed gneiss, 8 augengneiss, interbedded in schists, 9 out of 8), decreasing metamorphism, gradual change to blue schists and slates, 10 quartzite, 11 slates, yellowish-greenish, amphibol-porphyroblasts slates ("Stäbchen- and Tüpfelschiefer"), 12 amphibolite (south of camp near Mele), 13 clear coloured, yellow-greenish slates, porphyroblasts, 14 dark schists, 15 fine-grained chlorite schists, 16 paragneiss, with layers of quartzite, chlorite-sericite gneiss, partly coarse-grained, 17 clear-coloured schists, 18 large series of paragneiss of Nagi, chlorite gneiss, 19 blue schists, 20 quartzite, with dolomite-like layers, 21 schists, 22 large series of the Angbung gneisses, paragneisses, conglomerate gneisses (of the type of Baitadi gneiss and also of the Ulleri type), thrust fault within the Angbung conglomerate gneiss series, 23 chlorite schists, 24 banded, hard coarse-grained, chlorite gneiss.
(Thrust plane between 6 and 7).

Calcareous formations are missing. The whole series might be of Carboniferous-Permian age. This interpretation is supported by comparison with the Rangit zone in Sikkim, on the opposite (eastern) side of the Singalila range. The Rangit zone bears coal and has been determined as Carboniferous by the geologists of the Geological Survey of India. Tectonically, the Rangit zone is situated at the same level as the Angbung zone, underneath of the great crystalline mass, which is connected with Kangchendzönga and which has for a long time been considered as a huge "recumbent fold". We thus have no reason to doubt the Carboniferous age of at least a portion of the rocks in the Angbung zone.

### *15) The Siwaliks*

The Nepalese portion of the Siwaliks is only a small part of the overall extension of roughly 4000 km of the Siwaliks from Baluchistan in the west to Burma in the east.

#### *A) General*

The Siwalik zone or briefly the "Siwaliks", forms a belt between the Ganges plain and the Main Boundary Thrust, with an average width of 25–30 km. In one section only near Dharan in eastern Nepal, is the Siwalik belt interrupted for a few kilometers. The Ganges alluvium at this place lies directly in front of the overthrust Nawakot nappes.

In this volume the Siwaliks are dealt with in general terms only, since a full detailed description will be given in volumes nr. 3–5.

The Main Boundary Thrust has a tectonic definition which does not say anything about the formations on either side of it. It is a thrust-fault and partly a thrust-plane, along which the older formations are thrust over the Siwalik series. For long distances in Nepal, the Main Boundary Thrust is identical with the front of the overthrust nappes. In Nepal, the nappes directly adjoin the Main Boundary Thrust for a distance of 250 km (plate 6). This is the case for the Nawakot nappes between the sections of Piuthan and Dharan. West of the Piuthan section, the schuppen zones of Piuthan and Dailekh (plate 6) are adjacent to the Main Boundary Thrust. It has been mentioned in the chapters on the individual tectonic units, that in places they reach the Main Boundary Thrust with a considerable angular discordance.

According to the investigations of Medlicott and Middlemiss the Main Boundary Thrust was considered to be not only the front of the overthrust nappes and the outcrop of the basal thrustplane, but also the primary northern boundary of the Tertiary Siwalik formations. This means that during the Tertiary period it was the primary boundary between the southern foot of the mountains and the fans of the Siwalik material.

Arnold Heim has again and again postulated the theory for the Siwaliks of an old eroded land surface, onto which the advancing nappes would have been overthrust as "relief thrusts". According to the investigations of the present author, it is probable that the Siwalik formations reach far to the north underneath the overthrust nappes. Consequently, the present outcrop of the Main Boundary Thrust cannot be considered as the primary northern limit of the Tertiary Siwalik formations. The interpretation of A. Heim thus appears to be proved in some areas of Nepal. The Siwalik formations consist of detrital material of the enormous thickness of 5–6 km. The material is composed of sandstones, clays, marls and conglomerates. The rocks of the Siwaliks show great similarity to the detritus still being brought down by the rivers from the Himalayas today. With very few local exceptions (tectonic repetitions), this thickness of 6 km belongs to one single normal succession.

The lithological features of the Siwaliks indicate the origin of the formations. The very thick Middle Siwalik sandstones are the weathered and eroded detritus of the crystalline nappes (Kathmandu nappes, Khumbu nappes and Hiunchuli nappes). One finds in this sandstone the same mineral components as in the crystalline masses of the nappes, namely felspar, quartz, muscovite, biotite, hornblende, tourmaline, magnetite, garnet, kyanite, epidote, rutile and zircon. There are zones in the Nepalese Siwaliks, where the Middle Siwalik sandstone surprisingly takes superficially the character of a granite.

The Siwaliks in general hold the same position as the Molasse in the Alps. They are of Tertiary age, and range from upper Oligocene to lower Pleistocene.

Medlicott and Middlemiss created the three main divisions of the Siwaliks, namely Lower, Middle and Upper Siwaliks.

The former interpretation of the Siwaliks as being the scree fans deposited at the junction of the old rivers with the Ganges trough, has partly to be abandoned. The lower and middle Siwaliks show such a homogenity in all directions, which does not allow of this interpretation. The threefold lithological division into lower, middle and upper Siwaliks continues with astonishing regularity over the whole length (900 km) of the Nepalese Siwalik zone.

In addition, the minerals of the middle Siwalik sandstones are practically unsorted; both composition and texture suggest rapid sedimentation. Apparently the Siwalik rivers brought an enormuos quantity of material from the Himalayas in a very short time. Large areas of the Siwalik formations do not even show any bedding, but consist of large monotonous masses. It is sometimes very difficult to find any stratification in the masses of the middle Siwalik sandstones, or to recognize any dip. The aerial photographs provide much better information about the Siwalik structures in such cases.

It is astonishing that after more than 100 years of research in the Siwaliks, no better detailed stratigraphic subdivision is available. Undoubtedly this has been caused by the extremely poor stratigraphic differentiation within the three main groups. The fauna of the Siwaliks is very rich, but unless the findings can be identified with typical lithological horizons, the fossils cannot serve to determine finer divisions*. It is to the credit of Pilgrim, that he laid down the basis of Siwalik geology by evaluating a system with fossils (the main fossils are elephant bones), which range from lower Pliocene to upper Pleistocene.

For the reasons mentioned above, the investigations of the author in the Siwaliks also do not throw much new light on the stratigraphy. The Siwaliks zone was investigated only in the course of the general survey of Nepal and the author was glad simply to make use of the three clearly defined lithological divisions of the Siwaliks. In view of the enormous task of surveying the whole country, no additional time was left for special research on fossils. Attention was given to the structures of the Siwaliks, since this seemed to be essential with regard to possible petroleum prospecting.

In the following lines only the main pattern of the Nepalese Siwaliks will be dealt with.

From the tectonic point of view, the Siwaliks can be divided into two zones, a) the *thrust Siwaliks* and b) *the folded Siwaliks*. This corresponds with the Molasse of the Alps, where we also have a "thrust molasse" and a "folded molasse" (see profile plate 5). In the Alps there is in addition, the undisturbed molasse of the Swiss Midlands beyond the folded molasse. A corresponding zone of the latter is not exposed in Nepal, but it nevertheless exists and is undoubtedly buried under the Ganges alluvium.

The "thrust" Siwaliks are found along the Main Boundary Thrust. The thrusting of course cannot be compared with the nappes as the Siwalik thrusts are of minor magnitude. Also "thrust" Siwalik formations are not found along the whole Main Boundary Thrust, but are restricted to some localities.

The folded Siwaliks join the thrust part to the south. The structure is characterized by broken anticlines and synclines; it is very typical that the anticlines do not show a normal culmination, but have the beds erected to a perpendicular position in the axis of the anticlines. Thus, the Siwalik anticlines are of the same cuspate type as the structures in the molasse of the Alps (compare profile of the Alps, plate 5).

Also the folded Siwaliks do not extend throughout the whole Siwalik zone from east to west, but are limited to some special sections, in which the Siwalik belt is wider. The structures decrease to the south and gradually develop into flat upwarps and basins.

One main anticlinal structure seems to strike through nearly the whole country from east to west, since the most southern Siwalik hills show a dominantly northern dip. The valleys are therefore mainly isoclinal valleys, with a preferred east–west strike.

We do not know how far the Siwaliks zone extends to the south underneath the Ganges alluvium. In the Swiss alps, the Molasse fills the whole Midland basin and extends at some places even onto the Jura mountain ranges, which gives a total width of 150 km. In Nepal, the widest Siwalik zone is exposed in the sections of Dang and Chitawan of about 60 km each. We may conclude, that the Nepalese Siwalik zone has a magnitude which at least compares with the Alpine molasse, but probably exceeds the latter considerably. Thus the Siwalik formations continue underneath the Ganges alluvium for at least 90 km, in the sections where a broad belt is exposed on the surface. On the average, the exposed Siwalik belt is only 20 km wide. The extension of the Siwalik formations in the bottom of the Ganges trough is thus at least 130 km at places.

Let us now try to describe some important features of the Siwaliks from east to west. The names of villages and rivers may help us to understand the text. The profiles are numbered according to the complete system of numbers of the profiles by the author, which include 96 profiles from the Ganges plain to the Tibetan plateau. The following figures are just a selection and the whole range of profiles will be given later on in Volume number 3–5.

* In the past 2 years, the newly established Oil and Natural Gas Commission of India has started comprehensive research on the Siwaliks. The results already obtained look very promising.

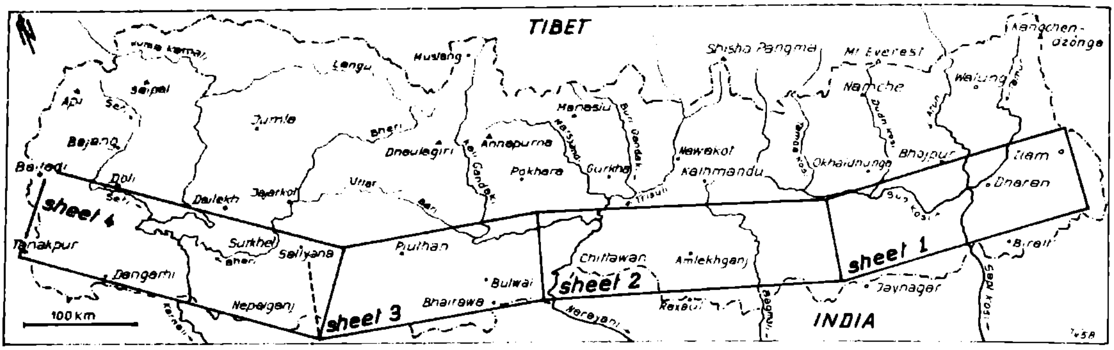



Fig. 82 Index map to the geological maps of the Siwaliks

### *B) Regional description*

Eastern Nepal

The influence of the Siwalik zone on the landscape has already been referred to in chapter 1. The Siwalik zone—or briefly the Siwaliks—form a belt between the Ganges alluvium and the Main Boundary Thrust of about 20–25 km average width. At one locality only, near Dharan in eastern Nepal, are the Siwaliks interrupted for a few kilometers; they disappear entirely in that area and the Ganges alluvial plain directly adjoins the Main Boundary Thrust. The Siwaliks show their maximum width of 52 km in the meridian of Dang, in western Nepal. We now shall deal with the Siwaliks, beginning in the east at the Sikkim border (figs. 83, 84 and 90).

The Siwaliks begin in a narrow belt at the eastern border of Nepal. Towards the west, exposures of the Middle Siwalik sandstones increase quickly to about 5 km width. In the area of the Kankai Khola, the Middle Siwaliks reach fairly far south, and attain a width of about 20 km between Ganjabari and the Bagra Khola, south of Danabari.

The general strike, as well as the structures, shows some particular features in this area. In general, the strike is directed towards the south-east, which has given that direction to the Kankai Khola. An anticline strikes through Ganjabari in a northerly direction, slightly curved convexly towards the west. A local syncline with a south-east strike is found north and north-east of Danabari. An anticline lies north of this syncline with axis in the same direction (fig. 90). In the west, near the Bagra Khola, the strike turns due south. Near Phungnangthar, which is situated on the Main Boundary Thrust, a new anticline with due east strike appears, but owing to the axial pitch, this anticline disappears eastward underneath the overthrust Khumbu nappes.

On the opposite side, toward Kherwa, the anticline of Phungnangthar decreases, and continues in the form of two local minor thrusts on either side of the anticlinal axis. The northern thrust remains entirely in the Middle Siwaliks, while the southern one strikes beyond the Siwaliks into the Ganges alluvium. It has caused the famous Siwalik thrust over the Ganges Alluvium, which has been described by the author in a preliminary paper (Hagen 1956). The sandstones of the Middle Siwaliks are hereby thrust along a clear cut by about 15 m over the topmost recent Ganges alluvium.

Between Bagra Khola and Dharan, the strike of the Siwaliks shows a slight bend towards the north-west, and near Dharan, the Middle Siwalik sandstones disappear at an angular unconformity beneath the overthrust Nawakot and Kathmandu nappes. For about 2,5 km, no Siwalik zone at all is exposed which is quite exceptional for the whole country; the front part of the nappes has advanced right down to the alluvial plain of the Ganges (plate 6).

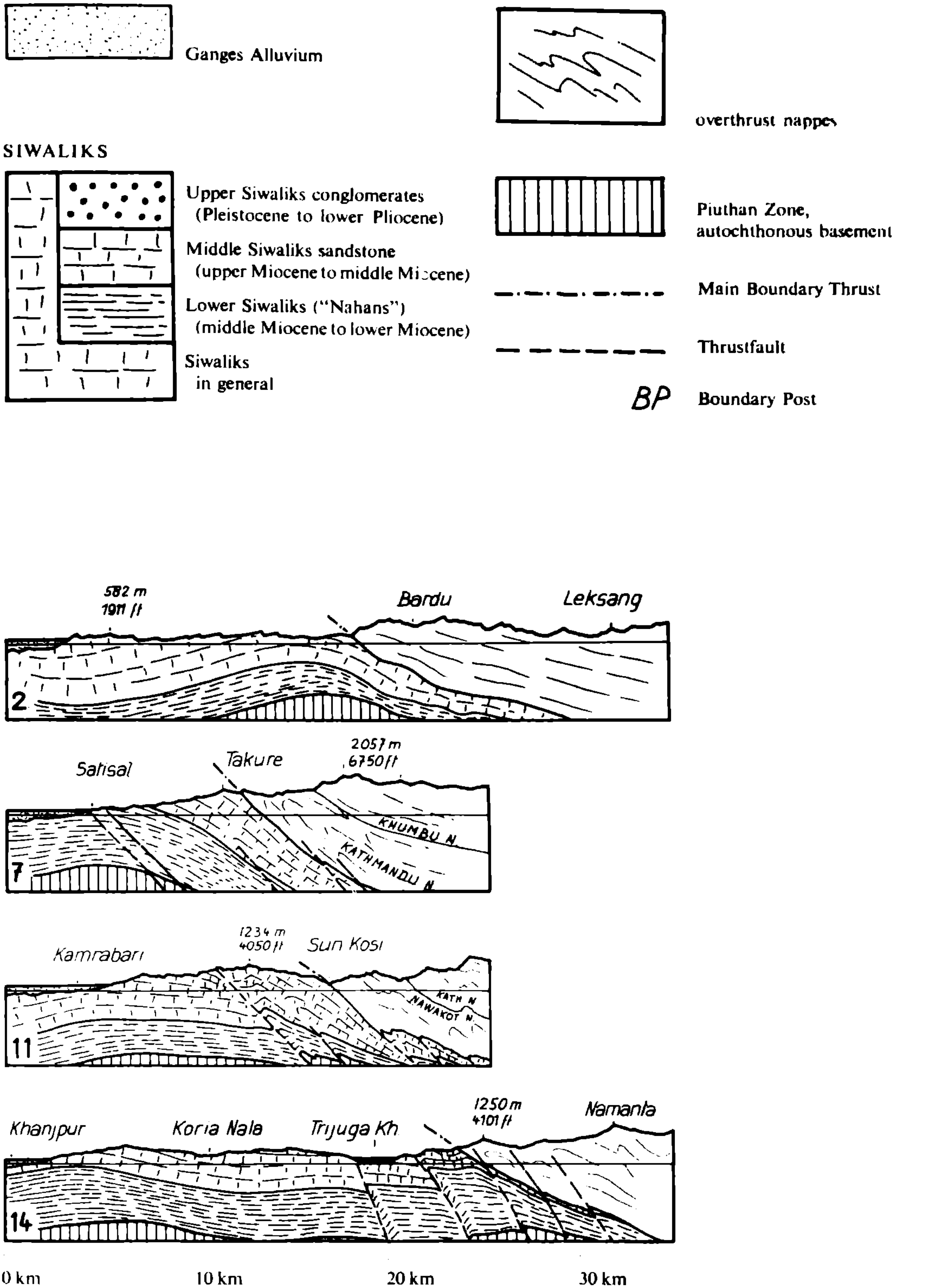



Fig. 83 5 profiles through the Siwaliks in Eastern Nepal Scale 1 : 300000

The Siwaliks reappear again west of Dharan, with a strike which appears to be turned slightly towards the west. The zone of interrupted Siwaliks thus coincides with some underground structures. A further break of strike can be recognized west of the Sapt Kosi; the strike is directed westwards between the Sapt Kosi and the lower course of the Trijuga Khola.

West of the Sapt Kosi, the Siwalik zone becomes suddenly wider again and reaches 30 km. However, structures in the Siwaliks do not appear before the section of Namje-Birnagar. East of Birnagar, a gentle anticline structure strikes with a slight curve towards the east. A syncline structure with south-east strike is found between Betaha and Lalpatta. In the same section, for the first time (proceeding from the east) the brown shales of the Lower Siwaliks are exposed in a local overthrust (fig. 84, profile 18).

A transverse structure strikes in a south-south-east direction through Namje (fig. 90). It is a transverse fault, in which the eastern side is transposed to the south. At the same time, the edges of the thrust fault are bent into a broken anticline in the northern part of the structure.

The transverse structure of Namje is of greater importance than may appear in a brief glance. In addition to the Lower Siwalik shales the upper Siwalik conglomerates also occur for the first times in this section. They are exposed in the Mahamanda Danda, the range south of the Tawa Khola (fig. 84, profiles 24–33).

Another transverse structure with southerly strike is found further west, near *Tintale* (fig. 90). A transverse transposition was not recognized at this locality; however the edges of the fracture are also warped up into a broken anticline.

New Siwalik structures suddenly commence to the west of the Tintale fault, especially in the zone adjacent to the Main Boundary Thrust (fig. 90). Two anticlines are exposed, and in the northern one Lower Siwalik shales occur. Northwest of Tamarni, a local syncline was found (fig. 90).

Further, the Siwalik zone narrows in the Tintale transverse structure abruptly from 30 km width to only 18 km. An anticline 50 km long commences at Lalpatta; this anticline caused the Dun valley of the Kamla river (fig. 90 and plate 6).

The geological situation on the southern border of the Siwaliks and west of the Kamla river is not clear, since the author has not covered that special area. It seems that the Kamla river follows a transverse structure, where it enters the Ganges plain, since west of the river, the Siwaliks seem to be transposed to the south abruptly (fig. 90).

The Main Boundary Thrust shows in eastern Nepal some interesting features. Northwest of Batase (fig. 90), the Sun Kosi river enters the Main Boundary Thrust, and follows it for about 3 km, but then turns north-east and re-enters the Kathmandu nappes (plate 6). Near Bangring, the Sun Kosi leaves the overthrust Nawakot and Kathmandu nappes again and follows the Main Boundary Thrust more or less as far as Kurule (fig. 90). At this place the river again enters the nappe zone. Only near Chatra, the river (now named Sapt Kosi) finally breaks through the Siwaliks to the south (fig. 90).

Thus, between Batase and Bangring, the overthrust Nawakot—and Kathmandu nappes form a "semi-outlier" (Halbklippe) on the Siwaliks. The formations of the Nawakot and Kathmandu nappes have been preserved from erosion by their position in the Mahabharat syncline, which strikes at a considerable angle out of the nappes across the Main Boundary Thrust into the Siwaliks. The Mahabharat syncline in a proper sense terminates here on the Siwaliks and only reappears again east of the Arun river, but is there considerably transposed to the north (fig. 90). In the area between Batase and the Arun, only minor synclinal structures represent the Mahabharat syncline which is so large elsewhere.

In a limited area, east of the Arun and near Dharan, the strike in the overthrust nappes is directed parallel to the Main Boundary Thrust and the Siwaliks. East of these areas we again find an extraordinary angular-discordance between the Kathmandu-Khumbu nappes and the Siwaliks (fig. 90). Near Andheri, the Kathmandu nappes terminate (finally) on the Main Boundary Thrust and also the overlying Khumbu nappes with their south-south-east strike meet the Main Boundary Thrust at an

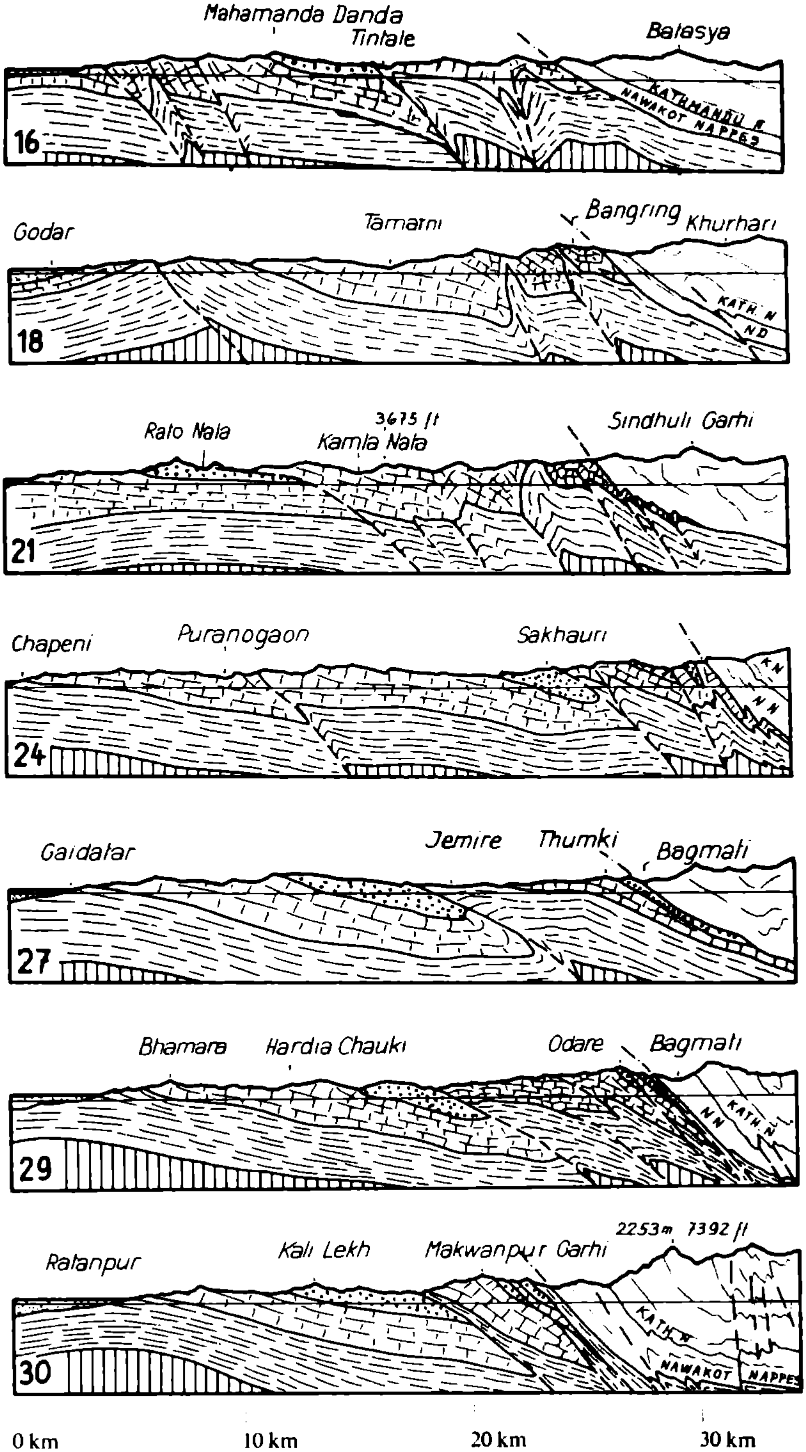



Fig. 84 7 geological profiles of the Siwaliks in eastern Nepal angle. Only from Phungnangthar onwards to the east, the overthrust Khumbu nappes strike more or less parallel to the Siwaliks.

Between Phungnangthar and east of the Kankai river the Khumbu nappes again strike at an angle to the Main Boundary Thrust. A cross point of a normal west-east anticline and a transverse north–south structure is found near Langling, where the Kankai river enters the Main Boundary Thrust (fig. 90). The transverse structure does not continue into the Siwaliks.

East of Langling there are further transverse structures in the nappes, which meet the Main Boundary Thrust at nearly a right angle (fig. 90). Most of these structures do not continue beyond the Main Boundary Thrust into the Siwaliks. Only the Gangabari anticline traverses the Main Boundary Thrust and enters the Siwaliks.

Generally speaking, the Siwaliks in eastern Nepal can be divided in four distinct sections. The most easterly section, between the Sikkim border and Phungnangthar is characterized by a dominant south-south-east strike of the Siwaliks and a similar strike in the nappes, but by transverse structures confined to the nappes. Only the most easterly anticline in the nappes crosses the Main Boundary Thrust into the Siwaliks. All other transverse structures in the nappes end on the Main Boundary Thrust.

Probably the transverse anticline of the Kankai river corresponds to the southern extension of the great Telok transverse structure, which borders the eastern flank of the tectonic window of Angbung.

In the section between Phungnangthar and Dharan, structures in the overthrust Kathmandu and Khumbu nappes were not recognized. Instead the strike of the nappes forms an angle with the Main Boundary Thrust near Andheri.

The section between Dharan and the Namje transverse fault, is characterized by the lack of structures in the Siwaliks. The semi Klippe of the overthrust Nawakot and Kathmandu nappes near Batase suggests a relief-overthrust, because the strike of the beds in the Siwaliks does not coincide with the thrustplane at the base of the nappes. The nappes have undoubtedly been thrust over an eroded surface.

The abrupt widening of the Siwalik zone between the Namje fault and the Sapt Kosi gives reason to the adoption of the theory of uplift of this area "en bloc" (as a whole). It is not very difficult, to correlate this uplift with the huge Arun anticline in the north. West of the Namje fault, all the structures and beds on either side of the Main Boundary Thrust are more or less parallel. The "pushing" forces were apparently directed equally towards the south-west. In the section Dharan-Phungnangthar, however, the cross-structures can easily be interpreted in terms of two different directions and phases of mountain building; the nappes were first thrust over in a west-south-west direction and in a subsequent phase, the Siwalik structures were created with an west–east strike. Forces in this phase must have been directed southward and, in this same phase, parts of the fronts of the nappes were pushed further south over already eroded surfaces of the Siwaliks.

In this same area of the Sapt Kosi, crustal movements are still active. The Siwalik overthrust upon the recent Ganges alluvium near Kherwa has been mentioned. Near Dharan, the whole Ganges alluvium has been uplifted from 200 m to 400 m at the foot of the hills. Owing to this uplift during the past 100 years, the course of the Sapt Kosi has been deflected. Originally, this big river flowed straight south from the gorge in which it enters the plain but owing to the upheaval of the Ganges plain near Dharan, the river was deflected westward every year, causing the wellknown damage during heavy monsoon rains.

It must be mentioned that further southeast near Kanchanpur in the Ganges plain, isolated terraces have been found. It is in this same area, that Professor W. Filchner recognized great anomalies in his magnetic survey. There is no doubt that crustal movements are still going on in this area, and that structures are buried underneath the Ganges alluvium. This may be of importance with regard to possible petroleum deposits.

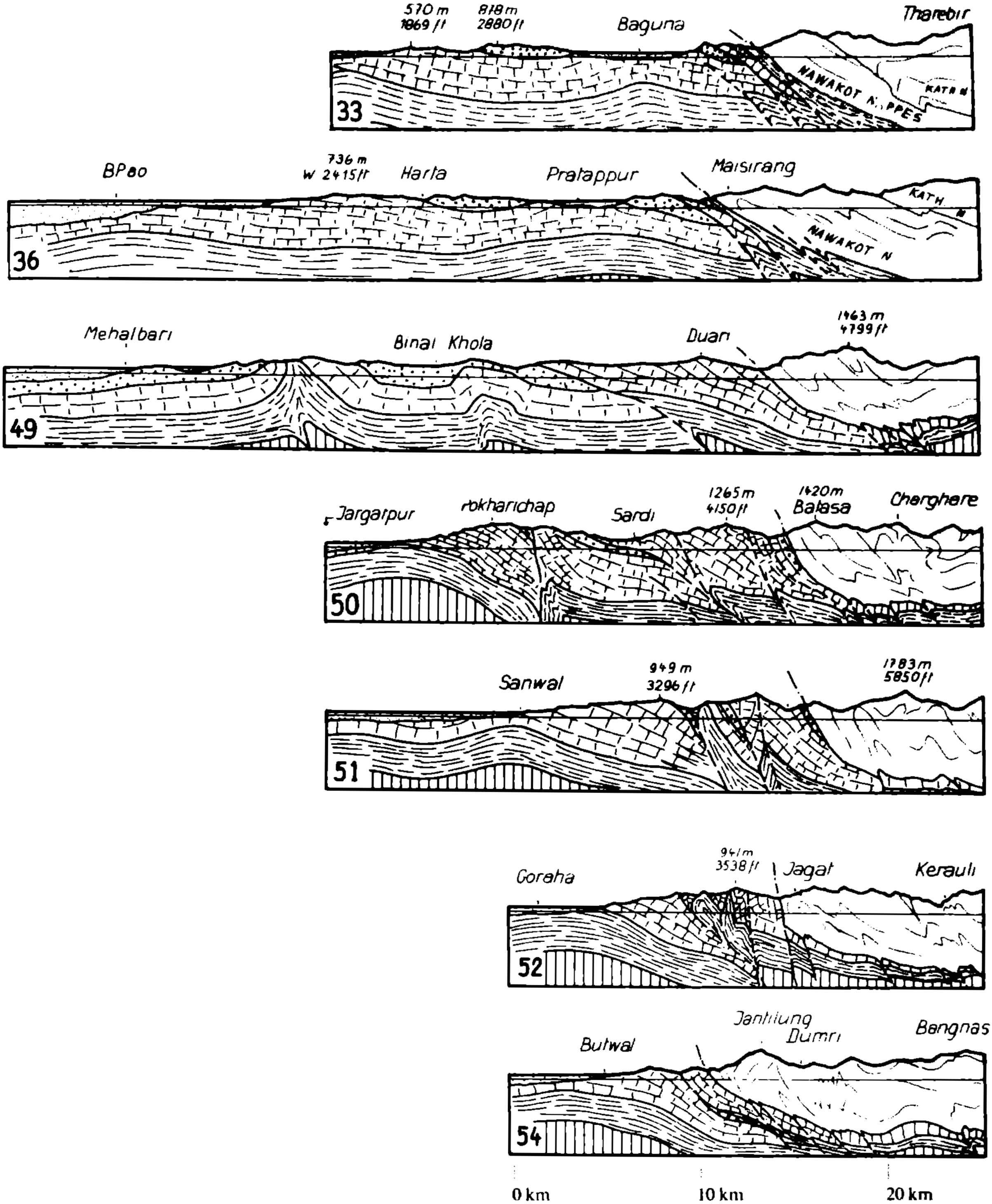



Fig. 85 7 geological profiles of the Siwaliks in central Nepal

In connection with youngest crustal movements, we may further ask, why the Sun Kosi near Batase does not continue its southern course into the Ganges plain (fig. 90). The Batase pass elevates the river bed by not more than 400 m. It seems perfectly possible that the Sun Kosi originally flowed across the Batase pass, and then later on by a sub-recent uplift of the Siwaliks was deflected towards the east. Finding of river gravels originating from the northern nappes in the Trijuga valley south of Batase, would easily confirm this theory. The author, owing to lack of time, was not in a position to visit the lower part of the Trijuga valley.

Proof of recent upheaval of the Siwaliks was found a little west of this place. This arose in the stream which drains the valley at the southern flank of the Siwaliks near Muksar. In 1955, large boulders of crystalline rocks of the Kathmandu nappes (gneisses, granites) were found on the southern flank of the Siwalik range. These crystalline formations do not occur in the Siwaliks, but originate further north beyond the watershed of the Siwaliks. Thus the Muksar river must some time ago have originated north of the Siwaliks, in the crystalline masses of the Mahabharat range. A recent or sub-recent upheaval of the Siwalik range must have blocked this river, and must have deflected its upper course westward to Tintale.

Central Nepal (map fig. 91)

This zone of the Siwaliks is characterized by a number of structures in the normal east–west strike; by an increase of the Upper Siwaliks and the Lower Siwaliks, and by a considerable divergence of the structures west of Hitaura. The divergence has caused the vast Dun valley of Chitawan and further structures in the south. Especially in this section the overthrust Siwaliks are increasingly important (fig. 85, profiles 49–51, fig. 86, profile 65).

The strike and the structures in the overthrust nappes are parallel to the Siwalik strike. Transverse structures are lacking in the overthrust nappes as well as in the Siwaliks. The mountain building forces were apparently directed uniformly towards the south-west.

I want to point out especially, that the nearest nappe zone to the north, is marked by a considerable convergence of the structures in the nappes (plate 6). The Siwaliks are closest to the Kathmandu roots in this section, namely not more than 45 km from Chitawan to Himalchuli (plate 6). The nappes adjoining the Siwaliks in this central Nepal portion belong entirely to the Nawakot group. There is no doubt that the many kilometers thick Siwalik formations of the Chitawan have acted as a rigid block during the late movements in the Midlands. The then already overthrust Nawakot nappes were folded in front of the Chitawan block and the Siwalik block itself was pushed as a whole to the south, creating further Siwalik structures in front of it (south).

West of the Narayani river the Chitawan Dun narrows very quickly (fig. 92). Near Butwal, the Siwalik zone is only represented by a uniform narrow belt of Middle Siwalik sandstone, perhaps repeated by a thrust-fault.

New structures commence again west of Ratomate (figs. 92 and 86, profile 56). There is a broken anticline (cuspate) between Ratomate and Manbarre. Parallel to it, further south, strikes the large syncline of Harrebarre. Northwest of this locality, the structures diverge and their number increases (figs. 92 and 86, profiles 64–69).

The large Rapti Dun opens to the west, into the Ganges plain (this Rapti is not to be mixed with the Rapti river in the Chitawan, south of Kathmandu). On the southern flank of the Rapti Dun, great masses of Upper Siwalik conglomerates occur (fig. 92). Near Bangesal, even a Siwalik thrust can be recognized; light coloured Middle Siwalik sandstones are thrust in the form of a half circle onto Upper Siwaliks.

The mountain range which borders the Rapti Dun to the north, is built of a great broken anticline, with perpendicular beds in the axis (fig. 92). Lower Siwaliks occur in two separate belts, in the axis of the broken anticlines (fig. 86, profile 62).

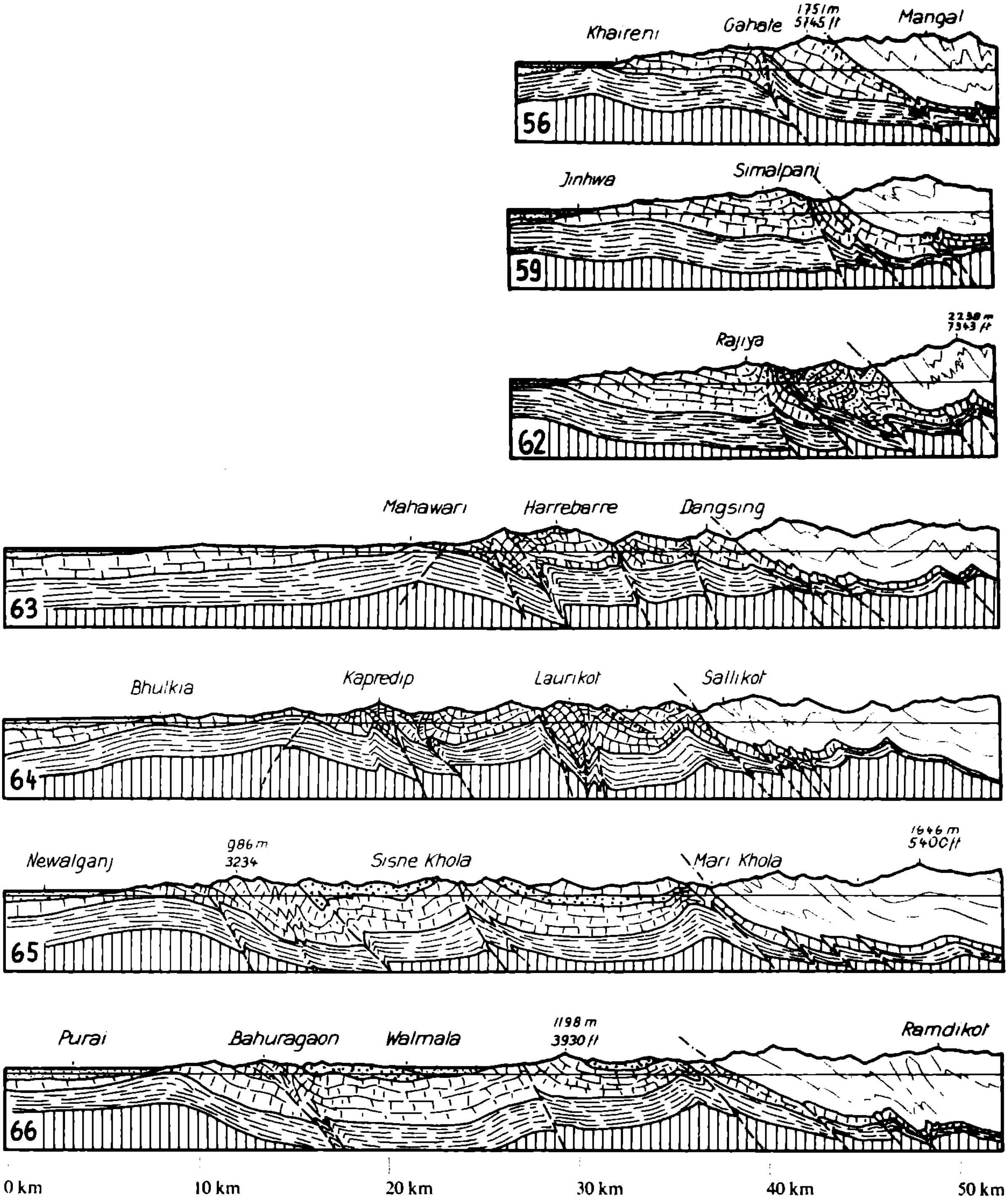



Fig. 86 7 geological profiles of the Siwaliks in western Nepal

In the section, in which the Rapti Dun measures its greatest width of 10 kilometers, the Dang Dun begins further north (plate 6). The Dang Dun is 70 km long and at most 17 km wide. The Siwalik zone is only exposed in a very narrow belt at the northern rim of the Dang Dun. In some places the Piuthan schuppen directly adjoin the Main Boundary Thrust (fig. 92). The structure in the bottom of the Dang Dun seems in general to be an anticline (fig. 87, profile 71). Upper Siwalik conglomerates with southerly dip occur on the southern flank of the Dang valley, while the Middle Siwaliks of the northern flank dip north, parallel to the Main Boundary Thrust.

Different from the other Duns (Chitawan, Rapti), the Dang Dun is at the higher level of 600 m above sea level (compared with an average of 200 m for the other Duns).

We have seen in central Nepal that the strike on both sides is more or less parallel with the Main Boundary Thrust. This changes west of Manbare (fig. 92) and it is certainly not just incidental, that these variations coincide with the western termination of the Nawakot nappes (plate 6). As described in the foregoing chapters, the Nawakot nappes pass gradually westward into the Piuthan zone. The upper Mesozoic-Tertiary schuppen of the Piuthan zone show both strike and structures which are directed due west. Since the Main Boundary Thrust strikes south-east, there is an angular discordance with the Main Boundary Thrust.

The strike on either sides of the Main Boundary Thrust is normal again between Bangesal and the eastern end of the Dang Dun (fig. 85). In the eastern part of the Dang Dun however, the angular discordance appears again along the Main Boundary Thrust. The Piuthan schuppen strike west, while the Main Boundary Thrust and the Siwaliks show north-western directions. When standing on the Mahabharat Lekh of that area, north-east of the Dang Dun, and looking toward west along the strike of the Piuthan schuppen, those schuppen appear to be directed into the Dang, and to be cut laterally by the Main Boundary Thrust. In general, this section between Manbare and Dang with its numerous anticlines, synclines and lateral transpositions of the axis shows great similarity with the structure of the Jura mountain range in Switzerland. The anticlines of the Siwaliks with the broken top, are not however of the soft Jura type. They are characteristic of the structures in the Alpine molasse too.

Western Nepal

We have noted above that the Rapti Dun opens towards the west into the Ganges plain. The southern Siwalik range pitches into the alluvium east of Nepalganj. The lower part of the Rapti valley is an isoclinal valley (fig. 93).

Quite a number of structures commence from the western portion and termination of the Dang Dun (plate 6). Long-range main structures are lacking but there are a number of minor transposed structures. In the area of the Sarda river, the structures are entirely built of Middle Siwalik sandstones; further west, some Lower Siwaliks are exposed in the broken anticlines (fig. 92).

Between Chuchekanda and Garbha, the transverse structures increase in magnitude. The strange flexure of the Thuli Gad is caused by such transverse structures (fig. 92).

West of Garbha, a thrust Siwalik zone is built by northerly dipping Upper Siwalik conglomerates. These conglomerates pass up gradually into recent alluvial gravels and boulderbeds. The alluvial cover shows the same northerly dip as the underlying Upper Siwaliks. The tilting must therefore be considered to be very recent (fig. 89, profile 95).

The most striking proof of recent crustal movements has been found in this area in western Nepal. It is the overthrust of Siwalik formations over the recent Ganges Alluvium of a magnitude far exceeding the Kherwa thrust in eastern Nepal (fig. 92). An anticline strikes north-west from Chap and turns east of *Petkot* towards the west and south-west. 3 km from Petkot, the anticlinal faulting in the axis gradually passes into a thrust-fault and overthrust. The brown shales of the lower Siwaliks and the grey sandstones of the Middle Siwaliks are thrust along a visible length of 150 m over the topmost, unconsolidated Ganges alluvium. Undoubtedly, the overthrust continues back underneath the allu-

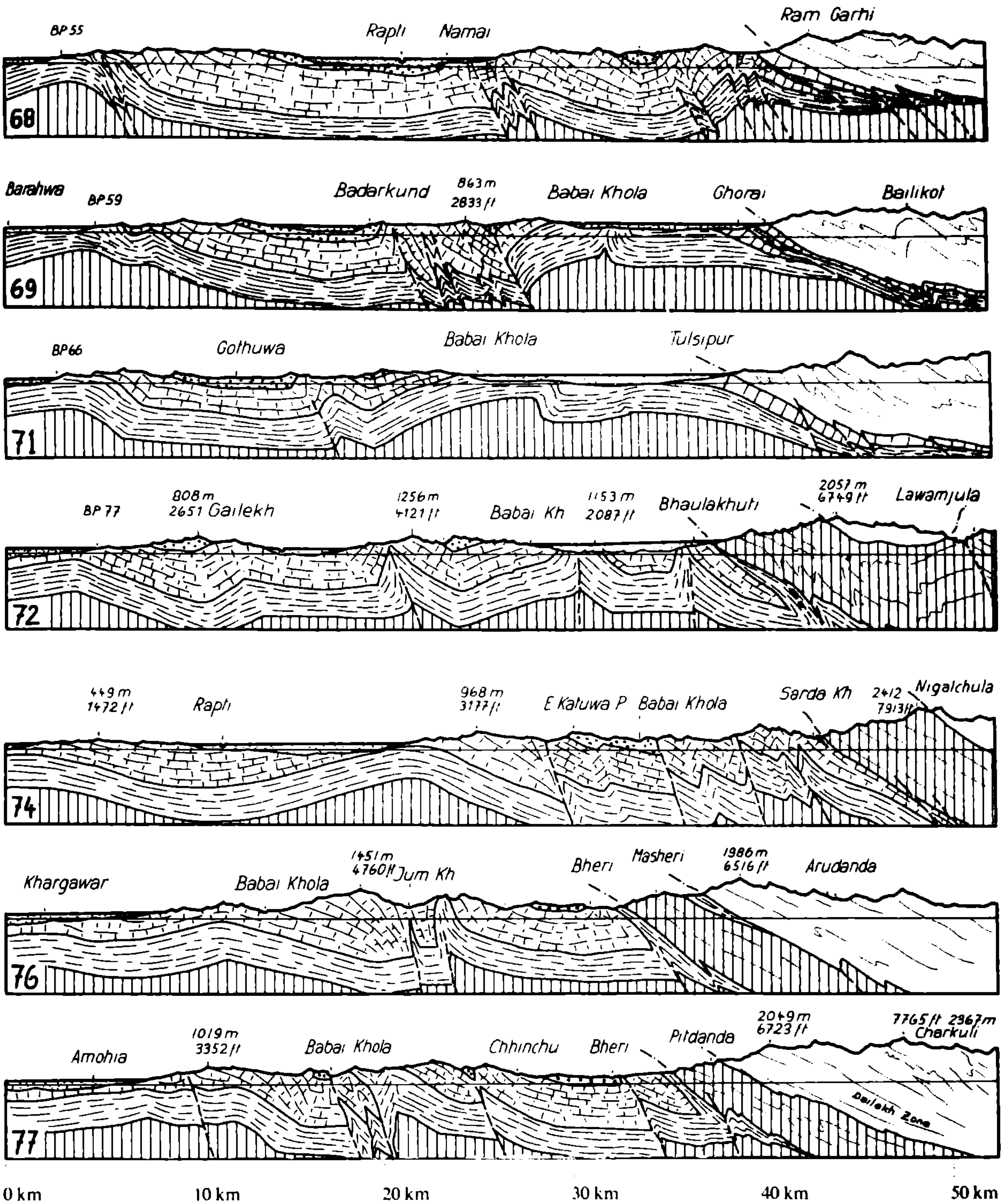



Fig. 87 7 geological profiles of the Siwaliks in western Nepal

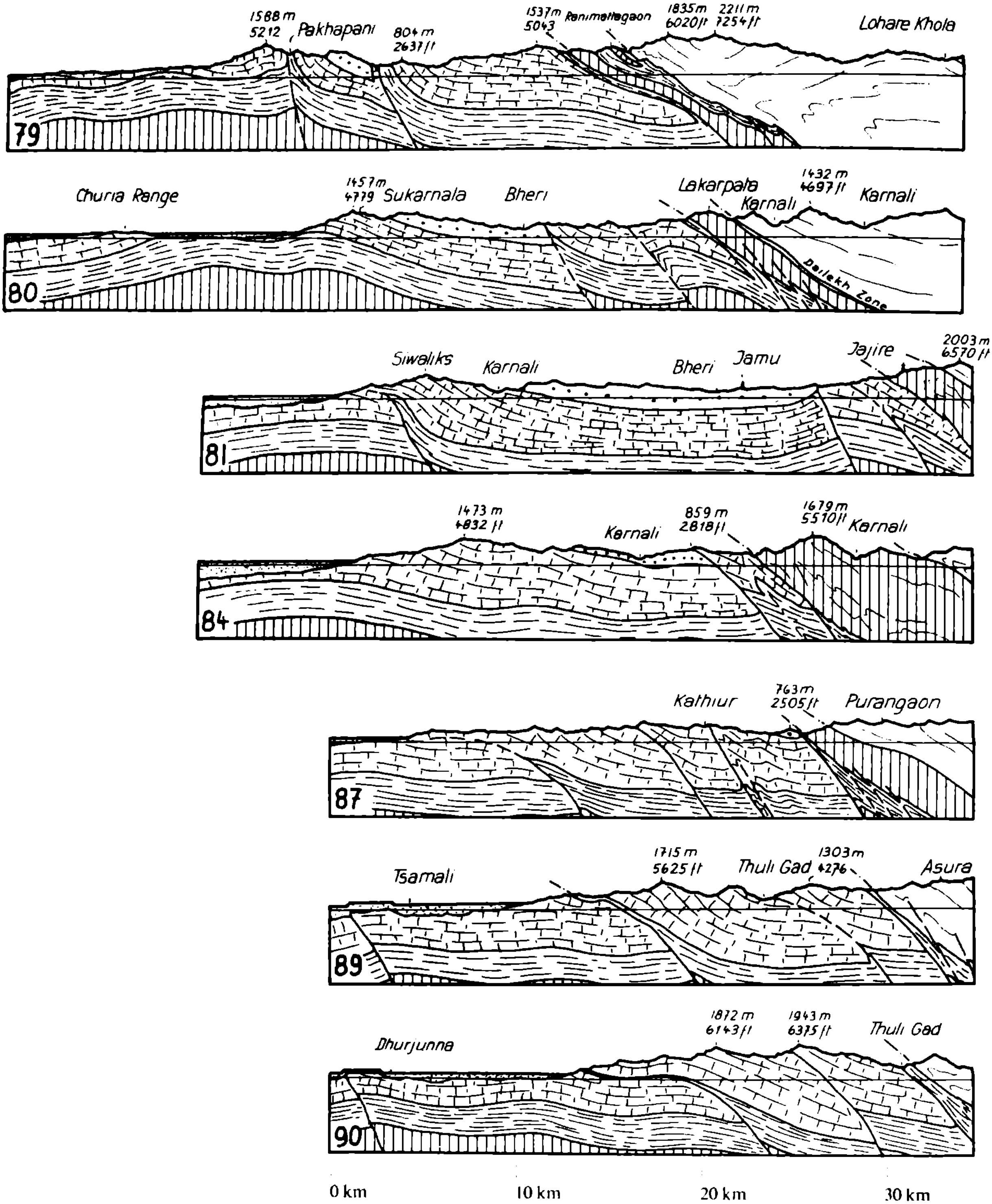



Fig. 88 7 geological profiles of the Siwaliks in western Nepal

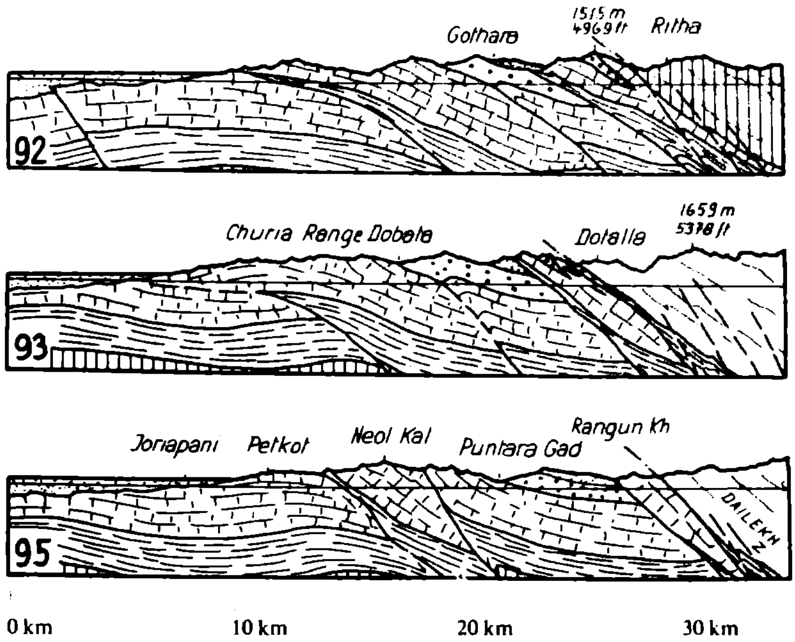



Fig. 89 3 geological profiles of the Siwaliks in western Nepal
(The overthrust of the Siwaliks over the Gangetic Alluvium concerns the thrustplane 1 km north of Petkot, profile 95. However it does not show up in this section since it lies 2 km east of Petkot).

vial filled valley at the foot of the hills. The overthrust is very well exposed in a newly eroded river (fig. 89, profile 95).

There are still other proofs of young crustal movements in the same area; between Dangarhi and Tsamali, there are a number of isolated terraces 10 km from the foot of the hills, within the Ganges plain.

The most westerly transverse structure was found through Pipal Thok, east of Tanakpur (fig. 93). The Kali Ganga (not to be taken for the Kali Gandaki in central Nepal) apparently follows a transverse structure through the Siwalik range. The structure itself is not visible, but the Siwalik range east of the river seems to be transposed to the south, compared with the western side of the Kali Ganga (fig. 93).

As a conclusion and *summary* for the Siwalik zone in Nepal, we may well separate various tectonic zones. As in the Alpine molasse, we find a thrust Siwalik zone and folded Siwaliks. The folds gradually die out southward into the Ganges plain. The overthrust Siwaliks are found close to the Main Boundary Thrust, but not continually throughout the whole length between the Sikkim border and the Kumaon border. Some further correlations with regard to the drainage pattern, will be dealt with in the following chapters.

Reconnaissance flights and photogeological studies by the author in 1961 and 1962 after the submission of the manuscript for this volume, have supplied further information on the Siwaliks. This will be given in the forthcoming volumes 3 to 5.

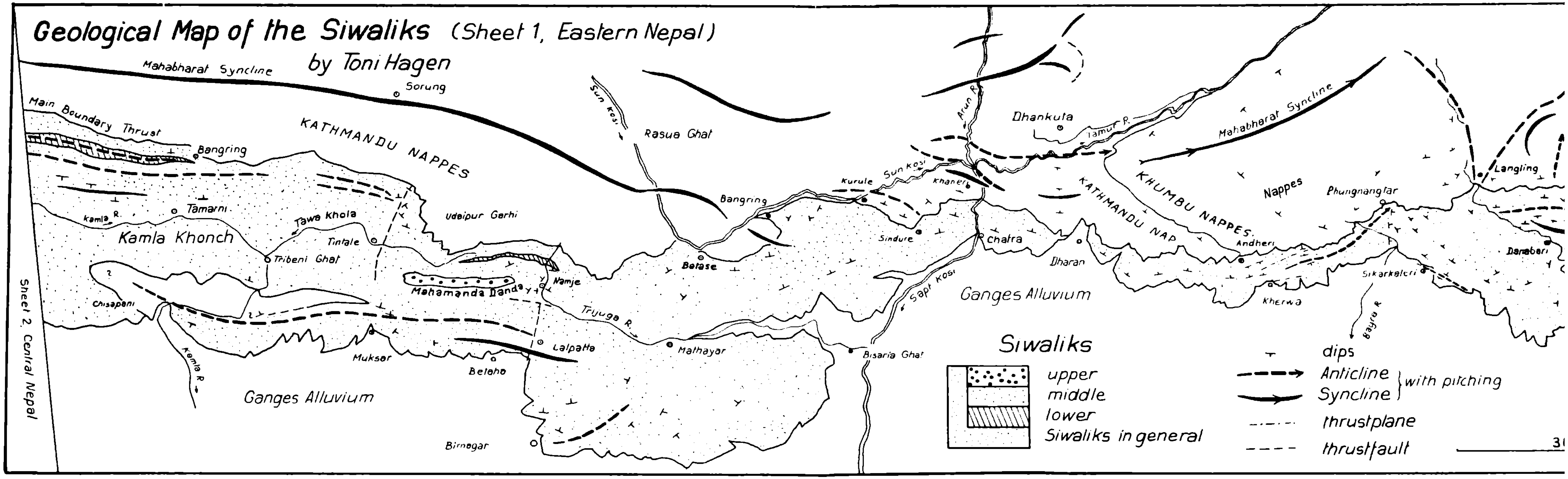
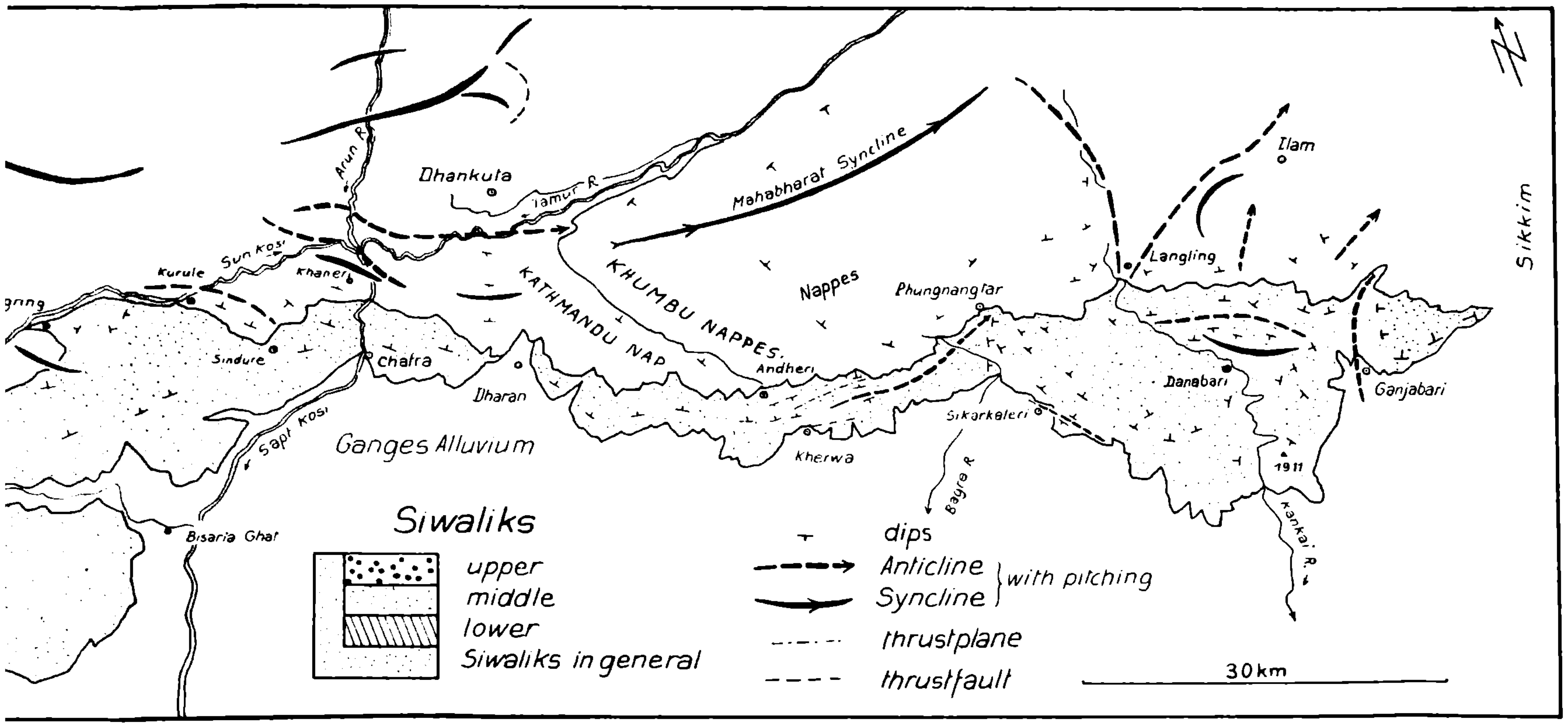



Fig. 90 Geological map of the Siwaliks (sheet 1, eastern Nepal)


Dhankuta
Arun R.
Tamur R.
Mahabharat Syncline
Ilam
Sun Kosi
Kurule
Khanei
Langling
Sikkim
Nappes
KATHMANDU NAP
KHUMBU NAPPES
Phungnangtar
Sindure
Chatra
Dharan
Andheri
Danabari
Ganjabari
Sikarkateri
Kherwa
Sapt Kosi
Ganges Alluvium
Bagra R.
1911
Kankai R.
Bisaria Ghat
Siwaliks
upper
middle
lower
Siwaliks in general
dips
Anticline
Syncline
with pitching
thrustplane
thrustfault
30km

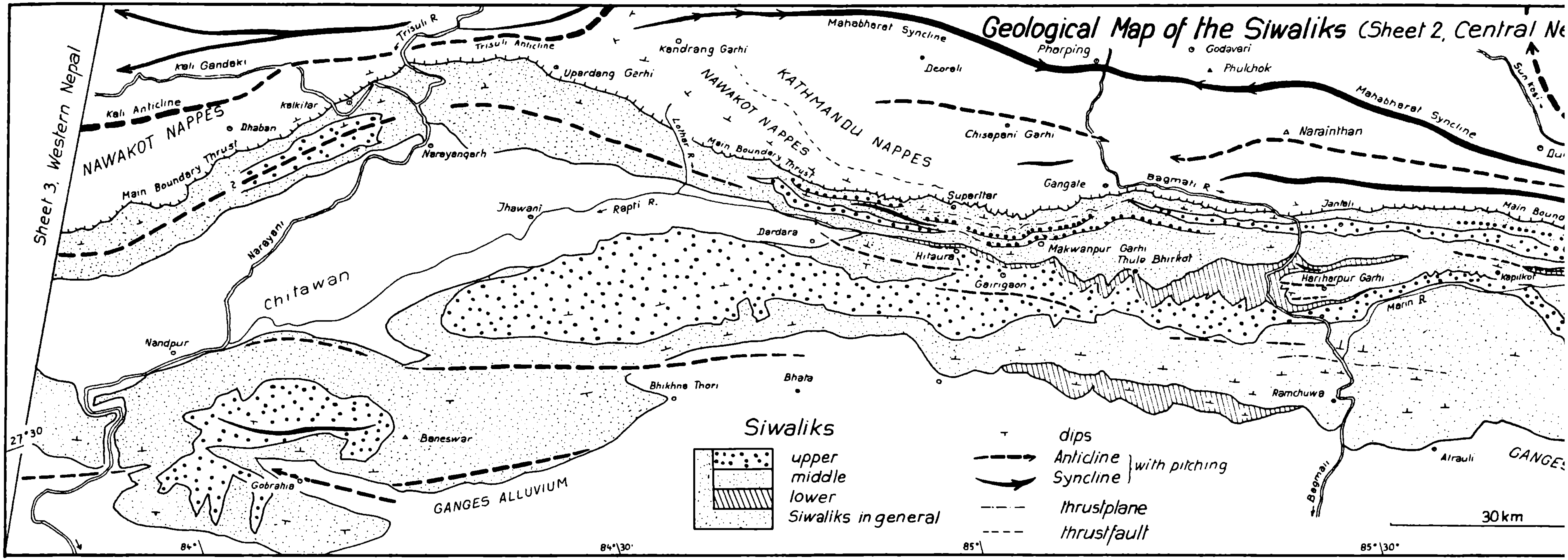
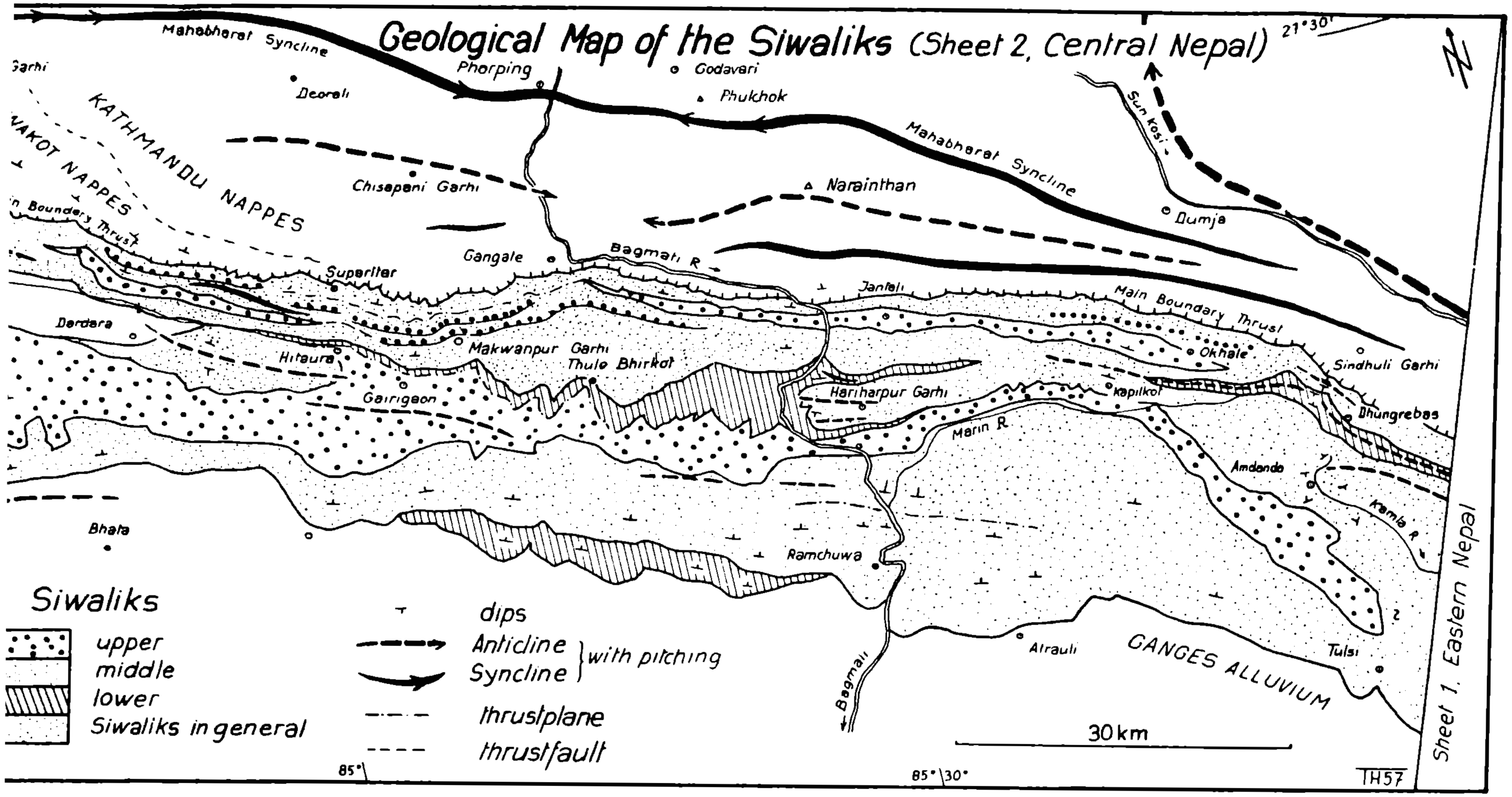



Fig. 91 Geological map of the Siwaliks (sheet 2, central Nepal)


Geological Map of the Siwaliks (Sheet 2, Central Nepal)
Mahabharat Syncline
Phorping
Godavari
Phukhok
Deorali
KATHMANDU NAPPES
NAKOT NAPPES
Chisapani Garhi
Narainthan
Mahabharat Syncline
Sun Kosi
Dumja
Main Boundary Thrust
Superiter
Gangale
Bagmati R.
Janteli
Main Boundary Thrust
Dardara
Hitaura
Makwanpur Garhi
Thulo Bhirkot
Okhale
Sindhuli Garhi
Gairigaon
Hariharpur Garhi
Kapilkot
Dhungrebas
Marin R.
Amdando
Kamla R.
Bhata
Ramchuwa
Alrauli
GANGES ALLUVIUM
Tulsi
Bagmati
Siwaliks
upper
middle
lower
Siwaliks in general
dips
Anticline
Syncline
with pitching
thrustplane
thrustfault
30 km
85°
85° 30°
TH57
Sheet 1. Eastern Nepal

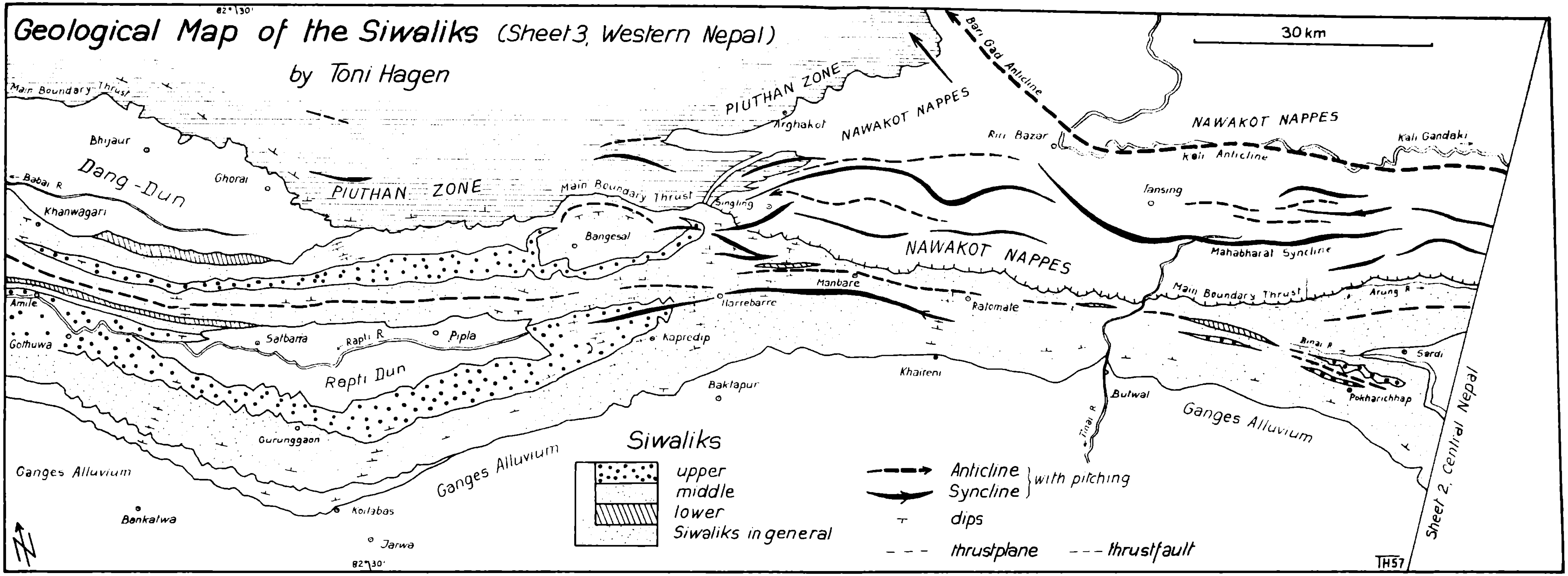



Fig. 92 Geological map of the Siwaliks (sheet 3, western Nepal)

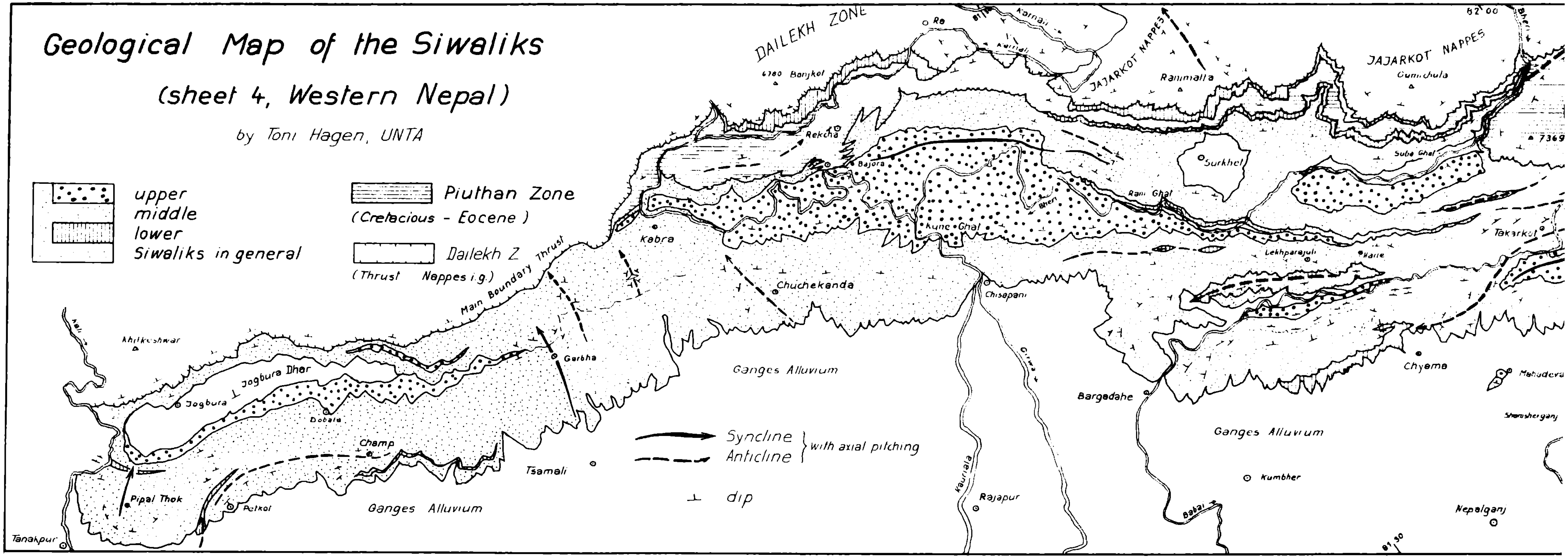



Fig. 93 Geological map of the Siwaliks (sheet 4, western Nepal)

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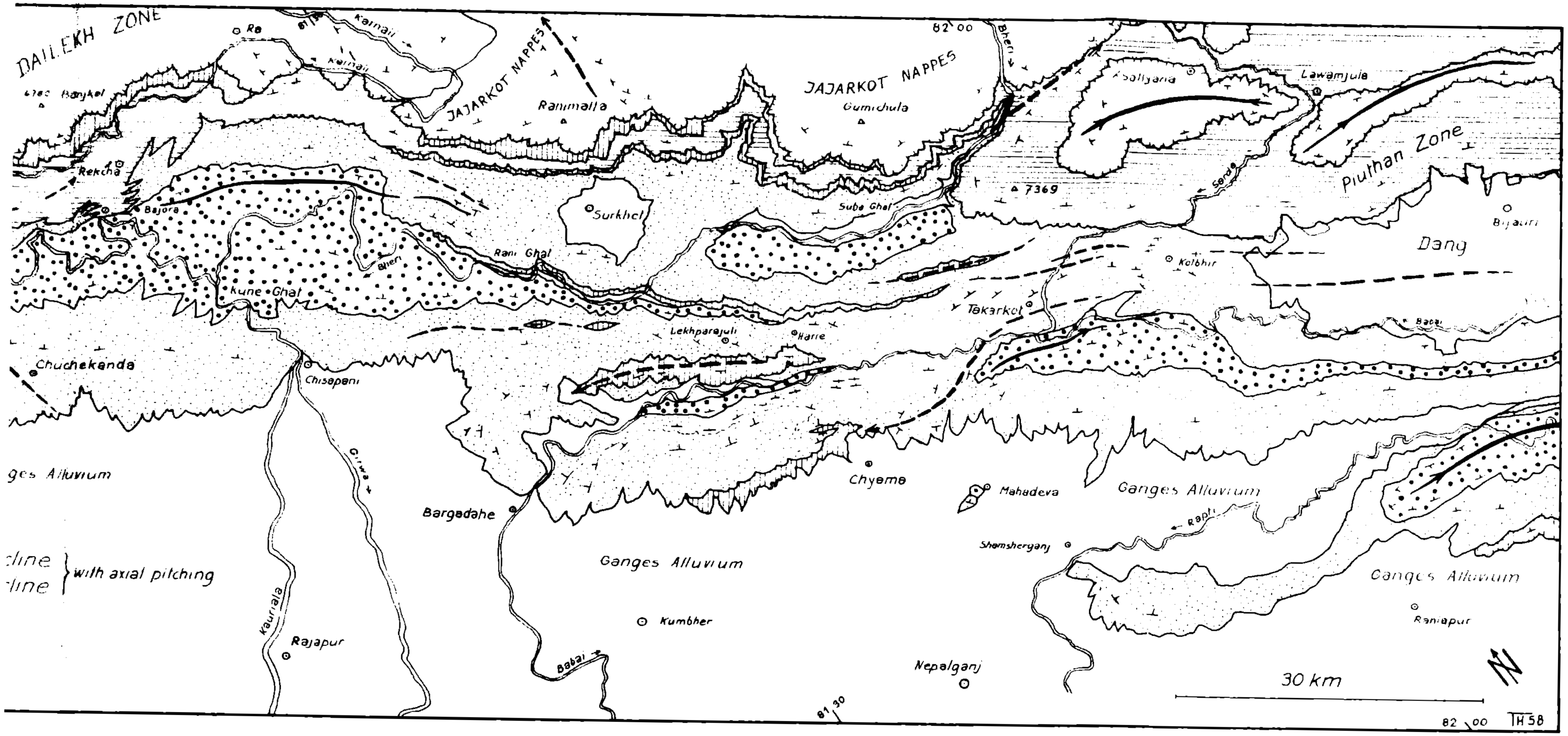


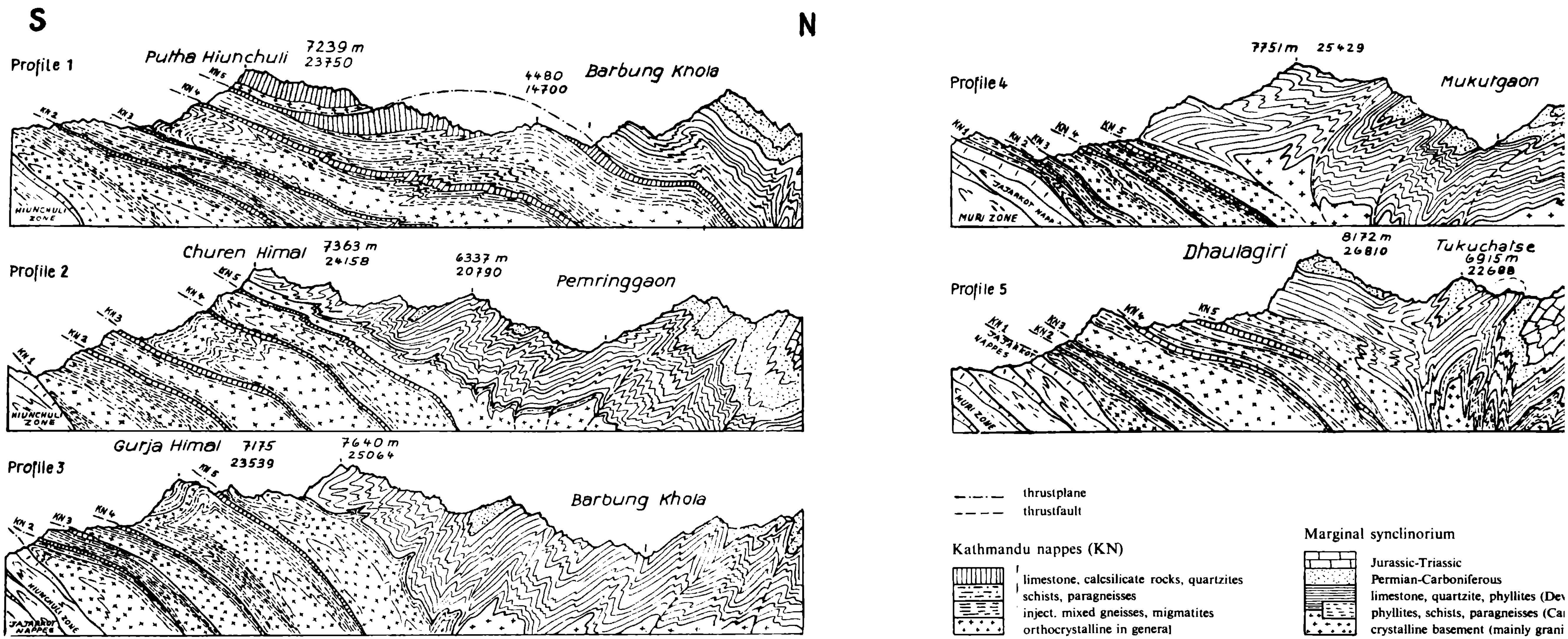
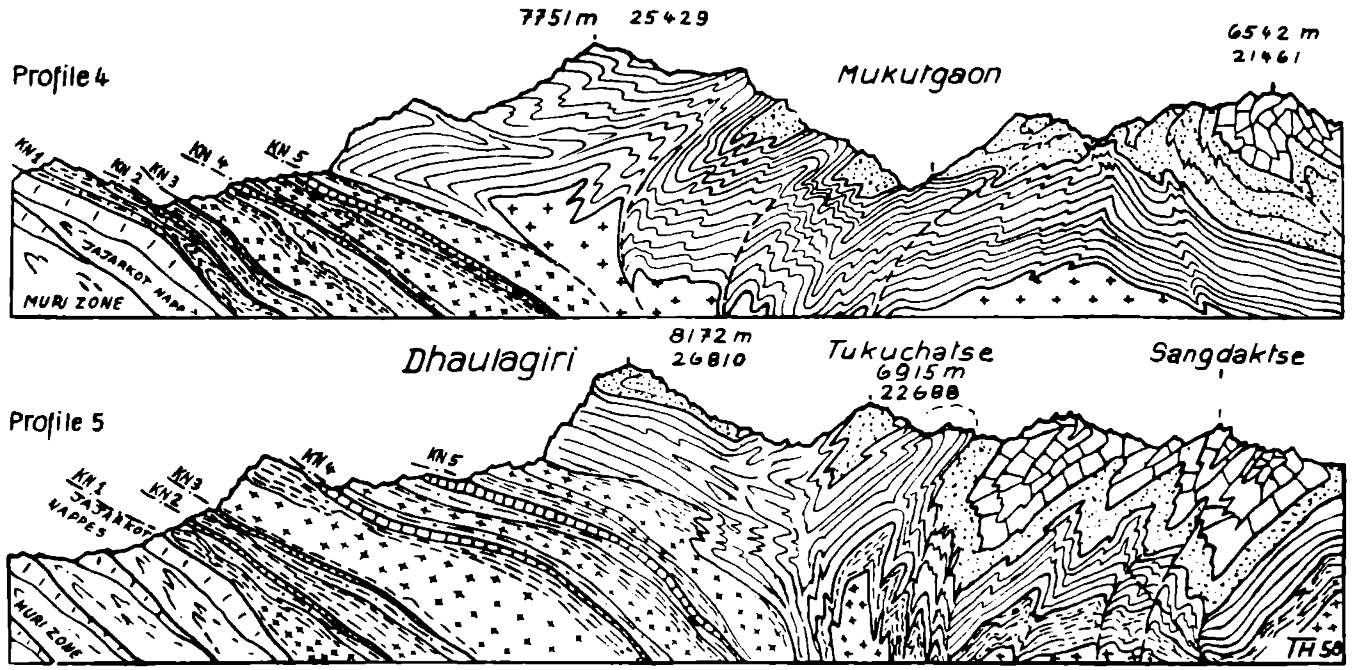



Fig. 94 5 geological profiles of the Dhaulagiri group




—.—.— thrustplane
— — — — thrustfault

Kathmandu nappes (KN)

limestone, calcsilicate rocks, quartzites
schists, paragneisses
inject. mixed gneisses, migmatites
orthocrystalline in general

Marginal synclinorium

Jurassic-Triassic
Permian-Carboniferous
limestone, quartzite, phyllites (Devonian-Silurian)
phyllites, schists, paragneisses (Cambrian?)
crystalline basement (mainly granites)

# CHAPTER 4
# SOME REGIONAL DESCRIPTIONS

Geographers and geologists are naturally most interested to learn some facts on the structure of the highest mountains of the world. Detailed descriptions of those areas will be given in the successive volumes, dealing with the regional geology. Nevertheless, the following lines might throw some preliminary light on the geological structure of the highest mountains of the world. They may especially unveil the specific structural and geological outlay as described in general terms in the foregoing chapters, and which is characteristic for the Great Himalayan Range.

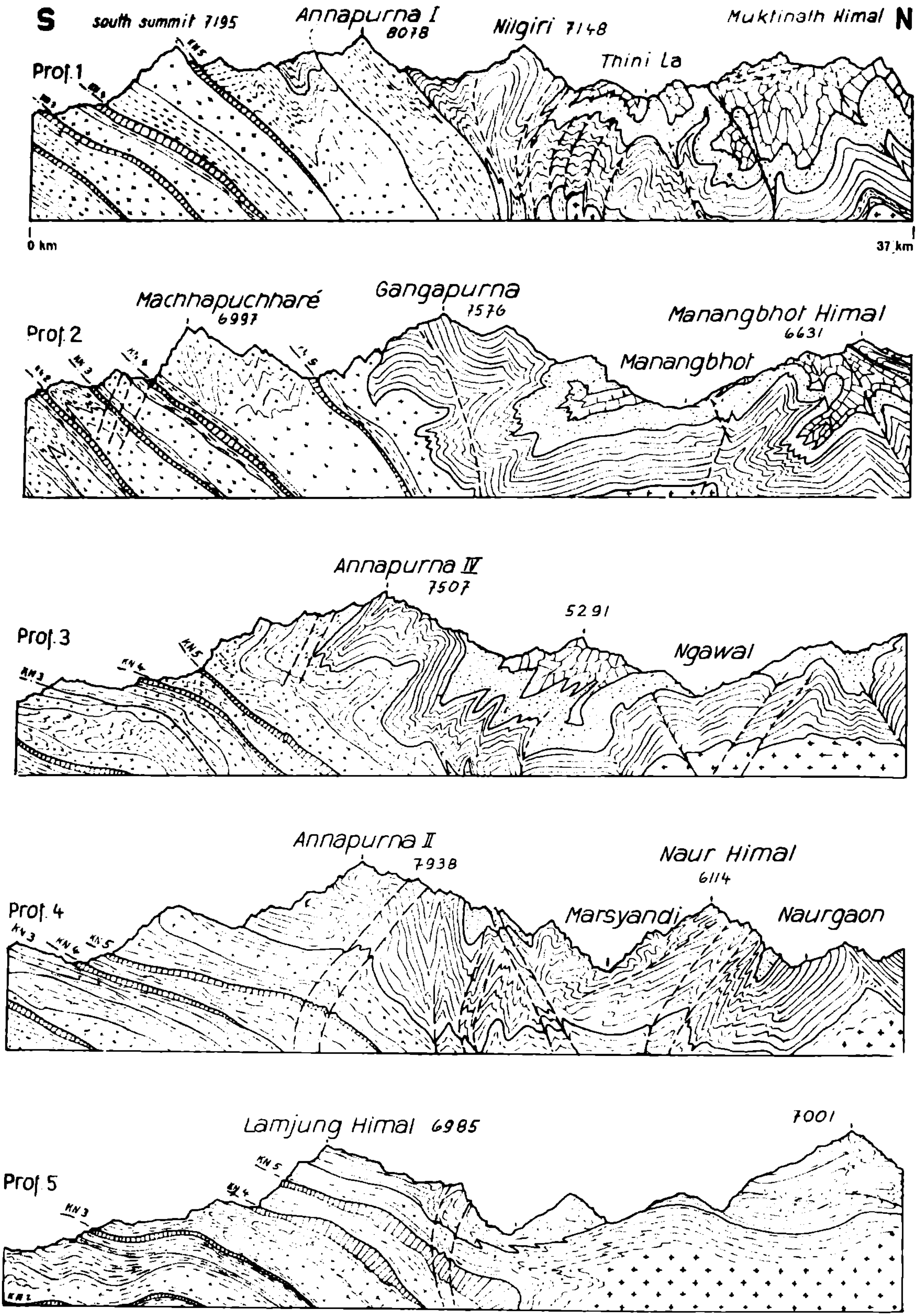
### *1) Dhaulagiri group*

The Dhaulagiri peak (8172 m) is the most western of the Nepalese eightthousanders. Though the main peak of the Dhaulagiri is an isolated bold pyramid, the Dhaulagiri chain includes a number of high peaks, which extend from east to the west on a distance of more than 50 kilometers. The following are the main peaks of the Dhaulagiri group (from east to west): Dhaulagiri (8172 m), little Dhaulagiri (7751 m), unnamed peak 7640 m, Gurja Himal (7174 m), Churen Himal (7363 m) Putha Hiunchuli (7239 m) and unnamed peak 6536 m.

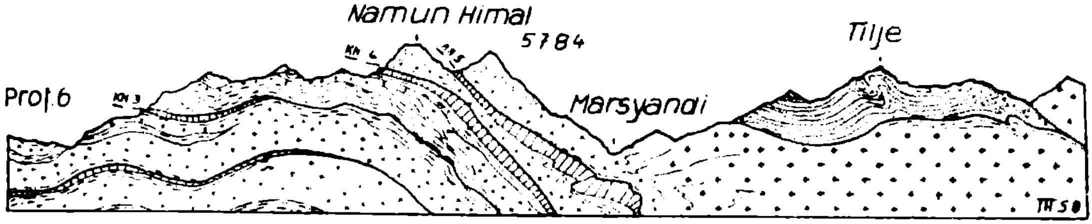
On the whole length, the Dhaulagiri group follows the boundary between the roots of the Kathmandu nappes and the Tibetan Marginal Synclinorium (fig. 94). The Himalayan Schuppen zone is not well developed in the Dhaulagiri group. Thus, the highest peaks are built without exception by the sediments lying normally on the root of the Kathmandu nappe nr. 5. The southern flank of the Dhaulagiri group is one of the highest mountain wall of the world, since the rivers (Gurja Khola, Mayangdi) have cut their beds right down to 1000—1500 m. The southern flank is built by the outcropping crystalline roots of the Kathmandu nappes. In the sections of the Gurja Himal (fig. 94, profile 3) and of the Churen Himal (profile 2) the roots of the higher nappes show some large anticlinal folds. It appears, that those nappes (Kathmandu nappes 3 and 4) have in this section not reached far towards the south. The anticlinical folds can well be seen in the southern flank of the Gurja Himal.

The sediment cover on the topmost root (Kathmandu nappe 5) is extremely thick in the sections between little Dhaulagiri and the Churen Himal (profiles 2, 3, 4 in fig. 94) and show also considerable reverse folding (directed toward the north). Those are mainly limestone of probably Silurian—Devonian age. In the east (profiles 4 and 5), the underlying paragneisses and granulites are partly replaced by turmaline granites, which join directly the limestones, (i. e. near Lete, in the Kali Gandaki valley). The Dhaulagiri peak itself is a massive pyramid of limestones. The contact between the limestones and the underlying gneisses is found at the foot of the southern wall. The extreme thickness of the Silurian—Devonian limestones in the eastern flank is tectonically accumulated. There are abundant folds in those limestones, and north of Tukucha they show a strong southern dip. The Tukuchatse (6915 m, fig. 94, profile 5) is built of probably Permian rocks, which lie in a reverse syncline. The Dhaulagiri summit proper is built by Permian formations, which were proved by finding of fossils in specimens collected by the Swiss expeditions of 1953 and 1960. The summit series form a lying anticline, directed towards the south (fig. 94).

The area north of the Dhaulagiri group is geologically most interesting, since the wide Tibetan Synclinorium of Langu shows most complete stratigraphic formations with characteristic structures (fig. 38, profile of the Thakkhola).



S
south summit 7195
Annapurna I
8078
Nilgiri 7148
Muktinath Himal
N
Prof.1
Thini La
0 km
37 km
Machhapuchharé
6997
Gangapurna
7576
Manangbhot Himal
6631
Prof.2
Manangbhot
Annapurna IV
7507
5291
Prof.3
KN 3
KN 4
KN 5
Ngawal
Annapurna II
7938
Naur Himal
6114
Prof.4
Marsyandi
Naurgaon
Lamjung Himal 6985
7001
Prof.5
KN 5
KN 4
KN 3




—·—·— thrustplane
— — — — thrustfault

Kathmandu Nappes (KN)

- limestone, calcsilicates, quartzites
- schists, paragneisses
- injext. mixed gneiss, migmatites
- orthocrystalline in general

Marginal Synclinorium

- Jurassic-Triassic
- Permian-Carboniferous
- limestone, quartzite, phyllites (Devonian-Silurian)
- phyllites, schists, paragneiss (Cambrian?)
- crystalline basement (mainly granites)

Fig. 95 6 geological profiles of the Annapurna group

Towards the western termination, the Dhaulagiri root-arc diverges from the normal eastsoutheast -westnorthwest strike towards the west into the Hiunchuli range, and involves the Hiunchuli zone. The Kathmandu roots on the other hand turn toward the northwest and continue in the next root arc, that one of the Kanjiroba Himal, (plate 6 tectonic sketchmap). Near Chandul Gömpa, in the joint between the Dhaulagiri arc and the Kanjiroba arc, the Barbung Chu (upper course of the Bheri river) traverses the Great Himalaya Range in the Kathmandu roots.

The overthrust of the Kathmandu nappes over the Jajarkot nappes can be observed near Dana, in the Kali Gandaki gorge.

*2) Annapurna group*

The Annapurna group, well known from the first ascent in 1950 by the French expedition, is situated in central Nepal. The Annapurna range has an extension of 70 kilometers and shows the most manyfold aspects in many respects. There are quite a number of particular peaks, among those are the boldest of the world. From geological standpoint, the Annapurna range might be the most interesting of the whole Nepal Himalaya, since the whole range is easily accessable from all directions, especially also from the northern flank, which lies entirely on Nepalese territory.

The following are the peaks of the Annapurna range (from west to east): Nilgiri north summit (7033 m), Nilgiri south summit (6838 m), Annapurna 1 (main summit, 8078 m), Annapurna south summit (7195 m), Gangapurna (7577 m), Machhapuchhare (6997 m, see fig. 134), Annapurna 4 (7508 m), Annapurna 2 (7937 m), Lamjung Himal (6985 m) and Namun (5787 m). Most of those peaks are already climbed. However, the existing map of the Survey of India (Quarter Inch) shows a number of errors. For example, the south summit is directly connected with the ridge of the main summit (see volume 2). The Machhapuchhare is undoubtedly one of the most beautiful mountains of the Himalayas at all. Its rise out of the subtropical lowland near Pokhara, 800 m (central Nepal) is unique (fig. 134).

The whole Annapurna range is naturally framed by the Kali Gandaki gorge in the west and the Marsyandi gorge in the east. Also the northern flank drops into a deep valley, the Manang valley, which follows the complicated sedimentary formations of the Tibetan Marginal Synclinorium.

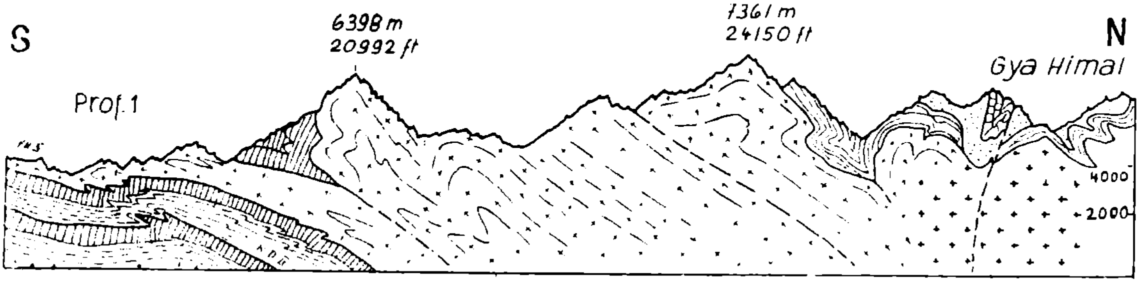
Similarly as the Dhaulagiri group, the southern flank of the Annapurna range is built by the northern dipping crystalline roots of the Kathmandu nappes. The main summit is formed by dark paragneisses and schists which are intruded by granitic bodies, layers and dykes. The contact to the Silurian limestone is not far in the north of the main summit (fig. 95). Both summits of the Nilgiri group are built by the Ordovician -- Devonian limestones. Those show at the northern flank reverse folding, in which, towards the Thini La, Mesozoic sediments are involved. The ridge, which connects the main summit with the south summit shows also sediment formations, which lie in an overturned syncline within the crystalline of the root of the Kathmandu nappe 5 (fig. 95, profile 1). In the section of Machhapuchhare -- Gangapurna (profile 2) the contact between the crystalline formations and the sediments lies in the center of the group. Gangapurna is entirely built out of the limestones, which show beautiful reverse folds, while the Machhapuchhare is a bold pyramid of granite-gneisses. Those gneisses are also folded (profile 2). Between the Gangapurna and the Annapurna 4 there is a very deep gap in the range, which does certainly not exceed 5800 m altitude. East of this gap, the mountains form one single chain. Both, Annapurna 4 and Annapurna 2 are built entirely of sediments, which show a number of folds, partly of reverse character (fig. 95, profiles 4 and 5). Especially the northern flank of Annapurna 2 is very much folded, right down to the Marsyandi river.

The Tibetan Marginal Synclinorium, which follows the Marsyandi valley, shows a strong axial rise from the west to the east. Thus, from Manang towards the east successively younger formations occur in the bottom of the valley. Near Manang Rhetic limestones were found. Opposite of Pisang, Carboniferous formations (the famous yellow band series) are exposed, while east of Pisang the Devonian limestones rise very steep towards the east. The particular beds of those limestones form the surface from 3100 m right up to 5800 m. Being the rising bottom of the Marginal Synclinorium, they have the shape of one half of a huge funnel (see fig. 27). East of Kupar, due to the axial rise, the crystalline basement of the Marginal Synclinorium occurs at the surface.

### *3) Gurkha Himal*

The Gurkha Himal consists of three major peaks, namely the Manaslu (8125 m), the Himalchuli (7864 m) and the unnamed peak of 7835 m lying between them.

The whole group is by the Marsyandi and the Buri Gandaki separated from the rest of the Great Himalaya Range. The topographic strike of the Gurkha Himal does not fit into the normal strike, it appears to be turned towards a northwest -- southeast strike (plate 6).



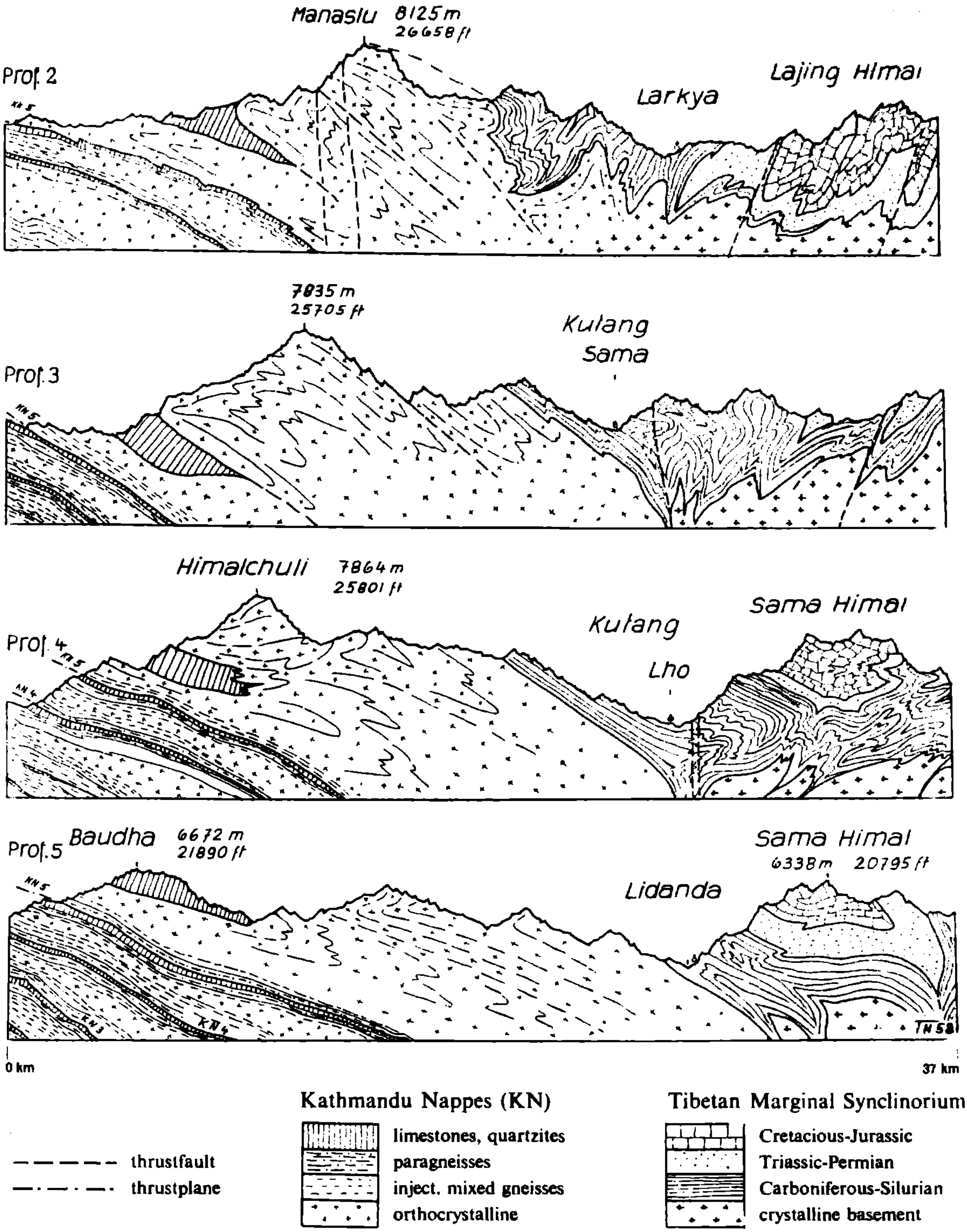



Fig. 96 5 geological profiles of the Manaslu group

Similarly as the Dhaulagiri group and the Annapurna group, also the high peaks of the Manaslu group are built by the top root of the Kathmandu nappes. However, the Gurkha Himal show some deviations. The Himalayan Schuppen zone is absent in the Gurkha Himal. Further, the granites have intruded into much higher series, namely right up to the Mesozoic formations north of the Larkhya La (fig. 96, profile 1). The contact of the granite itself is irregular. We may conclude that this intrusion took place in a late stage. The Manaslu granite, which builds the Manaslu itself and most of the other peaks, including the northern peak of 7361 m, can thus not be compared with the intrusion of the main masses of the Kathmandu nappes. It is in some way correlated with the Mustang granite, with which it appears to be in direct connection due to the unnormal strike towards the northwest (plate 6). The eastern termination of the Marginal Synclinorium of Manang strikes into the southern flank of the Gurkha Himal. We find the respective limestones south of peak 6398 m (fig. 96, profile 1), south of the Manaslu (profile 2), south of the peak 7835 m and south of Himalchuli. The latter shows, like the foregoing peak, a number of folds, partly of reverse character. In the Baudha (6672 m) the sediments die out finally. We see, how in general, the eastern termination of the Manang Marginal Synclinorium is not just an axial outcrop. The Manaslu granite, forming the Manaslu root arc, has pressed from the north and gradually narrowed and overturned the sedimentary filling of the synclinorium (fig. 96).

The summit of Manaslu (8125 m) lies just on the boundary between the granite and the Silurian limestone. The lowest calcareous beds interbedded with granites occur on the top (profile 1).

The Marginal Synclinorium of Kutang (upper course of the Buri Gandaki valley) is thus not in direct connection with that one of Manang. It appears to be transposed towards the north. The structures and formations within the Kutang Synclinorium nevertheless show great similarities with the area of Manang (fig. 96).

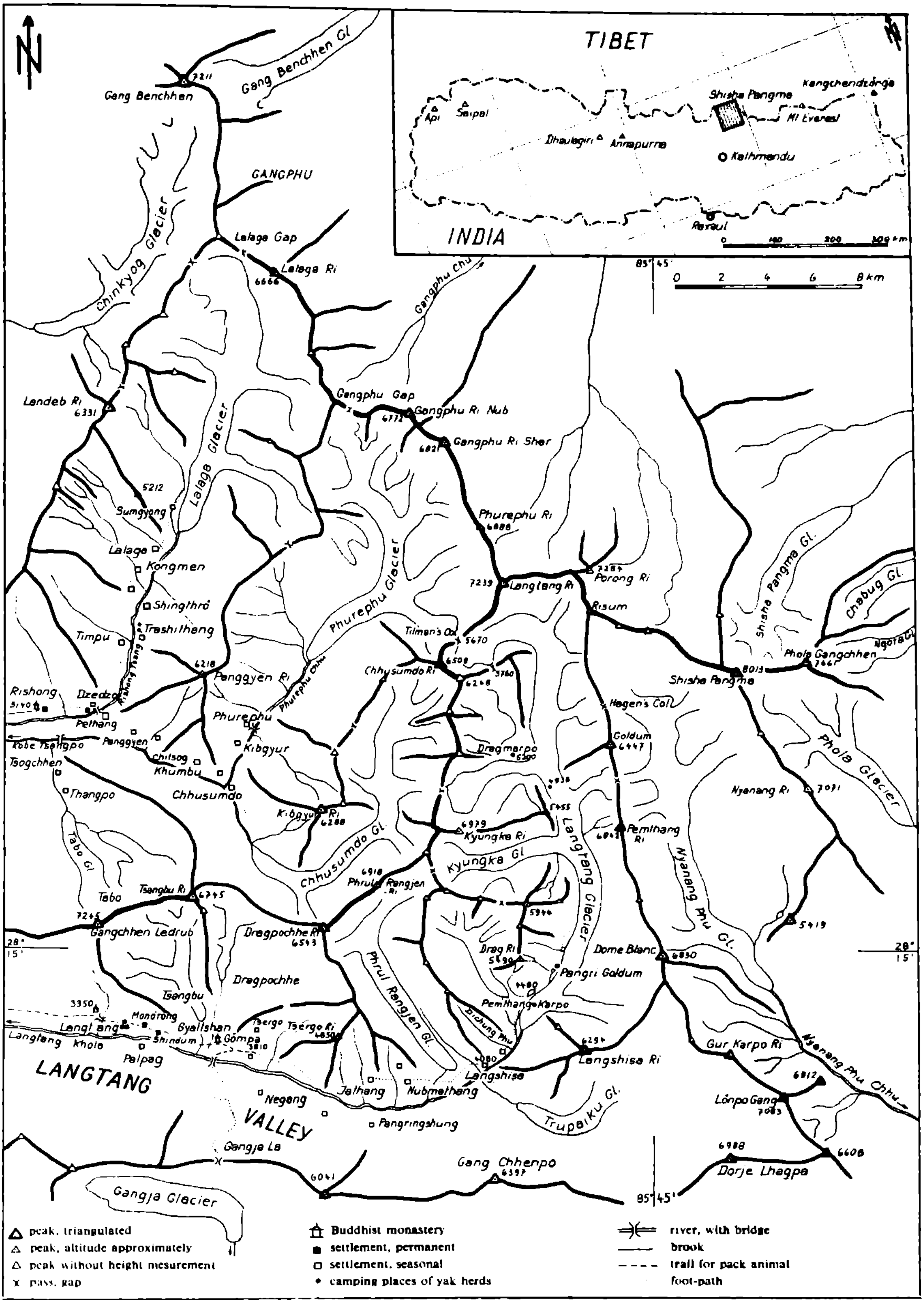
### *4) Langtang—Shisha Pangma*

This mountain group, which is situated due north of Kathmandu, was a long time neglected by surveyors. It is really the only area, in which the existing Quarter Inch map of the Survey of India shows major mistakes. According to this map, the Langtang Himal and the Jugal Himal (Lönpo Gang 7083 m, fig. 97) are connected in a straight line.

It was the famous explorer Tilman, who in 1949 made the first trip to the Langtang valley, with the intention to find the Shisha Pangma, the then last eightthousander, which was not known from the south. To his surprise, he did not meet the mountain range between the Langtang Himal and the Jugal Himal, but found the Langtang valley reaching far to the north, at least 25 kilometers. Tilman, in spite of climbing the pass passing over into the Kyirong basin, did not see the Shisha Pangma. It was covered by clouds and thus remained the "unknown" eightthousander. It was then the author, who in 1952 also climbed up the upper course of the Langtang valley and found the Shisha Pangma group. His findings were condensed in the first topographic sketch map of that area (Lit. Hagen, T., 1956). Later on, Peter Aufschnaiter visited also the Langtang valley and prepared a detailed map, which is given in fig. 97. Shisha Pangma itself is situated in Tibet (just 6 km east of the Nepalese border). But it is evident, that the whole of the Langtang valley belongs to Nepal, the boundary following the main watershed between Nepal and Tibet.

From the geological standpoint, the Langtang—Shisha Pangma group takes an exceptional position. The Shisha Pangma itself lies far north (20 km) of the roots of the Kathmandu nappes. These

Fig. 97 Sketch map of the upper Langtang valley and the Shisha Pangma group (opposite)
(after Peter Aufschnaiter, by courtesy of "Die Alpen", monthly review of the Swiss Alpine Club)


TIBET
INDIA
Api
Saipal
Dhaulagiri
Annapurna
Shisha Pangma
Mt Everest
Kathmandu
Raxaul
0 2 4 6 8 km
85° 45'
Gang Benchhen Gl
Gang Benchhen
GANGPHU
Chinkyog Glacier
Lalaga Gap
Lalaga Ri
6666
Gangphu Chu
Landeb Ri
6331
Lalaga Glacier
Gangphu Gap
Gangphu Ri Nub
Gangphu Ri Shar
5212
Sumgyong
Lalaga
Kongmen
Shingthro
Trashithang
Timpu
Phurephu Ri
6888
Phurephu Glacier
7239
Langtang Ri
Porong Ri
Risum
Shisha Pangma Gl.
Chabug Gl.
Tilman's Col
5670
Chhusumdo Ri
6508
6248
Phola Gangchhen
Shisha Pangma
8013
6218
Panggyen Ri
Rishong
Dzedzo
Pethang
Phurephu
Kibgyur
Hagen's Col
Goldum
6447
Phola Glacier
Panggyen
Tsogchhen
Chitsog
Khumbu
Chhusumdo
Thangpo
Dragmarpo
Njanang Ri
7071
Kibgyur Ri
6288
Kyungka Ri
6979
Pemthang Ri
Chhusumdo Gl.
Kyungka Gl.
Langtang Glacier
Nyanang Phu Gl.
Tabo Gl
Tabo
Tsangbu Ri
6745
Phrul Rangjen Ri
6918
5944
Gangchhen Ledrub
Dragpochhe Ri
6543
Dome Blanc
6830
Drag Ri
Pangri Goldum
Dragpochhe
Phrul Rangjen Gl.
Tsangbu
Pemthang Karpo
Langtang
Mondrong
Gyalshan
Tsergo
Tsergo Ri
Langtang Khola
Shindum
Gompa
Palpag
LANGTANG
VALLEY
Langshisa Ri
Gur Karpo Ri
Langshisa
Nyanang Phu Chhu
Jathang
Nubmathang
Negang
Trupaiku Gl.
Lönpo Gang
7083
Pangringshung
Gangja La
Gang Chhenpo
6388
6608
Dorje Lhagpa
Gangja Glacier
28° 15'
peak, triangulated
peak, altitude approximately
peak without height mesurement
pass, gap
Buddhist monastery
settlement, permanent
settlement, seasonal
camping places of yak herds
river, with bridge
brook
trail for pack animal
foot-path

roots build the high peaks of the Langtang Himal and of the Jugal Himal. Further, due to an axial culmination in this section, the Tibetan Marginal Synclinorium is not represented by the sedimentary filling, but only by the crystalline basement (fig. 98). From structural standpoint, the Tibetan Marginal Synclinorium is well developed by folds, thrustfolds, reverse folds and even a large synclinal structure. The latter is for example to be seen between Langtang Himal and Gangphu Ri Nub (fig. 98, profile 2).

However, the Shisha Pangma section must be considered as a kind of a transitional zone: From here towards the east, the Khumbu nappes develop out of the back of the Kathmandu roots. (See tectonic map of central Nepal, fig. 44). Langtang Ri (profile 3) and Shisha Pangma (profile 4) may thus at the same time be considered to belong to the Khumbu roots. With view from the west, out of the Marginal Synclinorium of Kutang – Kyirong (fig. 44), the Shisha Pangma can as well be considered as a part of the Tibetan Marginal Range. In general, as mentioned above, the Shisha Pangma is an axial culmination, which has played an important role on the tectonics of the whole section, right down to the Siwaliks. It was a kind of a pivot for the Midlands structures and in the shade of which the Kathmandu syncline was formed.

### 5) *Cho Oyu group*

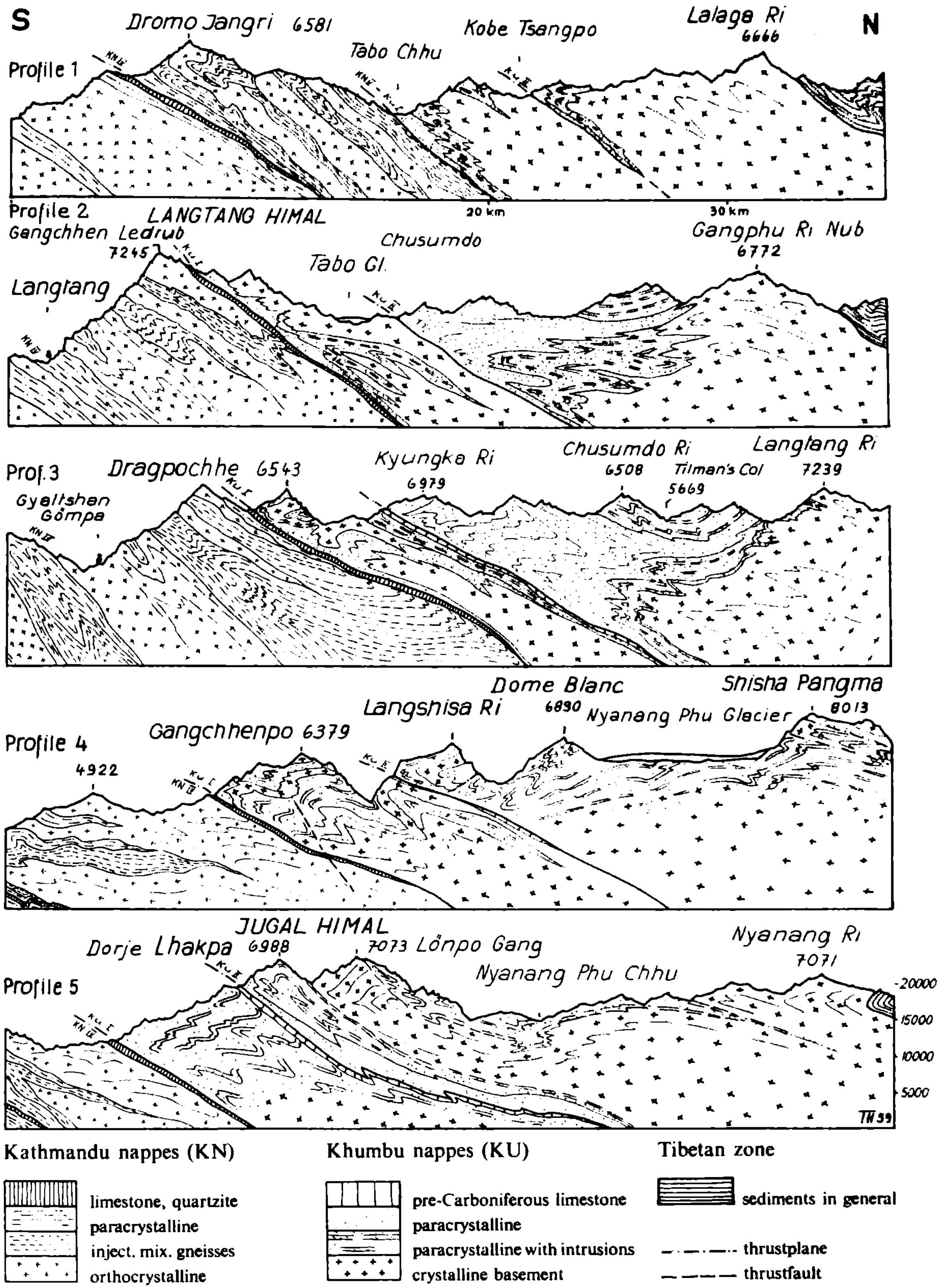
The Cho Oyu has become well known for being climbed by a very small Austrian expedition, (H. Tichy) without using oxygen and without having the abundant equipment and supply which normally are available for the major climbing expeditions.

The Cho Oyu (8153 m) belongs in a wider sense to the Everest group. It is situated only 28 km west of Mount Everest. The well known trade route of the Sherpas, crossing the Nangpa La (5806 m) passes only a few kilometers west of the Cho Oyu.

D. Odell was the first geologist to carry out fieldwork on the northern flank of the Cho Oyu (1924). The southern side was investigated by A. Lombard in 1952 and by the author in 1954.

There are certainly mountain ranges in Nepal which are much more interesting from geological standpoint than the Cho Oyu group. The main portion, especially the southern flank is built by gneisses and granites. Only the top carries a sedimentary cover, similarly as the Mount Everest. The southern flank of the Cho Oyu is characterized by a number of thrustplanes and thrustfaults (fig. 102, profile 2). A number of Schuppen can be recognized, similarly as in the Everest area. However there is no direct connection with the tectonic units of the Everest area, since in the Choy Oyu as well as in the Khumbu, the tectonic schuppen do not show a large longitudinal extension. (Compare the descriptions of the following page 123). In general, the Schuppen of the Cho Oyu are characteristic for the Himalayan Marginal Schuppen zone, as found nearly along the whole length of the northern flank of the main roots. Also the granite peak (7257 m) west of the Nangpa La shows the same Schuppen. The Nangpa La itself is not a real pass, but rather a plateau-like gap in the main range. A traverse anticline strikes in north – south direction through the Nangpa La. In general, the crystalline series south of the Cho Oyu – Gyanchung Kang range show a flat dip, with minor local structures. They are all built of the crystalline formations of the Khumbu nappes. In the area of Thami (profiles 2 and 3) they fill even a wide syncline. This syncline is situated on the back of the Kathmandu roots in the Numbur (6957 m), Karyolung (6681 m) and Kwangde (6194 m) range. They might be considered as the expression of the Tibetan Marginal Synclinorium on the back of the Kathmandu roots. The Kwangde (6194 m, profile 3) shows also the complicated reverse folds, which are characteristic for the southern rim of the Marginal Synclinoria. It appears to be probable, that the Khumbu nappes

Fig. 98 5 geological profiles of the Langtang – Shisha Pangma group (opposite)


S
N
Profile 1
Dromo Jangri 6581
Tabo Chhu
Kobe Tsangpo
Lalaga Ri 6666
Profile 2
20 km
30 km
LANGTANG HIMAL
Gangchhen Ledrub 7245
Chusumdo
Tabo Gl.
Gangphu Ri Nub 6772
Langtang
Prof. 3
Dragpochhe 6543
Kyungka Ri 6979
Chusumdo Ri 6508
Tilman's Col 5669
Langtang Ri 7239
Gyaltshen Gompa
Dome Blanc 6830
Shisha Pangma 8013
Langshisa Ri
Nyanang Phu Glacier
Profile 4
Gangchhenpo 6379
4922
JUGAL HIMAL
Dorje Lhakpa 6988
7073 Lönpo Gang
Nyanang Ri 7071
Nyanang Phu Chhu
Profile 5
20000
15000
10000
5000
TH 59
Kathmandu nappes (KN)
limestone, quartzite
paracrystalline
inject. mix. gneisses
orthocrystalline
Khumbu nappes (KU)
pre-Carboniferous limestone
paracrystalline
paracrystalline with intrusions
crystalline basement
Tibetan zone
sediments in general
thrustplane
thrustfault

have been thrust from their roots in the north (today Cho Oyu—Gyanchung Kang) towards the south into the Tibetan Marginal Synclinorium north of the Kwangde—Numbur range.

*6) Everest group*

The Mount Everest is today probably the best known eightthousander from geological standpoint. This however does not at all mean that the geological problems on the Mount Everest are solved. The various geologists who have done fieldwork in the Everest area have not seen the whole of the Everest group, but only parts of it. Mt. Everest being on the Tibeto—Nepalese border, permission was never granted for fieldwork from both countries simultaneously, either one or the other of the two territories being forbidden land. However the author has had the advantage to have geological knowledge of the adjoining areas and was able to base on the foregoing research work of other geologists.

The geological investigations of the northern flank (Tibetan area) goes back as far as 1921, (M. Heron). N. E. Odell accompanied the British Mount Everest expedition in 1924. He is still today the Geologist who has climbed the highest altitude in the Everest group (8600 meters). L. R. Wager studied besides the geology especially the origin and shape of the valleys, as has been described in the chapter 5. The southern flank of Everest was opened in 1950 only, when Nepal abandoned the policy of a "forbidden land". A. Lombard, who accompanied the first Swiss Mount Everest Expedition was the first geologist to visit the Khumbu. His most important findings were published in a number of preliminary papers and also in a comprehensive volume (Lit. 1958).

It is natural in a mountain system of such a magnitude as Mount Everest and without possibility for the particular geologist to do fieldwork in the whole of the area, that the interpretations differ considerably. Like most of the Nepal Himalayas, the highest mountain ranges, built of metamorphic series do not contain any fossils, thus stratigraphy remains rather theoretical.

When the author entered the Khumbu in 1955, after foregoing 5 years of geological fieldwork in the Nepal Himalayas, the series forming the top of Mount Everest were considered to be of Permo-Carboniferous age, since they were connected with the Lachi series of L. R. Wager in Sikkim.

A. Lombard gave the basic tectonic divisions of the Khumbu area. The names of the various tectonic units of Lombard do not coincide with those of the author who was led to his names from areas beyond Khumbu. However, this is only a matter of convention and does not impair the fact that, basically A. Lombard and the author have found the same structural elements. Lombard's contribution for the Geology of Mount Everest is especially important by the results obtained by his cooperation with the Petrologists M. Gysin and D. Kummenacher.

According to Lombard, the main portion of the Khumbu area is taken by his Khumbu nappe nr. 1. Lombard's Khumbu nappe is subdivided into a Khumbu nappe "inférieur" (lower Khumbu nappe) and a Khumbu nappe "supérieur" (upper Khumbu nappe). These subdivisions correspond to the Khumbu nappe 1 and 2, of the author, separated by the Kumjung series (see figs. 100 and 101).

According to Lombard, the whole formations overlying the Kumjung series form one single nappe right up to the southern foot of the Nuptse—Lhotse flank. They would be overlain by the Khumbu nappe no. 2, consisting of the Nuptse Schuppe and the Nup La Schuppe (west of Khumbu glacier). The overthrust of the Nuptse Schuppe over the underlying series were confirmed by the author too. However, Lombard's huge masses of the Khumbu nappe supérieur (upper Khumbu nappe 1) are by the author subdivided into the Khumbu nappe 2 and the Khumbu nappe 3. Those are separated by the Pangpoche series. (Fig. 100 and 101). Further, there are higher Schuppen within and on the author's Khumbu nappe 3, namely the Makalu Schuppe (figs. 100, 101 and 106). The following sketch may help to explain the correlations between Lombard's and the author's tectonic interpretation.

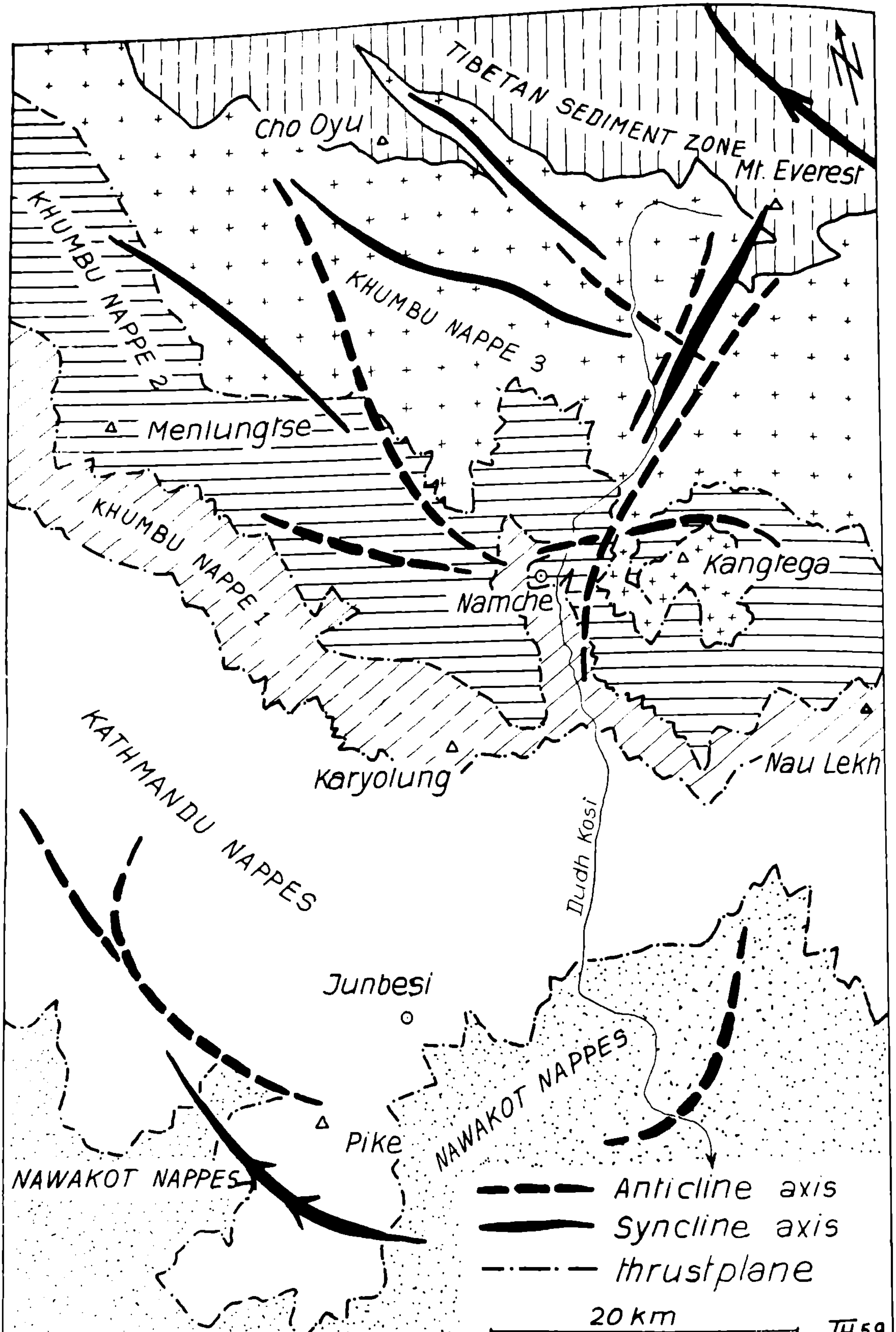
| A. LOMBARD | | T. HAGEN | |
|---|---|---|---|
| Tibetan Plateau ("Dalle du Tibet") | | Tibetan Plateau | |
| | | | thrustplane |
| Khumbu nappe 2 | Nup La Schuppe<br>Nuptse Schuppe | Everest Schuppe | |
| | | Changri Schuppe / Nuptse Schuppe | |
| | | | thrustplane |
| Khumbu nappe 1 | upper (supérieur) | Makalu Schuppe | |
| | | | thrustplane |
| | | Khumbu nappe 3 | |
| | | | thrustplane (Pangpoche series) |
| | | Khumbu nappe 2 | |
| | | | thrustplane (Kumjung series) |
| | lower (inférieur) | Khumbu nappe 1 | |

The tectonic divisions by the author have been made based on tectonics and the lithology. The rock formations are rather monotonous; non metamorphic or low metamorphic sediments are mostly absent, excepted the top of Everest—Lhotse. It may appear to be rather risky to establish tectonic units simply by tectonic features. However, the tectonics are of such a magnitude in the Everest group, that they were the main point in building the highest mountain of the world. The tectonic picture at the southern flank of the Everest group is especially confusing due to the fact, that we find there a cross-point of a number of structures, i. e. normal WNW—ESE striking structures, NE—SW striking transverse structures, and in addition structures which do not fit into either of the two main tectonic directions. The tectonic picture is on the southern flank of the Nuptse—Lhotse group especially difficult to interpret, since only the transverse structure occurs in a diagrammatic section. The normal structures (east—west striking) are almost impossible to figure out. But the normally (longitudinal) striking structures are responsible for the subdivision into various tectonic units. It can be concluded, that the eastern flank of the Everest—Lhotse group, the Kangshung flank, takes a key position for studying the structure of Mount Everest. The same role is played by the eastern flank of the Makalu —Chomo Lönzo group (figs. 127, 128, 129). Since the whole area between Mount Everest and the Arun river shows a strong axial pitch towards the west, the said flanks show really true diagrammatic sections.

P. Bordet established a much more simple tectonic picture of the Everest group than Lombard and the author. According to him, there would be a normal, non interrupted stratigraphic succession from the Barun gneiss (main body of the author's Khumbu nappe 3) right up to Everest. His view is also given in his section of fig. 15. No tectonic subdivisions are shown, nor any of the reverse structures and dips of the Karma—Kangshung area.

There is a main difference in the view regarding the position of the Nuptse granite. According to Bordet, the granite is of Tertiary age, and should have intruded in the thrustplane during the overthrust of the "Everest phyllade" to the south, in the area of the Imja basin. The Nuptse granite (which is according to him identical with the Makalu granite) would thus be post-tectonical, after thrusting of the nappes had been completed. The overthrust of the "Everest phyllade" towards the south was a minor tectonic accident, not really disturbing the normal stratigraphic succession. Excepted this small overthrust the Makalu granite appeared to overlie normally the Barun gneiss.

According to Lombard—and the author agrees to this view—Intrusion of the Nuptse granite took place before the overthrust. The rigid granite body was the base of the later Nuptse Schuppe.


TIBETAN SEDIMENT ZONE
Cho Oyu
Mt. Everest
KHUMBU NAPPE 2
KHUMBU NAPPE 3
Menlungtse
KHUMBU NAPPE 1
Kangtega
Namche
Karyolung
Nau Lekh
KATHMANDU NAPPES
Dudh Kosi
Junbesi
NAWAKOT NAPPES
Pike
NAWAKOT NAPPES
Anticline axis
Syncline axis
thrustplane
20 km
TH 59

Both views allow easily to consider the Nuptse granite as Tertiary, since the overthrust of the Nuptse Schuppe is undoubtedly of very late age, possibly late upper Tertiary—Pleistocene (compare page 148).

The petrological studies by D. Krummenacher unveiled not great differences from petrological standpoints in the various series. This however does not necessarily lead to the conclusion, that the whole area of the Imja—Khumbu basin is also tectonically one and the same unit.

The explorer, who approaches the Everest group from the Khumbu (southern side) is overwhelmed by the phantastic wall of the Nuptse—Lhotse flank, which rises abruptly out of the soft-shaped lowland of the Imja and Khumbu basins, with average heights of 5000—6000 m only. It is difficult to scale the magnitude of this wall; the explorer cannot imagine that, from a standpoint near Dingpoche for example, there is still a distance of 17 km to the foot of this wall. Only the beautiful map of the Everest group made by Erwin Schneider shows, that a number of glaciers extend from the foot of the said wall toward south for many kilometers. The topographic relief, prepared after this map makes all other bold peaks south and west of the Imja basin (Ama Dablam 6856 m, Tsolatse 6440 m and Taboche 6542 m) just disappear compared with the huge elevated mass of the Everest group proper. It is evident, that the mentioned peaks do not form a "Gipfelflur" with the Everest. There is a clear level of peaks amongst the minor mountains, but the mass of Everest surmounts the whole surroundings. Unquestionably, the Everest group cannot be considered just as an erosive remainder out of an ancient elevated mass. The complicated tectonics lead necessarily to the conclusion, that local tectonic rise has made the Everest group the highest mountain of the world. The reader may read the chapters on the Imja and Khumbu basins, in Lombards publication (Lit. 1958) and especially examine the excellent sketches, then he may realize, that there is really no single square kilometer without enormous tectonic disturbances, like folds, local thrusts, thrustfaults and abrupt changing of dips.

Just below Pangpoche (figs. 101—106), we enter the main crystalline masses of the Khumbu nappe 3. Those formations have been named the Samso series. They consist of paragneisses, granitized gneisses, migmatites and chloriteschists. The structures are tremendously complicated; often the dips are vertical.

But in general the Samso series form a huge anticline, the axis of which runs in north—south direction along the main valley from the junction Imja Chu—Lobuche Chu. The axis of this transverse structure shows a northern pitch (figs. 106 and 107).

The contact of the Samso series to the overlying series is a tectonic one. The Clochetons series (which have their name after Lombard from the ridge between the Khumbu glacier and the Nuptse glacier, fig. 101) are overthrust over the Samso series. They consist of mainly paragneisses, and schists with granitic intrusions. They are greatly tectonized, but show in general a dip toward the eastnortheast. From morphological standpoint of view they differ clearly from the underlying Samso series; so clearly, that even in the topographic relief prepared from the Schneider map it can be recognized at once.

At the foot of the southern flank of the Nuptse, the Nuptse granite is overlying over the Clochetons series. This contact shows all signs of a tectonic thrustplane. This view agrees with Lombard, but differs with that one of P. Bordet, who considers the Nuptse granite in principle as the normal succession upon the Clochetons series.

At the opposite side (western side) of the Khumbu valley one looks in vain for the western continuation of the Clochetons series. There are only small layers of schists and paragneisses underlying the bold massive granites of the Taboche and the Tsolatse (Figs. 100, 101). From tectonic standpoint, the said granite bodies form klippen and are at the same level as the Nuptse granite, though not in direct

Fig. 99 Tectonic sketch map of the Solu and Khumbu areas (opposite) connection with it. For, the Nuptse granite does not continue from the Nuptse ridge towards the west across the Khumbu glacier (fig. 101).

The Clochetons series covers wide areas in the Imja basin. Their dip is towards the southeast rather flat and partly even directed southwards. From the southern peak of the Clochetons ridge, a new series appears between the underlying Samso series of the Khumbu nappe 3 and the Clochetons series, namely the Ama Dablam series. Those are mainly granites, and they show in the said peak a strong eastern dip (fig. 101, 106). Above the Ama Dablam series, there are further granite masses, one building the top of the Ama Dablam peak. They all dip strongly towards the east into and underneath the black Clochetones series. Further towards the east, in the ridge between the Chukhung glacier and the Amphu Labtsa glacier, a new series—the Amphu Labtsa series—occurs between the Clochetons series and the granite bodies. The Amphu Labtsa series is a formation of paragneisses with intrusions, the intrusion zone overlying the granites. The granite occurs again in the basin north of the Amphu Labtsa pass (fig. 101). The three described series (granites, Amphu Labtsa intrusion zone and Clochetons series) form a tectonic unit, the Makalu Schuppe. This tectonic unit, is lain in a transverse syncline, the axis of which strikes from the ridge between Nuptse and Lhotse towards the south into the area of the Chukhung glacier. This is the Everest transverse syncline which has been published first by P. Bordet (1958). We are not surprised about this fact, since we have seen as early as 1954 (page 46) that all the highest mountains of the Great Himalaya Range in Nepal are situated in transverse synclines. The topographic relief being reverse to the structure with this regard (see T. Hagen, 1956).

The southern flank of the Nuptse—Lhotse is one of the most interesting geological exposure. The Nuptse granite (fig. 101) forms a huge anticline, overturned toward the east, and with the axis striking north—south (figs. 101, 105 and 107). Overlying to the granite we find black sediment formations, the so-called "pelitic" series of Everest. The contact is a very sharp line on the top and on the eastern flank of the Nuptse anticline (fig. 121). On the western flank, in the western ridge of the Nuptse the main body of the Nuptse granite sends a number of layers and digitations up into the overlying "pelitic series". On this ridge, the dip is directed due west. The Nuptse granite disappears underneath the Khumbu glacier. The overlying sediment series—the Nuptse series—occur once more in the northwestern ridge of the Nuptse, towards the bend of the Khumbu glacier. It also occurs at the foot of the northern flank of the Nuptse, in the so-called Cwm. The dip is very steep toward the north, thus it is surprising enough, that the same granite occurs again at the opposite side (northern) of the Cwm (fig. 101). Unquestionably, there is a tectonic structure in the Khumbu glacier, especially in the Cwm which has brought the granite at the northern side of the Cwm to a higher level.

Tectonic interpretation of areas of such altitudes meets tremendous difficulties. The author has not been himself in the Cwm, but investigated the area from the opposite side, from the southern ridge of the Pumori. Fieldwork in such high altitudes has to be confined to a few traverses on the most accessable routes. General comprehensive views from different angles are in general out of possibilities. The accurate map produced by Erwin Schneider was in this special case a most valuable means for correlating the various formations. The accurate topographic relief especially unveils many interesting outlooks, and enables solving of certain problems.

The "pelitic" series building the Nuptse, Lhotse and Mount Everest gave so far a number of problems. The topmost formations were considered as Permo—Carboniferous. Most characteristic in this "pelitic series" is the "yellow band." This stretches through the upper part of the Nuptse southern flank, intersected and transposed by transverse faults (figs. 101, 122). The yellow band occurs again in the northern flank of Nuptse—Lhotse, towards the foot of the Cwm, striking into the southwestern flank of the Mount Everest (forming a few minor folds).

It disappears towards the west. The yellow band can again be observed in the eastern flank of the Lhotse (Kangshung flank, see figs. 125, 127). The series above the yellow band have been named the Lhotse series, since they build the Lhotse peak. The yellow band series allows you to recognize without

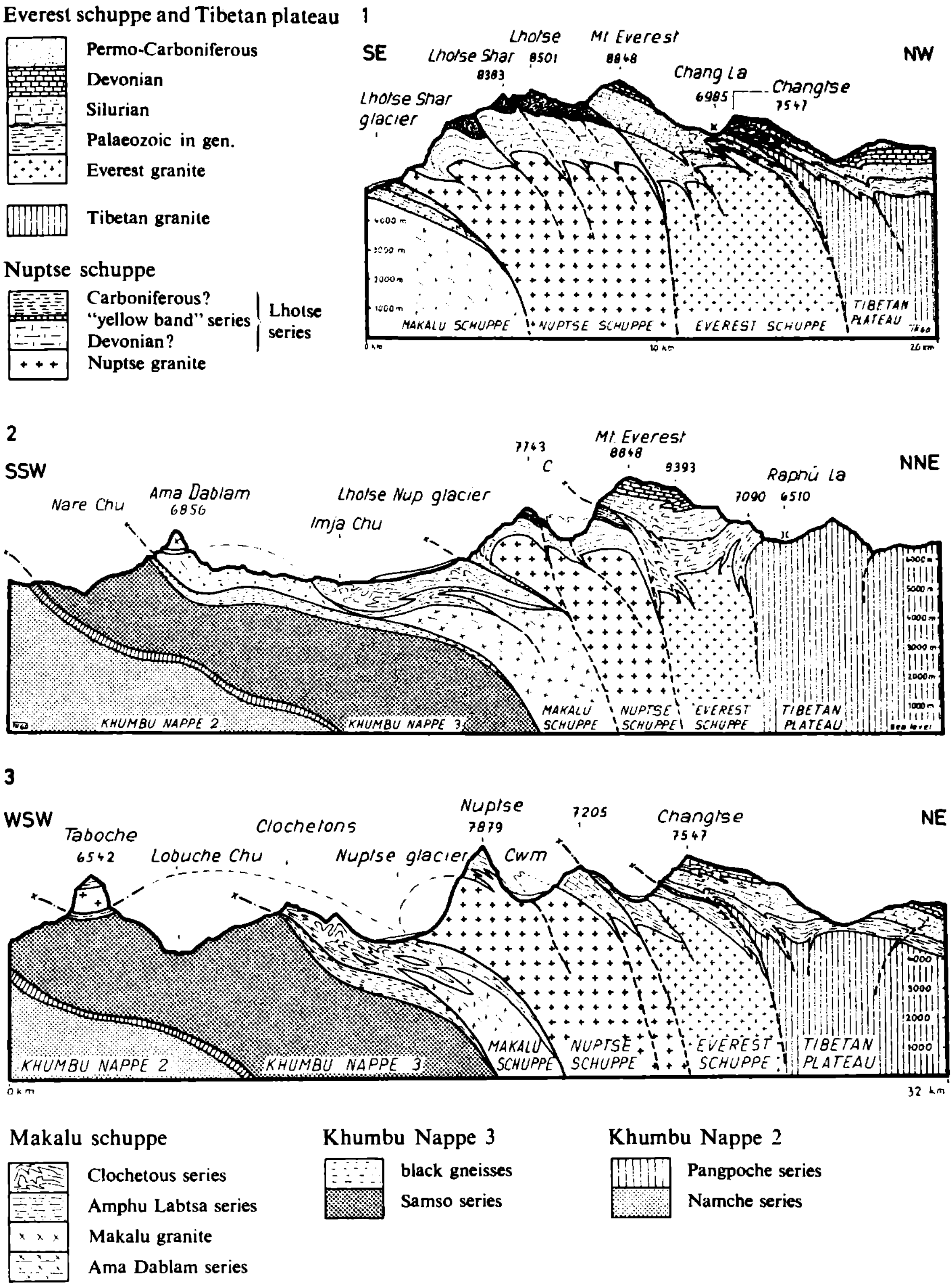



Fig. 100 3 geological profiles of the Everest group

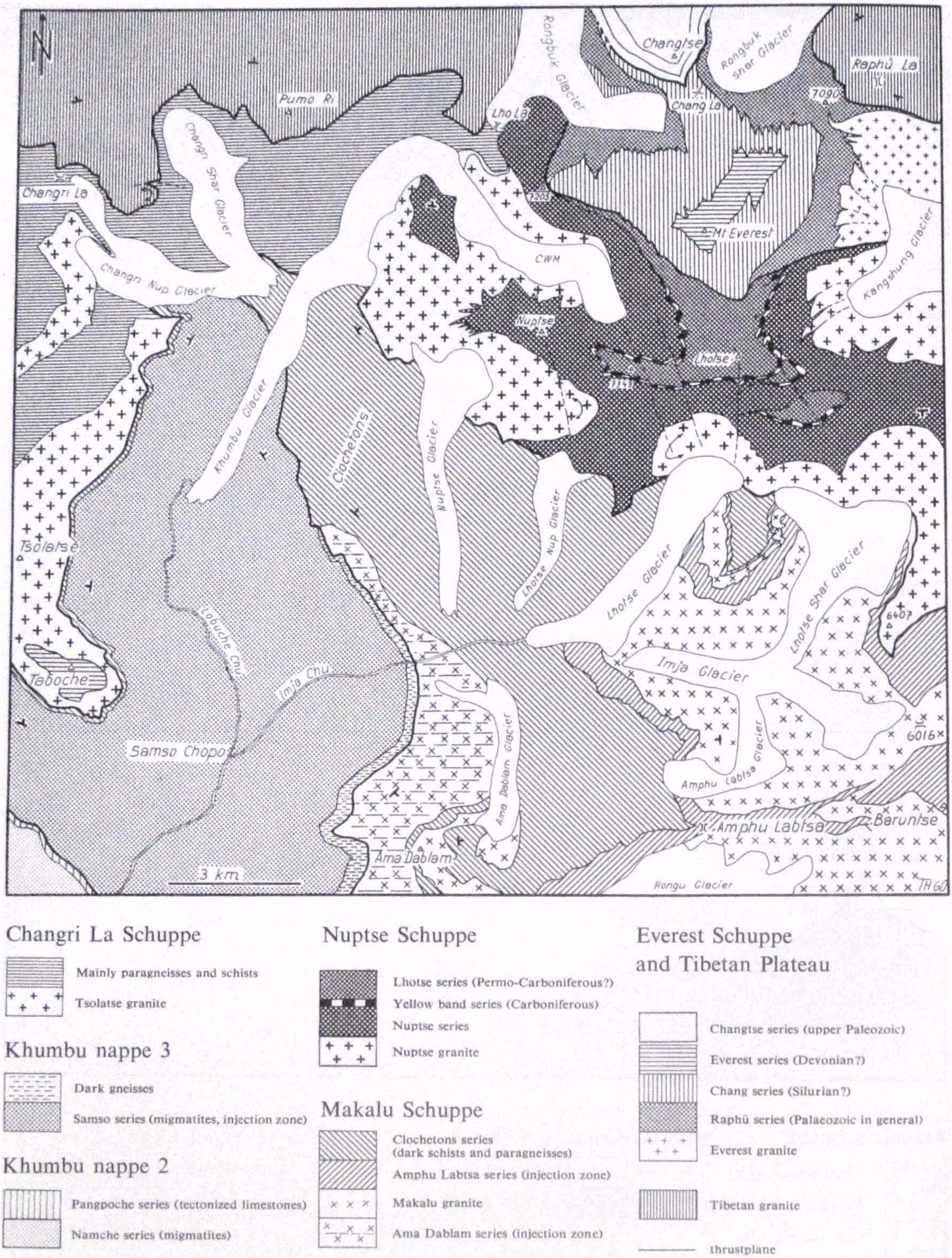



Fig. 101 Geological sketch map of the Everest group

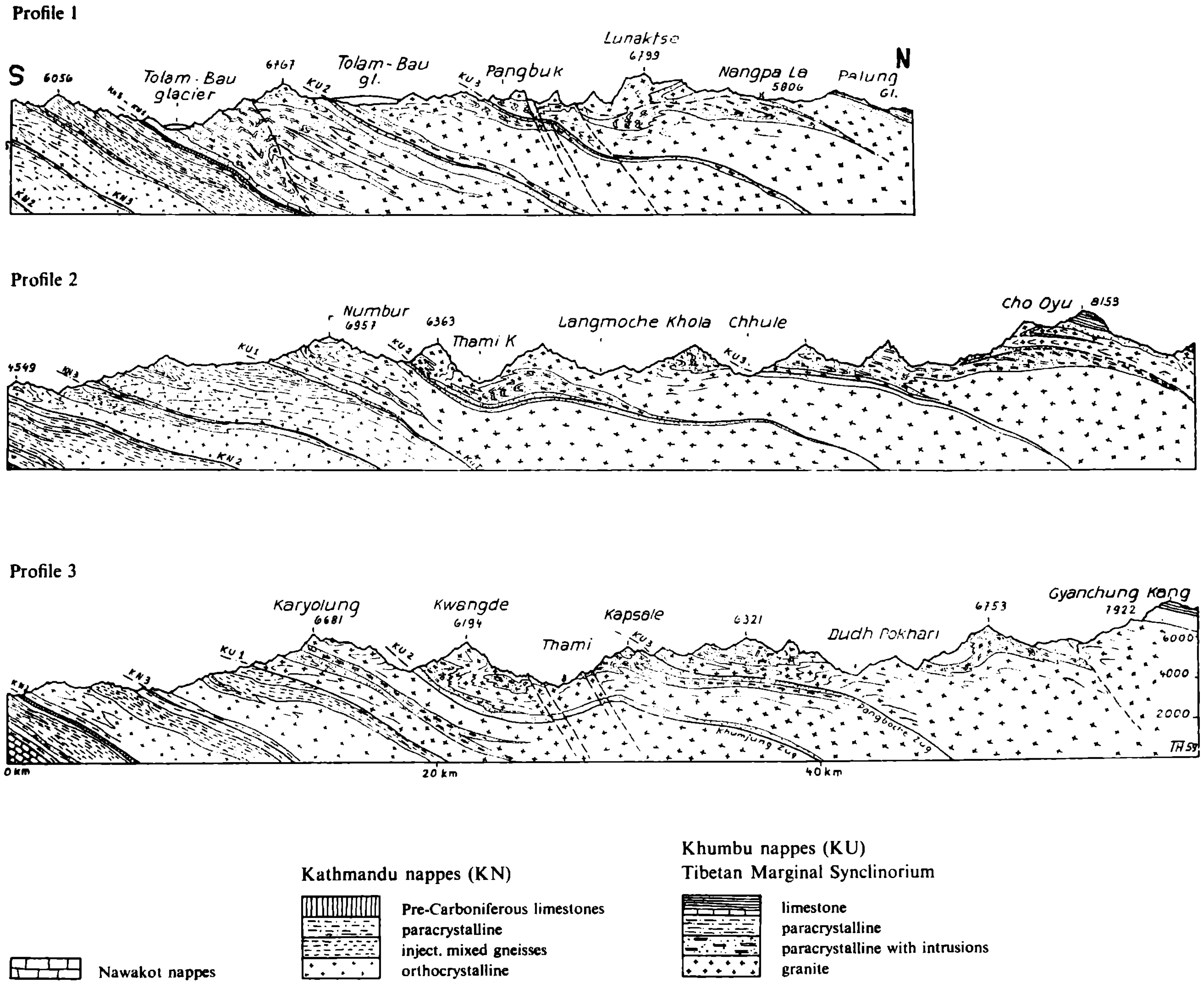
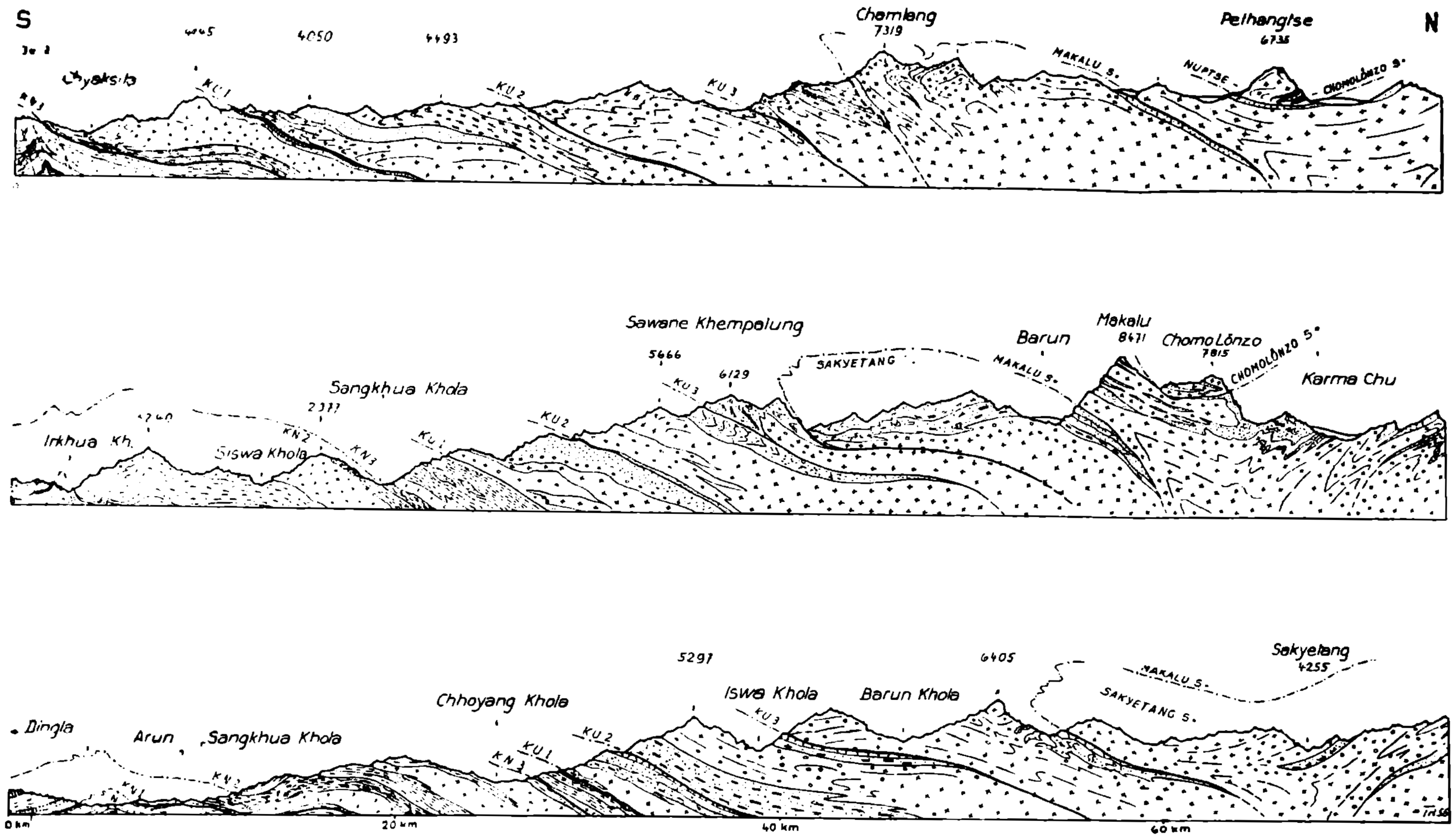



Fig. 102 3 geological profiles of the Cho Oyu group




Nawakot nappes

**Kathmandu nappes (KN)**

- Pre-Carboniferous limestones
- paracrystalline
- inject. mixed gneisses
- orthocrystalline

**Khumbu nappes (KU), Marginal Schuppen**
**Tibetan Marginal Synclinorium**

- limestone
- paracrystalline
- paracrystalline with intrusions
- granite

Fig. 103 3 geological profiles of the Makalu group

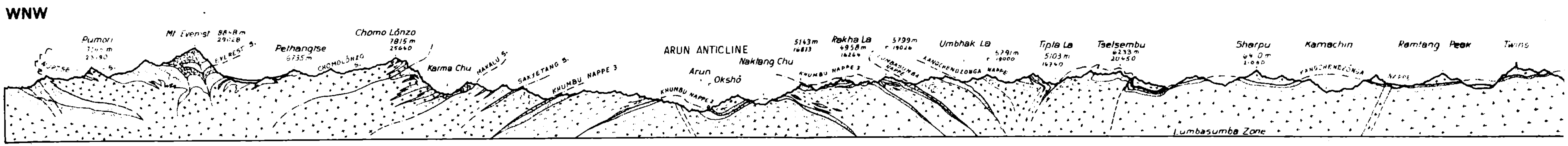
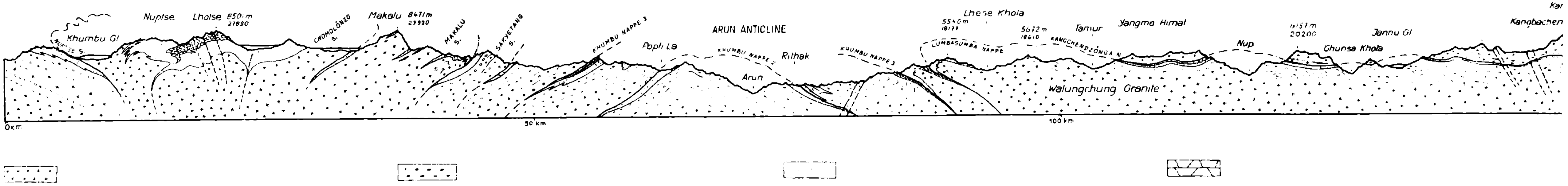



Fig. 104 Geological longitudinal profile from Mt. Everest to the northern flank of Kangchendzönga

If we connect in thoughts the corresponding tectonic units on either sides of the huge Arun anticline we come to the conclusion, the upwarp reached not less than 16 kilometers, P. Bordet consequently believes that 16 kilometers of crystalline rocks have been eroded in the Arun anticline.




Crystalline in general:
dominantly orthocrystalline,
partly granitic

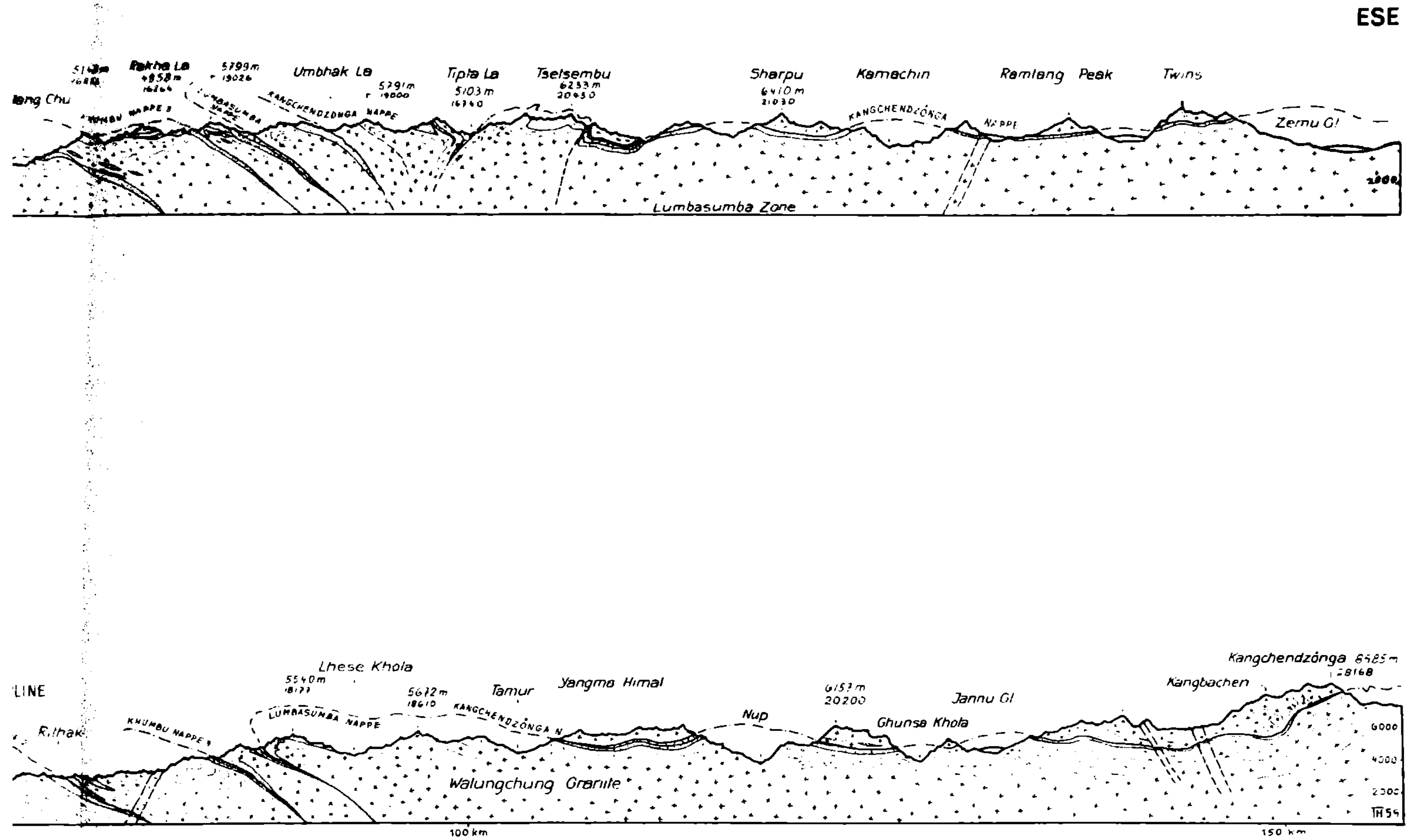
Mixed crystalline in general,
dominantly augengneisses

Paragneisses in general,
micaschists, schists,
"pelitic series" of Everest

Carbonaceous series of various ages
dominantly Carboniferous-Triassic east of the Arun

Fig. 105 Geological longitudinal profile from Lhotse—Makalu to Kangchendzönga

The corresponding tectonic units on both sides of the Arun anticline show a clear structure as recumbant folds, which terminate on the flanks of the Arun anticline. The sediment cover of the crystalline limbs is at some places still complete. Thus the corresponding units overlying the Khumbu nappe 2 have never been connected accross the Arun anticline.




Paragneisses in general, micaschists, schists, "pelitic series" of Everest

Carbonaceous series of various ages dominantly Carboniferous-Triassic east of the Arun

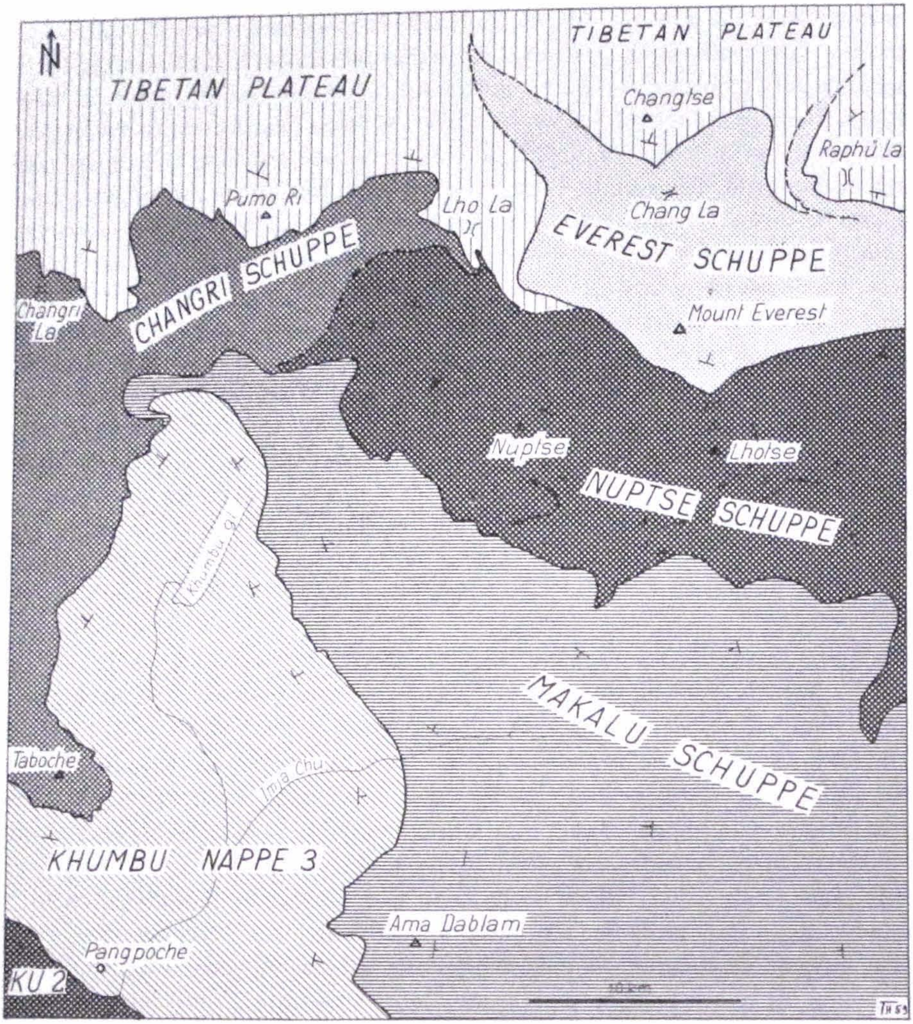
thrustplane

difficulties the minor structures, in the otherwise lithologically rather monotonous "pelitic" series. For example with the aid of the yellow band, two faults can be seen in the southern flank of Lhotse (fig. 122). The axis of those thrustfaults strike northnorthwest—southsoutheast (see also fig. 101, profile 1). The southern wall of the Lhotse (fig. 122) below the yellow band series, shows a huge frontal fold with axis in the normal longitudinal east—west strike. The beds build the vertical wall and have also caused one of the highest overhang of the world. The granite, corresponding to the Nuptse granite, occurs at the base of the wall. The granite forms — more or less symmetrically to the Nuptse anticline—a similar transverse structure, but overturned towards the west, that means the forces have in this area been active from east to west. This however is only a local feature, the overlying Nuptse series ("pelitics") have to a certain degree an independent tectonic mechanism, which is directed towards the southeast.

Lombard and Bordet consider the Nuptse—Lhotse series right up to Everest as a normal sucession. The top series of Everest were so far considered to be of Permo-Carboniferous, the underlying formations have neccessarily to include the Devonian. Consequently, a serious discrepancy occurred: Where are the Devonian limestones, which on all the other highest peaks of Nepal show thick series and cover wide areas north of the crystalline roots and towards the Marginal Synclinoria? Is there a primary stratigraphic gap? On the other hand, the author does not doubt at all on the Carboniferous age of the yellow band series: Those were found along the whole Himalayan Marginal Schuppen zone, at Manang, at Marpha, in the Langu basin etc. At some places they were proved by fossils to be of Carboniferous age.

The Carboniferous age of the yellow band series would fit to the Permo-Carboniferous age of the Everest limestones. But the problem remains: where are the thick calcareous formations of the Silurian and Devonian? While this publication was in the press, a new paper by A. Lombard and M. Gysin came in very handy. It shows the minute description of the succession of rock specimen collected by the members of the Swiss Mount Everest Expedition in 1956 (leader A. Eggler). Lombard suggests the Everest limestones to be of Devonian age. According to the microscopic and chemical analysis of the samples, the Everest "pelitic" series consist of low metamorphic rocks.

Lombard considers the Everest limestones to be of Devonian age, while the lower "pelitic" series necessarily would belong to the Cambrian. The author agrees fully to the Devonian age of the Everest limestones. They fit well to the findings in other high peaks. (Manaslu, Annapurna 2, Dhaulagiri western part). Regarding the yellow band series, we can't help to separate them from the Everest series. Evidence for such a separation was found in the Kangshung flank. This side shows enormous tectonic features. Those are not only confined to the sediments, but also to the underlying crystalline. This crystalline basement—due to an axial rise towards the east—occurs in the eastern flank of Makalu and Chomo Lönzo (figs. 126—130). A great number of folds, thrustfolds, thrustplanes and faults can be observed, besides extensive reverse structures with southern dip. If we project—according to the axial pitch towards the west—those structures into the section of Everest Lhotse, we find them in a depth of at least 12 kilometers underneath the Everest. That means, those structures in the Kangshung flank are not mere superficial features, but are major tectonic marks. Details of those structures are given in figs. 126—130, further in profiles 1 and 2 in fig. 100. We have consequently to separate an Everest Schuppe, which is overlying or adjoining the Nuptse Schuppe (fig. 101). The thrustplane of the Everest Schuppe can clearly be seen also in the southwestern flank of Everest (fig. 5 of Lombard, Lit. 1958). Three series were reconnoitered in the Everest Schuppe: The Raphü series (intrusion zone of the paragneisses); the Chang series ("pelitic series"), and the Everest series (Everest limestone, Devonian). The whole Everest Schuppe shows an axial pitch towards the west (fig. 107). The dips are thus directed towards north and even northwest. By this axial pitch, the crystalline basement of the Everest Schuppe does not occur northwest of Everest, in the West Rongbuk glacier. The granite occurring at the foot of the southwestern flank of the Changtse is tectonically spoken higher than the Raphü series of the Everest Schuppe; it belongs to the Tibetan zone (fig. 101).




| | | | |
|---|---|---|---|
| ——— | thrustplane | △ | peak |
| ⊃ | fold | ∘ | settlement |
| ⋌ | dip | ][ | gap |

Fig. 106 Tectonic sketch map of the Everest group

On the Raphü La there are reverse structures, with the crystalline dipping south. This is the western most reverse structure in the Everest area. They disappear further west.

If we now consider the general strike (eastsoutheast—westnorthwest) it appears, that the southern edge of the Tibetan Plateau does not continue from the Raphü La towards the west. The granite of the Tibetan Plateau occurs again west of the Lho La, in the Khumbutse (fig. 101 and 107). This seems to be transposed much to the south. The Lho La especially forms a kind of pivot of various structures. Out of this area, the Khumbu nappe 2 of Lombard develops, but to quote him: "It cannot be seen

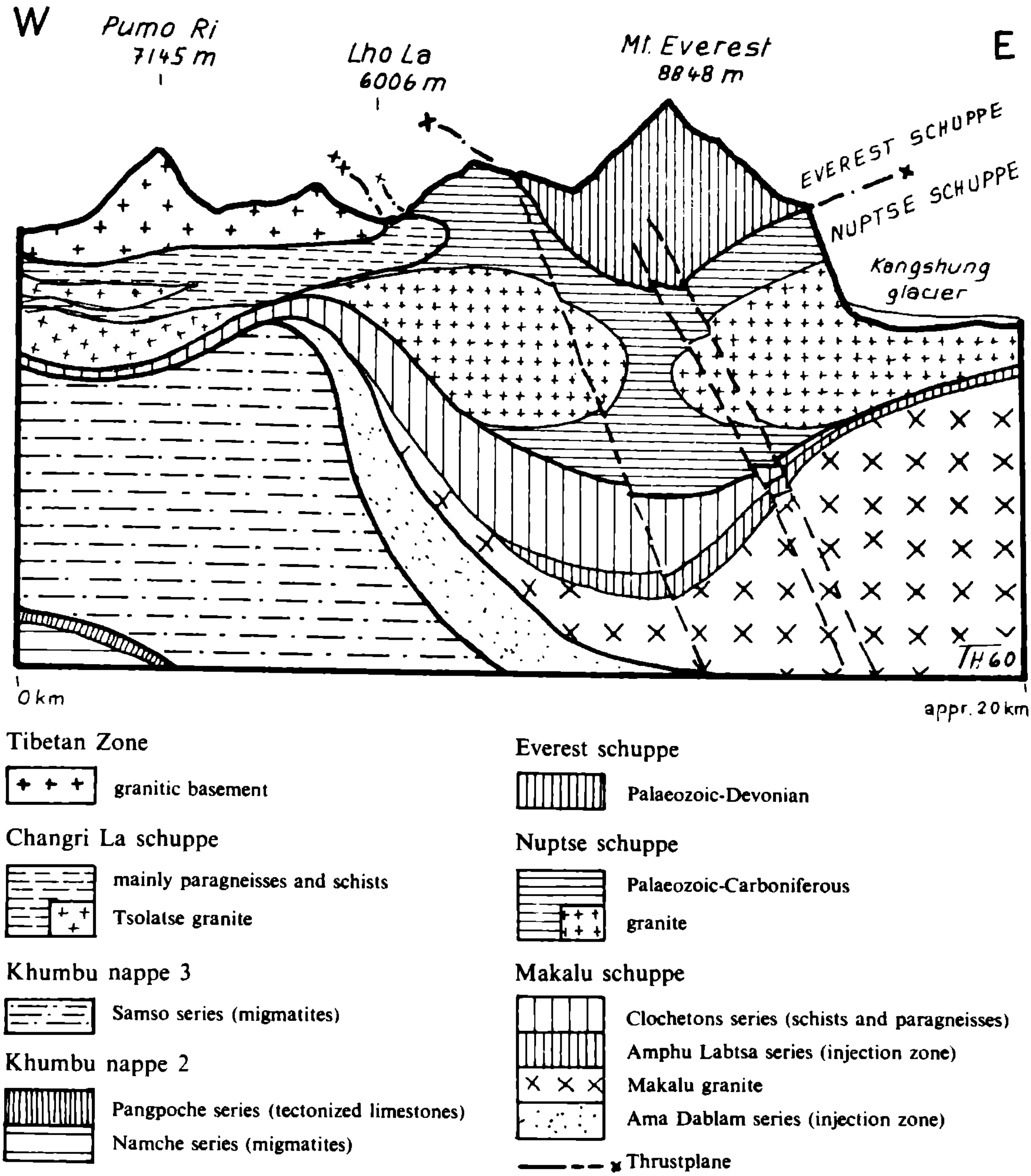



Fig. 107 Longitudinal profile sketch of the Everest group (not to scale)

from where the Khumbu nappe 2 is originating nor where it continues". The author named the series west of the Khumbu glacier and between the Samso series (Khumbu nappe 3) and the Tibetan zone (granite of the Pumori) Changri Schuppe. It is certainly at the same tectonic level as the Nuptse Schuppe, but cannot be considered as its direct western continuation (fig. 106). The Changri Schuppe is enormously tectonized, with structures in all directions. It is evident, that also the Tibetan zone of the Pumo Ri–Khumbutse develops out of the joint between the Everest Schuppe and the Nuptse Schuppe. That means, the Everest Schuppe decreases from the Kangshung flank toward the west and

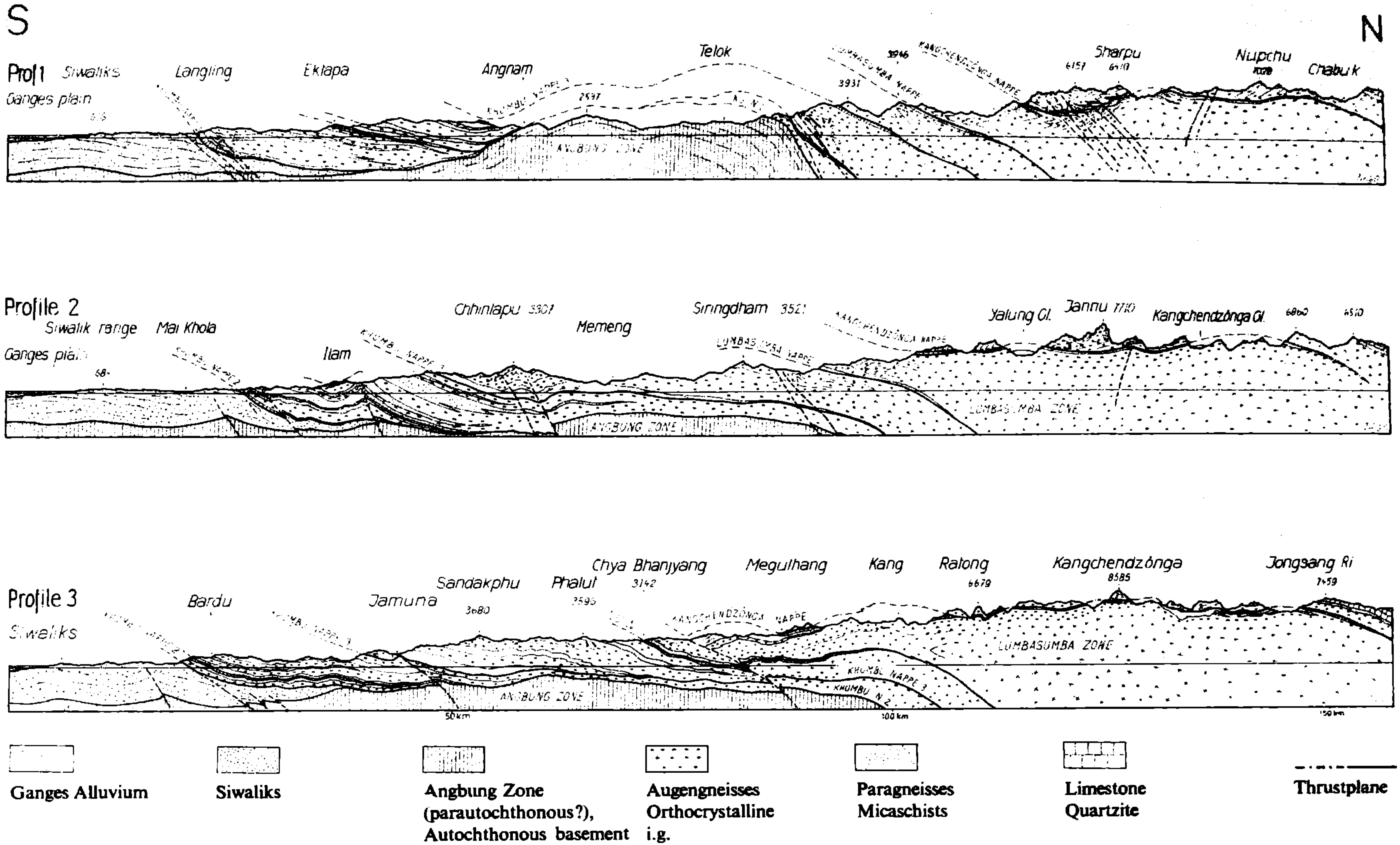



Fig. 108 3 geological profiles from the Kangchendzönga group to the Gangetic plain disappears in the area north of the Lho La (fig. 106). The Everest Schuppe is thus the topmost tectonic unit in the whole section between the Arun and the Nangpa La. The eastern portion of the Everest Schuppe with its reverse structures can be compared with the Tibetan Marginal Synclinoria. The Nuptse Schuppe, as well as the western portion of the Everest Schuppe correspond to the Himalayan Schuppen zone, which joins north of the roots of the big nappes through the whole Nepal Himalayas.

Towards the east, in the Chomo Lönzo—Makalu group, the structures are more characteristic. The Tibetan Marginal Synclinorium is about 25 km wide (fig. 128), the reverse structures and southern dips covering large areas. Due to axial rise, the eastern continuation of the Nuptse Schuppe into the Chomo Lönzo can easily be observed. The Makalu granite, separated from the Chomo Lönzo Schuppe by a remarkable thrustplane (figs. 128, 129) builds the Makalu.

Also due to the axial rise towards the east, no sediments occur east of Mount Everest. They strike high into the air, and the granite formations reach far towards the north, covering the whole Karma and Tashirakha areas. The sediments occur again only east of the Arun, in the Lumbasumba range (figs. 24 and 104).

It is most interesting to see, how the southern boundary of the Tibetan Plateau does not form one single edge, but is intersected and transposed. Thus for example, the Tibetan Plateau near the Raphü La (fig. 106) appears to be tectonically higher than the Everest Schuppe, and especially higher than the Plateau near Changri La. The divergence of crystalline, mainly granitic roots from the Himalaya into the Plateau is characteristic for the whole area of the Nepal Himalayas. It was first found in the Manaslu area.

Out of this outlay we conclude also a chronological succession. Mountain building, i. e. the thrust of the various Schuppen having continued from west to east.

# CHAPTER 5
# THE RISE OF THE HIMALAYAS AND THE ORIGIN OF THE DRAINAGE PATTERN

### *1) The main range is not the watershed*

Ever since there have been geographers in the world, their interest has been caught by the Himalayas, the highest mountains of the world. Many scientists have tried to explain the origin of the Himalayas and why they have been built up into the highest mountains, exceeding all other mountain ranges in the world.

The explanation of the excessive height of the Himalayas has for a long time been based on theories rather than on field investigations. These theories were manyfold, some of them using the famous "isostasy" of the ice age glaciation, etc. Dyhrenfurth, the reknown Himalayan explorer, created the term "Hebungsinsel" (lifted island) to describe the dissection of the main range of the Himalayas into various groups, which seem to have been lifted "en bloc" over a basement of about 4000 m altitude.

In addition, the mountain ranges and the drainage pattern of the Himalayas show a quite extraordinary relationship, rarely found in any other mountain system in the world. The main range is not identified with the main watershed; the big rivers originate on an other mountain range far to the north, and cross through the much higher main range in fantastic *transverse gorges*. Geologists have for a long time been inclined to accept the idea that the particular drainage pattern is older than the main range of the Himalayas. There was really no other reasonable explanation for the immense transverse valleys.

The first geologists dealing with these problems were those who accompanied the pioneering British expeditions from the northern (Tibetan) side in the early twenties of this century. The first paper on the origin and the height of the Himalayas and its correlation with the drainage pattern (especially in the Everest area) was written by L. R. Wager in 1922.

The Itinerary of L. R. Wager followed the upper course of the Arun river (which is called Phung Chu in Tibet) from the Nepal border right up to its source far to the north on the eastern flank of Shisha Pangma. Fig. 109 shows the profile of the whole Phung Chu-Arun course by D. N. Wager. He noticed the break in the river course from Kharta (3350 m) downwards, where the river crosses the main range of the Himalayas.

D. N. Wager also believes in the ancient origin of the drainage pattern and the later uplift of the main range.

According to him, the original watershed lay at the southern edge of the Tibetan Plateau. Due to excessive erosion from the south (steeper gradient, more rainfall) the river would have cut gradually backward, and captured parts of the former Tibetan Plateau. The loss of mass in the deep valleys would have caused an isostatic movement, which by uplift of the respective area (edge of the former Tibetan Plateau) would have performed the isostatic balance. The excessive height of the Himalayas, roughly 3000 m above the average level of the Tibetan Plateau, was caused by this isostatic uplift.

Wager reflected: "If one were able to level the mountains in Sikkim and eastern Nepal and fill up the valleys with the masses gained by cutting the high ranges a plateau would be created, the surface of which gently drops from 4600 m on the present margin of the Tibetan Plateau down to the Ganges Plain." Wager drew the section of the Arun-Phung Chu (fig. 109) and marked the high peaks which all form a plane ("Gipfelflur") dropping gently from the present main range towards the north. This theory seems to be fascinating and convincing.

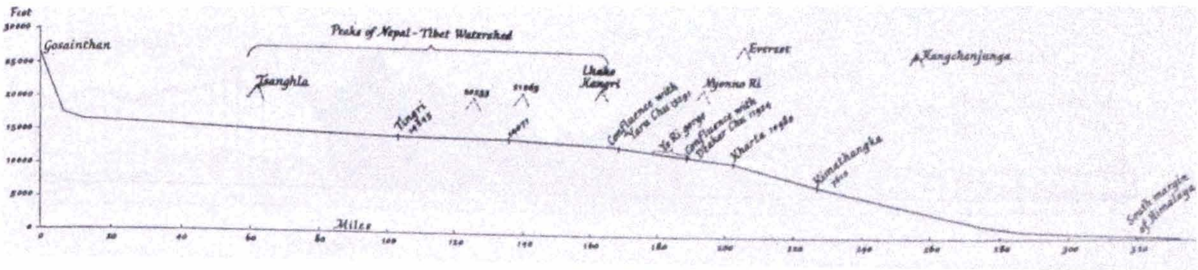



Fig. 109 Profile of the Phung Chu -- Arun river course in Tibet and Nepal, by D. N. Wager (1922)

Wager already noticed the step in the river course, where it traverses the main range of the Himalayas.
According to Wager, levelling of the high peaks and filling the valleys with the material would produce a plane, which gently dips from the watershed on the edge of the Tibetan Plateau (4600 m) down to the Ganges plain.

N. E. Odell also considered the isostatic uplift. However, according to him, this uplift was not caused by loss of mass in the eroded valleys, but by melting of the huge ice cap of the Himalayas after the ice ages.

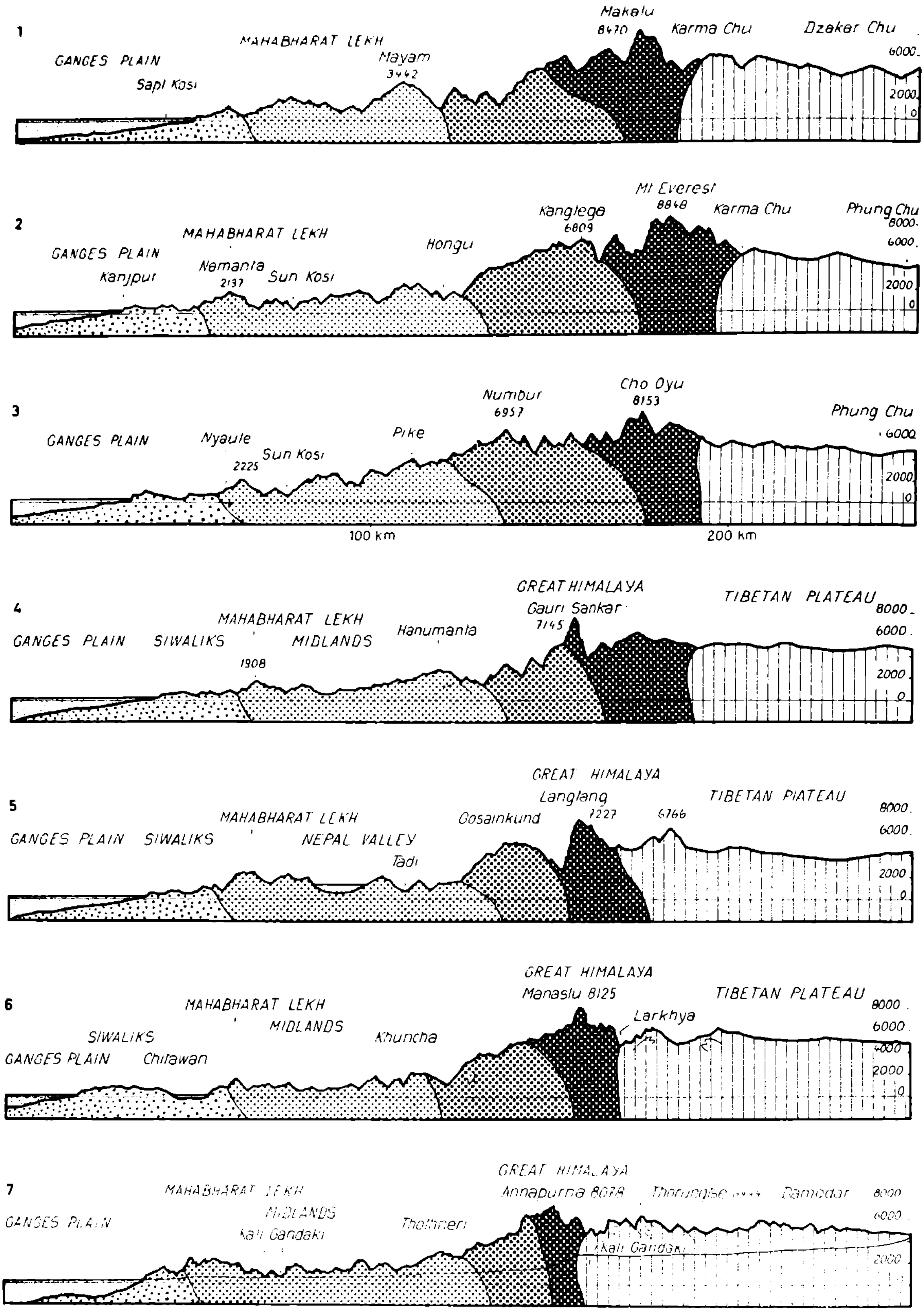
Neither theory takes any regard of the geological structures of the mountain system itself. It is understandable that such a picture of mountain building is much too simplified. According to the investigations of the author glaciation during the ice-age has not played a very important role in shaping the Himalayas. Moraines are hardly found below 2300 m, and also the high valleys show surprisingly little signs of glaciation in the form of moraines. The Thakkhola valley between Annapurna and Dhaulagiri for example has an entirely fluviatile shape and character.

On the other hand it is astonishing, that L. R. Wager does not mention the huge anticline in the Arun valley, which entirely dominates the geological picture of that area.

Let us see and recall some of the most important facts, which relate directly to the history of the Himalayas.

## *2) Tectonic position of the main range of the Himalayas*

It is relatively easy to find a reasonable reply to our question: how have the Nepal Himalayas risen to such an excessive altitude? We have only to study the enclosed profiles of the Nepal Himalayas, which reach from the Ganges Plain right up to the Tibetan border. Even the layman will be able to recognize, that the main range is with very few exceptions built out of the roots of the main crystalline nappes (Kathmandu- and Khumbu nappes) or out of the marginal Schuppen, which adjoin the roots to the north. To illustrate this fact more clearly, some simplified profile sketches have been abstracted from the main geological profiles (fig. 110). According to the tectonic profiles, given in plates 2–5 the tectonic situation of the highest mountains from east to west is as follows: Kangchendzönga, 8585 m (profile 2) is an exception; it is situated on a huge anticline south of the roots. Jongsang Ri, 7459 m is on the back of the Kangchendzönga nappe; this area (north of Jongsang Ri) lies in Tibet and has not been studied in the field. It is thus uncertain, whether Schuppen exist there. Makalu, 8471 m (profile 11) is built of the crystallines of the Makalu schuppe, a slice in the marginal Schuppenzone on the back of the Khumbu nappes. Mount Everest, 8848 m (profile 14) and Lhotse, 8501 m, are part of the topmost schuppe of the marginal schuppen zone with their calcareous formations. Cho Oyu, 8153 m, lies in the normal sediment cover of the topmost Khumbu root (profile 17).


1
GANGES PLAIN
Sapt Kosi
MAHABHARAT LEKH
Mayam
3442
Makalu
8470
Karma Chu
Dzaker Chu
6000
2000
0
2
GANGES PLAIN
Kanjpur
MAHABHARAT LEKH
Nemanta
2137
Sun Kosi
Hongu
Kanglega
6809
Mt Everest
8848
Karma Chu
Phung Chu
8000
6000
2000
0
3
GANGES PLAIN
Nyaule
2225
Sun Kosi
Pike
Numbur
6957
Cho Oyu
8153
Phung Chu
6000
2000
0
100 km
200 km
4
GANGES PLAIN
SIWALIKS
MAHABHARAT LEKH
1908
MIDLANDS
Hanumanta
GREAT HIMALAYA
Gauri Sankar
7145
TIBETAN PLATEAU
8000
6000
2000
0
5
GANGES PLAIN
SIWALIKS
MAHABHARAT LEKH
NEPAL VALLEY
Tadi
Gosainkund
GREAT HIMALAYA
Langlang
7227
6766
TIBETAN PLATEAU
8000
6000
2000
0
6
GANGES PLAIN
SIWALIKS
Chitawan
MAHABHARAT LEKH
MIDLANDS
Khuncha
GREAT HIMALAYA
Manaslu 8125
Larkhya
TIBETAN PLATEAU
8000
6000
4000
2000
0
7
GANGES PLAIN
MIDLANDS
Kali Gandaki
Thothneri
GREAT HIMALAYA
Annapurna 8078
Damodar
Kali Gandaki
8000
6000
2000

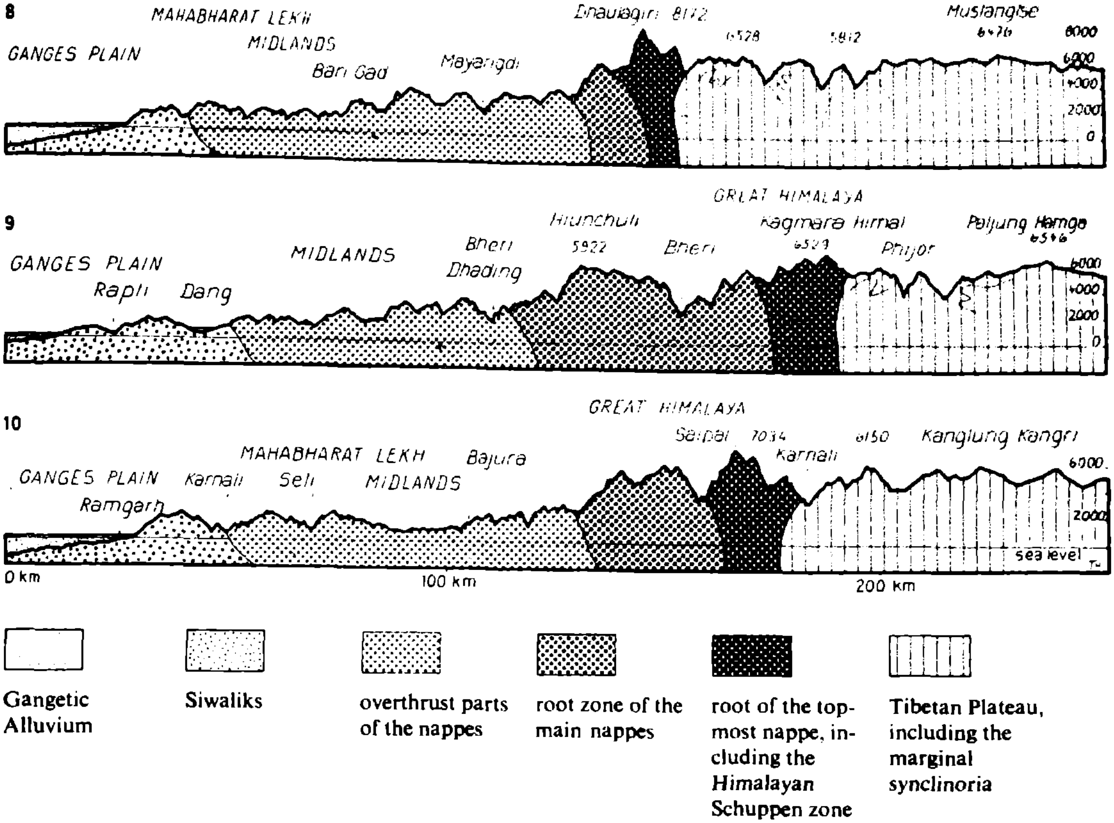



Fig. 110 10 tectonic diagrammatic sections from the highest peaks of the Nepal Himalaya to the Ganges plain

(heights 3 times exaggerated)

Numbur, 6957 m (profile 17) is situated on the root of the Khumbu nappes. Kangtega, 6809 m (profile 14) is built from the crystallines of the Khumbu nappes 2 and 3, but is really lying above the root of the Khumbu nappe 1. Gaurisankar, 7145 m (profile 20) is situated on the roots of the Kathmandu nappes. Shisha Pangma, 8013 m (profile 27) is an exception; it is situated on an axial culmination of the Tibetan marginal mountain range. The Langtang, 7245 m (profile 30) is situated on the crystalline of the roots of the Kathmandu nappes. Ganesh Himal 7406 m is built of the crystallines of the Kathmandu nappe 5. Manaslu, 8125 m (profile 46) has its summit just on the junction between the granite of the Kathmandu root 5 and its normal sediment cover. Annapurna, 8078 m (profile 55) has the main summit on the top of the crystallines of the Kathmandu nappe 5. Other summits of the Annapurna range (Annapurna II and Gangapurna) are built of the normal sediment cover of the Kathmandu root 5 (profile 51).

Dhaulagiri, 8172 m (profile 59) is built of the sediments on the back of the Kathmandu root no. 5. The high peaks of western Nepal (Kanjiroba 6867 m, Api 7132 m, Saipal 7034 m) are all situated on the normal sediment cover on the back of the topmost roots (profiles 70, 80, 86).

Gurla Mandata, 7728 m in Tibet close to the north-western corner of Nepal is an exception. This isolated high mountain forms an anticline on the Tibetan Plateau. However, the anticline also develops into nappe roots towards the east (fig. 36).

In the profiles of fig. 110, the tectonic units are much simplified and the height-scale is three times exaggerated. Thus the position of all the highest peaks in the Nepal Himalayas from the point of view of tectonics appears extremely clear.

### *3) Ancient origin of the transverse structures*

When considering the longitudinal profiles of the Nepal Himalayas (figs. 26 and 27) the configuration of the highest peaks appears to conform with that in the transverses profiles: All of them are situated in longitudinal synclines. The whole chain of the Great Himalaya Range is intersected by transverse structures into different groups (the "Hebungsinseln" of Dyhrenfurth). Each transverse valley follows a transverse structure, the most important ones being the huge Arun anticline between the Kangchendzönga and Everest groups and the Thakkhola graben, which is caused by faults and thrustfaults. It is evident that the transverse structures go back to pre-orogenic times; the lay-out of these transverse structures has determined the later drainage pattern with the dominating transverse rivers.

In the Arun valley, on its eastern flank in the Lumbasumba Himal, it is clear that the Arun anticline has existed in some way before the uplift of the main range. The great crystalline nappes are certainly affected and involved in the huge anticline upward, but the higher nappes east of the Arun river as well as the corresponding Schuppen on the western side in the Makalu-Chomolönzo group show clear front-folds of the crystallines inbetween the Tibetan sediment wedges (figs. 104 and 105). This means that the higher nappes and Schuppen (Lumbasumba nappe and Kangchendzönga nappe) on the eastern side have never been connected with the Sakyetang Schuppe, Makalu Schuppe and the Chomolönzo Schuppe, west of the Arun valley. There must have been a primary gap along the Arun section. Bordet mentions that 16 km thickness of crystalline series has been eroded from the huge Arun anticline. This is unlikely, since such very large nappes have never existed across the Arun valley.

The dilemma of different interpretation is understandable; P. Bordet considered the Arun anticline as post-orogenic, because he saw only the upwarped Kathmandu- and Khumbu nappes. A. Lombard, basing his investigations on the southern flank of Everest, considered the transverse structures as earlier than the rise of the Himalayas. Both of these authors are right; the transverse structures are certainly of ancient origin, but they have also been renewed during the whole main stage of the rise of the Himalayas.

Due to the transverse structures, the longitudinal profile of each single mountain group between two transverse valleys shows a syncline. This fact appears to be surprising and may be quite against general expectance. Mount Everest especially is not situated on an axial culmination, but rather in a depression (figs. 104, 105 and 107).

A further result of the longitudinal syncline structures within the single mountain groups is the configuration of the roots in arcs, which join like garlands (plate 6).

### *4) Mesozoic origin and rise of the Tibetan Marginal Range*

In the Thakkhola graben, features have been found which prove the Mesozoic origin of the Tibetan marginal range. The flysch-like formations of the Thakkhola series, which have been determined as upper Mesozoic-Eocene, have transgressed in a basin of an old relief. The old mountain range (the Tibetan marginal range) had then been eroded to a certain degree, and was intersected by valleys, in which the Thakkhola series have been deposited with considerable unconformity. They transgressed over various series, which vary in age between Permian and Jurassic; this is especially well displayed

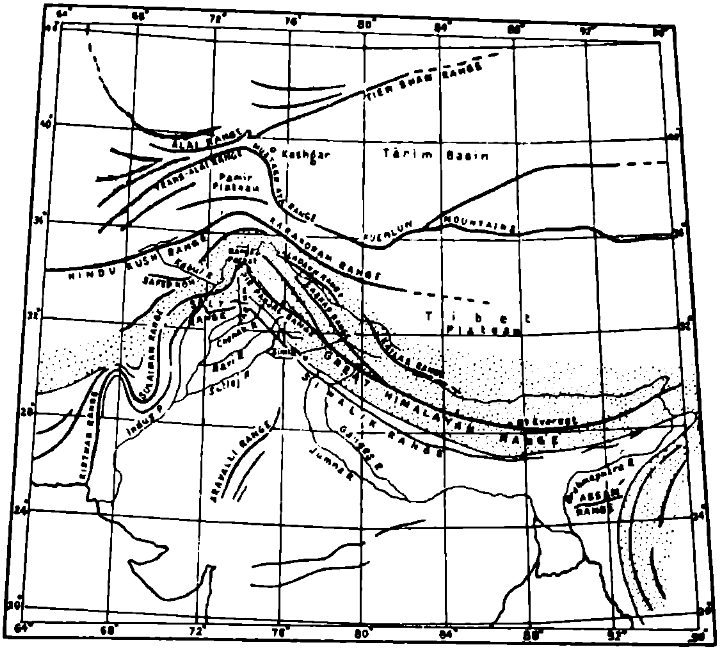



Fig. 111 The Himalayan Geo-Syncline after Burrard and Mushketow
(dotted area, Lit. 1934)

in the Thorungtse range (fig. 40) north of Muktinath and in the area of Damodar Kund. It is very probable, that not only has the Tibetan marginal mountain range been built during upper Mesozoic, but also the main portion of the Tibetan synclinorium. The whole structure of these synclinoria (plate 4, 5, profiles 46, 51, 55, 59; fig. 37) shows folds, thrustfolds, faults and thrustfaults. This type of structure is quite different from the nappe structure further south. The whole configuration leads to the idea of a complicated graben structure, with numerous faults and fractures which reach very deep into the crystalline basement. The top parts of the faults have acted especially in the sediments of the trench margins so that they were folded towards the sunken parts of the troughs. As a result folds are directed towards the center of the troughs, i. e. reverse folds at their southern flank.

It has already been mentioned in chapter 3/4 that the synclinoria do not extend in one single line from east to west, but are transposed against each other. This is illustrated in fig. 113.

In the Alps, new investigations have shown that prior to the overthrust of the great nappes the area of the alpine geosyncline was intersected by numerous fractures, faults, Horsts and Graben, which had already during the middle Mesozoic caused primary mountain ranges. By minute stratigraphic research it was possible to determine the age of the faulting. It is now the general view, that the great nappes in the Alps were not developed out of folds and recumbent folds (as is always shown in obsolete textbooks) but out of such faults and Horsts.

In the Himalaya, it has been proved that during Mesozoic time the Himalayan syncline was also intersected by fault systems running parallel to the later strike. Those which occurred north of the later nappe roots can still today be recognized. However the fault systems were evidently not restricted to the Himalayan geosyncline, but also the later nappe zones were involved in faulting. The large formations of breccias in front of the Nawakot nappes are proof of mountain building already occurring during Triassic and lower Jurassic ages.

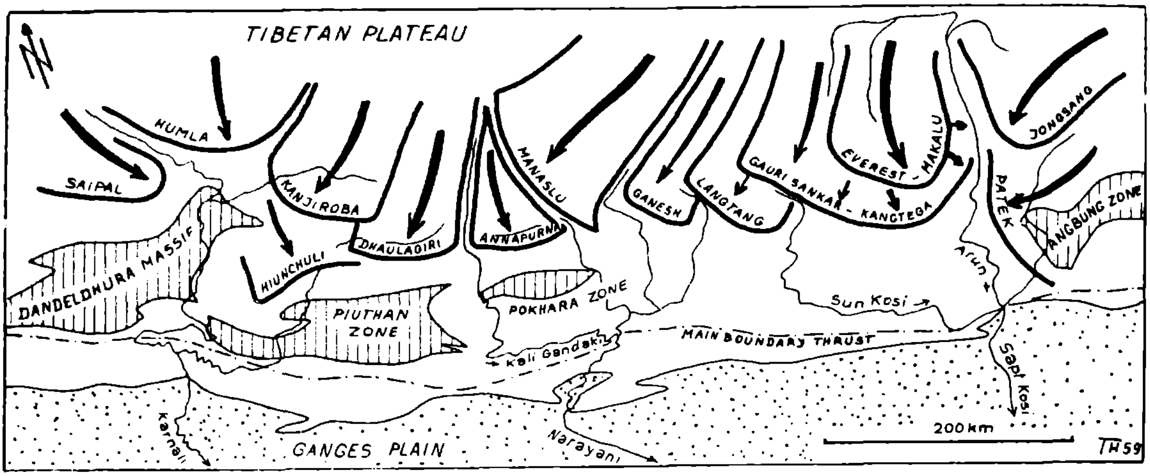



Fig. 112 Sketch map showing the various thrust blocks at the southern edge of the Tibetan Plateau
(The lined areas denote autochthonous and parautochthonous zones which later on were partly buried by the overthrust nappes)

The Tibetan marginal synclinorium has to be considered as the original southern margin of the Tibetan plateau. The initial rise of the Tibetan highland apparently began at rather an early stage; the southern edge, during that rise was broken and faulted.

As conclusion we have to consider the Tibetan marginal range as the original main watershed between the Ganges drainage pattern and the Tsangpo system. This watershed had been created long before the great nappes of the Himalayas were overthrust to the south, and long before the present main range had reached its excessive altitude. The Tibetan marginal mountain range might have reached about 2000–3000 m above sea level, before uplift of the Tibetan plateau. Together with the rise of the plateau of 4000 m, the final altitude of the Tibetan marginal range reached 6000–7000 m, which is the altitude, still today found in this mountain range. Erosion has worked very slowly in this range since it very soon became protected from the heavy rains and erosion by the rising barrier of the great Himalaya range in the south.

The Tibetan marginal range is still today the main watershed between the Ganges drainage pattern and the Tsangpo system. In western Nepal this mountain range forms the Nepal-Tibet border north of the Langu synclinorium (plate 6), namely in the Changla Himal, the Kubri Kangri and the Palchung Hamga Himal.

From the Thakkhola to the east however, the watershed has moved still more to the north owing to tectonic events to be described in the following chapter.

*5) Tectonic lakes north of the main range*

Further indications to explain the unique system of ranges and rivers were found in the Thakkhola, north of Dhaulagiri and Annapurna. The whole basin, caused by a huge transverse structure, is filled by Tertiary and especially Pleistocene formations of an extraordinary thickness. They consist of lake deposits, clays, sandstones and marls with varves and are superposed by large formations of boulder beds. The lower portions of these formations show special tectonic features with small folds and faults. but on the whole, these wellbedded series show a strong rise towards south, to the northern foot of the main range. There is no doubt, that the whole Thakkhola basin has once been

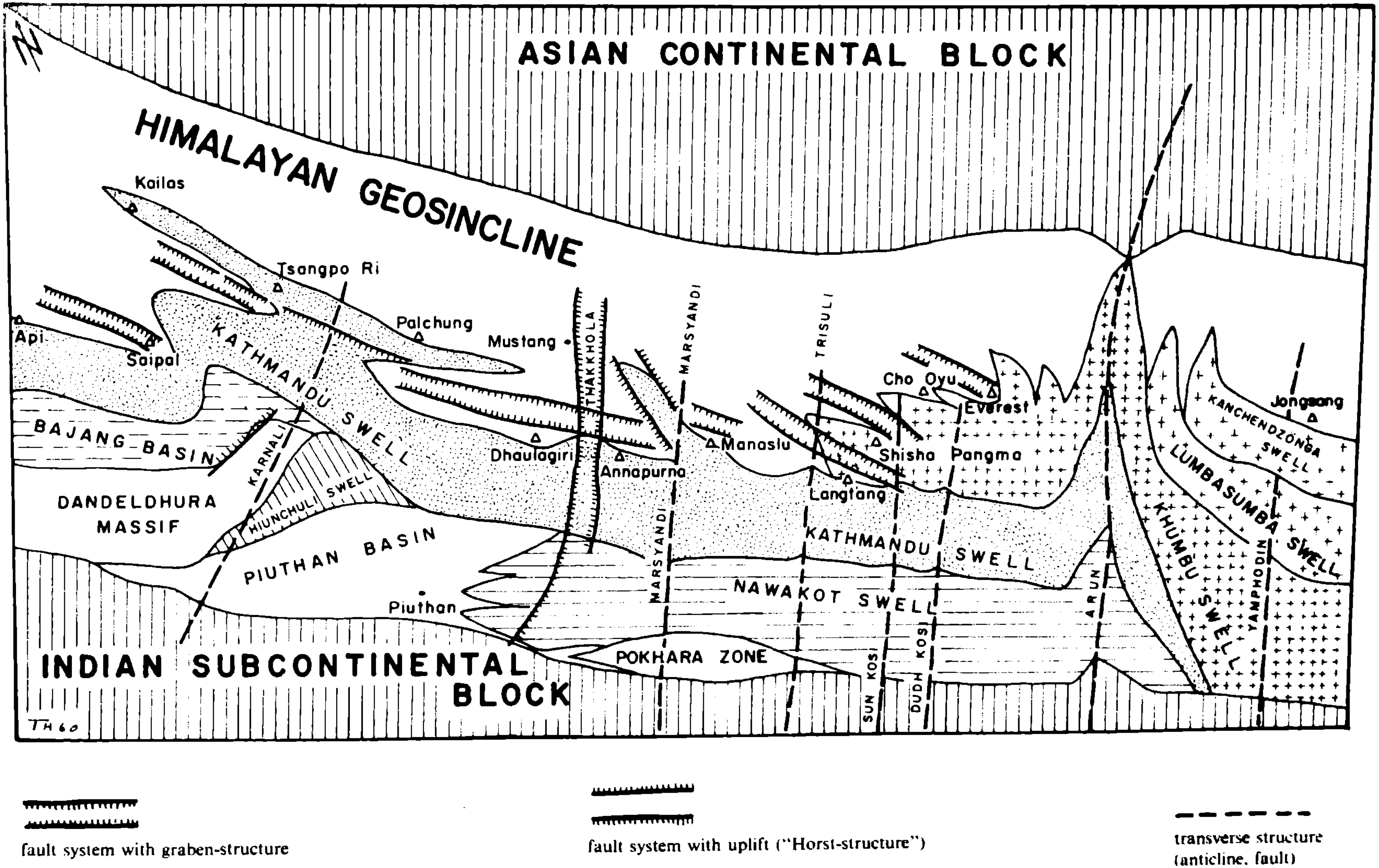



Fig. 113 Sketch map of the pre-orogenetic Himalayan geosyncline

filled up by a lake. This lake was of tectonic origin. The crystalline roots of the big nappes were raised so rapidly, that the Kali Gandaki river did not find the time to erode its riverbed accordingly (fig. 136).

Such lake deposits were found in most of the other transverse valleys north of the main range. In the Langu basin, in the Manang valley in the Buri Gandaki valley north of the Manaslu and Ganesh group, in the upper course of the Trisuli in the basin of Kyirong Dzong. Apparently lake deposits occur in the upper course of the Arun too. The other valleys since they lay in Tibet were beyond range of the author's fieldwork.

However, in no other valley than in the Thakkhola, are traces of the former lake so well visible. The Kali Gandaki drops form Chukhgaon to Dumpu only about 600 m, in a horizontal distance of 40 km. From Dumpu to Dana it drops 1000 m within a course of a few kilometers only. The flat bottom of the valley north of Dumpu is pretty wide, and the southern part of the alluvial valley bottom is not at all cut by a gorge. The Kali Gandaki river flows in a broad plain as far as Dumpu, and there as soon as it enters the crystallines, it drops into the tremendous gorge. The crystallines are exposed in the river bed and the southern edge of the plain. There is no doubt, that at a short distance to the north, the solid rock under the alluvial plain is deep below the surface. Possibly, glacial erosions might have worked too in forming the southern part of the underground basin. But there is no doubt that the crystallines near Dumpu are still at present in a stage of uplift. Thus the roots of the Kathmandu nappes are still rising.

### *6) Crustal movements south of the main range*

We have already dealt with the structures of the Midlands in chapter 2, paragraph 2. Besides the upwarps into anticlines and the faults, the Mahabharat range as a whole shows a strong topographical rise compared with the Midlands. This mountain range thus forms a natural barrier for the Midlands towards the south. Proof of this relative uplift of the Mahabharat Lekh has been found at several places.

These crustal movements are best illustrated in the Kathmandu valley. The religious legend tells of a former lake in the Nepal Valley, and Geology has proved this to be true. There was a large lake in the Kathmandu valley, which is now filled up by thick Pleistocene formations; in the young Bagmati gorge they show a considerable dip from the northern foot of the Mahabharat Lekh (near Tinpani Bhanjyang) to the north into the valley. The beds drop by 250 m from Tinpani to Patan.

Similar features were found in other valleys too. Especially well developed are the lake deposits in the Tila valley near Jumla, in the Karnali valley north of Porapalni and near Diplang west of Gurkha.

In the Tila-Karnali valley the old lake deposits have remained as river terraces on either flank of the deep valley, cut in the mountain range of the Fore-Himalaya. These terraces rise from Chilka in the Tila valley not less than 400 m towards the south to the Bartha Lagna, giving firm proof of a considerable late uplift of the Fore Himalayan Range north of Dailekh.

So far we have spoken of an uplift of the Mahabharat Lekh relative to the Midlands. It would possibly be more correct to speak of a sinking of the Midlands relative to the Mahabharat Lekh. Indeed, the former lakes in the Midlands are nothing else than sunk and drowned valleys.

A comparison with the so-called "Alpenrandseen" of the Alps (Alpine marginal lakes) seems to be logical. It was the great master of Alpine Geology, Albert Heim, who has first explained the origin of these sunken valleys. He believed he had found old river terraces near the lake of Zurich with reverse (southern) dip; the reverse dip was for Heim the proof of sunken valleys. He explained the origin of the sunken valleys as caused by sinking of the whole body of the Alps after completion of building up, due to isostatic re-adjustment.

Other scientists believing in glacial erosion and its strong effect on shaping the surface, denied the theory of Heim. According to them, the basin of the lakes was eroded by the ice-age glaciers and afterwards during the retreat of the glaciers was protected from being filled up with alluvial deposits due to the existence of dead-ice masses. The reverse dipping river terraces on the lake of Zurich have by recent field investigations proved to be outcrops of the molasse, and the Alpine marginal lakes have therefore originated according to those authors from mere glacial erosion.

This explanation however can hardly be considered to be the final proof. It is really surprising that both the Alps and the Himalayas show the marginal lakes. In the Nepalese Midlands, with altitudes of not more than 700–2000 m, glacial erosion is entirely out of the question and could not have played any role in forming such basins. We thus have to consider the lakes in Nepal as real marginal lakes, caused by a tectonic sinking of the great Himalayas relative to the Mahabharat Lekh.

The *Siwalik zone* is also involved in a number of very young crustal movements; it has been dealt with in detail in chapter 2, paragraph 15.

While the features described above which are visible on the surface, are direct proof of the crustal movements, there are other indications which also tell of young uplifts in the Himalayas. The transverse valleys in the main range have without exception a characteristic profile, which is a modified "V" shape. The slopes of the "V" getting steeper toward the lower part of the valleys and being perpendicular in the gorge and in the bottom. Such kinds of valley shape are caused by uplifts, through which the rivers achieve a steeper gradient and thus more erosion power (Fig. 135).

# CHAPTER 6
# RECONSTRUCTION OF THE HISTORY OF THE RISE OF THE NEPAL HIMALAYAS

## *1) The Himalayan Geosyncline*

The view of nappe structure in the Himalayas has been accepted since the early thirties, in the investigations of the geologists of the Survey of India and by other scientists, who have carried out private expeditions. The origin of nappes has generally been explained by crustal movements, which were not only vertical, but also horizontal. It was Emile Argand, the famous Swiss geologist who, using his knowledge of the Alps, gave as early as 1922 a comprehensive tectonic outlook in his fundamental work on the "Tectonic of Asia". Argand had made his reputation in the Swiss Alps, where he was a principal explorer and promotor of the nappe theory. His cross-section of the Himalayas, given in the above-mentioned publication is still valid in principle today. It really has not been corrected or modified (fig. 8). According to him, the Indian subcontinent has drifted towards the north, to the Asian continent, and folded and thrust the Himalayan Geosyncline, which was lying in between (fig. 8). Due to a rise of the northern continental mass (the Tibetan plateau) the overthrust of the nappes was directed towards the south.

In principle Argand's conception was ahead of the later description, given by Burrard and Mushketow in 1934. The latter show the main ranges of the Himalaya right inside of the Himalayan geosyncline (fig. 111), while according to a sketch of Argand (fig. 8) the nappes have been created out of the southern margin of the Himalayan geosyncline and even out of the northern edge of the Indian subcontinent.

The area of the Nepal Himalayas might, according to the investigations of the author, have looked in the upper Mesozoic just before the first phase of rise of the Himalayas, as drawn in the sketch map (fig. 113).

All the zones, which later on should have built the Himalayan mountains, were lying at the southern margin of the Himalayan geosyncline. During the Mesozoic age, after the Triassic formations of the Nawakot zone and the Bajang zone were deposited, but before rising of the Tibetan marginal range as the first mountains in the Himalayas, three main swells occurred in the geosyncline. These swells formed the primary lay-out of the later nappes. The backbone of the swells within the geosyncline was the Kathmandu zone. The Nawakot swell joined east of the section of Dhaulagiri to the south, while the Khumbu swells lay to the north. The latter (fig. 113) had a complicated shape with partial swells pitching northwards into the Tibetan sea, joining to the north of the Himalayan geosyncline. The Lumbasumba and Kangchendzönga swells occurred east of the Arun section only (fig. 113).

The Kathmandu swells in the east (east of the Arun) turned towards the south. In the west (west of Karnali), they were also transposed towards the south. In the arc formed by the Kathmandu swells and from its western branch towards west there were basins with Mesozoic formations, the Nawakot zone and the Bajang zone. The latter was in the south bordered by the Dandeldhura massif, which also formed a large landmass. The Hiunchuli zone (including the Jajarkot zone and Dailekh zone) joined the angle between the Kathmandu swell and the Dandeldhura landmass. South of the Hiunchuli zone, the Piuthan basin extended as far as the margin of the Indian subcontinent, and joined the Nawakot swell in the east and the Dandeldhura massif in the west. The Nawakot swells pitched into the Piuthan basin in form of partial swells. We do not know much about the character of the swells but uplifts and sinking by faults are proved by the findings of breccias and conglomerates in the Mesozoic formations in the Nawakot zone for example.

The northern margin of the swells, their flank facing the sea of the Himalayan Geosyncline, was characterized by a number of faults and thrust faults, the primary lay-out of the later Tibetan marginal synclinoria. Also the facies was different between this marginal zone and the open sea of the geosyncline in the north.

In the same stage, before the rise of the first mountain range, the area of the Nepalese Himalayan Geosyncline was intersected by transverse structures (fig. 113).

Most of them were anticline structures, the Arun anticline having the greatest magnitude. In the Thakkhola section there was an exceptional Graben structure (fig. 113). Various granitic and basic intrusions accompanied the breaking up of the southern marginal zone of the Geosyncline into longitudinal graben and horsts.

### *2) The rise of the Tibetan Marginal Mountain Range*

This mountain range was the first one, which rose out of the Himalayan zone. Due to the convergence of the two continental blocks (fig. 8), the Geosyncline was pressed and in its weakest zone was pushed and raised into mountain ranges. An uplift of the whole geosyncline and of the bottom of the former Tibetan sea was connected with the compression. As a result, mountain ranges were built at the northern margin of the fault zone. The fault zone, the graben and horsts themselves were compressed and the complicated structures of the marginal synclinorium resulted.

Due to the special configuration of the former Tibetan marginal zone with its transposed fault systems, the rising Tibetan marginal range did not take the form of one single chain, but was also divided into several ranges, which were interposed with each other. Interposition followed a law, according to which each next range in the east was transposed towards the north (fig. 112). Accordingly, the Tibetan marginal synclinoria suffered a similar break up and relative transposition (plate 6).

The phase of the first mountain building in the Nepal Himalaya is called by the author the *Thorung phase,* after the Thorung range near Muktinath, north of Annapurna (fig. 38). At this locality, the Mesozoic mountain building was first found and studied, and also proved by fossils.

The Tibetan marginal mountain range, built in the upper Mesozoic, formed the first main watershed in this part of the world. Its northern flank was drained by the tributaries of the Tsangpo, the southern side by the Ganges system. The non-symmetric lay-out of the drainage pattern was created right from the beginning. Since the birth of the first mountain range the southern rivers have had a steep gradient and the northern ones a very gentle one. Since the rising Himalayan range stretched an excessive distance east and west, the Tsangpo, Sutlej and Indus had to run a very long course (up to 2000 km) before they found a way out of the mountains to the oceans in the south. The tributaries of the Ganges on the other hand ran after a distance of little over 200 km into the Ganges sea, which was created shortly after the time of the rise of the first mountains.

The rivers flowing from the Tibetan marginal range down to the south followed the old transverse structures which created zones of weakness in general. In addition all of them have been rejuvenated right from the first phase of mountain building to the end of the orogenesis. Small rivers draining the basins of the synclinoria north of the Kathmandu and Khumbu swells (fig. 113) were collected by those rivers, which used the transverse structures to break through the swells. The Tibetan marginal range might have had an altitude of about 2000–3000 m, of which a part was caused by the beginning of the general uplift of the Tibetan plateau.

Erosion was entirely different on the two sides of the marginal range, not only due to the different gradient, but also on account of the change of climate. The former Tibetan sea was drying out, and gradually became a highland. The rising mountain range protected the highlands against the rain-bringing winds from the south. All the water was lost on the southern flank, while the air after having passed the Tibetan marginal range, was dry. The northern area was drying out, and thus erosion decreased still more. The rivers draining the southern flank, with their excessive erosive power, eroded back in those areas, in which transverse structures made it possible for them to do so.

This has happened in two areas, namely in the Thakkhola with its transverse fault system, and in the Arun valley with its huge transverse anticline.

### *3) Thrust of the great nappes*

The Nawakot nappes are the lowest nappes in the whole tectonic system. Consequently, they were the first nappes to be lifted and thrust over great distances towards the south. Their place of origin was the marginal area between the Himalayan geosyncline and the Indian subcontinent, probably in the zone of the most southern longitudinal (east-west) fault system. The author considered the over-thrust of the Nawakot nappes to be of Miocene age. The synclinorium apparently proved to be rather rigid during this phase.

We have to bear in mind that these nappes were created from a zone, which was already dissected by a drainage pattern. Due to the uplift of the Tibetan plateau, which evidently had continued during the whole phase of overthrust of the nappes, the rivers had owing to their steep gradient sufficient power to erode their valleys accordingly into the rising Nawakot mountain range.

The Jajarkot nappes are the next higher nappes to the Nawakot nappes (fig. 16 and plate 6). They occur in western Nepal and have been thrust over the Nawakot nappes. The Hiunchuli nappes soon followed in overthrust (fig. 112).

From tectonic point of view, their roots and thus their thrust segment is situated in line and in continuation with the Dhaulagiri segment; pushing forces were directed due south. It is the *Dandeldhura massif* (plate 6) that has caused such an enormous divergence of roots, as is seen between the Humla- and the Hiunchuli segments and root arcs. This massif undoubtedly also caused the lack of nappes to the south and south-east of it. The Dandeldhura massif broke the main impulse of the pushing force from the north.

As a result the massif has been as a whole slightly pressed towards the south, thus showing a fan structure on the southern margin. The Dailekh zone with its various slices might have been originated after the overthrust of the main nappes. It is possible that the Dandeldhura massif has pressed the former Dailekh zone into various schuppen, but it is difficult to date the slicing in the Dailekh zone.

Certainly, the Dandeldhura massif has played some role in formation of the southern Schuppen (Dailekh roots, western terminations of the Hiunchuli and Jajarkot nappes (plate 6), since the strike of the Schuppen conforms to the boundary of the Dandeldhura massif. The age of the Banjkot root (plate 6) is certainly very young, since these Schuppen have deflected the Karnali river into the great river bends of Ra.

Regarding the Dandeldhura massif which forms in general two huge anticlinal structures, it can be seen from the tectonic map (plate 6) and from the profiles (plates 4, 5, profiles 80 and 86), that this massif has not been overthrust by the Bajang nappes. The northern anticline on the other hand has been overthrust by the Kathmandu nappes (in the tectonic outlier of Danukhana). The main southern mass of the Dandeldhura zone might thus have risen before the overthrust of the Bajang nappes. The Kathmandu nappes are really overthrust across both the Bajang nappes and the Dandeldhura massif. We might thus date the rise of the massif between the Bajang nappe and the Kathmandu nappes, which however does not give any information about the age of the granite. The Jajarkot nappes which continue the Dailekh zone to the east, seem to have overthrust the Piuthan zone, after the latter had been sliced to a certain degree (at least in its northern part).

The Kathmandu nappes are the next higher units, overlying directly the Nawakot nappes. There was probably no real interruption between the overthrust of the Nawakot nappes and that of the Katbmandu nappes. Due to the fact, that both of these nappe-groups consist of several single sheets which have been piled one upon the other, the whole phase of overthrusting might have lasted for a longer period, perhaps from middle to upper Miocene.

However it may be possible, that part of the nappes was eroded to a certain degree, before the next higher units were overthrusted. The Bajang nappes show some gaps, which might have been caused not only by primary stratigraphic transgressions, but by erosion before being overthrust by the Kathmandu nappes. However in the general survey it is not possible to give such detailed information. Additional detailed field studies would be needed to prove the ideas mentioned above.

*The Khumbu nappes* occur in eastern Nepal; they have also been overthrust on to the Kathmandu nappes in one single continuous phase of thrusting. However in the Everest area, the segment is doubled (fig. 112). The Everest-Makalu segment is situated within the larger Gaurisankar-Kangtega segment. This special configuration is expressed by the considerable divergence of the roots of the Kathmandu nappes and the Khumbu nappes. The space produced between the two different root zones was wide enough to allow the Khumbu nappes to be overthrust towards the south, until they reached the roots of the Kathmandu nappes (fig. 99—102, plates 2, 3, profiles 14 and 17).

The area of the thrust and more or less horizontally bedded Khumbu nappes between the two root zones, originated the valley of a unique situation called the Khumbu, which is the home of the Sherpas. When considering the geographic pattern of the various nappes, it is evident that overthrusting has not only gradually involved areas from south to north, but also from central Nepal towards the east. The pattern of the roots (plate 6) does not show one single chain; it indicates not only a geographic succession, but also a chronological succession of thrusting which began in Central Nepal, and continued gradually towards the east and west. However, the proof by corresponding transgressions is still lacking.

It is evident, that the transverse structures played a most important role in dividing the overthrusts laterally into a geographic and chronological succession. The ancient transverse structures proved to be zones of weakness, both for the creation of nappes and earlier as already stated, for the primary lay-out of the drainage pattern. It seems that the zone of the fault systems in the roots and in the northern adjoining synclinorium broke up into different thrust blocks or thrust segments, when the convergence of the Asian continental block and of the Indian subcontinental block reached its maximum in the second half of the Miocene age (fig. 112).

The arrangement of these thrust segments also shows that the direction of pushing of the different segments was neither identical, nor uniformly parallel towards the south-west. The different thrust segments show considerable deviations, which may also be seen in the fig. 112. The Annapurna segment was pushing due south. The neighbouring Manaslu segment pushed from the east, that is nearly at right angles. The four segments of Manaslu, Ganesh, Langtang and Gaurisankar-Kangtega, were directed parallel towards the southwest.

South and west of the Kanjiroba segment, the main push was directed towards the south (in the Hiunchuli segment) and towards the south-east (in the Saipal segment).

In eastern Nepal, on both sides of the Arun, the main forces converged. The Arun anticline was immensely reactivated during the nappe phase.

In general, it may be seen from fig. 112, that Annapurna takes a central position in the roots of the nappes and the thrust segments of the Nepal Himalaya.

In consequence of the division of the root zone and the hinterland into different thrust segments, the separating transverse structures were reactivated; existing anticlines were upwarped; vertical and horizontal movements weakened the respective zone still more. Thus the drainage pattern found all facilities to cross the rising nappe mountains in the south.

When studying the map sketch in fig. 113 it is striking to see that all the different thrust segments could be named after the groups of the highest mountains, each thrust segment corresponding to one of those mountain groups. Since the laterally bordering anticlines rose again it can easily be concluded, that the particular thrust segment shows a synclinal character.

We thus have the explanation for the surprising and unexpected syncline character of the highest mountains of the world.

There are also further reasons for the origin of the highest mountains in the synclines. When considering a particular thrust segment it is evident that the main force of horizontal push was in the center of each segment, while in the lateral marginal zone the horizontal forces decreased. It is thus understandable that the roots in the central part of each particular segment were pressed to the highest peaks.

Parallel to the rise of the mountain range, the Ganges trough sank. The weathered and eroded material from the rising mountains was brought down by the rivers and deposited in the basin of the Ganges as the Siwalik formations.

We may ask what has been the altitude of the nappe range proper. It is of course difficult to give any indication, but the nappe-Himalaya might during this first phase have reached between 3000 and 4000 meters, which means a magnitude similar to that of the Alps. The Tibetan marginal range might have reached about the same altitude since the Tibetan plateau was steadily rising.

Between the two mountain ranges (the Tibetan marginal range and the Himalayan nappe range) there were valleys, originated in the synclinoria. All these valleys were drained by rivers which flowed (and still flow) in easterly or westerly directions until they met one of the great transverse rivers breaking through the nappe range to the south (fig. 113).

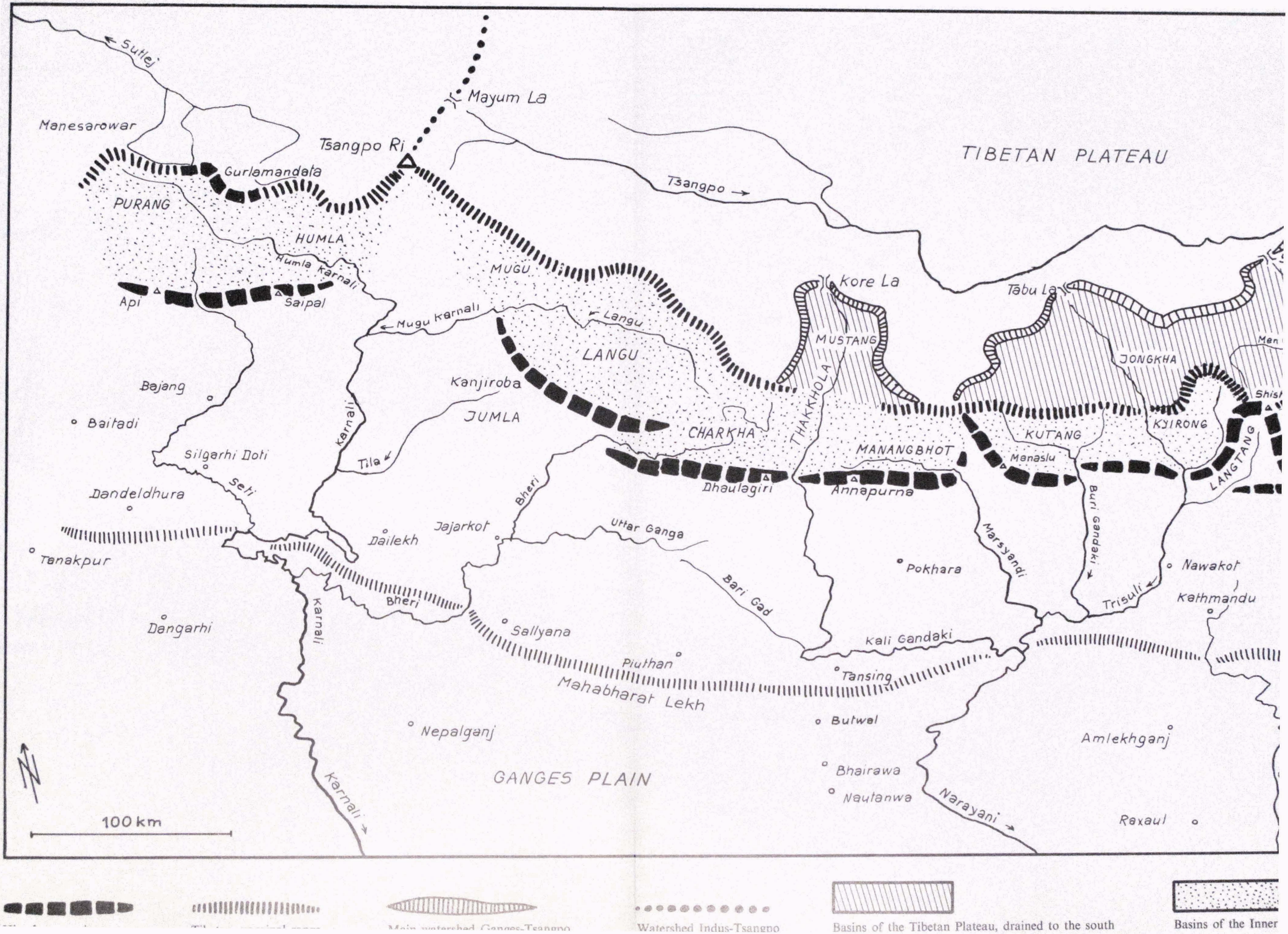
### *4) The rise of the Himalayan Marginal Schuppen*

So far in our tentative history there is no explanation for the Himalaya having such an excessive height compared with the Alps. The roots of the nappes had certainly not reached such a steep dip as they show today, nor did they exceed very much in altitude the thrust parts of the nappes.

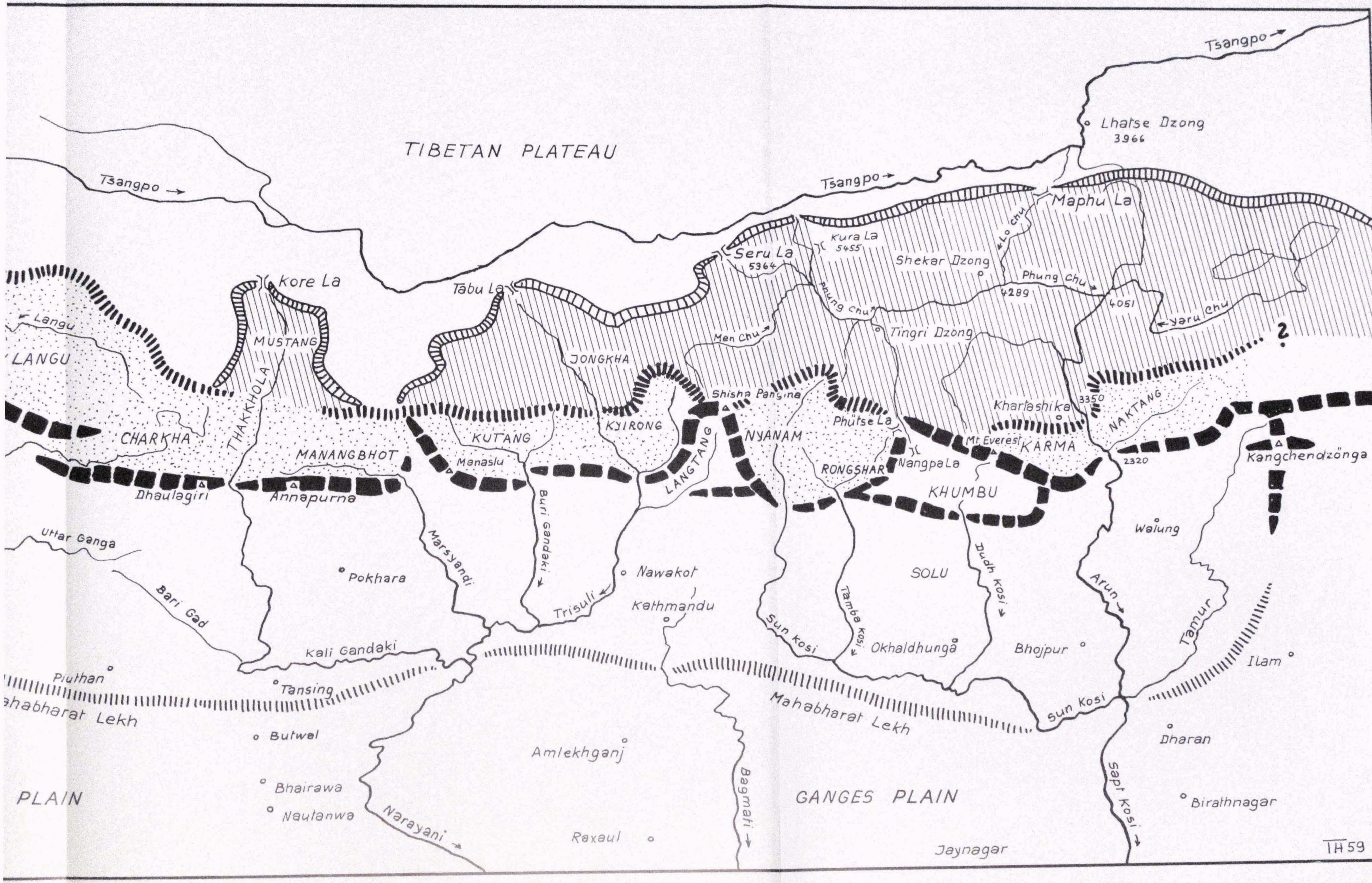
It might have been in the lower Pleistocene, when new horizontal pressure caused by a further convergence of the two continental blocks involved the whole mountain building once more in great fluctuations. As in previous phases, the zone on the back of the roots was seized by the new forces, in consequence to the law so far followed, that mountain building since the overthrust of the lowest Nawakot nappes has involved gradually more northerly zones.

In the new horizontal pressure, the roots became steeply inclined or vertical and were pressed upwards. In addition the zone adjoining the north of the roots was sliced. It seems as if still further nappes should have been created and joined to the north of the already existing nappes, but for some reason, the forces produced uplift instead of large horizontal overthrusts. It is in this phase, in which the Himalayas became the highest mountain range in the world. Indeed, as mentioned before and seen in fig. 110 all the highest mountains (with very few exceptions) are built from the roots of the great nappes, or the normal sediment cover of the topmost root, or from the schuppen close to the topmost root.

By raising the roots of the main range, these mountains became the main climatic barrier. The northern area became dry, all the rain beeing lost at the southern flank of the main range. Thus, erosion on the southern flank of the main range was enormously stronger than on the northern slopes. The ridge of the main range was gradually moved to the north. When we consider this northern move-



Sutlej
Mayum La
Manesarowar
Tsangpo Ri
TIBETAN PLATEAU
Gurlamandata
Tsangpo
PURANG
HUMLA
Humla Karnali
MUGU
Kore La
Tabu La
Api
Saipal
Mugu Karnali
Langu
MUSTANG
JONGKHA
LANGU
Bajang
Kanjiroba
Baitadi
JUMLA
CHARKHA
THAKKHOLA
KUTANG
KYIRONG
MANANGBHOT
Manaslu
Silgarhi Doti
Karnali
Tila
Dhaulagiri
Annapurna
LANGTANG
Dandeldhura
Seti
Bheri
Buri Gandaki
Jajarkot
Uttar Ganga
Dailekh
Marsyandi
Tanakpur
Pokhara
Nawakot
Bari Gad
Kathmandu
Bheri
Trisuli
Dangarhi
Sallyana
Kali Gandaki
Piuthan
Tansing
Mahabharat Lekh
Butwal
Nepalganj
Amlekhganj
Bhairawa
GANGES PLAIN
Nautanwa
Narayani
Raxaul
100 km
Watershed Indus-Tsangpo
Basins of the Tibetan Plateau, drained to the south
Basins of the Inner




Watershed Indus-Tsangpo

Basins of the Tibetan Plateau, drained to the south

Basins of the Inner Himalayas

Fig. 114 Sketch map showing the drainage pattern and the watersheds of the Nepal Himalaya

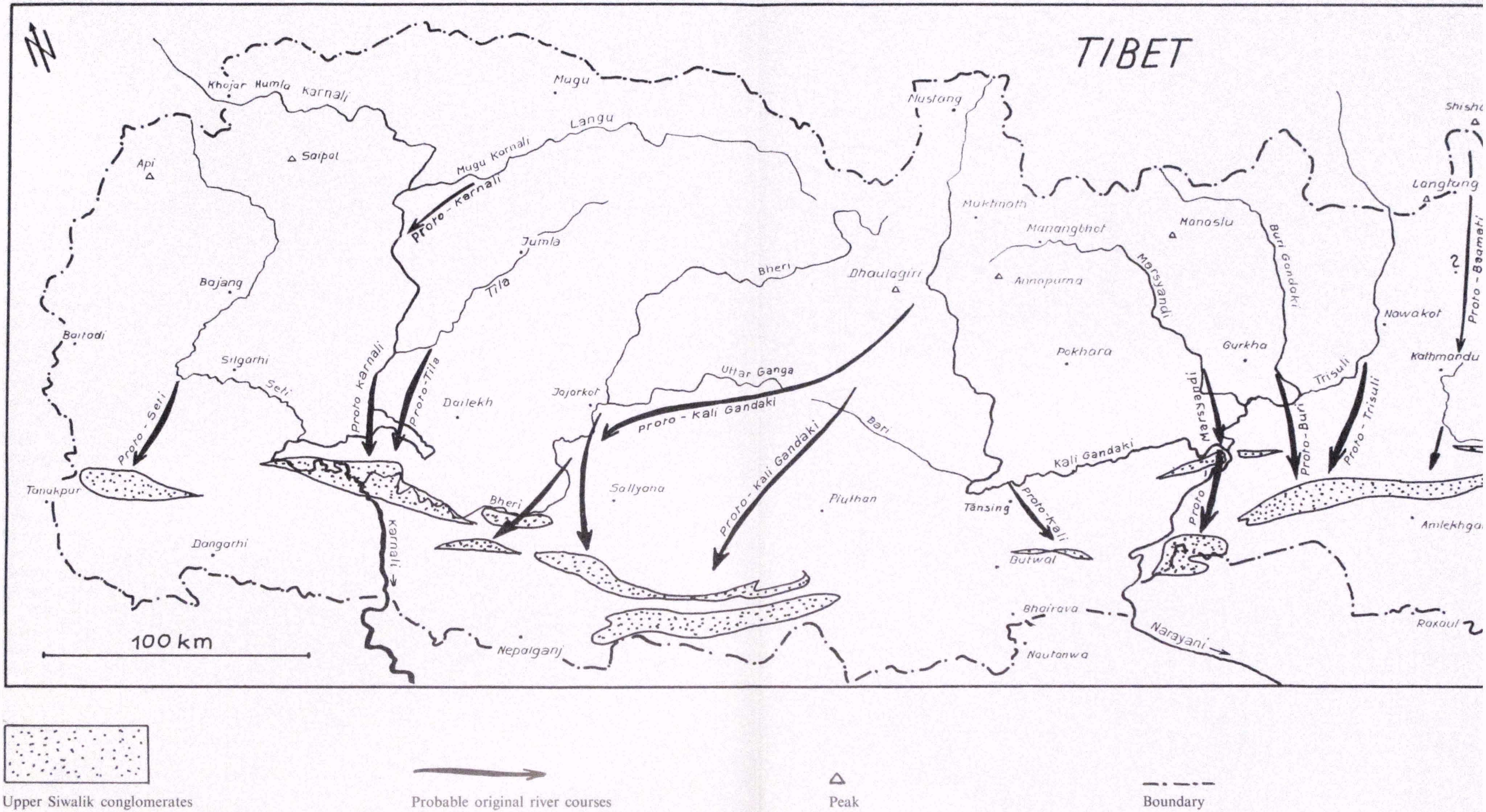
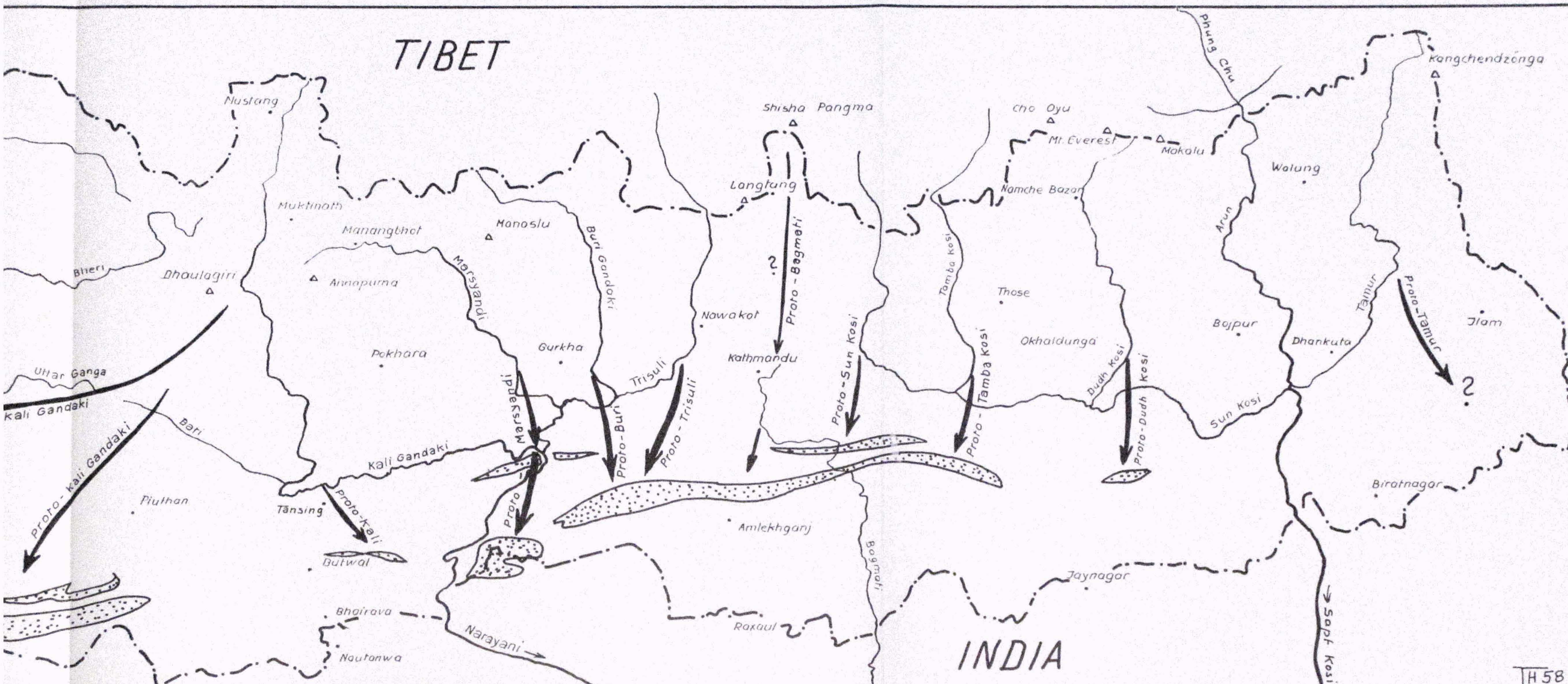



Fig. 115 Sketch map showing the fans in the Upper Siwalik conglomerates and their relation to the present and ancient drainage pattern




△ Peak

—·—·— Boundary

ment of the ridge in our profiles of the highest peaks (fig. 110) we see clearly, that originally the highest ridge with the highest peaks was situated on the crystalline roots of the main crystalline nappes.

In the Everest area, if we were to remove the summit back towards the south it might also lie on the roots of the Khumbu nappe 3.

In the last push of the thrust segments, the main force was developed in the center of the particular arc. The result was more intensive slicing in that part of the southern edge which lay in front of the centre, and not those on the lateral margins. This explains why the main Schuppen are limited to the central part of the segments. The Schuppen thus do not extend and continue beyond the particular thrust segments. They are especially connected between several thrust segments. For example in the Arun valley, when we consider the longitudinal profiles (fig. 104 and 105) the schuppen on the western side (Sakyetang-Makalu-Chomolönzo- and Everest-Schuppen) are not connected with the corresponding nappes on the eastern side (Lumbasumba nappe, Kangchendzönga nappe), nor has the connection ever existed. The Arun valley has been a primary gap, since the forces on either side of the valley were directed more tangentially (especially in the main nappe phase). We thus cannot say that the Arun anticline reached an altitude of 15 km, and that 15 km of crystalline rocks have been eroded in the Arun valley.

The expression "Hebungsinsel" by G. O. Dyhrenfurth (lifted island) is correct in our view. Perhaps not exactly in the same sense as Dyhrenfurth has applied it but nevertheless the different mountain groups between the transverse valleys possess their excessive height of 8000 m above the broad basement of about 4000 because of the rise of the roots and marginal Schuppen. The intersection of the great Himalaya range into different groups is not merely due to erosion, which has left some groups of high mountains out of a former single chain of a levelled 8000 m altitude. The excessive height of the particular groups is caused primarily by local uplift.

We may ask what has happened to the drainage pattern and the rivers which crossed the main range towards the south. The main range by now far exceeded with its 8000 m the height of the Tibetan marginal range (6000–7000 m), which is the origin of the main rivers. Were the main rivers traversing the nappe mountain range stopped by the uprising roots; were they deflected or were they able to erode their river beds accordingly? Today the transverse rivers still cross the great Himalaya range. It is thus evident, that erosion in the gorges kept balance with uplift of the roots and Schuppen. However, the balance was for some time interrupted, when the roots rose so fast that the rivers formed tectonic lakes north of the roots. Uplift of the roots still continued when the lakes had disappeared. This is proved by a dip of the old lake deposits from the main Himalaya range towards the north (see description in chapter 4, paragraph 5).

The characteristic step in the gradient of the great transverse rivers within the crystalline roots proves the very young age of the uplift of the roots and marginal Schuppen. It undoubtedly still continues, for the valley does not show a mature shape; the rivers flow in gorges with perpendicular rock walls (fig. 135).

### *5) Crustal movements south of the main range, origin of the Midlands*

So far the southern slope from the great Himalayan range to the plain was a gradual one, with a steep gradient at the southern flank of the high range down to about 3000 m and from here a gentle regular dip toward the Ganges basin. The Nepalese Midlands did not as such yet exist. The transverse rivers flowed, after having crossed the main range, more or less due south.

We may now try to evaluate the Upper Siwalik conglomerates, their geographic distribution and their confluence in the Ganges basin, marked by fans of the conglomerates. Doing so, we can make the unexpected observation that no Upper Siwalik conglomerates are situated in front of the present big rivers (fig. 115). From west to east we may recognize the following fans: The Jogbura fan in front of the supposed prolongation of the Seti river; Karnali fan in front of the straight prolongation of the Karnali and Tila rivers; the fans of Dang in front of the prolongation of the Bheri river; the fan of Rapti in front of the prolongation of the Kali Gandaki river; the small fan of Butwal in front of the Kali Gandaki bend of Riri; the long fan zone in front of the Marsyandi-Buri Gandaki-Trisuli-Bagmati-Sun Kosi and Tamba Kosi rivers; and the small fan in front of the Dudh Kosi.

Surprisingly we do not find any upper Siwalik fan in front of the Arun, a further proof that in ancient times the Arun drained areas far behind the great Himalaya and in its very long course did not deposit such coarse grained material as the Upper Siwalik conglomerates. Possibly, some Upper Siwaliks might be buried under the Ganges alluvium near Dharan. But certainly, it can not be a large area, since the Upper Siwaliks do not extend far south from the Main Boundary Thrust.

Further crustal movements caused faults, fractures and gentle fold tectonics which changed the southern slope of the Himalayas again considerably. The zone of the frontparts of the main nappes rose relative to the northern area. The Mahabharat Range was created. This rise was a relative one; we do not know how much the northern area sank relative to the Mahabharat Lekh. But the fact remains that a mountain range rose to the south of the Midlands, thus forming the Midlands and giving it a natural barrier to the south.

The original rivers, which had so far been following directly southwards (according to the map in fig. 115) found their way out of the hills dammed. They chose a way along the northern foot of the Mahabharat range in areas of weakness, and crossed through the Mahabharat Lekh in zones weakened by tectonic events. Some of the big transverse rivers found in their longitudinal course (east–west) an easy path for erosion mainly in the Midland anticline. This anticline had by its faultlike character destroyed the rocks considerably. For example, the Kali Gandaki drops into the Midland anticline near Riri Bazar, where the Bari Gad already eroded its valley in the western part of the same anticline. Frome there it flows in the Midland anticline (the Kali-Trisuli Anticline) and collects on its eastern course a number of minor tributaries.

The Trisuli drops into the Trisuli anticline near Nawakot and follows it westwards for about 100 km. It collects on its way the Buri Gandaki and the Marsyandi, both big transverse rivers.

In eastern Nepal, the Mahabharat Lekh dammed the original outlets of the Sun Kosi, the Tamba Kosi and the Dudh Kosi. It is the Sun Kosi which first reaches the Sun Kosi anticline (Midland anticline) and then receives all the other rivers as northern tributaries. Pre-determined by the Arun trans, verse structure, it leaves the hills near Chatra. It is thus the late uplift of the Mahabharat range-which united the many original rivers into three main river systems. The whole drainage from the Nepal Himalayas leaves the hills at only three spots through the Karnali, Narayani and Sapt-Kosi rivers.

The special pattern of the rivers in the Midlands, with their extended west–eastern courses and long narrow river bends around mountain ridges, creates a number of excellent sites for hydro-electric dams. Those would not need any barrage, but merely a water intake, a tunnel through the mountain range and a water outlet. Nepal would probably be in a position to produce the cheapest hydroelectric power (details of these sites have been submitted in a general report to H. M. Government of Nepal).

The relative rise of the Mahabharat range against the Midlands had still further consequences. Some of the valleys sank and great lakes were created in them. Best known is the Kathmandu valley; fossils (elephant bones) enable us to determine the age as middle Pleistocene.

The rise of the Mahabharat Lekh south of Kathmandu continued even after the lake had disappeared; the lake deposits show a considerable dip from the northern foot of the Mahabharat Lekh (near Tinpani) towards the north (to Pharping).

There were also quite a number of lakes in other valleys, for example in the Tila valley, in the Darondi valley, in the Sun Kosi valley and in others. They are all proved by lake deposits of which those in the former Tila-Karnali valley north of Porapalni are in the form of terraces and show a strong northern dip. In that valley also, the rise of the southern range continued after the water of the lakes had broken through the mountain range.

The lakes of Pokhara undoubtedly had the same origin as the other former lakes in the Midlands, although other factors have also affected these particular lakes. Probably the whole valley was once filled by a single lake. The basin has been filled up by the scree from the nearby Annapurna range. The top layer consists of hard re-cemented material, containing large size boulders of glacial type. The huge deposits in the Pokhara plain, in which the Seti has cut a very narrow 70 m deep gorge, do not consist of normal fluvatile material. The author believes that in some kind of catastrophe huge morainic material was brought down from the Annapurna range, and deposited as a top layer of the normal river alluvium. The limestones undoubtedly belong to the Silurian-Devonian formations, which build the main portions of Annapurna nr. 2 and the Gangapurna. It seems possible that the huge moraines deposited on the southern flank between 3000 and 4000 m during ice age, have been brought down very fast by the rivers, perhaps initially by landslides. The river course from the Annapurna range to the Pokhara plain is not more than 25 km in distance and it can thus be explained that rather large boulders have come down so far to the Midlands. The remaining lakes of Pokhara have all been filled, not in the upper part by the rivers supplying the lakes, but from the lower end where the river leaves the lake. This can be seen especially well on the main lake, called the Phewa Tal. The limy material with the cemented large boulders is limited to the eastern end, where the river leaves the lake.

Latest crustal movements were found in the Siwaliks. The thrust of the Siwaliks has to be considered entirely as a young tectonic movement. Active tectonics in the Siwaliks are still going on as is proved by overthrusts of the Middle Siwalik sandstones over the topmost Ganges alluvium at two places found by the author (Kherwa and Petkot). A comprehensive description of the Siwaliks was given in chapter 2, paragraph 15.

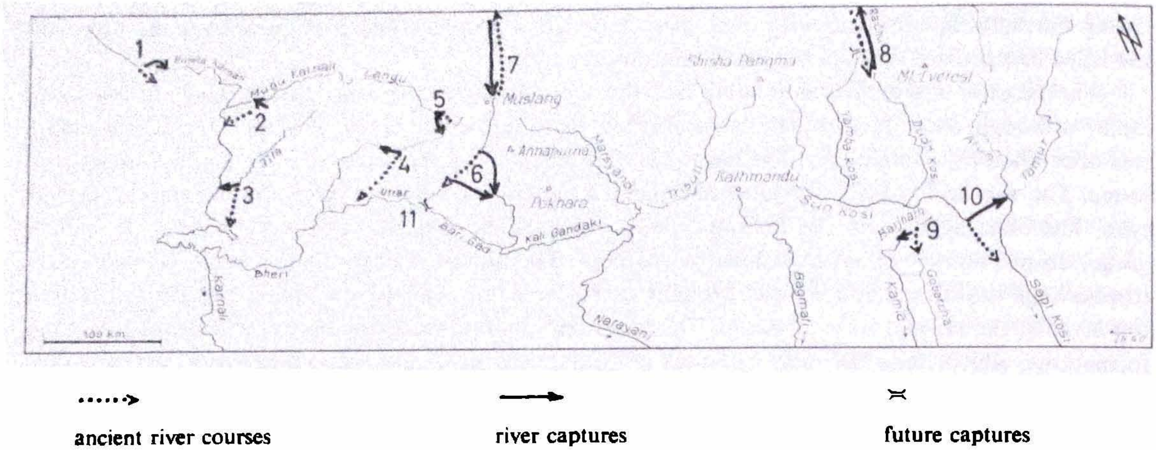
The latest reactivation of the transverse structures apparently belongs to the same phase as the origin of the structures in the Midlands, because the oversthrust nappes are without exceptions involved and affected by the transverse anticlines.

### *6) Final Shape of the drainage pattern*

The drainage pattern north of the main range was also the subject of considerable alternations. In general in western Nepal the main watershed between the Ganges system and the Tsangpo system remained on the Tibetan marginal mountain range (fig. 114). East of the Kali Gandaki river however, the powerful erosion from the south caused the watershed to move northward, especially in zones which were weakened by the tectonic transverse structures. Due to the Thakkhola fault and graben through which the Tibetan marginal range was interrupted, the upper course of the Kali Gandaki was able to capture parts of the former Tibetan plateau (see fig. 114). Also the upper course of the Trisuli captured portions of the former Tibetan plateau in the Jongka basin.

Finally the Arun drains an area of roughly 30 000 square-kilometers north of the main range, of which the main portion undoubtedly belonged to the former Tibetan plateau. It is proof of the enormous magnitude of the Arun transverse anticline and its activity throughout all the time since the rise of the first range in the Himalayas. The watershed between the Phung Chu and the Tsangpo is at some places only a few kilometers from the Arun (fig. 114). It can be predicted, that (geologically speaking) within a very short time the Phung Chu and Lho Chu will capture the whole upper course of the 600 km long Tsangpo river near the Tabo La, Seru La, and or May La.

North of the great Himalayan range, the rivers follow dominantly synclinal structures, while south of the main range, the rivers are without exception cut into anticline structures.




## Fig. 116 Sketch map of the river captures

1 *Humla Karnali*. The upper course of the Humla Karnali river, which drains the wide basin of Taklakot in Tibet shows a sharp river bend towards the northeast, when entering Nepal. The Nara pass (4900 m) is situated in the straight prolongation of the river course before the bend. The ancient course of the Humla Karnali flew over the mentioned pass towards the southeast. – 2 *Khater Khola*. This is a striking sample of a river capture. Details are given in figs. 117 and 118. It can be compared with the Maloja pass in the Engadine (Swiss Alps). – 3 *Tila river*. The Tila drains the high basin of Jumla. Ancient river terraces were found at the northern flank of the Mabu pass and the Bartha pass, showing a strong dip towards the north. The Tila river had thus an ancient course across the Bartha pass. Later on, it was captured by a tributary of the Karnali laterally from the west. – 4 *Barbung-Bheri*. The Barbung river (upper course of the Bheri river north of the Dhaulagiri group) flew formerly across the pass which is now the Jang La. Later on, it was captured laterally from the Bheri. This capture was favoured by the uplift of the Hiunchuli Schuppen zone. – 5 *Barbung-Langu*. The present upper course of the Barbung was in ancient times the origin of the Langu river. Due to stronger gradient from the south, the upper course of the Langu was deflected by capture into the Barbung valley. – 6 *Mayangdi-Uttar Ganga*. This is also a classic capture. The upper course of the Uttar Ganga valley is very flat and high, and is in no proportion to the small river. The upper end of the Uttar valley is formed by the Lumsum pass, which shows a very gentle gradient towards the Uttar (southwest) and a surprisingly steep gradient towards the Marsyandi valley (northeast). Ancient river terraces continue towards the northeast direction into the gorge of the Kali Gandaki (between Annapurna and Dhaulagiri). The ancient Kali Gandaki flew formerly into the valley which is today the Uttar Ganga. – The present Kali Gandaki gorge can also be considered as a lateral river capture from the southeast. – 7 *Mustang*. The upper course of the Mustang valley was formerly drained towards the north by a tributary of the Tsangpo. Initiated by the rift valley of the Thakkhola, the Kali Gandaki river was able to erode backwards and to seize considerable parts of the former Tibetan Plateau. – 8 *Dudh Kosi-Ra Chu*. It is well possible that the former river draining the Nangpa La in ancient times had its origin far further to the north and was later on captured by the Ra Chu, a southern tributary of the Phung Chu. Thus, the watershed (as an exception in the Himalaya) moved towards the south. It may be seen from the tectonic structure, how the Phung Chu—Arun river has cut a very deep transverse gorge right from the beginning of the Himalayan orogenesis (see text pages 138). – 9 *Muksar*. The Gobarchal river had its original spring much further north, in the Mahabharat Lekh (proved by granitic boulders near Muksar, south of the Siwalik range). Then it was captured by the Baijnath river, an eastern tributary of the Kamla river. – 10 *Batase*. The Sun Kosi originally flew from Kampu Ghat (in the sharp river bend) straight south into the Trijuga valley. Then it was captured from the east and is now joining the Arun.

It must be mentioned, that not all of the river captures shown in this map are pure captures. At the localities numbered with 3, 4, 9 and 10, crustal movements have decisively helped causing the deflection of the river courses. The changes described under No. 2, 5 and 6 are pure river captures, caused by mere erosion.

At two places (8 and 11) rivers will be captured in near future (geologically spoken). The Phütse La surmounts the Ra Chu only for 150 m, and, the Rongshar Chu (Tamba Kosi) having a much steeper gradient, it will soon capture the Ra Chu to the Ganges system.

The Bari Gad (11) has also a much steeper gradient than the Uttar Ganga. Yet the watershed between the two rivers is not more than 70 m above the Uttar river at Dhor Patan.

As in the Alps there are a number of river captures (fig. 116) and perhaps the most striking is that of the Rara lake in north-western Nepal (figs. 117 and 118). The Mugu Karnali has an old river course, which continued westward from Gum and followed the valley which is today drained by the Khater Khola. The surface of the old valley is still preserved today in the basin of the Rara lake, 3000 m above sealevel. Very clear river terraces continue from the Rara lake, gently rising towards the upper course of the Mugu Karnali and the Langu river. From the area of Galwa, 30 km further to the west, an eastern tributary has eroded back and captured the Mugu Karnali near Gum from the north. At present, the rock lip at the upper end of the Rara lake measures not more than a few meters above the level of the lake. Opposite the lake, there is a fall of 1000 m from the lip down to the Mugu Karnali, in a horizontal distance of not more than 5 km. One could call this pass the "Himalayan Maloya" after the famous capture of the upper part of the Inn river in the Engadine in the Swiss Alps.

Further river captures have been found in the upper course of the Bheri river, which is called the Uttar Ganga. The wide valley of Dhor Patan does not at all correspond to the meager present brook. It is an old valley, the upper part of which has been captured by the Mayangdi near Lumsum. On the Lumsum pass, the flat valley drops at once very steeply from 3300 m down to 1800 m. It may even be possible that the Uttar Ganga valley corresponds to an ancient course of the Kali Gandaki (as indicated in fig. 115). In the same area, a new river capture will be effected very soon (geologically speaking); the upper course of the Bari Gad with its steep gradient has approached the Uttar Ganga near Dhor Patan to within only about 300 m. The rock lip, separating the flat Uttar Ganga valley from the steep Bari Valley rises only about 70 m above the valley bottom of Dhor Patan; the Bari Gad, with its higher erosive power, will cut this very soon.

Another river capture is imminent on the Phütse pass, north of the Nangpa La (eastern Nepal). The Rongshar Chu running to the south, has much more erosive power than the Dzakar Chu (fig. 116) which has a three times longer course through the Phung Chu-Arun to the Ganges plain. The pass is not more than 150 m above the bottom of the Dzakar valley, while at the other side the valley of the Rongshar drops very steeply to the transverse gorge west of Gaurisankar.

Further east it is quite possible that the Phung Chu has already captured the upper course of the former Thami Bhote Kosi near Tingri Dzong. The Nangpa La, the present watershed between Dzakar-Ra Chu in the north and the Thami Bhote Kosi in the south, is no real ridge but just a very flat gap. The upper part of the Thami valley also, is much too wide for the present river; it looks as if it was an ancient valley, which carried a much bigger river originating in the area of Tingri Dzong, and that it was then captured by the Phung Chu from the east. The Phung Chu in this area certainly had a much higher erosive power, owing to the deep Arun valley. We thus have a case, in which a transverse river has been finally stopped by the uplift of the roots and has been deflected to the next neighbouring transverse valley.

Closing the chapter on the origin of the Himalayas, we must point out how difficult it is, especially in the case of the rise of such a complicated mountain range, to divide natural history into various phases. Human spirit is always keen to bring "order" into the apparently so irregular events of natural history. Of course, the different phases discussed herein, cannot be entirely separated from each other; the uplift of the Tibetan plateau for example has played a role during all the other phases.

However, it may be said with a fair certainty, that the Tibetan Marginal Range is older than the overthrust of the great nappes, and that the excessive height is caused by a very young tectonic uplift of the roots, after completion of the thrusting.

It should be pointed out that this paper is a preliminary one giving the main tectonic lay-out, with the principal aim, of making the succeeding volumes on detailed geology more readable.

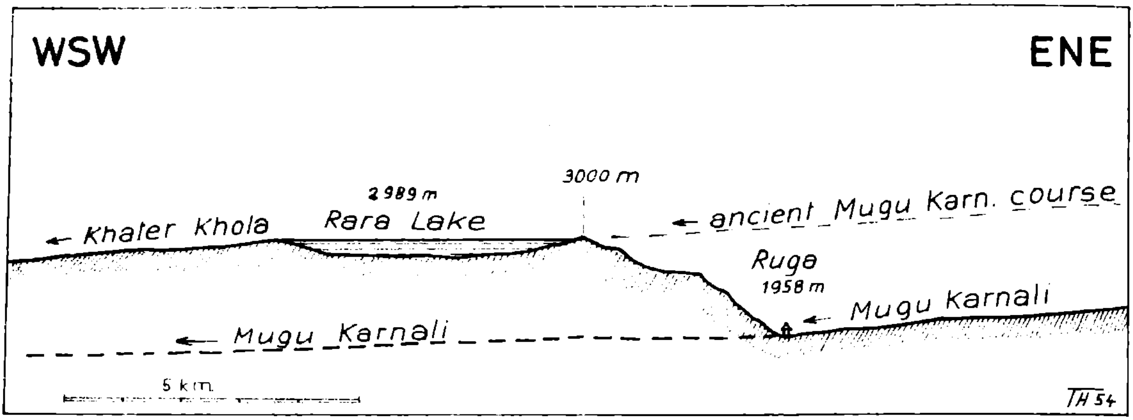



Fig. 117 Diagrammatic section of the Rara lake

The land swell at the upper end of the lake surmounts the level of the lake by a few meters only. Beyond this swell, there is a tremendous fall of about 1000 meters down to the Mugu Karnali at Ruga.

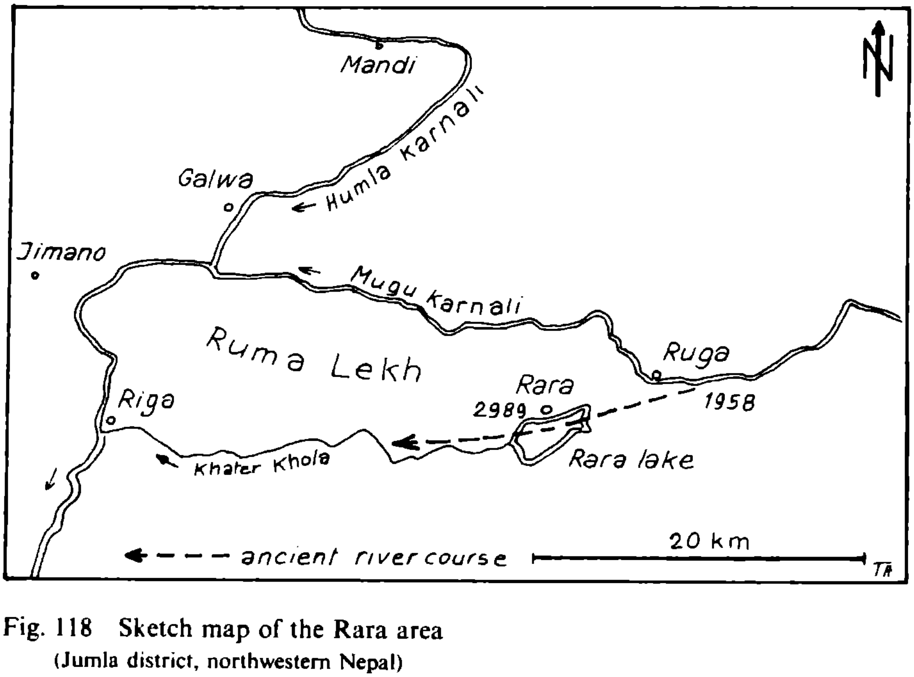



Fig. 118 Sketch map of the Rara area
(Jumla district, northwestern Nepal)

The valley of the Rara lake and the Khater Khola formed the ancient Karnali valley. Shoulders at both flanks of the Mugu Karnali valley continue beyond the eastern end of the Rara lake. An eastern tributary of the Humla Karnali river (which had its bed excessively deep eroded) in the Galwa anticline captured the Mugu Karnali from the northwest, in the area of Ruga.

# CHAPTER 7
# SOME COMPARATIVE STUDIES WITH THE ALPS

Every Geologist, having been able to do geological fieldwork in the Alps as well as in the Himalayas cannot help to be attempted to draw comparisons between the two mountain ranges. There are many common features between them but as many differences on the other hand. In spite of the fact, that the Alps and the Himalayas belong to the same mountain system—the Alpine system—which was built in the upper Mesozoic-Tertiary age, the Himalayas are considerably younger than the Alps.

From geological standpoint, nappe structure is common in both mountain systems. The Alps of course, after more than a century of systematic geological research by a great number of geologists, are much better known than the Himalayas. Nappe structure has been found in the Alps since a long time ago (beginning of this century), while in the Himalayas real nappes have been proved only since the late thirties. Nevertheless, nappe structure is well established in the areas studied so far.

In both areas, thrusting is considered to be caused by a convergence of the two continental blocks (Asian block and the Gondwana block, respectively the European block and the African block) and by narrowing the geosyncline lying between and pushing the corresponding formations out of the synclinal depth and thrusting them over long distances.

The difference of the thrusting direction between the Alps and the Himalayas is of no real importance from geological standpoint. However, the reason, why the nappes in the Himalayas have been thrusted from north to the south compared with the south–north direction in the Alps is still a matter of discussions and theories. Argand in his section given in fig. 8 gives a plausible explanation: According to him, the northerly rim of the ancient Gondwana block has sunk and thus underthrust the southern edge of the Asian continental block. The latter at the same time has been lifted (proved by the Tibetan highland) and thus contributed to the gradient from the north to the south. Consequently, the formations squeezed out of the narrowed geosyncline were overthrust towards the south. At the same time, the Indo-Gangetic trough has been formed simultaneously with the Himalayan orogenesis, and caused a difference of altitude of at least 8000 meters from the Tibetan Plateau down to the Gangetic plain.

Thus, the topographic relief in the first stage of the Himalayan orogenesis shows considerable differences compared with that one of the Alps. In the Alps, the back ("hinterland", Po-trough) of the nappes is even lower than the foreland (Swiss Midlands). It appears to be rather accidental (compared with the Himalayas) that the Alpine nappes have been thrust towards the north and not to the south. Consequently, the theory of active pushing and thrusting has commonly been adopted in explaining the nappe structure of the Alps. Gliding by gravity, as suggested by some geologists, has in general not been agreed on.

In the Himalayas however, gliding due to gravity is not out of any question. The roots of the nappes, building the highest mountains (8000 meters) have already at the beginning of the overthrust (with the rise of the Tibetan Plateau) been much elevated compared with the area which is now the Nepalese Midlands (1000–2500 meters) and into which the large nappes have been thrust. One could easily imagine that the Himalayan nappes have glided down from the high situated roots into the Midlands.

Considering the magnitude of thrusting, and the number of the nappes between the Himalayas and the Alps, we come to striking similarities. We may for this purpose compare the profile of the Alps (plate 5) with the tectonic profiles in the plates 2–5.

The longest overthrust in the Nepal Himalayas was found in the section of Everest (profile 14, plate 2), wherein the Kathmandu nappes have been thrust more than 70 kilometers from their root to the front in the Mahabharat Lekh. According to the section of the Alps (plate 5) the longest overthrust amounts to 80 kilometers (Klippendecke). However most of the Klippendecke has been eroded, and thus, the imaginated connection of the front parts in the Mythen peaks with the roots in the Tessin is still somewhat hypothetical. If we remain on more realistic ground and take the example of the Helvetic nappes, we find only a distance of overthrust of about 35 kilometers. The figures in the Adula nappe (penninic nappe group) are of the same magnitude. However, thrust distances of the Austro-Alpine nappes are considerably longer.

Similar as in the Alps, also in the Himalayas the nappes form some nappe groups, each of them containing a number nappes of similar lithological and tectonic character. The nappe groups in the Swiss Alps are (from bottom to top) the Helvetic nappes, the Penninic nappes and the Austro-Alpine nappes. In the Nepal Himalaya there is also a number of nappe groups, each of them consisting of a various nappes, namely from top to bottom: Khumbu-Kathmandu nappes, the Nawakot-Bajang nappes, and the Jajarkot-Hiunchuli nappes.

The number of overthrust nappes in the particular sections in the Nepal Himalaya may be seen in the fig. 17. The greatest number was found in the section West of the Arun with 11 nappes.

In the particular diagrammatic section through the Alps as given in plate 5 we find also three nappe groups, consisting of totally 5 nappes. However it must be mentioned that those 5 nappes are originated in two different root zones, which are partly separated by the Gotthard massif. A similar distribution of the nappes is found in our profile 70 (plate 5), in which the roots of the Jajarkot-Hiunchuli nappes are separated from the roots of the Kathmandu nappes by the Hiunchuli Schuppen zone (see also tectonic map plate 6). A similar situation is also found in the Khumbu area, where the roots of the Khumbu nappes are separated from those of the Kathmandu nappes by a broad zone of flat structures (profile 14, plate 2). In general we may say, that the number of oversthrust nappes in particular sections is similar in the Alps and in the Nepal Himalaya.

If we try to correlate the nappe groups of the Himalayas with those of the Alps, we meet some difficulties. In the Alps the Helvetic nappes consist of mainly Mesozoic formations, forming (especially in the front parts) a gentle fold structure. The Penninic nappes consist of Palaeozoic–Mesozoic formations with a structure of huge folds, and mainly abundant slices. The topmost nappes, the Austro-Alpine nappes finally do hardly have any folds, but are intersected in various thrust masses and slices ("Gleitbrett Tektonik", "Schollen").

It seems that regarding the structure, the Kathmandu and Khumbu nappes correspond to the Austro-Alpine nappes. The Nawakot-Bajang nappes show some similarities with the Helvetic nappes. In both nappe groups, the older formations have remained in the roots and in the back parts, while the overlying younger series have been thrust to the front. Especially striking are the similarities of the fold and thrustfold structures in the front parts of these nappes (figs. 119 and 120).

The Palaeozoic formations in the crystalline nappes of the Alps (Penninic nappes and Austro-Alpine nappes) are difficult to classify. Indeed, few fossils of pre-Carboniferous age have been found so far. The series are too much metamorphosed. Stratigraphic classification is thus based on lithological comparisons mostly. Until recently, the same phenomena was also adopted for the nappes of the Himalaya, where the overthrust southern parts have been named the "unfossiliferous zone". It was to be expected, that fossils might be found, since the Palaeozoic formations are—in contrast to the Alps—partly well developed and non- or low metamorphic. Crinoid limestones were found some time ago, but the main finding was a Trilobite from the Phulchok range, in the overthrust parts of the Kathmandu nappes. Thus, we have in central Nepal a pretty safe stratigraphic base for the Palaeozoics.

The main thrustplane in the Nepal Himalaya, namely the overthrust of the crystalline Kathmandu nappes over the sedimentary formations of the Nawakot nappes in central Nepal or the Bajang nappes in western Nepal may be compared with the overthrust of the Dent Blanche nappe (Austro-Alpine) over the Penninic sediments in the Wallis.

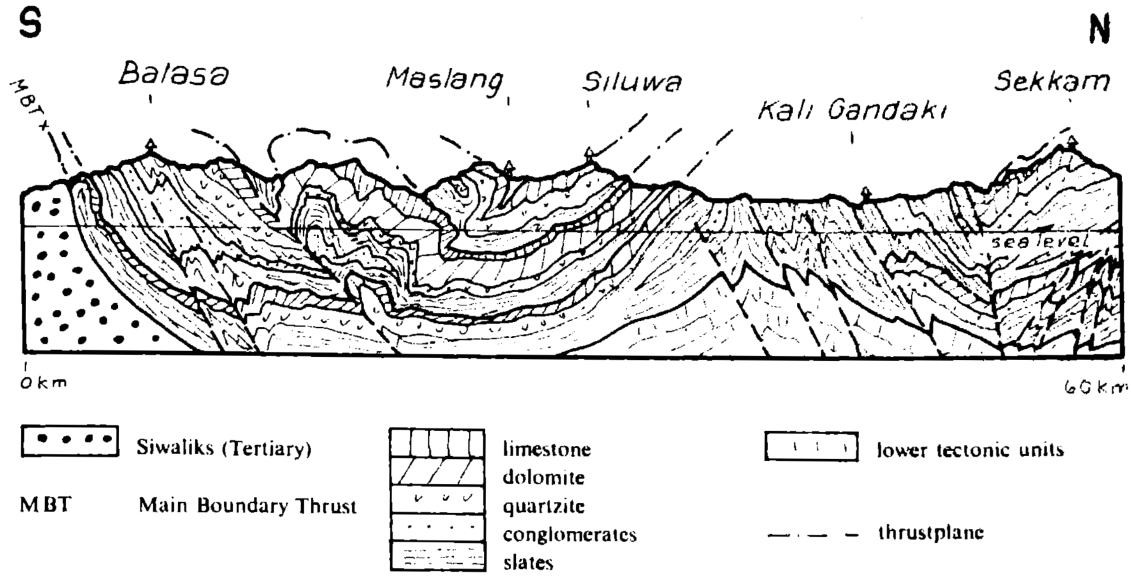



Fig. 119 Diagrammatic section of the front parts of the Nawakot nappes
(Tansing district, central Nepal)

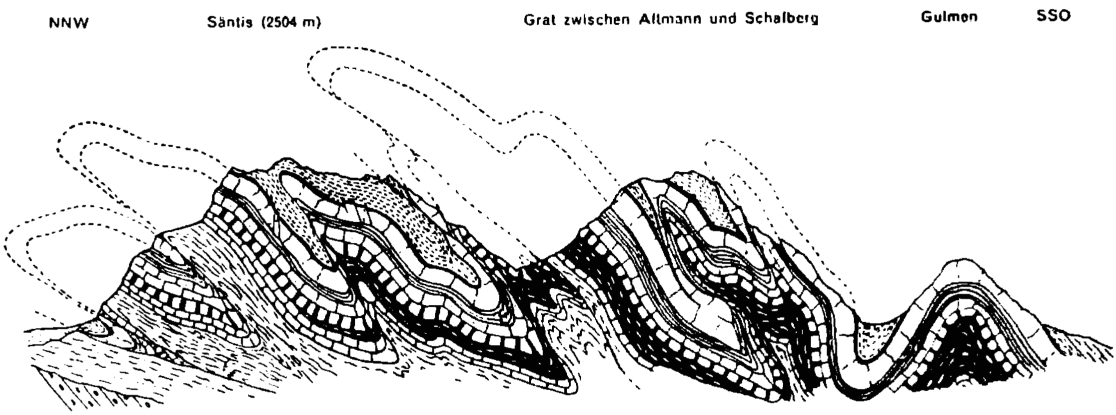



Fig. 120 Diagrammatic section of the Säntis range, Swiss Alps
(Front parts of the Helvetic nappes)
After Albert Heim and L. Schlatter

The thickness of the particular nappes is of a similar scope as in the Alpine nappes. However there are a number of nappes in Nepal which appear to have an excessive thickness. The Alpine nappes show an enormous irregularity regarding thickness in all directions. Large masses of the Alpine nappes are sliced into small tectonic units and Schuppen, while the Himalayan nappes appear to be more regular and rigid masses.

We may be attempted to explain the regularity of the Himalayan nappes with gliding due to gravity, as mentioned at the beginning of this chapter. Gliding might not have sliced and contorted the rock formations to such a degree, as may be expected by active pushing. However this explanation is rather a theory than based on scientific facts.

On the other hand, we must not forget, that in the Himalaya we are only at the beginning of geological research. It is thus very incomplete. If we go back in the history of geological interpretation of the Alps to the corresponding stage, we would also find a much simpler structure, with fewer but thicker nappes and much less slices and Schuppen. It is recalled here that still hardly 20 years back the Dent Blanche nappe was considered to be one single huge recumbent fold. In the meantime it has proved to consist of various sub-units ("Schollen").

The author does not doubt at all, that with encreasing knowledge of Himalayan geology a still much more complicated structural picture will be unveiled.

An equivalent of the Aar massif may be seen in the granitic Dandeldhura massif (profile 86, plate 5). Its northern flank is sliced in a similar way as the southern flank of the Aar- and Gotthard massifs. The sedimentary cover of the Dandeldhura massif in western Nepal is however more complete —especially the Palaeozoics—than in the Alpine massifs (fig. 74). Striking is the similarity regarding the roots of the Bajang nappes at the northern flank of the Dandeldhura massif. With their Mesozoic formations they correspond exactly to the Helvetic nappes and their roots at the southerly flank of the Aar-, Tavetsch- and Gotthard massifs.

There is a further equivalent of the Alpine massifs, namely the Bheri massif, occurring in the Bheri anticline in western Nepal (profile 70, plate 5). Like the Aar massif with its granites and crystalline schists overlain by transgressive Mesozoics and Nummulitics, the schists of the Bheri anticline are overlain by the Upper Mesozoic and Eocene formations of the Piuthan zone. The contact is partly a transgressive one, partly a tectonic one, since there are a number of wedges of the Piuthan formations, which reach into the depth between the joints and slices of the underlying schists and slates of the Bheri massif (fig. 66). A striking similarity for example with the Eocene wedges on the back of the Aar massif in the Muttsee-Kistenpass area (Glaris, Switzerland).

Most striking is the outcrop of the main thrustplane of the nappes at the front of the various nappes, the Main Boundary Thrust. It corresponds to the thrustplane of the Kalkalpen on the Molasse zone. The Molasse is the equivalent of the Siwaliks in the Himalaya. Both are of Tertiary formations, both can from structural standpoint of view be subdivided in the thrust Siwalik zone (thrust Molasse) and the folded Siwalik zone (folded Molasse). In both, the Himalayas and the Alps, the folds of the Molasse decrease with growing distances from the Main Boundary Thrust. In both mountain ranges also the Tertiary deposits have been erected to mountain ranges before the overthrust nappes had reached them. In both the Alps and the Himalayas, the nappes advanced partly on eroded Siwalik surfaces, and were pushed through erosive gaps further to the south, or north respectively.

The "Südliche Kalkalpen" of the Alps with their thick sediments correspond to the sedimentary formations of the Tibetan Synclinorium. However, in the Himalaya the sediments in the synclinoria are much more complete and embracing much lower formations, namely down to Cambrian. (Compared with the Carboniferous as the lowest series in the Südliche Kalkalpen, see profile in plate 5.)

The structures of the Südliche Kalkalpen show also some similarities with the synclinoria. However, the latter are much more complicated. Common are the reverse folds. In recent studies R. Staub pointed out the important role played by faults and fractures during the first stage of the orogenesis in the Südliche Kalkalpen. The Tibetan Marginal Synclinoria are considered to be of a trench (Graben) origin. The facies of the Tibetan Marginal Synclinoria recalls very much the Triassic formations of the Austro-Alpine nappes in the northeasterly Alps.

So far also age equivalents of the Bergell massif have been found in the Nepal Himalaya. There are granitic massifs of very young age north of (behind) the root zone, for example the Mustang granite or the Manaslu granite. But nowhere have granitic intrusions cut through thrustplanes. This does not say anything about the relative age of the granites and the thrustplanes, since thrustplanes do not exist in that area. Also in the Everest area, where for example the Nuptse granite is considered to be of Tertiary age, the granite bodies have not penetrated through the various thrustplanes. This may be explained by the fact that the Nuptse Schuppe is of upper Tertiary age. Nevertheless, the Mustang granite might well be of even younger origin, namely of Pleistocene age. The contact of the granite with the Mesozoic and lower Tertiary formations is quite irregular (profile 46, north of Manaslu, and figs. 38 and 40).

The fact, that the granites of the northern massifs (Mustang, Manaslu–Larkya) continue towards the south into the roots of the Kathmandu nappes, has also the equivalent in the Bergell massif.

The Tibetan Marginal Range has no equivalent in the Alps, at least not a visible one. The corresponding area is covered by the Po alluvium. We do not know what is buried under this alluvial plain.

Regarding the role of the Tibetan Marginal Range in the orogenesis of the Himalaya, a similar feature has been found in the Alps during the past 20 years. By minute stratigraphic investigations crustal movements of a fracture type were found in the Liassic formations, for example in the Glaris Alps. That means a mountain building long before the main diastrophism.

We come now to a remarkable difference between the Alps and the Himalayas, which concerns the roots. In the Alps they are not well exposed and in most areas eroded nearly down to the Po alluvium level. There is besides a considerable erosive gap in the nappes above the axial Gotthard culmination. These facts led to considerable speculations on the parallelisation of the nappes in eastern Switzerland (Bernina area) and in western Switzerland (Wallis). Lithological similarities and even identical formations allowed certainly some parallelisation. However, the different nappe arcs give still reason to many problematic thoughts. R. Staub showed in recent papers especially the role which was played by ancient transverse structures in building the Alps. Transverse structures, which extended far beyond the Alpine area, to the south as well as to the north. However those transverse structures are not so well developed that field geologists couldn't help to see them.

In the Nepal Himalayas the corresponding area is well exposed in the Great Himalayan Range and in the adjoining northerly area. The structural picture thus unveiled shows a much less alined layout of the various root zones than in the Alps, but a subdivision into several root arcs, all separated from each other by tremendous transverse structures.

We come now to the morphological features. Similarities with the Alps with this regard are much less frequent. The Himalayan main roots build the highest mountains, while in the Alps the roots are partly eroded nearly to sea-level. The highest mountains in the Swiss Alps (Monte Rosa, Bernina) are built on an anticline adjoining the roots, which corresponds to the Himalayan Fore Anticline (fig. 18). The highest mountain of the Alps at all (Mont Blanc 4800 m) is built by a granite massif, while in the Nepal Himalaya the massif do not exceed 3000 m above sea level. The highest peaks in the Alps are remnants of erosion, they form a clear Gipfelflur. The various groups of the eight-thousanders in Nepal have got their excessive height due to local uplift of the roots and the Himalayan Marginal Schuppen.

The main portion of the Alps show abundant but minor structures in the overthrust parts. In the Nepalese Midlands, there is a relative simple pattern of tremendous anticlines and synclines, some of which extend for hundreds of kilometers. The main structures in the Midlands have decisively influenced the layout of the drainage pattern, the main rivers following the anticlines, while the main mountain ranges (i. e. the Mahabharat Lekh) show a synclinal character. In the Alps, only the Rhone valley and the Vorderrhein valley follow structures (the southern flank of the Aar and Gotthard massifs), while all other big river courses are not identical with main structures. In the Nepalese Midlands, the topographic relief is reverse to the structure. North of the Midlands, the topographic relief corresponds with the structures: valleys follow synclines or Graben, while mountain ranges are built by anticlines. In the Swiss Alps, shape and height of the mountains are practically independent from the rocks and structures.

The unique drainage pattern of the Himalayas, with the transverse rivers cutting through main range has been dealt with in the chapter on the drainage pattern.

There remains one feature which is common in the Himalayas as well as in the Alps: The Alpenrandseen. This term originates from the old master of Alpine Geology, Albert Heim. He explained the reason of the Alpenrandseen by subsiding of the Alps relative to the foreland. Recent investigations tend rather to explain the Alpenrandseen entirely by glacial influence.

It is really puzzling enough to find Alpenrandseen, or at least there remnants in form of old lacustrine deposits in an area, which corresponds to the situation of the Alpenrandseen on either sides of the Alps (Kathmandu, Pokhara, Tila). The level of these ancient lakes (700–2000 meters) does exclude any ice age glaciation influence. We have at present no better explanation than that one given by Albert Heim one century back already.

Finally, in both mountain ranges, Quaternary crustal movements have been observed. While in the Alps those are confined to fractures only, in the Siwaliks clear overthrusts were found. Crustal movements and the rise of Himalayas are still going on; the characteristic convex-shaped valleys are visible proofs for it. In the Alps such valleys of this magnitude are rare.

To close this volume, we may say that so far in Nepal a grandeous structural layout of mountain building has been unvealed. Some features found enable new aspects of mountain building at all. Possibly, when the material will be published in full in the successive volumes, we may see more clear. But in general, the problems growing out of the—compared with the scope of the task—fragmentary investigations exceeds far the clarifications. The author would like to start fieldwork with the knowledge he has got now, once more right from the beginning.

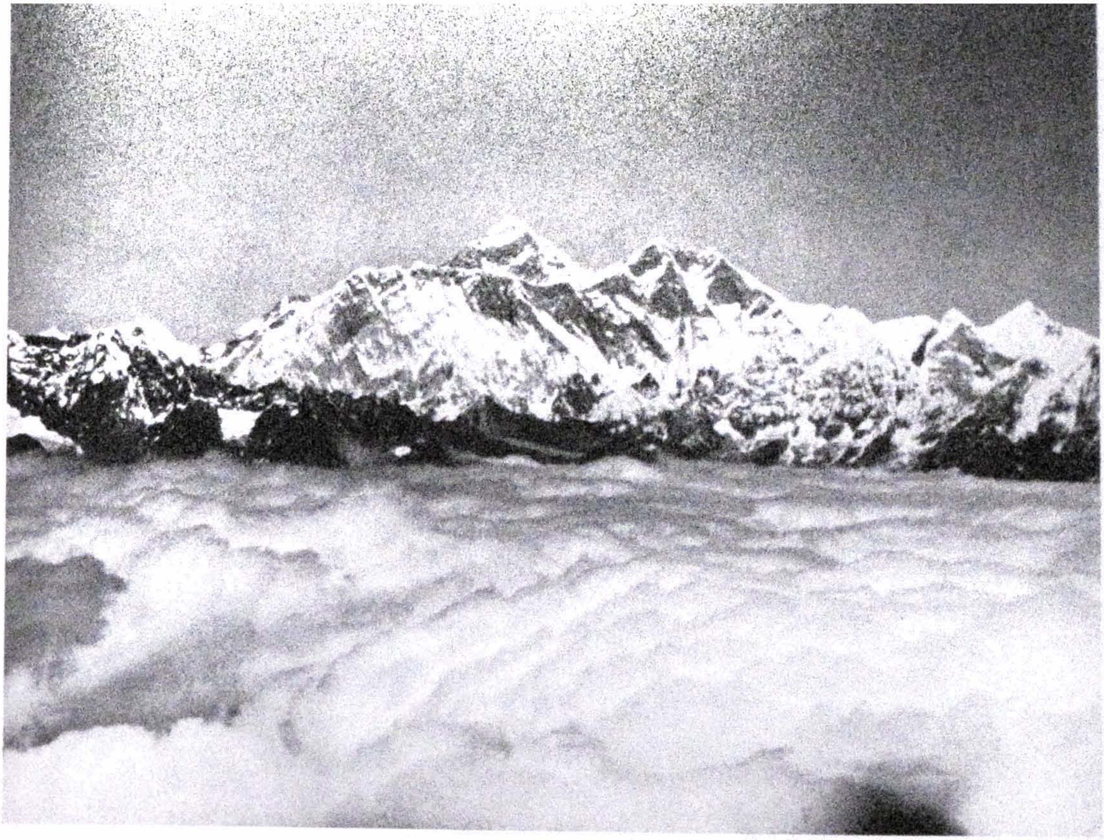
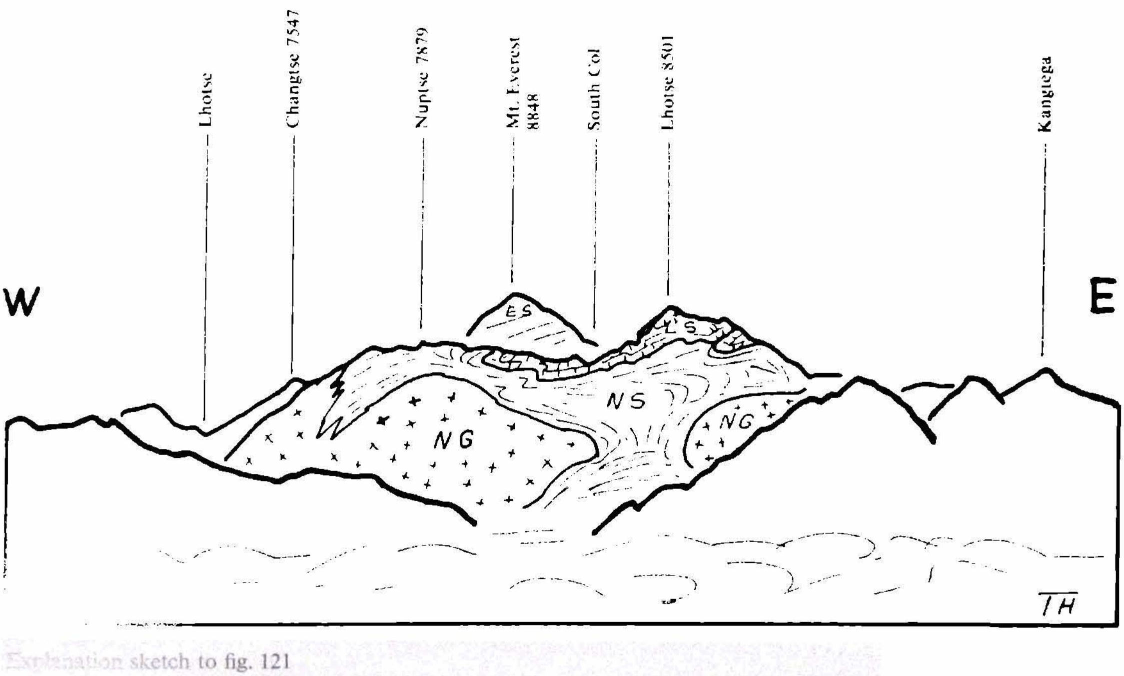


Fig. 121 Mount Everest Lhotse group, seen from the south
(Aerial photo T. Hagen)

The clear coloured Nuptse granite is well to be seen, as well as the dark coloured Nuptse series, which reach between Nuptse and Lhotse right down to the basin of the Imja. (Compare fig. 122)




Explanation sketch to fig. 121
ES = Everest series; LS = Lhotse series; NS = Nuptse series; NG = Nuptse granite.

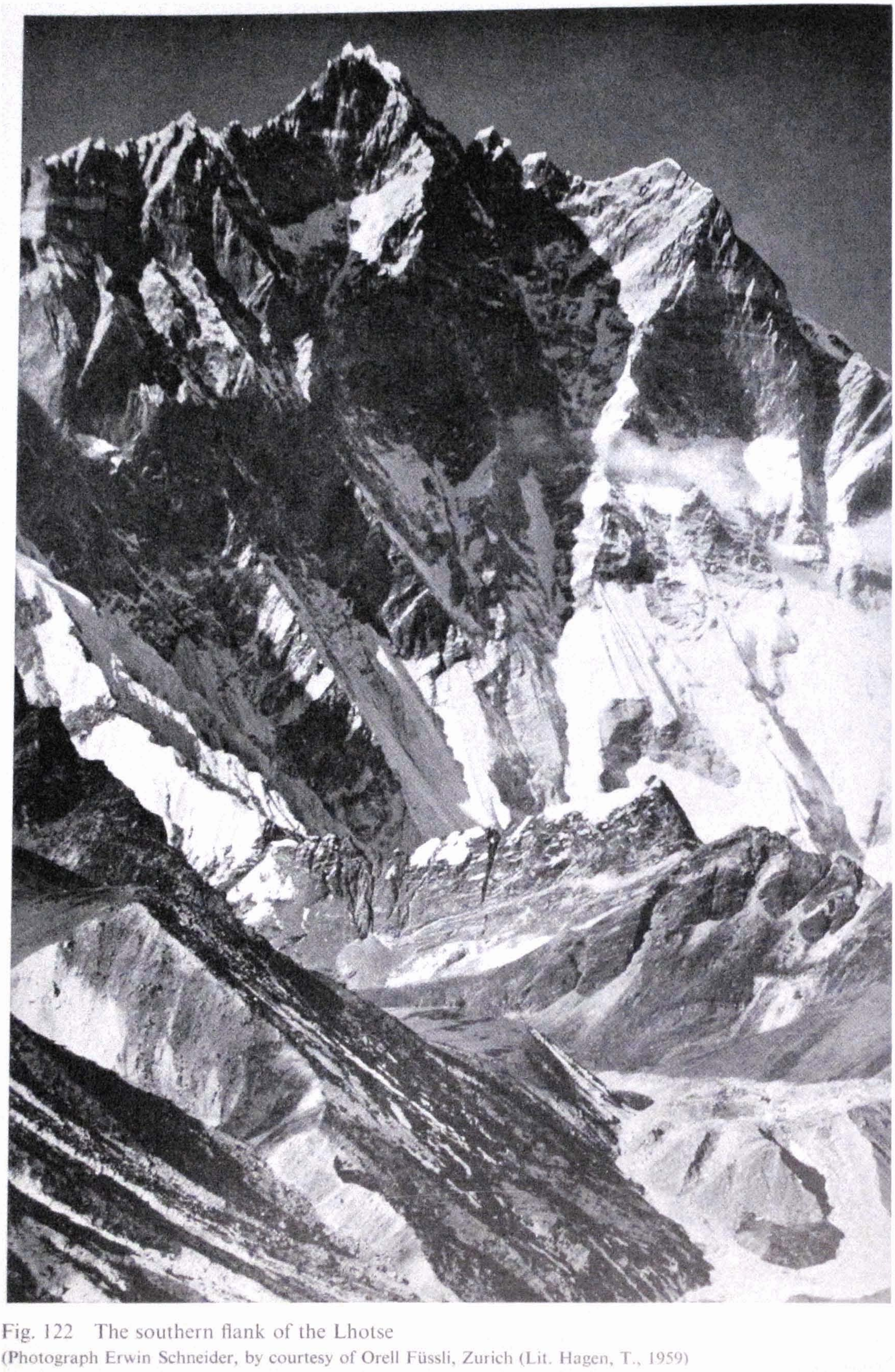
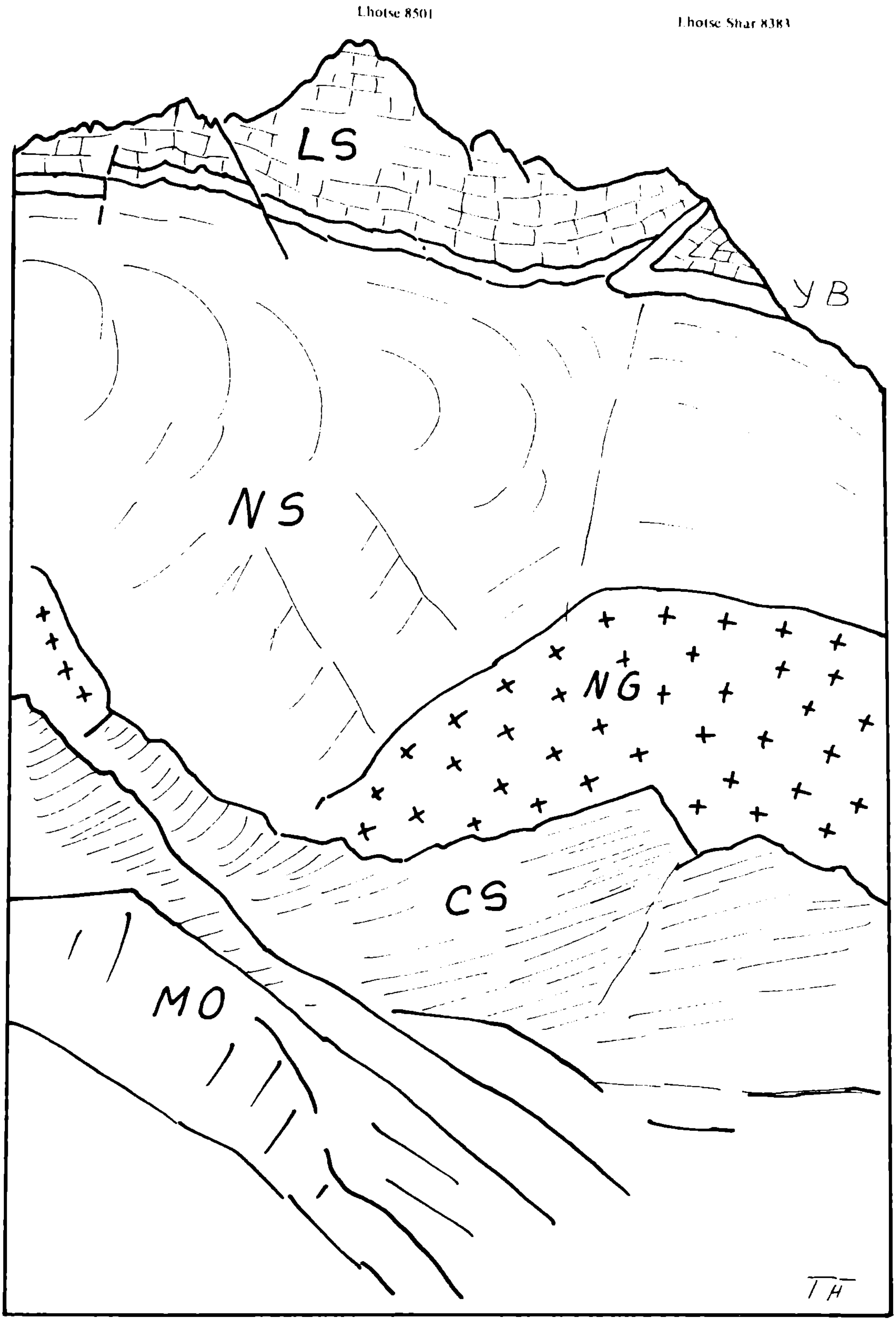


Fig. 122 The southern flank of the Lhotse
(Photograph Erwin Schneider, by courtesy of Orell Füssli, Zurich (Lit. Hagen, T., 1959)

The complicated fold structure is made well visible by the "yellow band series." The whole wall measures 3000 meters, a part of it being a tremendous overhang. It is caused by a huge fold heading towards the observer. The ridge in the foreground is built by the dark and soft northern dipping Clochetons series.




Explanation sketch to fig. 122
LS = Lhotse series; YB = Yellow band series; NS = Nuptse series; NG = Nuptse granite; CS = Cloche-tons; MO = Moraines.

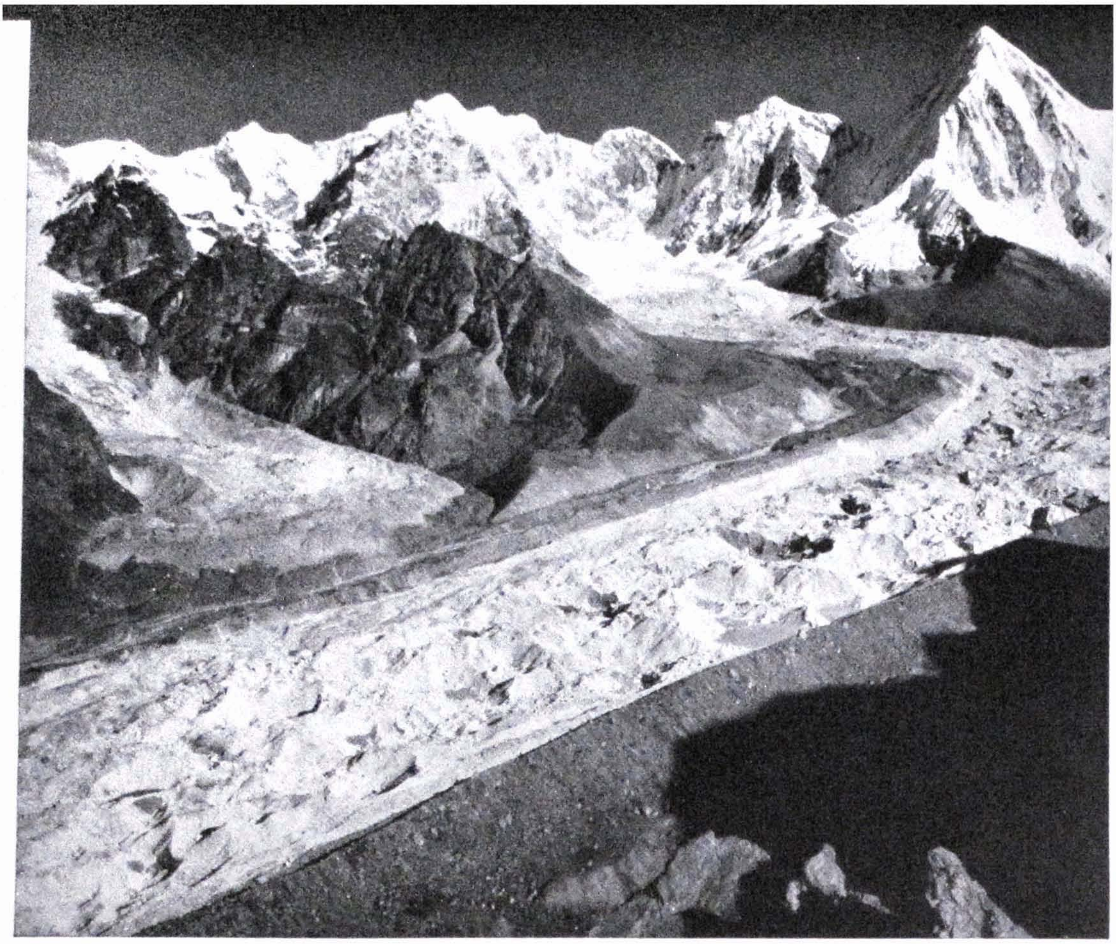
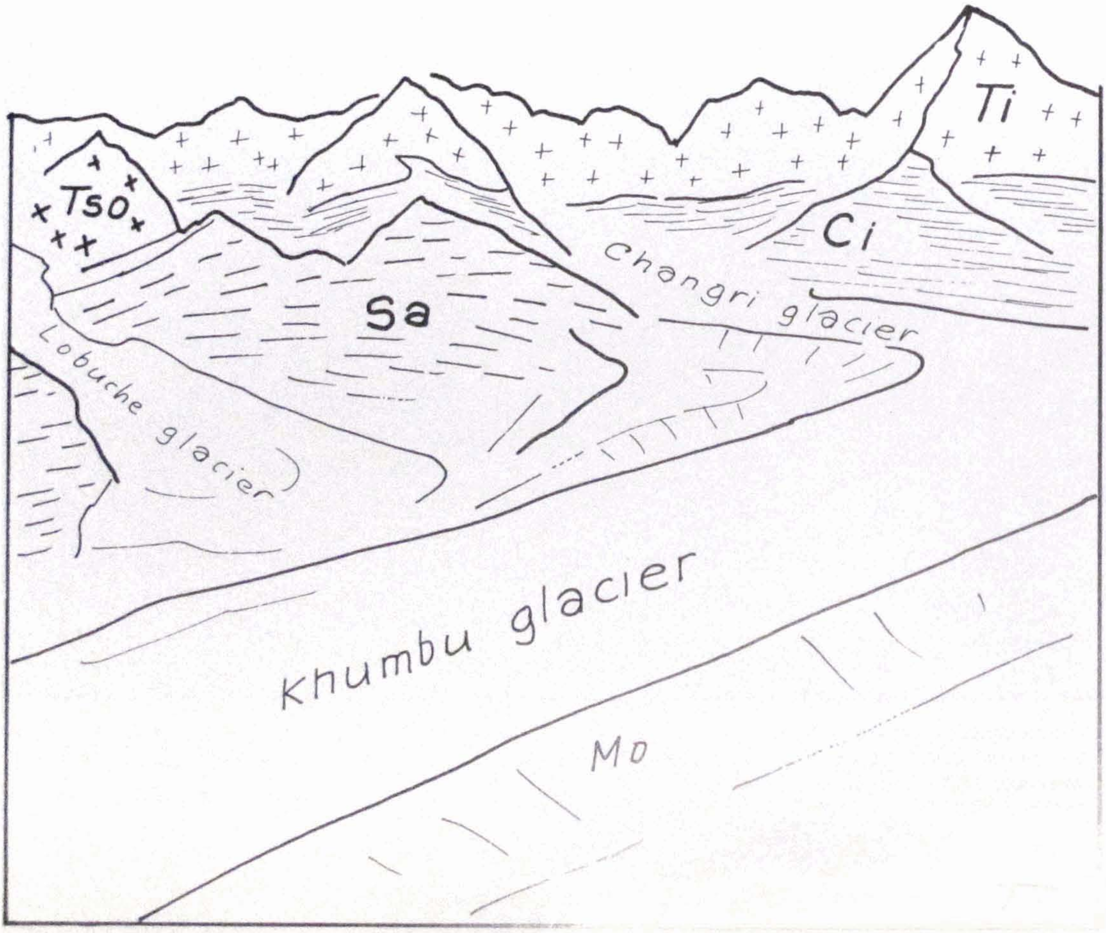


Fig. 123 View from the Clochetons into the basin of the lower part of the Khumbu glacier
(Photo Erwin Schneider, by courtesy of Orell Füssli, Zurich, Lit. Hagen, T., 1959)




Explanation sketch to fig. 123
Ti = Tibetan granite; Ci = Changri series; Tso = [illegible]

Fig. 124 Mount Everest from the southwest
(Photo Toni Hagen, by courtesy of Orell Füssli, Zurich, Lit. 1959)

The summit is built by well-bedded limestones of probably Devonian age. The western ridge at the right side [illegible] the Nuptse granite and the overlying intrusion zone.

Fig. 125 The Kangshung flank of the Lhotse-Everest group, seen from the east
(Photo Toni Hagen, by courtesy of Orell Füssli, Zurich, Lit. 1959)

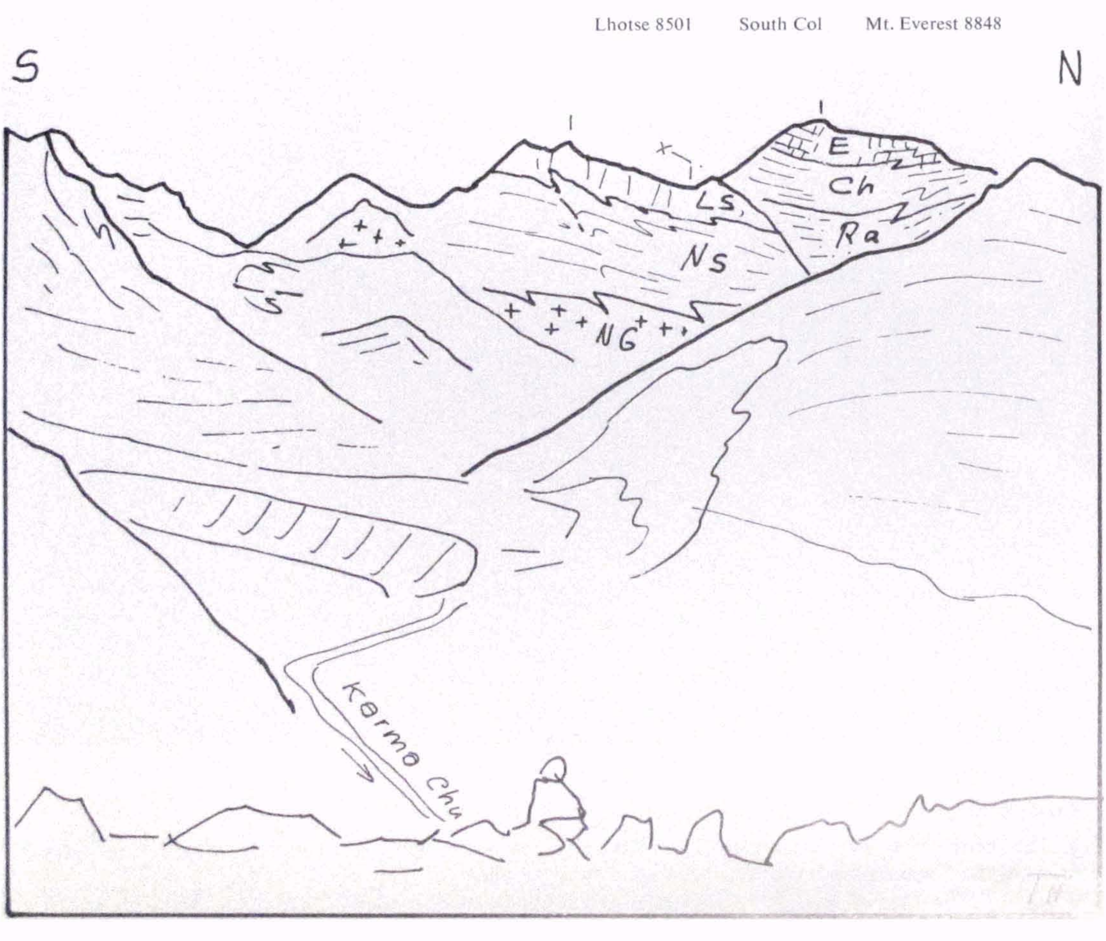
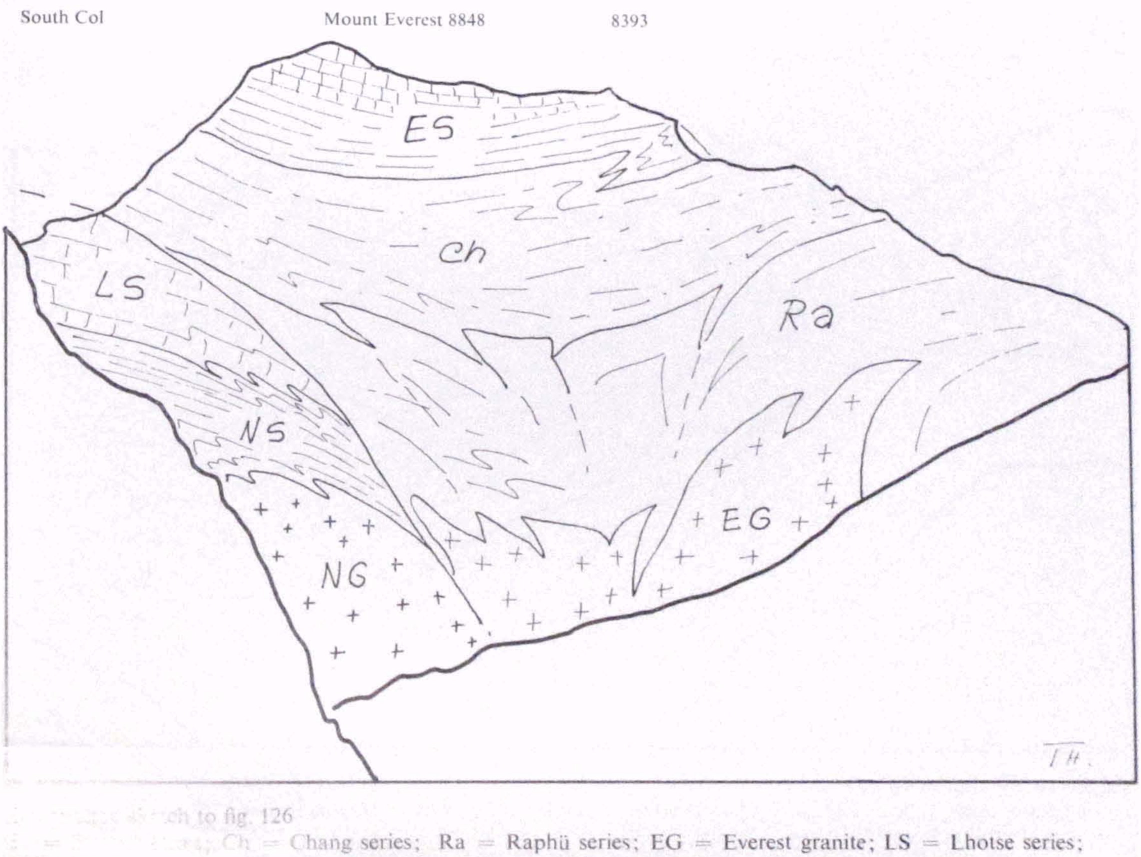
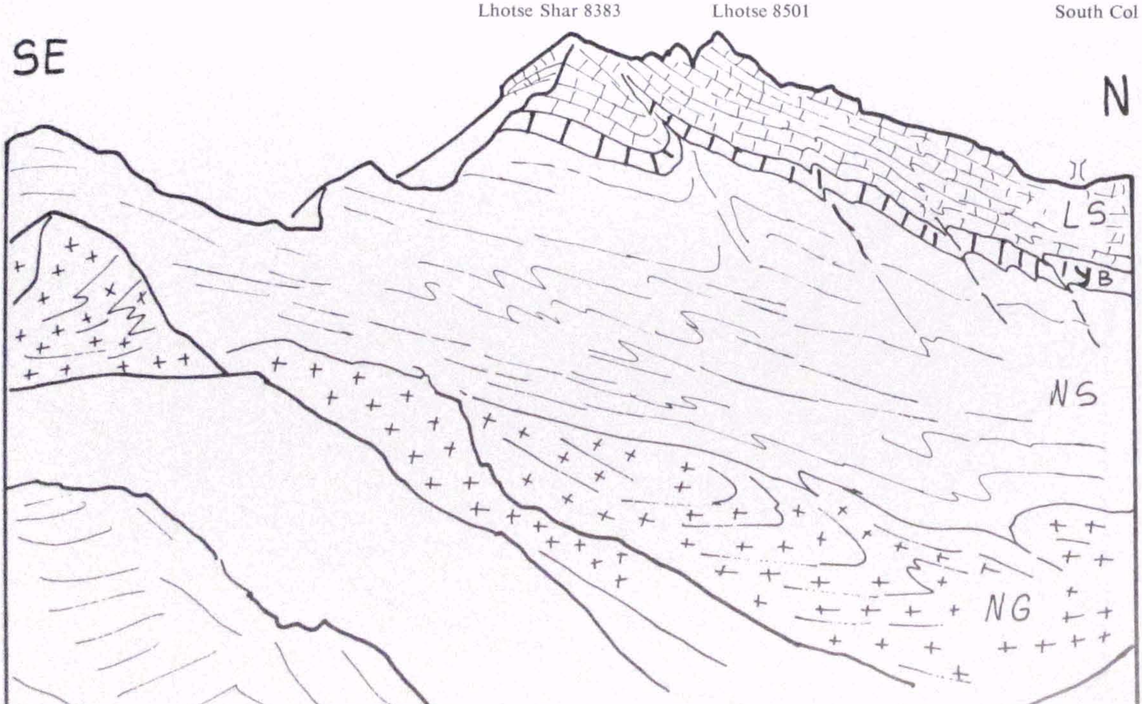


Fig. 126 The Kangshung flank of Mt. Everest
(Photo Toni Hagen)




[illegible] ch to fig. 126
[illegible]; Ch = Chang series; Ra = Raphü series; EG = Everest granite; LS = Lhotse series; [illegible]; NG = Nuptse granite.

Fig. 127 The Kangshung flank of the Lhotse
(Photo Toni Hagen)




Explanation sketch to fig. 127
LS = Lhotse series; YB = Yellow band series; NS = Nuptse series; NG = Nuptse granite

Fig. 128 The Makalu–Chomo Lönzo eastern flank
(Photo Toni Hagen)

In spite of the fact, that the whole flank is built entirely of crystalline formations, the structure of the Tibetan Marginal Synclinorium is well visible. The northeasterly ridge of the Chomo Lönzo (right side) consists of well bedded southern dipping rocks.

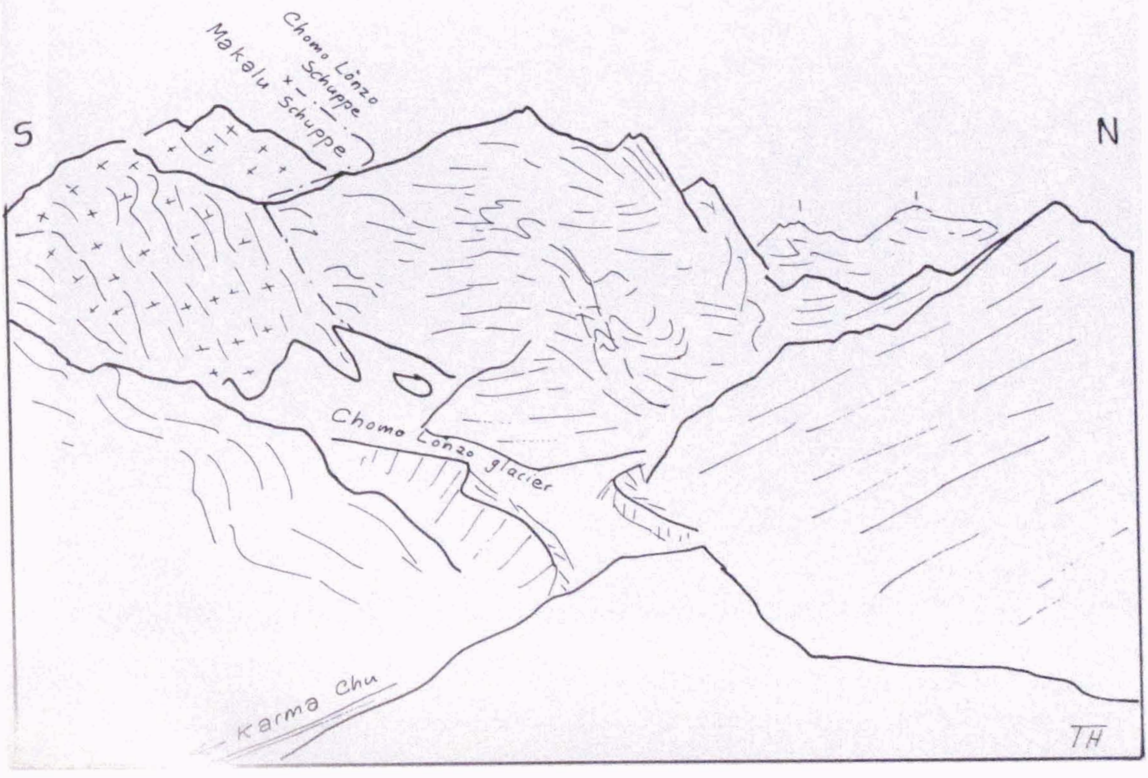


Fig. 129 Makalu, 8471 m, eastern flank
(Photo Toni Hagen, by courtesy of Orell Füssli, Zurich)
The base of the Makalu is far not a rigid mass, but shows a complicated structure (see fig. 103).

Fig. 130 Chomo Lönzo 7815 m eastern flank
(Photo Toni Hagen, by courtesy of Orell Füssli, Zurich, Lit. 1959)
See explanation in sketch to fig. 128.


Fig. 131 The Makalu–Chomo Lönzo group, seen across the Arun valley from the southeast
(Photo Toni Hagen)

The southerly dip north of the whole group is clearly to be seen. There is an ancient surface between 5000 and 6000 m, out of which the group rises abruptly.

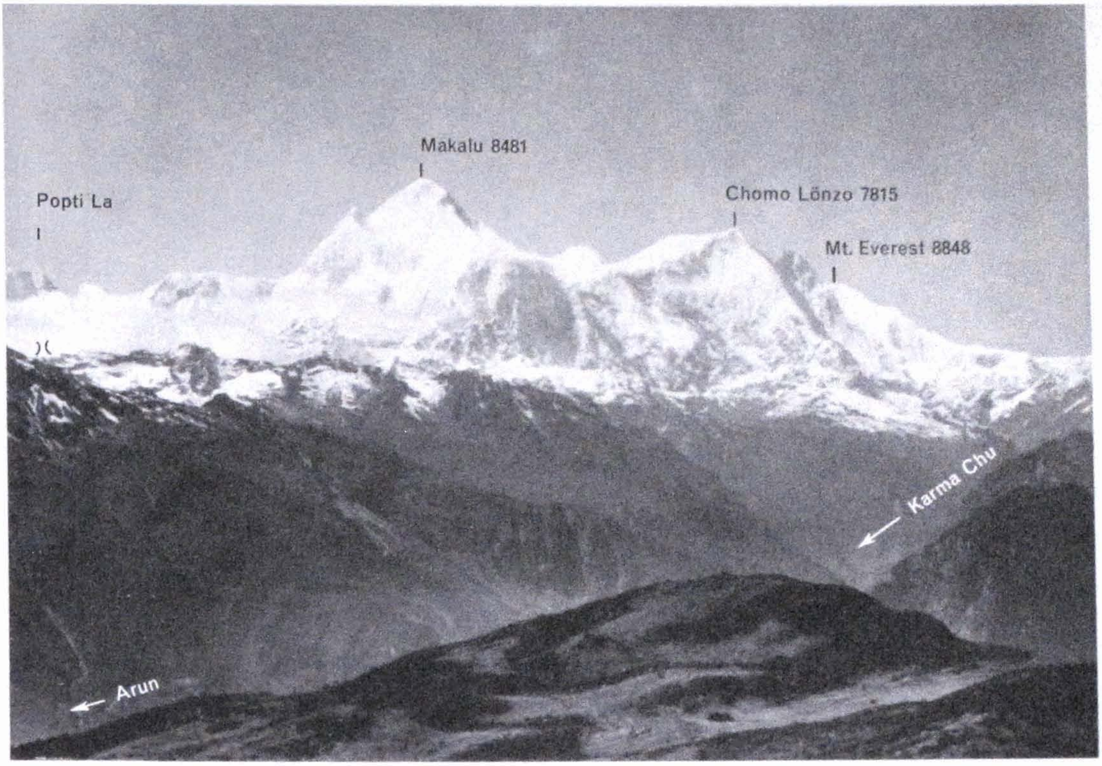



Fig. 132 The Makalu–Chomo Lönzo group seen from the east
(Photo Toni Hagen)

The group of the high mountains rise like "lifted islands" out of the lower and gentle-shaped basement. The Arun crosses in the foreground through the main range of the Himalayas at a level of only 1400 m.

Fig. 133 The outcrops of the Middle Siwalik sandstones
(Aerial Photo Toni Hagen)

An anticline pitches towards the right side.

Fig. 134 The Machhapuchhare 6997 m (Annapurna group), seen from Pokhara (800 m)
(Photo Toni Hagen)

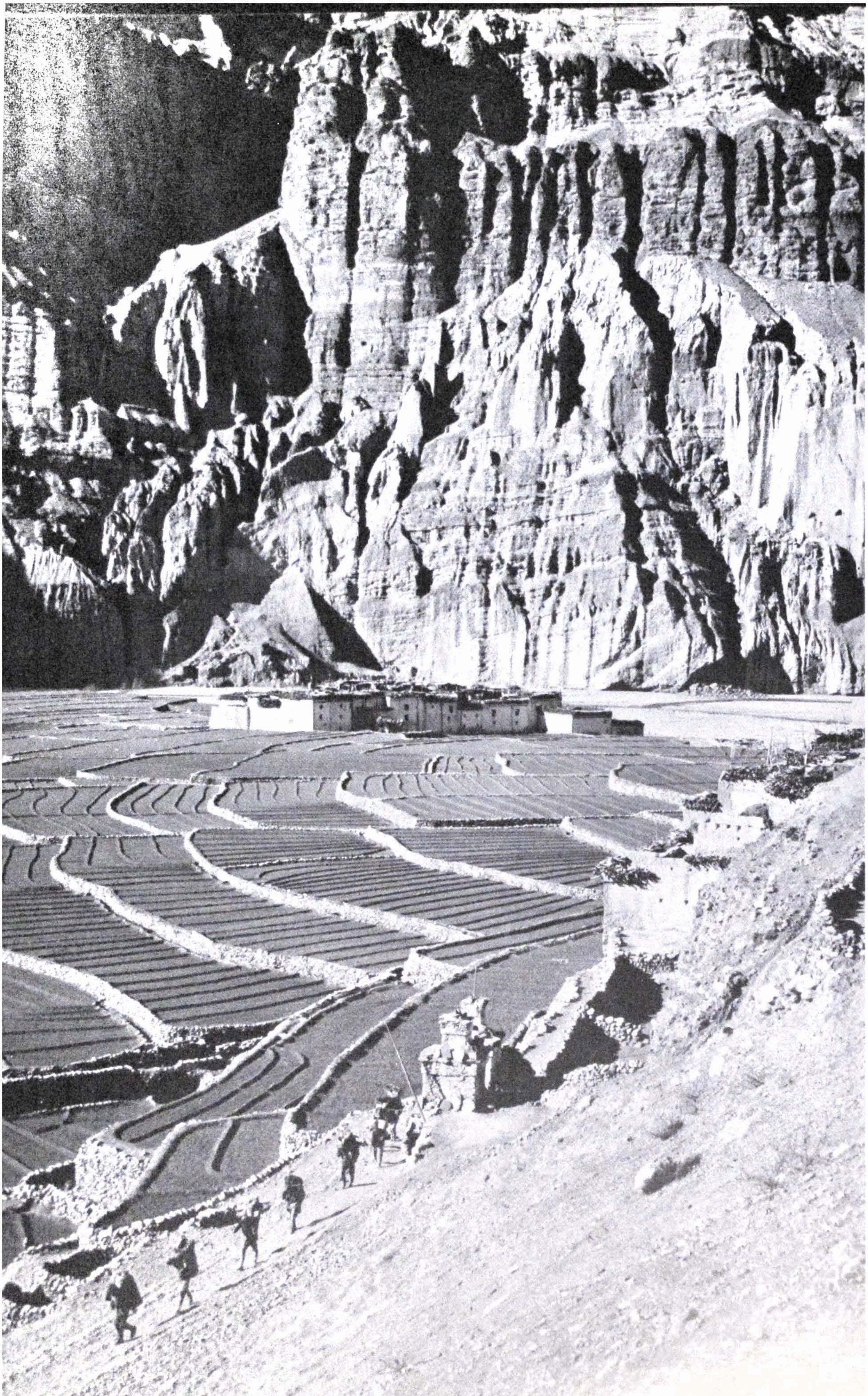
The distance from the observer is not more than 25 km, thus we have probably the greatest difference of altitude relative to the horizontal distance. The foot of the mountain group is built by the northerly dipping roots of the Nawakot nappes, while the upper part (above 3000 m) consists of the northerly dipping roots of the Kathmandu nappes.

Fig. 135 The transverse gorge of the Rongshar Chu (west of Gauri Sankar, eastern Nepal)
(Photo Toni Hagen)

The gorge shows the characteristic V-shape, with perpendicular rock walls towards the bottom, caused by increased erosive power.

Fig. 136 Chukh village, in the Thakkhola
(Photo Toni Hagen)

The Thakkhola shows a cannon like valley, cut in the upper Tertiary and lacustrine Pleistocene deposits.



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All the drawings for the figures in the texts have been prepared by the author

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* from the Ganges Plain to the Tibetan Plateau, 1 : 300 000

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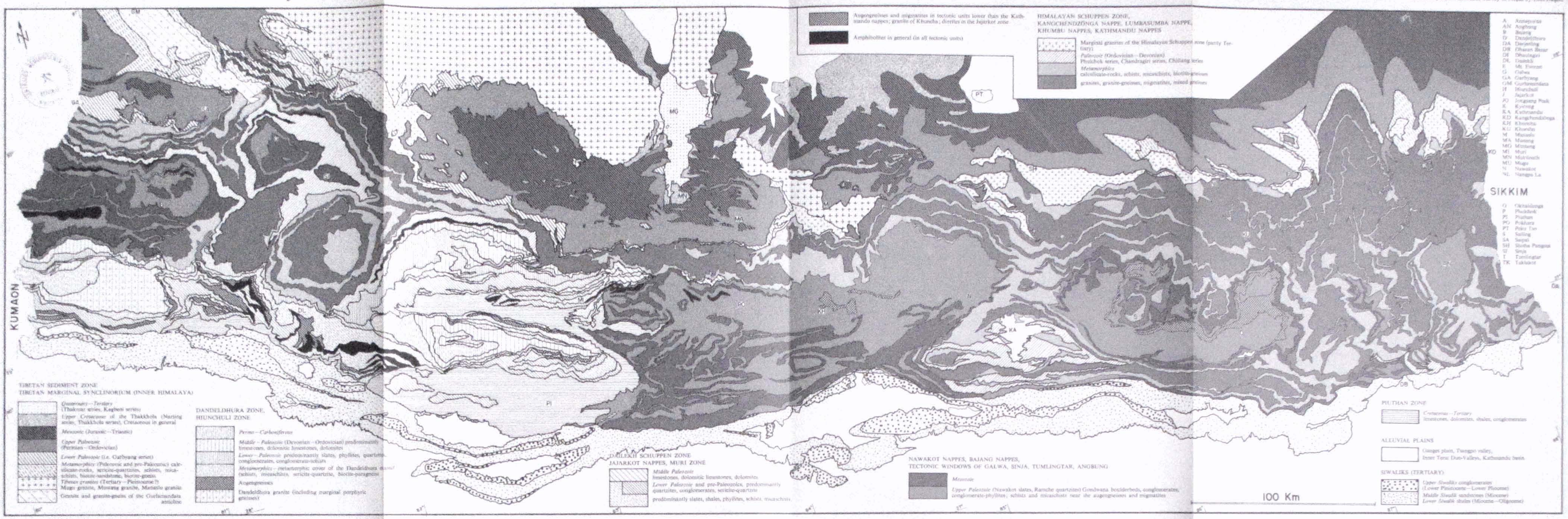
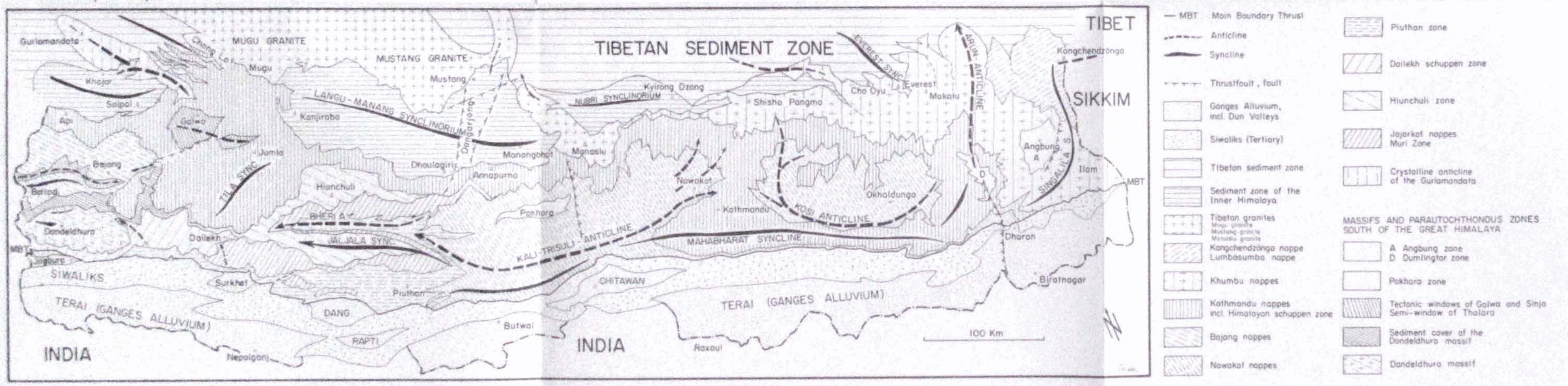
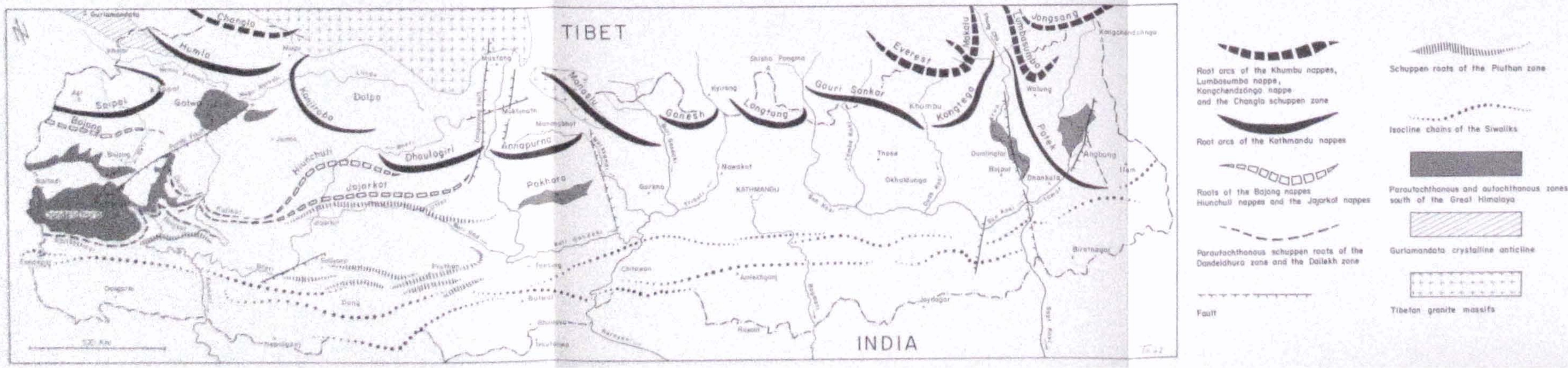
# GEOLOGICAL MAP OF NEPAL by Toni Hagen, 1950-1958 Scale 1:1.000.000

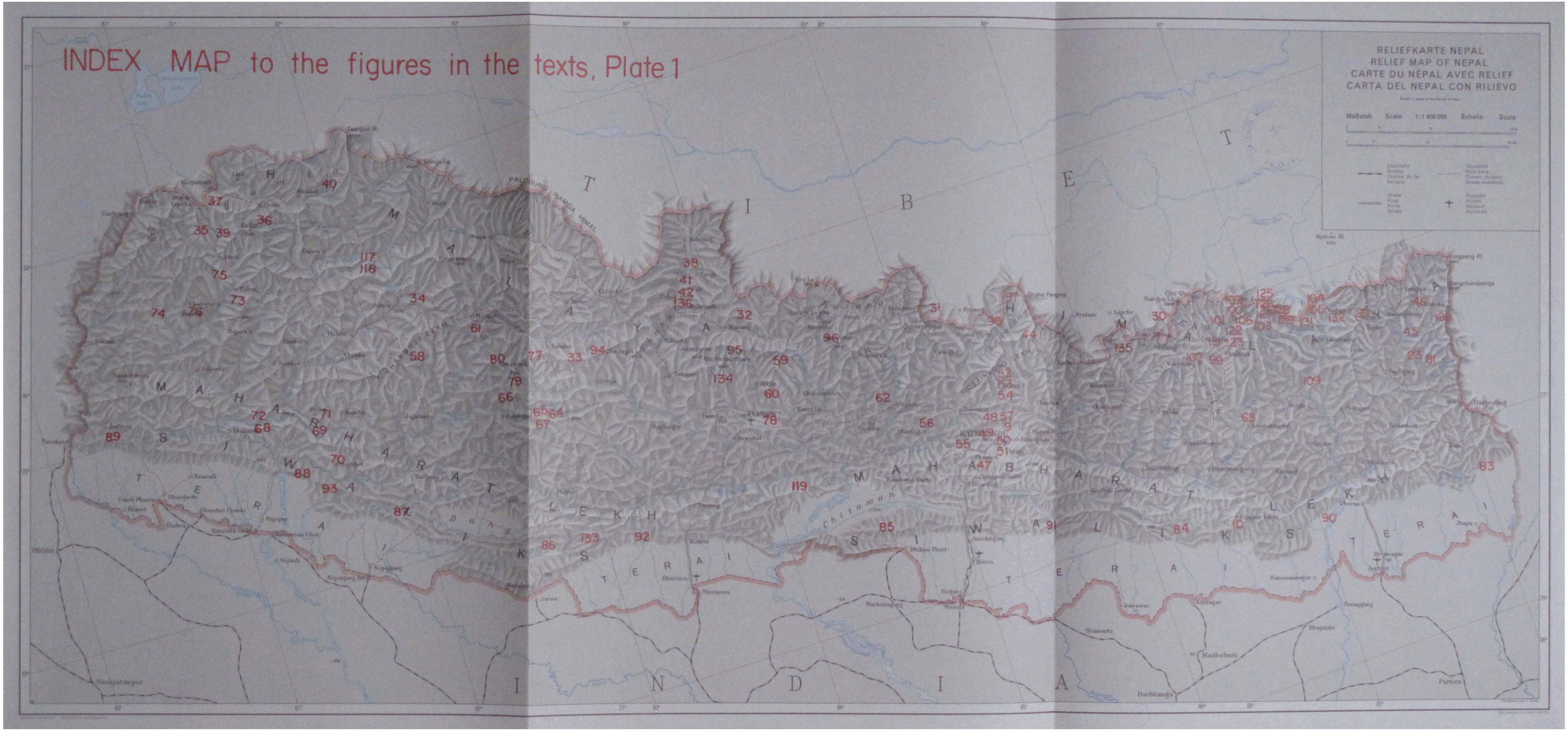


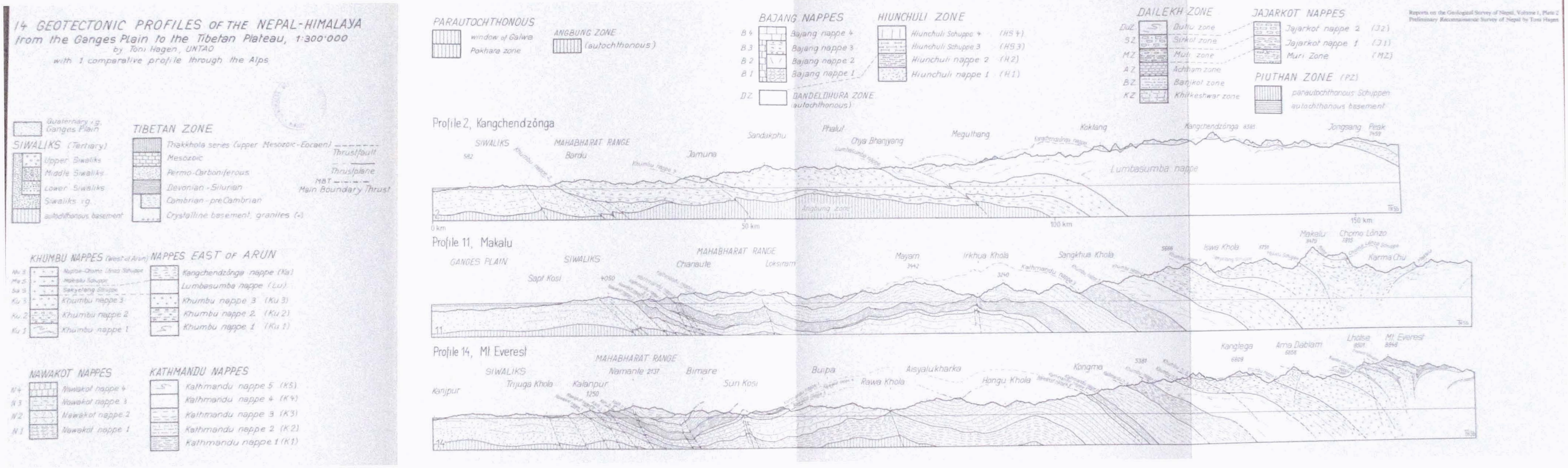

## Tectonic Map of Nepal

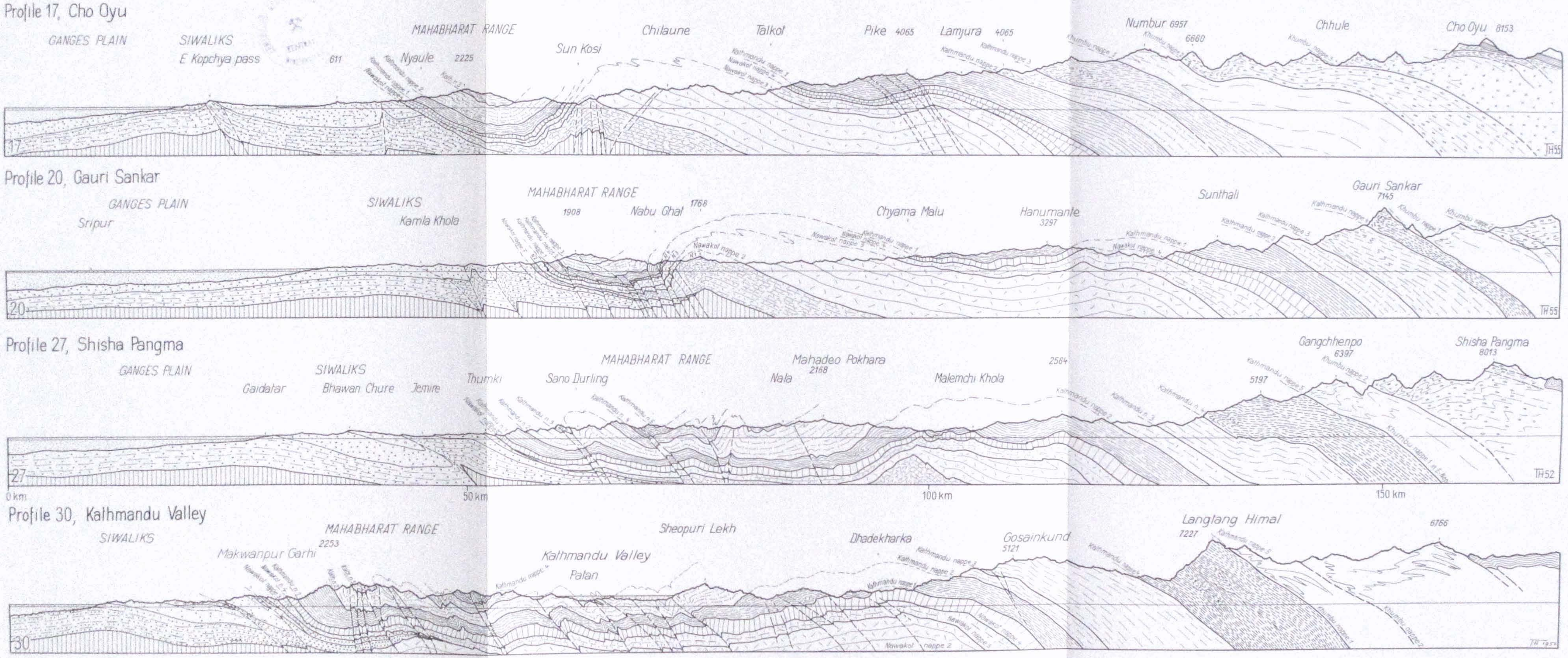


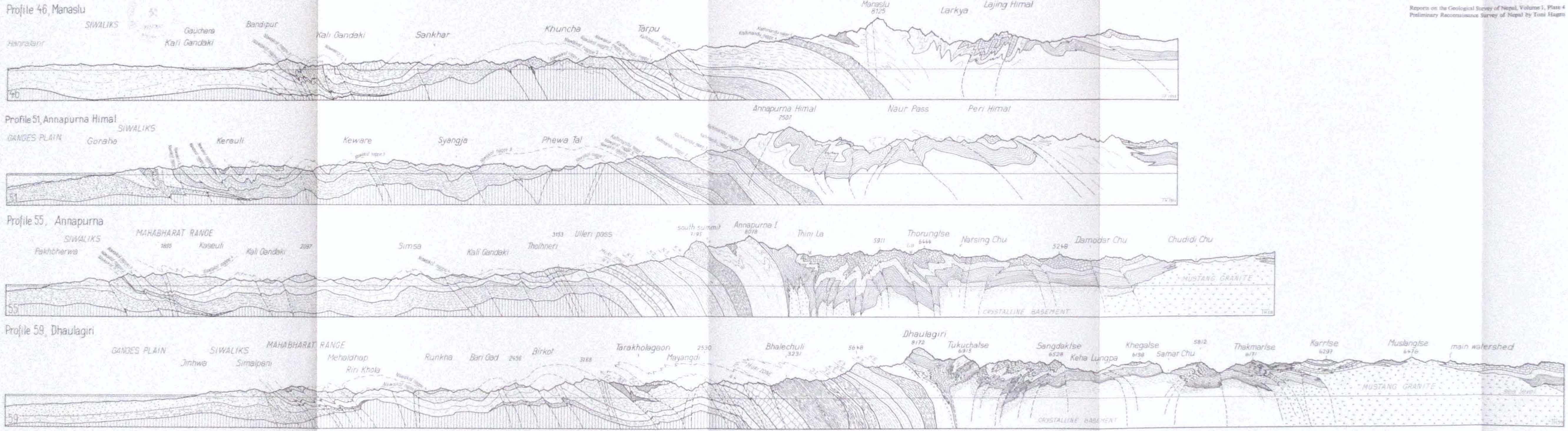

## Map of the root zones and of the autochthonous zones

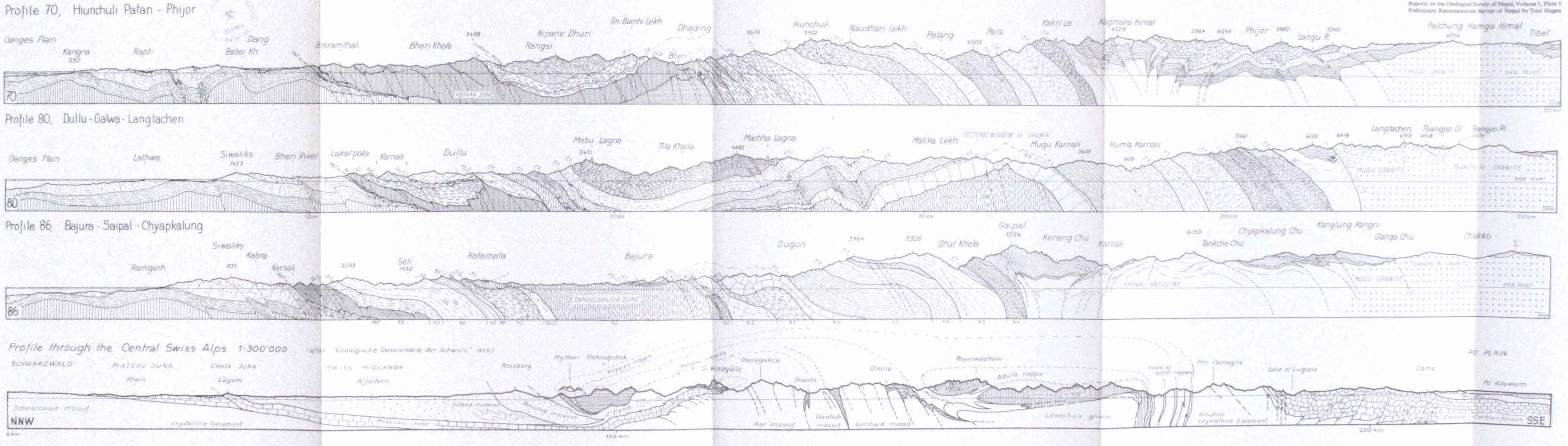



INDEX MAP to the figures in the texts, Plate 1
RELIEFKARTE NEPAL
RELIEF MAP OF NEPAL
CARTE DU NÉPAL AVEC RELIEF
CARTA DEL NEPAL CON RILIEVO
T I B E T
I N D I A
M A H A B H A R A T L E K H
S I W A L I K S
T E R A I
KATHMANDU
Chitwan


14 GEOTECTONIC PROFILES OF THE NEPAL-HIMALAYA
from the Ganges Plain to the Tibetan Plateau, 1:300'000
by Toni Hagen, UNTAO
with 1 comparative profile through the Alps
Quaternary e.g. Ganges Plain
SIWALIKS (Tertiary)
Upper Siwaliks
Middle Siwaliks
Lower Siwaliks
Siwaliks s.g.
autochthonous basement
TIBETAN ZONE
Thakkhola series (upper Mesozoic-Eocaen)
Mesozoic
Permo-Carboniferous
Devonian - Silurian
Cambrian - preCambrian
Crystalline basement, granites
Thrustfault
Thrustplane
MBT
Main Boundary Thrust
KHUMBU NAPPES (West of Arun)
Khumbu nappe 3
Khumbu nappe 2
Khumbu nappe 1
NAPPES EAST OF ARUN
Kangchendzönga nappe (Ka)
Lumbasumba nappe (Lu)
Khumbu nappe 3 (Ku 3)
Khumbu nappe 2 (Ku 2)
Khumbu nappe 1 (Ku 1)
NAWAKOT NAPPES
Nawakot nappe 4
Nawakot nappe 3
Nawakot nappe 2
Nawakot nappe 1
KATHMANDU NAPPES
Kathmandu nappe 5 (K5)
Kathmandu nappe 4 (K4)
Kathmandu nappe 3 (K3)
Kathmandu nappe 2 (K2)
Kathmandu nappe 1 (K1)
PARAUTOCHTHONOUS
window of Galwa
Pokhara zone
ANGBUNG ZONE
(autochthonous)
BAJANG NAPPES
Bajang nappe 4
Bajang nappe 3
Bajang nappe 2
Bajang nappe 1
DANDELDHURA ZONE
(autochthonous)
HIUNCHULI ZONE
Hiunchuli Schuppe 4 (HS 4)
Hiunchuli Schuppe 3 (HS 3)
Hiunchuli nappe 2 (H2)
Hiunchuli nappe 1 (H1)
DAILEKH ZONE
Dullu zone
Sirkot zone
Muri zone
Achham zone
Banjkot zone
Khirkeshwar zone
JAJARKOT NAPPES
Jajarkot nappe 2 (J2)
Jajarkot nappe 1 (J1)
Muri Zone (MZ)
PIUTHAN ZONE (PZ)
parautochthonous Schuppen
autochthonous basement
Profile 2, Kangchendzönga
SIWALIKS
MAHABHARAT RANGE
Bardu
Jamuna
Sandakphu
Phalut
Chya Bhanjyang
Megulthang
Koklang
Kangchendzönga
Jongsang Peak
Lumbasumba nappe
Angbung zone
0 km
50 km
100 km
150 km
Profile 11, Makalu
GANGES PLAIN
SIWALIKS
Sapt Kosi
MAHABHARAT RANGE
Chanaute
Loksiram
Mayam
Irkhua Khola
Sangkhua Khola
Iswa Khola
Makalu
Chomo Lönzo
Karma Chu
Profile 14, Mt. Everest
Kanjpur
SIWALIKS
Triyuga Khola
Kalanpur
MAHABHARAT RANGE
Namante
Bimare
Sun Kosi
Bulpa
Rawa Khola
Aisyalukharka
Hongu Khola
Kongma
Kanglega
Ama Dablam
Lhotse
Mt. Everest


Profile 17, Cho Oyu
GANGES PLAIN
SIWALIKS
E Kopchya pass
611
MAHABHARAT RANGE
Nyaule 2225
Sun Kosi
Chilaune
Talkot
Pike 4065
Lamjura 4065
Numbur 6957
6660
Chhule
Cho Oyu 8153
17
JH55
Profile 20, Gauri Sankar
GANGES PLAIN
Sripur
SIWALIKS
Kamla Khola
MAHABHARAT RANGE
1908
Nabu Ghat 1768
Chyama Malu
Hanumante 3297
Sunthali
Gauri Sankar 7145
20
TH55
Profile 27, Shisha Pangma
GANGES PLAIN
SIWALIKS
Gaidatar
Bhawan Chure
Jemire
Thumki
Sano Durling
MAHABHARAT RANGE
Mahadeo Pokhara 2168
Nala
Malemchi Khola
2564
5197
Gangchhenpo 6397
Shisha Pangma 8013
27
TH52
0 km
50 km
100 km
150 km
Profile 30, Kathmandu Valley
SIWALIKS
Makwanpur Garhi
MAHABHARAT RANGE 2253
Kathmandu Valley
Palan
Sheopuri Lekh
Dhadekharka
Gosainkund 5121
Langtang Himal 7227
6766
30


Profile 46, Manaslu
SIWALIKS
Gaucharis
Kali Gandaki
Bandipur
Kali Gandaki
Sankhar
Khuncha
Tarpu
Manaslu
8125
Larkya
Lajing Himal
46
Profile 51, Annapurna Himal
GANGES PLAIN
SIWALIKS
Goraha
Kerauli
Keware
Syangja
Phewa Tal
Annapurna Himal
7507
Naur Pass
Peri Himal
51
Profile 55, Annapurna
SIWALIKS
MAHABHARAT RANGE
Pakhbherwa
Kaseuli
Kali Gandaki
Simsa
Kali Gandaki
Tholhneri
Ulleri pass
south summit
Annapurna I
8078
Thini La
Thorungtse
Narsing Chu
Damodar Chu
Chudidi Chu
MUSTANG GRANITE
CRYSTALLINE BASEMENT
55
Profile 59, Dhaulagiri
GANGES PLAIN
SIWALIKS
MAHABHARAT RANGE
Jinhwa
Simalpani
Mehaldhap
Riri Khola
Runkha
Bari Gad
Birkot
Tarakholagaon
Mayangdi
Bhalechuli
Dhaulagiri
8172
Tukuchatse
Sangdaktse
Keha Lungpa
Khegatse
Samar Chu
Thakmartse
Karrtse
Muslangtse
main watershed
MUSTANG GRANITE
CRYSTALLINE BASEMENT
59


Profile 70, Hiunchuli Patan - Phijor
Ganges Plain
Kangra
Rapti
Dang
Babai Kh.
Bisramthali
Bheri Khola
Nipane Dhuri
Rangsi
Tin Bainhi Lekh
Dhading
Bheri
Hiunchuli
Naudhari Lekh
Palang
Para
Kakri La
Kagmara Himal
Phijor
Langu R.
Palchung Hamga Himal
Tibet
MUGU GRANITE
Profile 80, Dullu - Galwa - Langlachen
Ganges Plain
Lathwa
Siwaliks
Bheri River
Lakarpata
Karnali
Dullu
Mabu Lagna
Tila Khola
Machha Lagna
Malika Lekh
TECTONIC WINDOW of GALWA
Mugu Karnali
Humla Karnali
Langlachen
Tsangpo Gl
Tsangpo Ri
MUGU GRANITE
TSANGPO RI GRANITE
DANDELDHURA ZONE
Profile 86, Bajura - Saipal - Chyapkalung
Siwaliks
Kabra
Ramgarh
Karnali
Seti
Ralemata
Bajura
Dugun
Ghat Khola
Saipal
Kerang Chu
Karnali
Tankche Chu
Chyapkalung Chu
Kanglung Kangri
Ganga Chu
Chakko
KARNALI ANTICLINE
MUGU GRANITE
DANDELDHURA ZONE
Profile through the Central Swiss Alps 1:300'000
SCHWARZWALD
PLATEAU JURA
CHAIN JURA
SWISS MIDLANDS
Rhein
Lägern
Affoltern
Rossberg
Mythen
Frohnalpstock
Gr. Windgälle
Oberalpstock
Greina
Rheinwaldhorn
Adula nappe
Mte. Ceneri
Lake of Lugano
Como
PO PLAIN
Po Alluvium
Schwarzwald massif
crystalline basement
Mesozoic cover
folded molasse
Aar massif
Tavetsch massif
Gotthard massif
Leventina gneiss
Simano nappe
NNW
SSE
100 km
200 km