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THE GEOLOGY OF WEST NEPAL BETWEEN THE RIVERS KALI GANDAKI AND THULO BHERI

G. FUCHS AND W. FRANK

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The Geology of West Nepal between the Rivers Kali Gandaki and Thulo Bheri

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with 9 plates **) and 39 figures

Contents

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Abstract

A uniform stratigraphy is given for the Lower Himalayas of West Nepal. The succession starts with a monotonous slate formation of geosynclinal type, and is overlain by clastic shallow-water deposits and a thick carbonate complex at the top. The age of this nonfossiliferous sequence is discussed. Transgressive fossiliferous beds of Jurassic-Tertiary age are overlying. From the distribution of facies it may be concluded that the strike direction of the present Himalayas was already structurally effective during the deposition of the sedimentary sequence, that means at least from the Lower Palaeozoic on.

The rocks of the metamorphic complex are described and their genesis is discussed.

There is inverse metamorphism in the lower part of the Crystalline and normal metamorphism in its upper part. The latter gradually dies out in the basal beds of the Tibetan Zone.

The Himalayan orogeny has led to the formation of several structural units. The Siwalik Zone is overthrust by the units of the Lower Himalayas. The lowest structural element of the latter is the Tansing Unit, which seems to be parautochthonous.

It is overthrust by the Rukum Nappe, a discontinuous nappe. The overlying Chail Nappe splits into three subsidiary units in the Hiunchuli area. The lower two units show a normal stratigraphic sequence, resembling to that of the Tansing Unit. The crystalline complex consists of a lower less metamorphic and a higher migmatitic nappe. There is evidence for

thrust displacements of at least 90 *km.*, as fossiliferous nonmetamorphosed Tertiary beds are found in semi-windows beneath the overthrust metamorphic rocks of higher nappes (Chail Nappes).

Preface

The Austrian Geological Himalayan Expedition 1967 carried out investigations in West Nepal which are described in the present paper.

From previous work (HAGEN 1959 a, FUCHS 1967) we assumed that investigations in the geologically rather unknown areas between the rivers Kali Gandaki and Thulo Bheri and around Jumla and Hiunchuli would yield interesting results. These would be important for the understanding of the geology of West Nepal as well as for the solution of general geological problems of the Himalayas.

Our mappings, carried out between February and May 1967, revealed the stratigraphy, interesting facies relations, and the tectonical features of West Nepal. Due to the particular geology of the region problems were solved, the solution of which would not have been possible in other areas.

The routes we covered on foot are 1300 to 1500 *km*. The area, at least roughly investigated during the expeditions 1963 and 1967, comprises about one fifth of the area of the Kingdom of Nepal.

The team of the expedition consisted of two geologists Dr. Gerhard FUCHS (Geological Survey of Austria) and Dr. Wolfgang FRANK (Geological Institute of the Vienna University), and Mr. Paul KÖNIG, who was responsible for organization e.g. food supply, transport with porters etc.

The expedition was sponsored by the "Fonds zur Förderung der wissenschaftlichen Forschung", the "Bundesministerium für Unterricht", the "Kulturamt der Stadt Wien", the "Österreichische Akademie der Wissenschaften", the "Österreichischer Alpenverein", and other official and private institutions. To all of them we are highly indebted for having made our research possible.

We are very grateful to Professor Dr. H. KÜPPER, former director of the Geological Survey and Professor Dr. Dr. E. CLAR, head of the Geological Institute of the University, for their help and for having kindly given us leave for our studies.

The printing of the present paper was made possible by the financial aid of the "Fonds zur Förderung der wissenschaftlichen Forschung" for which we like to express our deep gratitude.

As most of Himalayan literature is in English, we have written this paper in that language. Therefore we are very grateful to Professor Dr. E. R. OXBURGH (Department of Geology and Mineralogy, University of Oxford) and Professor Dr. F. STEFAN (Vienna) for kindly going through the manuscript. Except the notes on our 1969 expedition which were put into the text later (pp. 59—63).

The type work was done by Miss L. BLÜMERT and Miss H. HORVATH, the drawings were made by Mrs. I. ZACK, Mr. J. KERSCHHOFER, Mr. L. LEITNER, Mr. P. MUNDSPERGER, and Mr. A. ROEDER. We are very thankful to all of them for their help.

Introduction

The area which was investigated in the course of our expedition (1967) as well as by the 1963 expedition is situated in W-Nepal between the longitudes of 82° and 84° E Greenw. and the northern meridians of 27° 44′ and 29° 23′ (Pl. 1).

Approaching from the S, from the Ganges Plains, one first reaches the foot hills—the Sub-Himalayas. In Nepal this zone is formed by the Siwaliks, the Upper Tertiary to Pleistocene molasse deposits of the Himalayas.

Climbing the southern slopes of the Mahabharat Range one enters the next geographical-geological unit—the Lower Himalayas. This zone comprises the range named above and the densely populated Midlands N of it. We find various pre-Tertiary formations, unmetamorphosed and in low grades of metamorphism as well as high grade crystalline rocks. There are also few occurrences of Tertiary rocks. The structural pattern is very complicated. Several thrust sheets are found lying one upon the other. Along the Main Boundary Thrust the Lower Himalayas as a whole are thrust over the Siwaliks.

The Higher Himalayas are a clear geographical unit—the conspicuous region of the Great Himalayan Range. But it is difficult to give a sharp geological definition: it is the zone of the roots, where the thrust sheets of the Lower Himalayas dip to the NNE. It is formed by metamorphic rocks (lower green schist to amphibolite facies) which we know already from outliers in the Lower Himalayas. In the highest thrust sheet the metamorphism of the rocks dies out towards the top and we find a gradation into the basal Early Palaeozoic formation of the Tibetan—or Tethys Zone. Some of the highest peaks of the Great Himalayan Range are built already by rocks of the Tibetan Zone.

The Inner Himalayas (T. Hagen 1960), the region between the Great Himalayan Range and the Tibetan Plateau, are formed by the formations of the Tibetan Zone. We find a rather complete fossiliferous sequence ranging from the Early Palaeozoic to the Upper Cretaceous. In the area investigated by us, T. Hagen has used the name "Tibetisches Randsynclinorium" for that zone. The structure shows folding, thrusts being insignificant. In this northern parts of the Himalayas we find some late orogenic granite intrusions.

Towards the N this zone grades into the Tibetan Plateau across the Nepalese border.

When G. Fuchs—one of the authors—started his investigations in West-Nepal in 1963 he could use no stratigraphical scheme either in the Lower Himalayas or in the Tibetan Zone.

There had been former attempts to find the true sedimentary sequence of rocks in the highly complicated Lower Himalayas (T. Hagen et al. 1952, P. Bordet 1961). Because of the lack of fossils these authors could give only tentative interpretations of the age of the beds. But as already stated by A. Gansser (1964, p. 148) there is much doubt about their stratigraphical interpretations which show many inconsistencies. The suggested sequences also do not have much in common with the known sequences of the surrounding areas. Neither in stratigraphy nor in tectonics were we able to follow the views of T. HAGEN and P. BORDET, but in the descriptions of the well-studied areas of the Northwestern and Central Himalayas we found many similarities to Nepal.

A visit to these areas in 1964 (Kashmir, Kulu-Mandi, Simla, Garhwal) has proved our suggestion that the rock sequences as well as the main structural units of Nepal and the NW-Himalayas are identical. Also in different tectonic units of the Lower Himalayas we found corresponding sequences which are fairly comparable to that of the classical Krol belt of AUDEN (1934). So we came to a uniform stratigraphy for all the Lower Himalayas (G. FUCHS 1967).

For the age of the unfossiliferous formations FUCHS follows the stratigraphical scheme of R. D. OLDHAM, G. E. PILGRIM, W. D. WEST, J. B. AUDEN and D. N. WADIA, who correlate the Blaini Boulder Bed to the Talchir Tillite of the Salt Range, and the overlying Krol Limestone to the Permian Productus Limestone.

We were able to show that the Chail Nappe found by G. E. PILGRIM and W. D. WEST (1928) in Simla is traceable throughout the Himalayas. Whereas in most regions this thrustsheet consists entirely of the thick Chail Series, we were able to recognize this formation as part of a true stratigraphic sequence in the Jangla Bhanjyang section (G. FUCHS 1967). This sequence, though being metamorphic, closely resembles those of the Shali- and Krol-Zones. This observation is highly important for the geological age of the Shali Series, and for the problem of the inverse metamorphism of the Crystalline Nappe.

The formations of the Jangla section seemed to continue to the W and this interesting sequence should be well developed in the Hiunchuli area.

The first investigations in W-Nepal made by T. HAGEN revealed some tectonic windows in the Jumla area.

This region of W-Nepal, situated W of the area studied by us in 1963, seemed to be especially favourable for detailed investigations. Therefore the Austrian Geological Himalayan Expedition 1967 went to this part of Nepal.

The route taken was: Pokhara—Tansing—Piuthan—Sallyana—Jajarkot—Jumla—Tibrikot—Kanjiroba and Hiunchuli area—Rukumkot—Piuthan—Butwal. The Geological Map (Pl. 1) is based on the observations along these routes and those from 1963. The field work was based on the quarter inch map but for part of the area we had better modern maps. Though there are still gaps, the map reveals the distribution of rocks and the structure of this part of Nepal, which is about a fifth of the country. In addition we were able to make observations which are of interest for the geology of all the Himalayas.

A. Stratigraphy

It is well known that there are entirely different sequences S and N from the Great Himalayan Range, and a direct correlation is not possible. In our publication (G. FUCHS, 1967) we have given a description of the sedimentary sequence in the Tibetan Zone of W-Nepal and we shall not discuss it further here. The richness in fossils is a great advantage for stratigraphical studies in that zone. By contrast in the Lower Himalayas there is nearly no direct evidence for the age of the beds. Only the comparison of many sections gives us the true original sequence of rocks, by means of analogies they may be correlated to rock formations of known age in neighbouring regions (e.g. Salt Range, Kashmir).

The present paper deals with the geology of the Lower—and Higher Himalayas, we have therefore to describe mainly unfossiliferous rocks of somewhat problematic age. We will describe the stratigraphic sequences according to the main structural units to which they belong: first the lower and southern units and then the higher ones which were deposited originally further north.

I. The Stratigraphy of the Tansing Unit

We have introduced the term Krol Unit for the lowest tectonic unit of the Lower Himalayas in Nepal (1967). Investigations in the course of our most recent expedition (1969), however, have shown that the tectonic position of the Krol belt is somewhat doubtful in the Simla area. In Nepal we therefore use the local name Tansing Unit after Tansing a well known place in W-Nepal (see Pl. 1).

The sequence of the Krol belt, that is the southernmost zone of the Lower Himalayas was described by J. B. AUDEN in his classic paper 1934 on a modern basis. A similar sequence is found in a more northern zone, in the Shali-Tejam Zone. It has already been argued in the previous paper (G. FUCHS 1967, pp. 9—12, pp. 141—144) that these two sequences should be correlated. This view is strengthened by the investigations of our 1967 expedition. Our view is that there are only slight facies variations in certain stratigraphic levels, the developments being otherwise identical. We therefore introduced the terms Krol- and Shali-Facies. In the area to be described the latter is by far the most important. We will comment on facies variations within the Tansing Unit when we describe the stratigraphical units.

1. Simla Slates

In undisturbed sections this formation is always found at the base of the Lower Himalayan sequences. It therefore frequently forms the cores of anticlines, e.g. Piuthan-Riri Zone, Andhi Khola. But as in Simla (locus typicus) the slates are often found detached in form of thrust masses, e.g. SW Tansing and the Simla Slates of the Rukum Nappe.

Slates predominate in the formation. They show a dirty greenish to grey, sometimes also rather dark colour. A fine lamination is characteristic. It is caused by an alternation of light silty and dark argillaceous laminae. Graded bedding is frequent. The sedimentary s-planes are cut by the slaty cleavage. Shear folds are frequently found. There are also old lineations folded by younger axes. The s-planes often show a silky lustre, but in most areas the slates are scarcely metamorphosed, phyllitic types being rather rare.

There are also highly sulphidic black slates intercalated in the Simla Slates in some regions, e.g. SE Piuthan, SW of the junction of Andhi Khola and Kali Gandaki. They grade into normal Simla Slates; otherwise they could be mistaken easily for the much younger Infra Krols or Shali Slates. They also show the white efflorescences.

Layers of fine-to medium grained grey or greenish sandstone, greywacke or rare pale quartzite are also found in the slates. But they form a rather small proportion of the total formation, especially in W-Nepal.

The area N and NE from the Immrun Khola seems to be an exception, as quartzites are rather frequent there. We find thick-bedded, light, green, and grey quartzitic sandstones and quartzites, carbonate sandstones with layers of arenaceous dolomite with brown weathering, and intercalated somewhat calcareous slates, and normal Simla Slates. The debris of these beds is blocky and few of the intercalated slates show a green to purple colour. Cross-bedding and rare ripple marks could be observed, and they could be mistaken for atypical Nagthats. But the beds grade into normal Simla Slates by intercalation. They belong to the same formation but they seem to mark its highest stratigraphic horizon, grading upwards into the Jaunsars (Chandpurs). Indeed they are found on the tops of the hills in the named Simla Slate area and near the overlying Jaunsars. But as the boundary between Simla Slates and Jaunsars is rather disturbed we could study no good sections.

There are also a few occurrences of bluish impure limestone and dolomite intercalated in the slates, e.g. between Balkot and the Mathura Khola, N Piuthan, in the Mari Khola (WSW of Piuthan). The thickness of these beds does not exceed a few meters. From better sections in other tectonic units it seems that these beds also belong to a high stratigraphic horizon in the Simla Slates (see p. 32). These beds are true sedimentary intercalations in the slates.

The Simla Slates are a monotonous formation about 1000 *m*. thick and are not subdivisible. They show the characteristics of geosynclinal sedimentation. Nearly everywhere in the Himalayas thick geosynclinal deposits form the base of the sedimentary sequence. These deposits were restricted to the Himalayan region, as the formations of about the same age found in the northern parts of the Indian Shield (Upper Vindhyans) or in the Salt Range (Cambrian) show different facies. Thus from the distribution of the sediments it appears that a geosynclinal trough existed in the Himalayas which already in the Late Precambrian-Early Palaeozoic shows the NW—SE direction of the much younger Himalayas.

Various local names are in use for these geosynclinal formations. The Hazara-, Attock-, and Dogra Slates are identical with the Simla Slates. In the Tethys Zone the Haimantas and Martolis seem to be equivalent. Towards the E we find calcareous-argillaceous sequences (Garbyang Formation, Dhaulagiri Limestone).

It is difficult to state the precise age of the Simla Slates because of the lack of fossils. A Late Precambrian age is generally assumed. The observations of D. N. Wadia (1934, pp. 134—143) are of most importance: In Kashmir the Dogra Slates grade into beds which have yielded Cambrian, and Ordovician/Silurian fossils without a significant change in lithology. So it appears that the sedimentation was continuous from the Late Precambrian up to the Silurian. This view of Fuchs is strengthened by the recent discovery of ill-preserved fossils in the Hazara Slates. R. G. Davies and Riaz Ahmad (1963), the authors of the short note, feel "that the presence of such forms suggests that the Hazara Slate Formation may not be Precambrian but Lower Palaeozoic" (p. 30). Haimantas as well as Dhaulagiri Limestone have yielded Lower Palaeozoic fossils in their higher levels and similarly show no break against the Precambrian.

G. FUCHS therefore has suggested a Late Precambrian to Early Palaeozoic (possibly even Silurian) age for the Simla Slates (1967, p. 10, Pl. 4).

2. Chandpur

The Simla Slates are overlain by thick clastic sequences known as Jaunsars. These can be subdivided into two formations, the Chandpurs and the overlying Nagthats. In some occurrences these two formations may be atypical and inseparable, in this case it is better to use the name Jaunsars.

The Chandpurs are a sequence of grey, green or purple splintery slates, greenish sericitic phyllites with *cm.-dm.*- and *m.*-layers of light coloured quartzite and brown to greygreen sandstone. Quartzite and sandstone are often schistose; if they are thick-bedded they may show current-bedding and ripple marks. Layers rich in chlorite, former tuffites, are also known in Nepal but they are less frequent than in the area described by J. B. AUDEN (1934). Calcareous layers are exceptional.

The thickness of the formation varies between some tens of meters and ca. 500 *m*. It is not possible to draw sharp boundaries against the Simla Slates below and the overlying Nagthats; there are gradations. The Chandpurs differ from the Simla Slates in their lighter colour due to lower content in pigment, and a more arenaceous character. They also show better sorting, siltstones being rare therefore, and the typical lamination of the Simla Slates is absent. Though obviously younger, the Chandpurs generally show slight metamorphism whereas the underlying Simla Slates are macroscopically nearly unmetamorphosed. The reason for this surprising fact could be, that in the dark pigmented Simla Slates crystal growth was hindered, whereas in the Chandpurs the same P/T-conditions have led to visible alterations.

Because of the lack of fossils there is much uncertainty about the age of the Chandpurs. In many undisturbed sections we were able to observe that the Chandpurs regularly are found between the Simla Slates and the Nagthats, and so FUCHS excludes the possibility of a Precambrian age. Considering the sedimentary successions in all the zones of the Himalayas and on admittedly somewhat theoretical considerations he favours an Upper Silurian-Devonian age (G. FUCHS 1967, Pl. 4 and Pl. 4 of the present paper).

3. Nagthat

The predominantly greenish Chandpurs grade at their top into the varicoloured Nagthats in which red predominates. Orthoquartzites and sedimentary structures indicating shallow-water deposition become very frequent.

The Nagthats in Nepal consist of an alternation of orthoquartzite, sandstone, slate, and less frequent dolomite. The orthoquartzites are often thick-bedded, medium to coarse-grained. Their colour varies from white to pink, red, and green. Characteristic are sporadic granules of red jasper and black haematite in the quartz matrix. Cross-bedding, symmetrical transverse ripple marks of varying directions, sometimes branching, interference ripple marks, flat pebble conglomerates, and fillings of mud cracks in the underlying slates can be observed very frequently (compare Figs. 12 to 14). Conglomeratic layers in the orthoquartzites with pebbles of quartz and jasper up to 5 *cm*. were observed only in one locality (ESE Lawamjula). The thickness of the quartzite beds varies from some decimeters to 3 *m*.

The predominantly pinkish to brown sandstones show ferruginous weathering. They are less frequent.

The slates are red, purple, green, and grey. Thin layers show desiccation cracks and mud curls (compare Fig. 14). In the Immrun Khola area black shales, similar to the Infra Krols, are also found as primary intercalations in the otherwise normal Nagthats.

In some areas thick beds of bluish grey dolomite with chert, intraformational breccias, stromatolites, and oolites, resembling the Shali Dolomite and layers of pink magnesian limestone are intercalated. The top surface of some dolomite beds are nodular. Though the carbonate rocks are more frequent near the top of the formation, forming a gradational passage to the Blainis, they also occur in lower levels, e.g. Immrun Khola, NW Piuthan, and in the Nagthats stretching from Dhorpatan to the area N of Rukumkot.

The presence or absence of dolomite beds in the predominantly clastic series, as well as the varying quartzite-slate ratio reflect primary facies variations. Quantitative analysis of these would be necessary for further studies. Also the cyclic sedimentation reflected by the described alternation of lithologies would be worthy of detailed petrographic investigation. In the course of our general survey we were unable to spend the time necessary for such measurements.

In the Nagthat zone running from Dhorpatan via Uttar Ganga to Byale, NNE of Rukumkot, a zone of thick-bedded orthoquartzite nearly free of shale intercalations forms the lower part of the formation (200—250 *m*.). This is the only instance, where the Nagthats of the Tansing Unit could be subdivided; they resemble the Nagthats of Chail Nappe 1 (Thulo Bheri).

Variations in thickness are partly caused by tectonics, partly they are of primary origin. The thicknesses observed are some tens up to 1000 *m*. (see p. 55).

NE of Piuthan but also S of the Mari Khola (WSW Piuthan) silicified coarse breccias are found containing fragments of pink dolomite. It is doubtful whether these rocks, which are of very restricted extension, are Nagthats.

The rocks of the Nagthats show a high grade of sorting (maturity) resembling the orthoquartzite-carbonate association (Pettijohn 1957). The sedimentary structures indicate deposition under alternating shallow-water—subaerial conditions. The frequency of haematite, causing the red colours, shows that the Nagthats were deposited in a fully aereated environment with a high oxidation-reduction potential (Eh) (Krumbein and Garrels 1952). The black shale intercalations of the Immrun Khola area indicate intermittent anaerobic conditions. Though exceptional, this occurrence could be of importance for palaeogeographic reconstructions. All this and the absence of fossils suggest sedimentation in a continental basin with long continued erosion of the surrounding areas, and with slow subsidence in the basin allowing repeated reworking of the sediments. The rate of subsidence was not uniform throughout the basin, as shown by the varying thickness.

On page 10 we noted that there are areas where the Nagthats are atypical and cannot be distinguished from the Chandpurs. In such cases we used the name Jaunsars, comprising both formations (e.g. middle Andhi Khola). The slates often predominate over the sandstones or quartzites; grey to greenish tints prevail the red ones. Sedimentary structures indicative of deposition in shallowest water are less frequent than in adjacent areas with great thicknesses of the Nagthats. These somewhat atypical Nagthats, which also are commonly not so thick, coincide frequently with thick developments of the Simla Slates. Reworking of Simla Slates could have been of local influence on the character of the Nagthats. A factor responsible for the abnormal development seems to be deficient supply of sediment.

As to the age of the Nagthats their gradation into the overlying Blainis is of importance (see discussion on p. 56). If view A is accepted, the age of the Nagthats seems to comprise the middle and lower parts of the Carboniferous. It is not to decide, if there is also Upper Devonian contained in the Nagthats.

4. Blaini

As stated above there exists a gradational passage from the Nagthats to the Blainis making the boundary an arbitrary one. Carbonate rocks may appear in the Nagthats but they become more important in the Blainis.

The famous glacial boulder beds described from the NW-Himalayas (R. D. Oldham 1888, T. H. Holland 1908, J. B. Auden 1934) could not be found in Nepal, but the Blaini limestone is well-represented. We find alternating pink, green, cream, and grey cherty magnesian limestones and dolomites, red, purple, grey, and green slates, red, green, or white sandstones and quartzites. The rather fine-grained to dense carbonate rocks are often thinly laminated with shale intercalations. Cleavage planes cut the bedding at steep angles forming shear folds (Fig. 1). The intercalated slates frequently show a silky lustre on s, caused by fine sericite, they may even become phyllitic.

Though less frequent, there also occur thick beds of grey cherty dolomite containing stromatolites. Intraformational breccias, arenaceous, or oolitic layers are not uncommon in the carbonate rocks. Weathered surfaces are mostly orange-brown, resulting from their content of haematite. In the area SSW from Tansing there are coarse breccias in the Blainis. All the components seem to be derived from the formation itself. This breccia is described by G. Fuchs (1967, p. 29).

The sandstones and quartzites, which contain granules of jasper and haematite show cross-bedding, flat pebble conglomerates and on s-planes fillings of mud cracks and ripple marks. Also washouts could be observed in the Blainis. These structures and the general character of the rocks suggest a rhythmic sedimentation in very shallow water. Except for the greater importance of carbonate rocks we find the same conditions as in the underlying Nagthats.

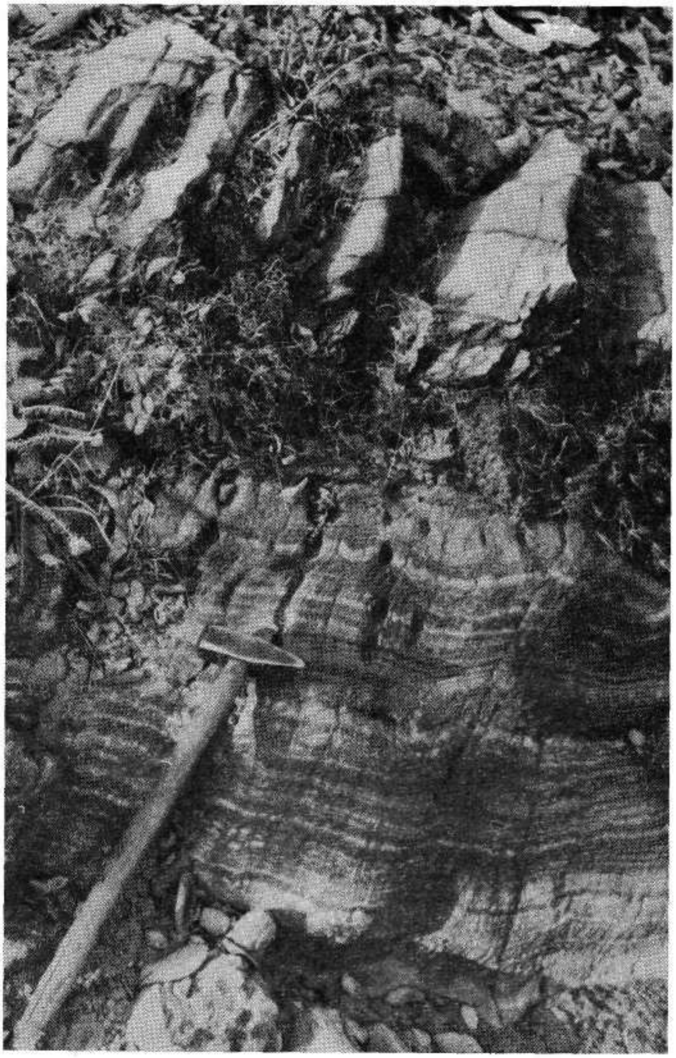

Fig. 1: Pink Blaini limestone laminated with red slate. Transversal s visible in the thinly laminated part. Swargdwar, W of Piuthan.

The haematite content may become sufficiently high for the rocks to form oolitic iron ores. A detailed description of the haematite bearing rocks of the Uttar Ganga is found in G. Fuchs (1967, pp. 48–52).

The thickness of the Blainis varies between some tens and hundreds of meters. In some areas the Blainis are completely missing. This is due to facies variations. In such cases the well-aereated facies of the Blainis is replaced by anaerobic black shale facies (Infra Krol type). There also seems to be some interfingering of facies. J. B. AUDEN (1934, p. 375) has already stressed the varied character of the Blainis as well as their intimate connection with the Infra Krols. In some areas of W-Nepal there is a passage from Nagthat into Blaini and from Blaini into the Shali Dolomite without any black shales (e.g. Surtibang Lekh, N Tansing). In many sections we find the sequence Jaunsar—Blaini—Infra Krol—Krol or Shali (e.g. Knee of the Riri Khola) and there are areas, where the Blainis are missing in the above succession (e.g. lower Bari Gad—Kali Gandaki—middle course of Andhi Khola). In the area Serpo lake (NW Rukumkot)—Thulo Bheri we find a gradation from Blaini to Shali with the black shales intercalated in the dolomites (Shali Slate type).

These observations reflect complicated facies conditions. Facies distribution and relationships are discussed on p. 55.

On the age of the Blainis FUCHS follows those geologists who have advocated the Blaini—Talchir correlation since OLDHAM (1888) for reasons given by G. FUCHS (1967). If this correlation is accepted the Blainis would have formed during the uppermost Carboniferous to Lower Permian. In addition the observation of "purple, pink, green and white crystalline limestones with purple and green shales and (?) volcanics" of Permo-Carboniferous age given by B. N. RAINA (personal communication) is of interest. This formation forms part of a fossiliferous sequence in the area between the Indus and the Zanskar Range. This would be the rare exception of Blaini facies occurring in the Tibetan Zone.

5. Infra Krol — and Shali Slates

Replacing the Blainis or following above them we find a formation of dark-coloured shales and slates. As these easily recognizable rocks form a marker horizon below the thick carbonate sequence of the Krols they are called the Infra Krols since MEDLICOTT (1864). As stated above there are areas, where these shales were never present and their place is taken by the Blainis.

The name Shali Slates is used by us for dark slates intercalated in the Shali Dolomite, as is found in the Sutlej area (locus typicus, WEST 1939).

The rocks are shales and slates, commonly thin-bedded, containing layers of siltstone and occasional arenaceous or carbonate intercalations. Black and dark grey predominates, but we find also grey and greenish-grey tints. Light efflorescences and bleaching of the highly bituminous slates are frequently observable in weathered outcrops.

The thickness of the slates may attain 200 *m*., but shows great variation, which is in part original and in part due to tectonic causes. Situated at the base of the thick dolomite complex or intercalated in the latter, the soft slates are highly contorted.

Towards the W where the Surtibang Syncline plunges under higher nappes the geology is very complicated. Thus the interfingering of the dark slates with Blaini or Shali is not directly observable. But there is no doubt that originally there was a 500—700 *m*. sequence of dark slates and dolomites interfingering particularly with the Blainis but also with the Shali Dolomite.

There are mainly thin-bedded black slates, bleaching when weathered which grade frequently into black thin-bedded dolomite with micro-breccias, Cleavage is common. Between the *dm*-layers of dark dolomite we always find a few centimeters of slate intercalated, except in rocks very rich in dolomite where middle-grey dense splintery dolomites may be interbedded too.

Under the microscope the dark dolomites are laminated and show bituminous stains and clouds which caused their macroscopically fine-clastic appearance. Diffuse cloudy silicification is also common. In the dark dolomites stromatolites were never found. The lithology of these thinly laminated dolomites is identical with that of the Krol A stage E of Solon, Simla area.

The sequence is best exposed along the Barikot Khola S of the junction with the Shib Khola. In the valley of Laikham and along the trail leading from the Barikot Khola to the S (near Aurali) the dark slates alternate with light layers of limestone and green slates of Blaini type. Interfingering was not found with the thick varicoloured Blainis of the Thulo Bheri Valley and E from it.

The rather extensive outcrops of Infra Krols in the Thulo Bheri valley near Halchaur NE of Dali were identified as Infra Krol after field work; thus it is possible that the black slate mass also comprises Simla Slates particularly in the south-western part.

6. Riri Slates

A slightly different facies occurs in the area of the Mahabharat Range between Riri Bazar and Lawamjula, and in the Andhi Khola region. As these rocks are typically developed in the Riri Khola at 83° 21′ E Greenw. and 27° 58′ 30″ northern latitude and their stratigraphic position could be established there, we suggest the name Riri Slates for this formation (Fig. 2).

The rocks are: light to dark grey, finely laminated shales and slates, partly graded, frequently being slightly calcareous. Characteristic is their yellowish colour when weathered. There are also green to purple partly silky slates containing arenaceous and calcareous layers. At a first glance the diverse lithologies resemble Simla Slates or Chandpurs. But there exist vertical and lateral gradations into Blainis as well as into Infra Krol Slates. There are good outcrops along the Riri Khola, showing primary alternations of the black shales (Infra Krol) and the slates described above. Though the zone is strongly tectonized the stratigraphic position of the Riri Slates is shown by the sections.

In the Riri Khola area we find the succession Nagthat—Blaini—Riri Slates—Infra Krol—Krol (Fig. 2). The grey laminated shales are subordinate in the Riri Slates of that region. But the latter rocks predominate in the area 12 *km*. ESE of Lawamjula, where the primary sequence is Riri Slates—thin Blaini—Krol. 9 *km*. NW of Piuthan the Nagthats are followed by Riri Slates (150—200 *m*.) and then by the Blainis (Pl. I). In the Andhi

Khola 25 *km.* NE of Tansing we find over the Jaunsars ca. 50 *m.* of dark grey bedded cherty dolomite, then grey and coaly black shales with intercalations of quartzite rather contorted (ca. 150 *m.*), then grey dolomite (15 *m.*), black shales (10 *m.*), Shali Dolomite (Fig. 3 on Pl. 9). No Blainis occur in that section. These Riri Slates were not separable from the Infra Krols on the map. The continuation of that zone towards WNW in the Kali Gandaki valley seems to be similar.

We suppose that the Riri Slates are a facies intermediate between the Infra Krol and the Blainis. The soft, grey, laminated shales grade into the black shales, the green and purple slates reflect the influence from the Blainis. So the facies of the Riri Slates is intermediate between areas of shallow water deposition in an aerobic environment (Blaini) and deeper basins with anaerobic still water sedimentation.

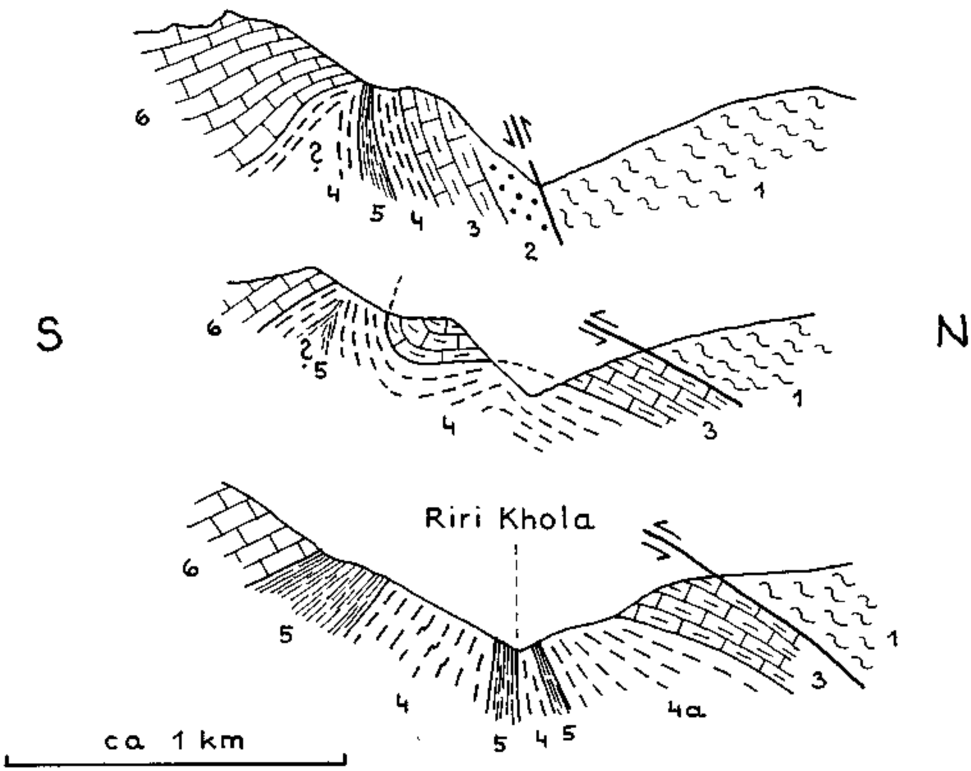

Fig. 2: Sections, 14, 10, respectively 8 *km.* W of Riri Bazar, showing the partly inverted northern limb of the Tansing Syncline.

1. Simla Slates
2. Nagthat
3. Blaini
4. Riri Slates

4a. Riri Slates similar to Chandpur

5. Infra Krol Shales
6. Krol, Shali

The age of the Riri Slates and the Infra Krols is established from their gradation into the Blainis as well as from their position at the base of the Krol carbonate rocks. Accepting the correlations of Blainis and Talchir, and of Krol and Productus Limestone, FUCHS suggests an uppermost Carboniferous but more probably Lower Permian age.

7. Krol and Shali

There are thick carbonate formations found in a certain stratigraphic position of the analogous sections in the outer parts and inner zones of the Lower Himalayas. The carbonate formations show some facies differences, and we therefore introduced the terms Krol for the outer and Shali Facies for the inner (northern) developments (G. FUCHS, 1967). When we visited the NW-Himalayas we found, that the Krols, fully developed in the Krol belt (J. B. AUDEN, 1934), show facies changes, when followed along the strike to other parts of the Himalayas (G. FUCHS 1967, pp. 11 and 141). In Nepal we were able to find the Krols only in the limbs of the syncline of Tansing; but even here in the northern limb the Krol Facies is partly replaced by the Shali Facies (e.g. NE of Tansing, and in the higher parts of the dolomites 7 *km.* SW of Riri Bazar). Thus the greater part of the carbonate rocks in question is developed in Shali Facies in western Nepal.

The Krols commence with 300 to 500 *m.* of dark, grey to blue, very fine-grained limestone. The rock is thin-bedded and shows fine lamination. This is caused by alternation of the dark limestone with thin light grey dolomitic laminae. Towards the top the limestone becomes more and more dolomitic and grades into ca. 500 *m.* of dolomite.

The dolomite is thin- and thick-bedded, and locally becomes massive. The colour varies from blue, brownish, grey to light grey. Nodules and laminae of chert are frequent.

Generally structures indicating shallow-water deposition are missing in the Krols. But stromatolites and shrinkage cracks in dolomite filled by limestone of the overlying bed, were observed in the northern limb of the Tansing Syncline, probably indicating a gradation into the Shali Facies.

At the top of the formation immediately below the Tal rocks arenaceous beds were found in the area W of the Sardena Khola, 7 *km.* SW of Riri Bazar. There are light quartzite beds, showing ripple marks, dolomites, and subordinate breccias and conglomerates alternating. The components of the latter are dolomite of various grey tints, shale, and quartzite embedded in a coarse arenaceous matrix. Lenses of arenaceous dolomite and dolomite breccia are found in the quartzite too. This is certainly a sedimentary sequence, and reflects regressive tendencies towards the end of the Krol deposition. The thickness of the succession is about 50 *m.*

13 *km.* WSW of Piuthan a band of dark dolomitic limestone (Krol) reduced to a few meters thickness, has a breccia bed at its top. The components (up to 8 *cm.* diameter) are quartzite and chert in a quartzitic matrix. This bed, a few meters thick, is overlain by the Tal Formation.

The finding of these rocks is of importance for Himalayan stratigraphy. The question, whether the Shali Quartzite of the Sutlej area still belongs to the Shali sequence, forming the highest part of it, or whether this quartzite corresponds to the Jurassic-Cretaceous Tal Series, which overlies an unconformity was left open in our publication 1967 (p. 145). Now it is evident, that the Shali Quartzite and similar beds at the top of Shalis or Krols belong to these formations and reflect a regression which had terminated the carbonate sedimentation.

The great majority of the carbonate rocks under discussion are developed in Shali Facies. The rocks are generally thick-bedded or massive, and less frequently thin-bedded dolomitic limestones and dolomites. Their colours are blue, dark to light grey, and cream. Arenaceous layers, intraformational breccias, and stromatolites are very frequent. The abundance of such structures is evidence for deposition in very shallow water. So the distribution of Krol and Shali Facies reflects shallowing of the water towards the N.

The stromatolites are of various types. The following forms, according to the nomenclature of LOGAN, REZAK and GINSBURG (1964) have been observed: SH-V, LLH-S, LLH-C, the first being most abundant (Fig. 4). Algal mats covered by intraformational breccias and colonies growing on the top of breccia layers were observed (Fig. 5; FUCHS 1967, Pl. 11, Fig. 5; FRANK and FUCHS 1970, Fig. 4).

The original thickness of the Shali Dolomite probably lies between 1000 and 1500 *m*.

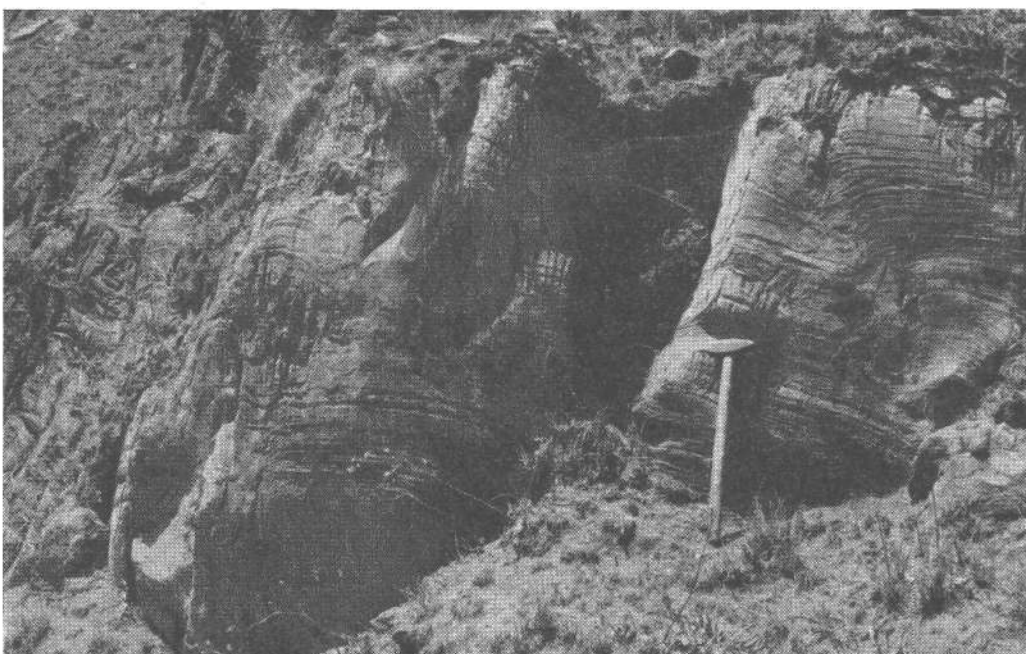

Fig. 4: Shali Dolomite with big stromatolite colonies (LLH-S). Surtibang Syncline NE Rukumkot.

At the base of the Krols and Shalis gradations are frequent, passing from the black or grey shales or from the reddish Blainis into the carbonate formations. It has been stated already that black slates (Shali Slates) are found intercalated in the dolomite. Especially in the area Thulo Bheri—Barikot Khola black shales and dolomites replace part of the Blaini and part of the Shali Dolomite (see p. 15).

At the top of the dolomites the boundary against the overlying Tal Formation is a sharp one, marking an unconformity. On the mountains 5 *km.* W of Masjem the top of the Krol Dolomite is marked by an erosion surface. Pockets in the dolomite are filled with conglomeratic shales of the overlying Tal Formation. There are also indications of an angular unconformity at the base of the Tals (Fig. 6), which is the first marked break in the sequence of the Lower Himalayas in Nepal.

Our investigations left no doubt about the equivalence of Krol and Shali. The age of these formations is less certain (see p. 56).

Fig. 5: Intraformational breccia in cherty Shali Dolomite. Sani Bheri W of Rukumkot.

8. Tal Formation

The oldest fossils found in the Tansing Unit are derived from the Tal Formation. The first fossils were discovered by MEDLICOTT (1864, p. 69) in Garhwal. This formation has also yielded fossils from various localities in Nepal (C. K. SHARMA, 1965 unpublished report, G. FUCHS 1967 and findings by our expedition 1967). But the formation is far from being rich in fossils.

The best outcrops of the Tals are in the Mahabharat Range, where these beds form the core of the large syncline. This situation is similar to the occurrences in Garhwal and in the Krol belt. But there are also Tal beds in more northern zones. Frequently they are found along thrust-lines there (Thulo Bheri, Rukumkot, Bari Gad).

The lower part of the Tal Formation is predominantly shaley exhibiting soft geomorphologic forms; in the higher part there are thick quartzite intercalations, forming coarse blocks in the detritus, which can be recognized from afar. The total thickness of the formation may reach 1000 *m.* in the Mahabharat Range.

The rocks forming the lower part are dirty green, grey, purple, and black soft shales, silty and sandy partly micaceous shales, cherty shales, shaley greywackes, and sandstones alternating. Shales as well as sandstones may be conglomeratic. The matrix is dominant and the well-rounded pebbles and cobbles are sparsely distributed throughout the rock without showing any sorting. The cobbles consist of white and green quartzite, red Nagthat quartzite, vein quartz, red calcareous shale, granite, chert, grey and blue limestone. The sizes of the components generally vary from centimeter to 30 *dm.*, but in some areas, e.g. E of Saki, there are boulders of Tal quartzite or breccia of 1 m^3. Tectonics could have formed such boulders by dislocation of quartzite horizons but the fact that we find all sizes from centimeters to meters, the smaller cobbles all well-rounded, supports a sedimentary origin. The cobbles sometimes show a polished surface due to tectonic movement, but this has not caused their roundness.

Conglomeratic zones are not confined to a specific horizon, but the basal 30 *m.* of the shales are frequently conglomeratic. Very characteristic for the Tals are the greywackes, greenishgrey rocks, frequently shaley, which contain angular pieces of feldspar and rock fragments mainly of the same formation. Generally these components are a few millimeters in diameter. Pieces as large as 5 *cm.* are exceptional and were observed only E of Tansing.

The fine to coarse-grained sandstones are frequently feldspathic and micaceous. The green to brown rocks grade upwards into shales. Remains or casts of plants are not infrequent.

In the upper part of the formation thick-bedded to massive quartzites with intercalated shales and sandstones are characteristic. The quartzites are white, grey, or green to blackish. Generally they show no internal bedding, ripple marks and cross- bedding being exceptional. In consequence they break into large irregular blocks. On the surface they often show millimeter to centimeter-holes caused by the weathering of patches of coaly matter. The quartzites show a characteristic greasy lustre. Frequently they are feldspathic to arkosic. By comparison with the Nagthat quartzites they are less well-sorted and the interlocking of the grains is less well developed.

There are also layers of breccia. The components are quartz, quartzite, jasper, haematite, chert, dolomite, feldspar, and shale chips of local origin, with diameters of a few centimeters, exceptionally up to 5 *cm.* These materials are derived from the underlying formations and probably also from the Precambrian of the Indian Shield. The recurrence of haematite in the

Nagthats, Blainis, Tals, and Dagshai-Murrees seems to reflect erosion of the North Indian iron deposits and resedimentation in the basin at the northern margins of the Indian Shield.

On the top or basal s-planes of the quartzites or sandstones bioglyphs are found. Sand waves have also been observed on s-planes of sandstone.

The quartzites alternate with shales and shaley sandstones similar to those already described from the lower part of the formation. Variation in the quartzite content shows a 20 to 30 *m*. rhythm.

The shales have yielded small high-spired gastropods and lamellibranchs in the area of Masjem. There are also rare lenses of bluish-grey partly recrystallized limestone, ca. 1 *m*. thick, intercalated in the shales of the higher Tal Formation. These limestones are lumachelles composed of lamellibranch shells. Prof. Dr. R. Sieber (Geol. Surv. Vienna) has kindly examined the fossils found by our expedition. The determinations are given below:

Lumachelles (found N of Masjem) consisting of molds of gastropods (*Promathildia*, and others) and pelecypods (*Modiola*, *Pleuromya*, *Homomya* and others). Though an exact determination is not possible, the first named fossils hint to a Jurassic age, the latter to a Jurassic-Cretaceous age.

Near Daban molds of probable *Trigoniidae* were found.

Undeterminable plant fossils are frequently found in all the Tal Formation.

Dr. K. Kollmann (RAG Vienna) kindly has examined a sample of limestone containing ostracodes: Their grade of preservation only allowed the determination as *Cypridae* or *Cytheridae*. The habitus of these forms points to a post-Palaeozoic, probably post-Triassic Mesozoic age. The great uniformity of the poor fauna indicates abnormal salinity (hypo-or hypersalinity).

Secondary alteration is visible in the Upper Tal Formation. The quartzites show frequent epigenetic iron and manganese mineralization (e.g. W of Masjem). These occurrences appear to be of no economic value. The ore solutions probably are derived from the Tal Formation. Silicification of the shales, intercalated to the quartzites, was described by G. Fuchs (1967, p. 30).

A very important question, which is not easy to answer, concerns the environment of the Tal Formation. Taking into account all the information about the Tals we may state: As in the NW-Himalayas (Auden 1934, p. 403) there are also areas in Nepal, where the Tals seem never to have been deposited (Surtibang Syncline, Chail Nappes). They have filled basins, elongate along the NW-SE strike of the later Himalayas, with an angular unconformity at their base (7 *km*. SW of Riri Bazar, Fig. 6; N Rukumkot). Generally they rest upon the Krols but in the Rukum Nappe they overlie the Simla Slates, in an apparently original and undisturbed sequence (Barikot Khola). The facies of the Lower Tals suggests, that after a period of extensive erosion a rather rapid subsidence occurred. Submerged under deep water sediments were deposited, which resemble to the Greywacke Suite (Pettijohn 1957) but without pronounced rhythms. The depositional environment was moderately aerated as demonstrated by the dark green and grey colours of the rocks. It is well-known that in formations deposited under such conditions fossils are frequently rare or completely missing, thus the fact, that fossils have not been recorded from the Lower Tals does not necessarily mean deposition in freshwater.

There is no basal conglomerate, though the basal shales are conglomeratic; the scattered cobbles of these tilloids (PETTIJOHN 1957) must have got into the shales by processes such as slumping or subaqueous mudstreams. Probably gliding has brought them from an adjacent litoral environment into the deeper parts of the basin.

To explain the large boulders of quartzite and breccia embedded in mudstone, which are derived from the Tal Formation we may assume that the basin was filled from the margins by more arenaceous material. Subaqueous mudflows could have carried already consolidated rocks from the margins in form of boulders into deeper parts of the basin.

Similarly we suppose that some of the structureless quartzites of the Upper Tal Formation formed from sandflows.

The increasing frequency of quartzite towards the top of the Tal Formation reflects regression. Surprisingly all fossil occurrences, and there are very few, are known from the regressive higher part of the cycle, from the Upper Tals. From the character of the fauna and the frequency of plant remains it appears that the prevailing conditions were not normal marine but brackish. The sea could have had access to the Lower Himalayan Basin in the Jurassic-Cretaceous, but the contrast with the sedimentary sequence of same age in the Tibetan Zone shows, that the basin always remained rather isolated. The end of the Tal cycle is marked by the thick quartzites at the top.

With the Tertiaries the Tals form the highest part of the sequence of the Tansing Unit. In consequence these rocks immediately underlie the outliers of higher nappes. Thus they are often highly disturbed, and we can describe only few informative sections.

Fig. 6 is a section across the Tansing Syncline and is the best for showing the distribution of the various rock types of the Tals. In the S we found clear evidence of an erosion surface at the base of the Tals. In the northernmost part of the Tals they dip constantly towards the N and join the Krols which dip gently towards the S. As we could not find any indication of a fault this situation is evidence for an angular unconformity.

The Masjem section, E of the above section, seems to be more disturbed, especially the higher parts towards the Dagshais. Therefore, the precise horizon of the fossil localities is unknown, but they definitely belong to the Upper Tals.

A detailed section at the northern bank of the Sani Bheri river NW of Rukumkot, shows the basal beds of the Tals. Also in this outcrop an angular unconformity is apparent from the strike of the rocks. The Shali Dolomite dips steeply towards SSW, whereas the overlying Tals show a dip towards SE at a moderate angle. This occurrence lies in a highly disturbed zone (see Pl. 1) and the Tals are tectonically reduced. This complicated zone continues into the Bari Gad, where windowlike outcrops of Tal beds were initially mistaken for Nagthats (compare G. FUCHS 1967, pp. 37—41, Pl. 2 and 3 to Pl. 1 and 2 of present paper).

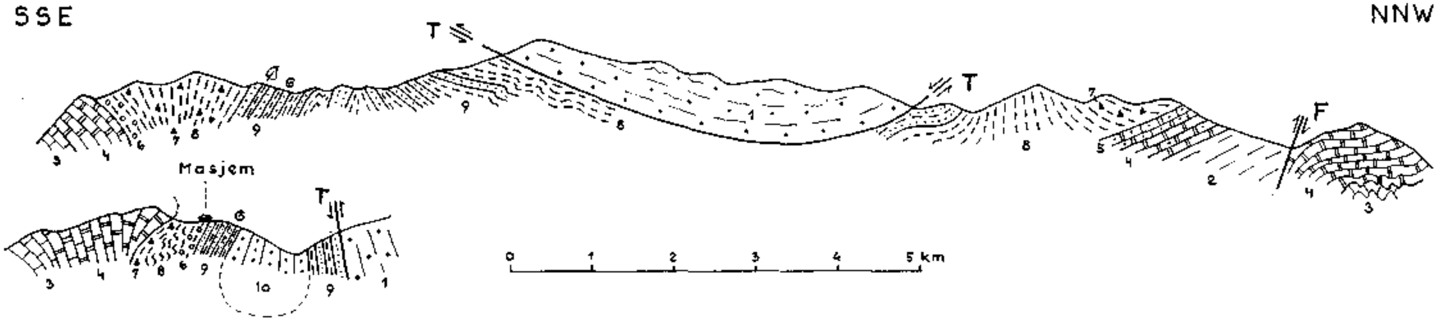

Fig. 6: Sections across the Masjem area.

1. Nagthat-Blaini
2. Riri Slates
3. Krol Limestone
4. Krol to Shali Dolomite } Krol
5. Shali Quartzite
6. Conglomeratic slates and sandstones
7. Greywacke shales } Tal Formation
8. Shales
9. Thick-bedded quartzite and intercalated shales
10. Quartzitic sandstone and subordinate shales — Dagshai

σ = Animal fossils
leaf = Plant fossils
T = Thrust
F = Fault

In one locality (on the trail from Swargdwar to Sallyana ca. 5 *km.* NW of Daban) we found an outcrop of an acid extrusive rock in the shales of the Tal Formation. The contact with the shales was not exposed. The extent of the effusive rock seems to be rather small. The rock is light grey and fine-grained, fracture planes being unregular and not smooth. Single quartz grains are discernible with the unaided eye. Very conspicuous are dark irregular pipes, 1—2 *cm.* thick, which penetrate the rock in an irregular way.

Under the microscope fractured phenocrysts of quartz form 25% of the rock volume; corrosion is observed but is not common. The phenocrysts are embedded in a vitreous matrix which is intensely stained with iron hydroxide. The dark pipes show sharp rims and are entirely vitreous but free of iron ore and phenocrysts.

Apparently this vitrophyry rock was formed by local volcanic activity in the Tal Formation. It could represent a near-surface dike or a volcanic vent. The dark pipes could be best explained as gas channels, which were subsequently filled by vitreous matrix.

9. Subathu (Up. Paleocene—Eocene)

Despite a careful search along our route we could not find Eocene rocks in the Tansing Unit. The most likely locality for such a discovery appears to be the Masjem area. In the zone where the Tals border the Dagshais we found no nummulitic rocks. Their absence may be primary or caused by tectonics.

10. Dagshai (Lower Miocene)

There is only one occurrence of Dagshais known to us in the Tansing Unit within the area mapped. N of Masjem we find the Dagshais ca. 1000 *m.* thick, but as they form the core of an isoclinal syncline the original thickness will be about half that value (Fig. 6).

The rocks are thick-bedded, partly massive, dirty-green to grey sandstone alternating with purple to brown silty shales. The hard sandstone is dominant, so the Dagshais form scarps. Some of the sandstones are quartzitic or arkosic.

The formation is lacking in fossils, probably being deposited in freshwater. The lithologic similarity to the Dagshais and Murrees of the NW-Himalayas is clear. On palaeobotanic and other evidence these formations are regarded as Lower to Middle Miocene (Lexique Stratigraphique 1956).

II. The Stratigraphy of the Rukum Nappe

In Simla the Shalis are overthrust by a nappe, consisting predominantly of Simla Slates, which is overthrust in turn by the Chail Nappe. In a similar tectonic position a scale of Simla Slates was found in Nepal (ca. 11 *km.* ENE of Rukumkot G. Fuchs 1967, p. 53). This occurrence was interpreted as a local complication. But our recent survey has proved the tectonic independence of this unit. It forms a nappe, which was thrust over the Tansing Unit for 40 *km.* and is overthrust by the Chail Nappe. In its stratigraphic characteristics too the Rukum Nappe shows individual features.

Whereas Simla Slates are not prominent in the adjacent parts of the Tansing Unit and Chail Nappe 1, a good portion of the Rukum Nappe consists of these slates. They show a normal development as described under I. 1., dark slates being rather abundant. Carbonate intercalations are known from the Barikot Khola NE Surakot.

The Simla Slates, several hundred meters thick, sometimes show slight metamorphism especially in the marginal parts. This has led to phyllitic s-planes.

The normal sequence exposed in the section of the mountain W Rukumkot shows the sequence of beds overlying the Simla Slates (Fig. 7).

The Chandpurs, finely laminated, green sericitic schists alternating with *cm.* to *dm.* layers of quartzite, are only ca. 40 *m.* thick.

The succeeding thick-bedded white to pink quartzites, containing granules of red jasper, contain intercalations of grey slate. These slates increase towards the top. The total thickness of this sequence, which corresponds to Nagthat, is only ca. 40 *m.* The adjacent parts of the Tansing Unit and of Chail Nappe 1 show typical and thick developments of the Nagthat. Thus Chandpurs as well as Nagthats seem rather poorly developed in the Rukum Nappe.

The Blainis commence with thin-bedded grey and white limestones and dolomites. The fine-grained, crystalline rocks show greenish sericitic s-planes. Lenticular, white calc schists with sericitic s-planes are very characteristic. They resemble those observed in the Blainis of the Chail Nappes. Alternating red and green slates and pink dolomites follow. The total thickness of the Blainis is estimated as 150 *m.*

The Blainis grade into thick-bedded dark to intermediate grey cherty dolomite. In the passage zone dark limestone alternates with dolomite. The thickness of the Shali stage is about 200 to 300 *m.* S of Rukumkot this dolomite succession exhibits stromatolites.

The Tal Formation follows with purple and green slates, silty slates, sandstones, breccias, the components of which are chert, and green, dark, grey, or white quartzites. The thickness probably does not exceed 150 *m.* in that section.

All the stages are well-represented in that section but the Jaunsar-Shali sequence seems reduced, especially the Jaunsars are somewhat atypical and thin. The Tals are well-developed throughout the Rukum Nappe whereas that formation is missing in the original adjacent sequences of the Tansing Unit (Surtibang Syncline) and Chail Nappe 1.

Going to the W the geology becomes increasingly complicated. The undisturbed succession as observed at Rukumkot becomes folded, thrust and partly inverted. Furthermore there are lateral changes of facies. There was not enough time to elucidate the geology of that region, it was only along the Thulo Bheri that the principal features were clarified to some extent (Pl. 1, 3 [2]). Apparently the complications were caused by compression along the steeply dipping northern limb of the Jaljala Syncline at Jajarkot. This has led to repetition of the succession in the form of 3 scales. The following remarks give some idea of the stratigraphy.

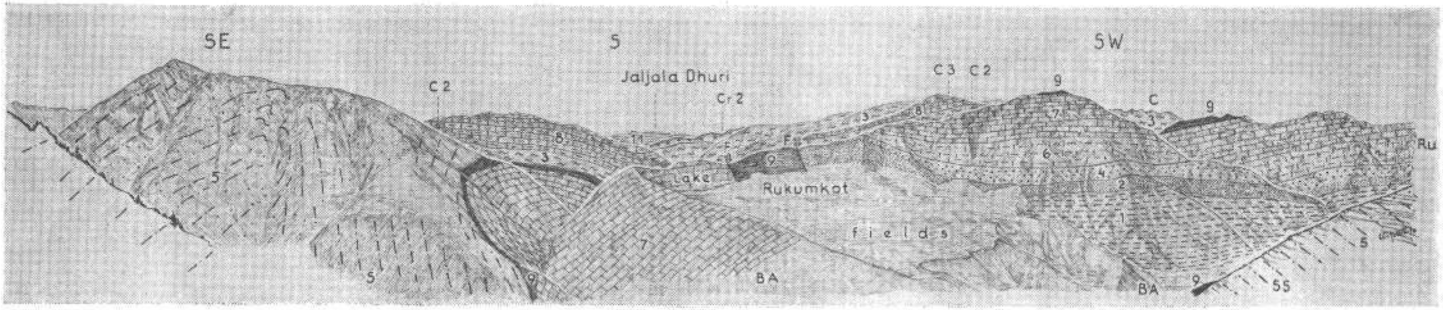

Fig. 7: The Rukumkot area seen from the N.

1. Simla Slates
2. Chandpur
3. Chail
4. Nagthat
5. Nagthat-Blaini
6. Blaini
7. Shali
8. Jangla Group (Blaini, Shali)
9. Tal
10. Crystalline rocks
11. Dhaulagiri Limestone

F = Faults
BA = Bari Gad Anticline
SS = Surtibang Syncline
Ru = Rukum Nappe
C 2,3 = Chail Nappe 2,3
Cr 2 = Upper Crystalline Nappe

The lowest wedge commences with a thin-bedded complex of Shali Limestone which is the direct continuation of that of Rukumkot. It is thrust on to the Tal Formation which forms its normal cover at Rukumkot. N of the bend of the Thulo Bheri, W of the confluence of the Sani Bheri with the Thulo Bheri, a 150 *m.* succession is intercalated between the underlying Tal quartzites and the overlying Shali, which may be Nagthat or Tal. Light-coloured, dense orthoquartzites alternating with laminated dark shales are very characteristic but also varicoloured slates and light limestones are found. The thicknesses of the quartzite layers change rapidly leading to lenticular forms. They are intensely folded with the shales. The succession described was observed nowhere else.

The following Shali Limestone is uninverted as shown by the stromatolites observed along the trail from the Thulo-Bheri towards N over a ridge to Paligaon. In the lower part the Shali Limestone contains an intercalation of dark, yellow weathering shales which pinch out towards W. Their maximum thickness of 120 *m.* may be tectonic in origin. The highest part of the Shali—the total thickness of the Shali is ca. 500 *m.*—consists of grey splintery dolomite.

The next wedge is better exposed along the Thulo Bheri river than on the trail over the heights. It commences with dark grey, partly green, and black, rarely arenaceous slates. White, yellow and grey layers of limestone, 10 to 50 *cm.* thick, are commonly intercalated. S of the pass over which the trail leads to Paligaon, light and dark, pure orthoquartzites follow, apparently concordantly. Probably this sequence represents a reduced succession of Riri Slate and Tal . At the bottom of the valley we find more abundant layers of dolomite, apparently intercalated in the Riri Slates. The dolomite is yellow to grey, thin-bedded, calcareous and contains chert. Also layers of light quartzite and dolomitic sandstone occur, the s-planes frequently being green.

The third wedge starts with thick (up to 350 *m.*) Riri Slates on the W-side of the Thulo Bheri valley. There are dark grey slates rhythmically laminated by *mm.* to *cm.*-laminae of sandstone; layers of dolomitic marl are also found. The rocks are locally cleaved. At Paligaon these Riri Slates grade into the overlying Shali Limestone, which forms precipices; further to the N in a tributary of the Gursu Khola the Riri Slates are succeeded by ca. 150 *m.* of light yellow quartzites with ripple marks, alternating with thin-bedded yellow to grey dolomites. The overlying Shalis form steep mountain faces too, but they consist of dark grey calc shales with some arenaceous layers. There seems to be a rather rapid change of facies. On the W-side of the Thulo Bheri valley typical Chandpurs underlie the wedge described but with a movement plane between. They comprise grey green, laminated schists, abundant fine-grained greenish quartzites and some layers of brown calc schist. The Chandpurs grade into the underlying Simla Slates. The high content of dark pigment of the latter disappears, the slates become more phyllitic and in the Chandpurs slightly calcareous phyllites are not so rare. The Simla Slates continue to Rukumkot where they form the base of the Rukum Nappe (see p. 25; Fig 7).

A peculiarity of the Simla Slates and Chandpurs of the Rukum Nappe are the metadiabases. They form lenticular bodies some tens of meters long and a few meters thick. Discordant boundaries, sometimes found, and silicification of the neighbouring rocks, which leads to bleaching, are evidence of their intrusive nature. Besides some loose blocks in the detritus, e.g. E side of the Thulo Bheri ca. 4 *km.* S of Dali, outcrops of metadiabase in the Chandpurs were found on the E-side of the Thulo Bheri valley at the junction with a tributary ca. 1.5 *km.* S of Dali. In the Simla Slates they are known from the N-side of the Barikot valley opposite of the village Khari, and in the Ranga Gad ca. 3 *km.* E of its flowing into the Barikot Khola.

The rocks are amphibole diabases with ophitic texture. The grain size may reach 5 *mm.* They show strong autometasomatic alterations. Weak metamorphism has led to local development of chlorite, albite, epidote-minerals, and actinolite. The metadiabases are absolutely identical with the best preserved eruptive rocks of the Chail Formation. As diabases occur in none of the younger formations these occurrences are additional evidence for the correlation of Chail and Chandpur.

The most interesting section is that of the Barikot Khola (Fig. 8). A thick succession of Simla Slates is immediately overlain by the Tal Formation and shows no signs of tectonic disturbance. From the mechanical properties of the rocks it appears rather unlikely, that the whole of the Jaunsar-Shali sequence could be squeezed out leaving the Simla Slates underlie the Tals without any evidence of such movements. We therefore explain this situation as further evidence for the unconformity at the base of the Tals (compare p. 22); this would, however, be the most pronounced one. The atypical character of the Jaunsars and the original thinning of the Jaunsar-Shali succession observed in the Rukum section, support the idea of an unconformity.

Thus the succession of the Rukum Nappe shows some unique features. First there is the great thickness of Simla Slates, a formation that is not exposed in the adjacent tectonic units. The Jaunsar-Shali succession deposited on the Simla Slate area is of insignificant thickness or partly missing. The beds also show a different character; they are more argillaceous, possibly because of sedimentary reworking of some of the higher parts of the Simla Slate. In the formerly adjacent areas, the Jaunsar-Shali sequence is exceptionally thick (several thousand meters). The sedimentary structures indicate deposition in very shallow water, which means that although the subsidence was considerable a rich supply of sediment kept pace. As structures indicating shallow-water deposition are very scarce, the succession of the Rukum Nappe seems to have been deposited in somewhat deeper water. The question arises, as to why this non-subsiding area with deeper water wasn't filled with sediment from the neighbouring areas. Something must have prevented the supply of sediment, e.g. islands could have formed barriers. The existence of such barriers may be indicated by the occurrences of Tal Formation immediately overlying Simla Slates. Uncertainty arises, however, as there is also the possibility that pre-Tal movements have caused the erosion of the Jaunsar-Shali succession. Taking into account the existence of a corresponding tectonic unit in Simla we must assume that the Rukum Nappe was a palaeogeographic unit of regional importance. For the Jaunsar-Shali period it formed a stable epirogenic

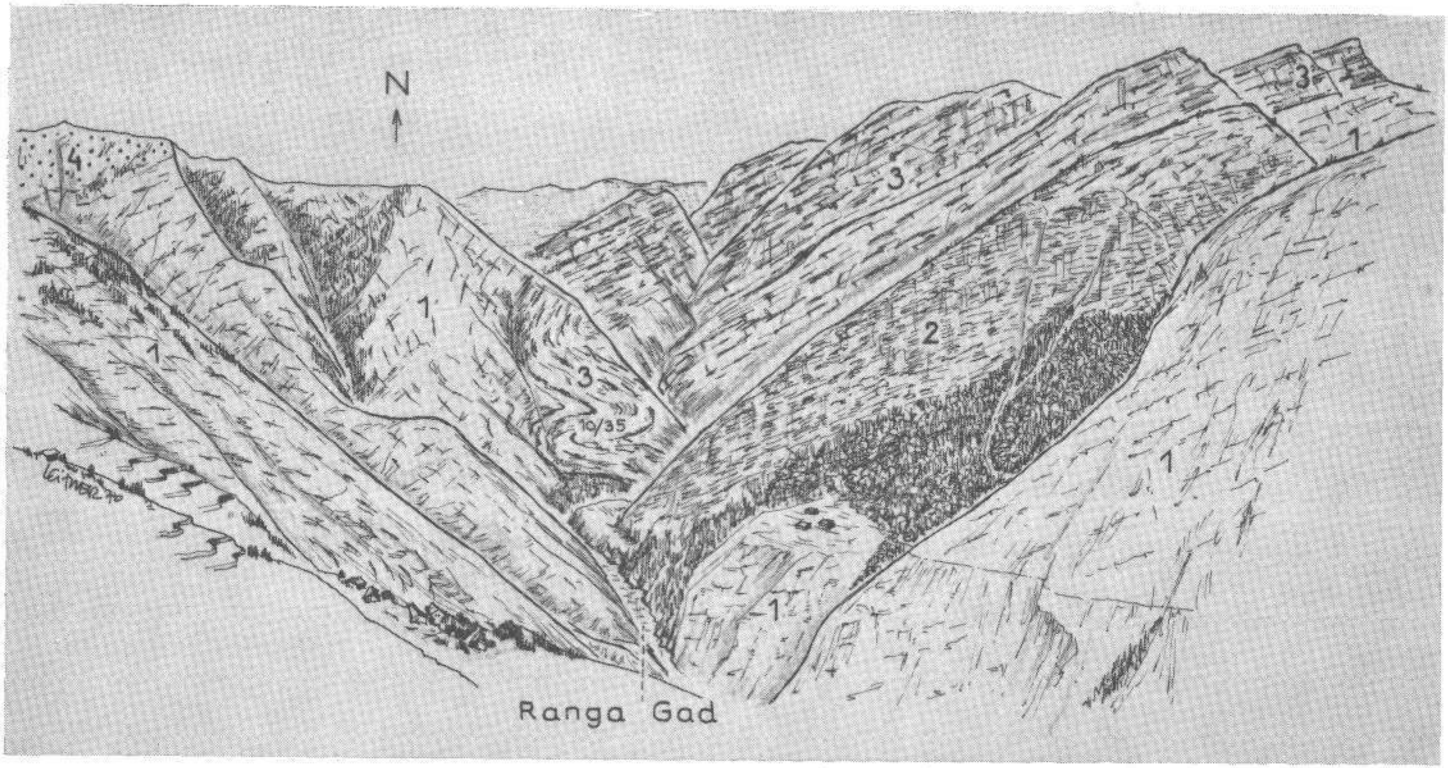

Fig. 8: View of Ranga Gad: The Rukum Nappe consists of Simla Slates (1) directly overlain by the Tal Formation (4). In the Simla Slates 2 marks a zone rich in limestone. Shali Dolomite (3) of Chail Nappe 1 shows local secondary folding with the rocks of the underlying Rukum Nappe (along axes plunging with 35° towards NNE).

zone separating rapidly sinking basins, namely the Chail basin in the N and the area of the Surtibang Syncline (Tansing Unit) in the S.

Subsidence of the Rukum zone has led to the deposition of a thick Tal sequence. As Tal rocks are unknown from the neighbouring parts of the Tansing Unit and from the Chail Nappe, which were areas of maximum accumulation during the preceding times, shifting of the zones of subsidence is indicated. This could have been brought about by Early Alpine tectonics. The Rukum zone is a weak zone because the more rigid Chail-Shali succession, which elsewhere overlies the mobile Simla Slate complex, is of insignificant thickness here.

The Tals consist of shales, sandstones and quartzites as described from the Tansing Unit. However, dark grey to black delicately laminated sandy shales with some quartzitic intercalations were found in the Barikot area. Such rocks were not observed in more southern zones. Wavy s-planes seem to be post-depositional, as they exhibit wavy folding of several laminae and are not confined to a specific layer, as would be expected in the case of a syn-depositional origin.

The Barikot area is of special interest as a good development of Tertiary rocks overlies the Tal beds in that region. Fig. 9 shows the undisturbed Tal-Tertiary sequence.

In absence of fossils it is not quite certain, whether the light, and blackish, thick-bedded quartzites and alternating dark, dirty shales are still Tal or the bottom part of the Eocene Subathus. Judging from their lithology these rocks seem to form the top portion of the Tals. Efflorescenses are found on weathered surfaces of the bituminous rocks.

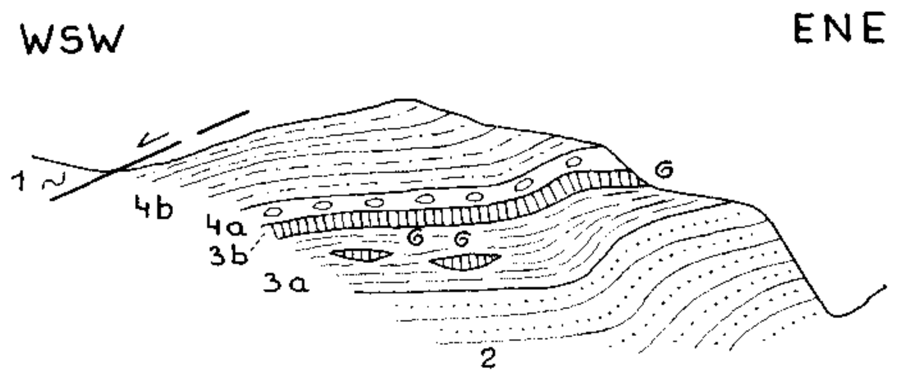

Fig. 9: The Tertiary beds of the Barikot valley.

1. Chail
2. Tal quartzite
3. Subathu:
   a) dark shales containing lenses of nummulitic limestone
   b) nummulitic limestone
4. Dagshai:
   a) basal conglomeratic sandstone
   b) sandstone and shales

Length of section ca. 300 *m*.

Dark grey shales of 25 *m*. thickness follow, in the upper 10 *m*. they contain the first lenses up to 30 *cm*. thick of marly nummulitic limestone with indeterminable gastropods and lamellibranchs. Thus the higher parts of the shales are certain Subathus, most probably the shales overlying the black quartzites also belong to that formation, showing same lithology. Then follows a 0.30 *m*. layer of lumachelle limestone. The bluish rock contains nummulites and indeterminable shell fragments. This limestone is somewhat breccious exhibiting millimeter to centimeter pieces of black shale and siliceous rock. These fragments are apparently derived from the underlying Tal rocks.

The top of the Subathus is formed by 4 *m*. of well-bedded, bluish nummulitic limestone without shell fragments. The limestones are somewhat marly. On the weathered surfaces the nummulites are well exposed.

Prof. Dr. A. PAPP (Palaeontological Institute of the Vienna University) has kindly examined the thin sections made from our samples (Fig. 5 in FRANK and FUCHS 1970). There are small radiate nummulites with distinct central pillar. Most frequent are perpendicular sections of *Assilina*. In their megalospheric generation they reach sizes of 5—7 *mm*., and in the microspheric generation 15 *mm*. They are forms of the group *Assilina placentula* DESHAYES.

The observable trend of evolution of the assilinas is the same all over Eurasia. Thus the assilinas are most important for the biostratigraphic evaluation of rock sections. *A. placentula* has a stratigraphic range from the Ilerdien to the lower Cuisien. Considering also the nummulites, the fauna of the samples indicates an uppermost Paleocene to Lower Eocene age.

The Dagshai Formation commences with a massive layer of green quartzitic sandstone. This basal bed which commonly is conglomeratic follows the Subathus after a break in sedimentation. A rhythmic alternation of thick-bedded green to grey quartzitic sandstone, and red or green, partly mottled shales follows. The sequence is 40 to 50 *m*. thick, terminated by a thrust plane at the top.

As in the case of the Tals, the deposition of the Tertiary beds was apparently confined to the Rukum Nappe in that area. Tertiary rocks are unknown from the rock sequences, which have been deposited adjacent to the Rukum Nappe. The subsidence of the former Rukum swell, which had begun with the deposition of the Tals, continued in the Tertiary. It was discontinuous as there are gaps between Subathu and Dagshai and probably between Tal and Subathu.

Finally it should be noted that this is the only occurrence of Tertiary rocks in the Lower Himalayas 95 *km*. N of the Tertiary foot hills in the S. Tertiary beds are not frequent in the Lower Himalayas and they are generally confined to the southernmost parts. The Tertiary rocks of the Shali window (Simla), for instance, have a maximum distance from the Tertiary Zone of only 42 *km*. The importance of the occurrence in Nepal is stressed in our discussion of tectonics.

III. The Stratigraphy of the Chail Nappes

In our publication (G. Fuchs 1967) it was pointed out that the Chail Nappe (Pilgrim and West 1928) is a structural unit which is not confined to Simla, but is represented nearly throughout the Himalayas. Whereas this nappe is composed exclusively of the Chail Formation in most parts of the Himalayas, we discovered a sedimentary sequence resembling that of the Krol belt or the Shali Zone overlying the Chail Series in the Jangla Bhanjyang section (W-Nepal) (G. Fuchs 1967).

We therefore concentrated the investigations of the 1967 expedition on that area. The Chail Nappe of the Hiunchuli-Thulo-Bheri region exhibits an excellent development of the sedimentary succession characteristic for the Lower Himalayas. We found the least disturbed sections there, and this is extremely important for Lower Himalayan stratigraphy.

1. Simla Slates

There is a zone consisting of thick Simla Slates underlying the Chails N of the Uttar Ganga. This could be an original succession. However, we suppose that these Simla Slates represent the roots of the Rukum Nappe. But assuming that the Rukum Nappe formed from an anticline, a view supported by tectonic considerations, the Simla Slates could stratigraphically underlie both, the Chandpurs in the S and the Chails in the N. In the course of our traverse along the Sisne Khola it was found impossible to draw sharp lines between the Chandpurs of the Tansing Unit and the Simla Slates, and between the latter and the Chails of the Chail Nappe. Gradational contacts are rather probable. Though the problems of that complicated zone are not entirely solved the Simla Slates could well stratigraphically underlie the Chails.

No doubt exists, however, about the situation N of the village Ukta (ca. 30 *km.* WNW of Tibrikot). Below ca. 1000 *m.* of Chail rocks, a sequence of Simla Slates, 700 to 800 *m.* thick, was found. The rocks show a fine lamination composed of grey to greenish layers of shale and siltstone, the former being dark the latter being lighter. Though these delicately bedded rocks are slightly affected by metamorphism (especially in the marginal parts phyllitic s-planes could be observed), they show the lithological character of the Simla Slates very typically. In the higher part of the slate-phyllite succession, about 220 *m.* below the top, there is a 20 *m.* thick zone of alternating limestone and slate. The finely crystalline grey, white, yellow, or green limestones, which show brownish weathering, form layers and lenses of decimeter to meter thickness. They are highly contorted and folded with the intercalated slates, and contain some thin slate laminae. There seems to be a primary interbedding of limestone and slate, disturbed by severe tectonics, which have affected the whole slate complex.

At the top of the Simla Slates again a gradation leads to the Chails.

This apparently sedimentary contact between the Simla Slates and the Chails is of great importance. The fact that the Simla Slates underlie the Chails which are generally overlain by a typical development of Nagthat are evidence for the Chail-Chandpur correlation (G. Fuchs 1967). There has been much dispute about the relations of Chail, Chandpur and Simla Slates (see Pascoe 1950, pp. 434, 440, and 454) the matter seems now to be settled by this new information.

2. Chail Formation

It was pointed out by G. Fuchs (1967) that the Chail Series, [the name was introduced by Pilgrim and West (1928)], is represented in nearly all parts of the Himalayas. It shows characteristic rock assemblages, slightly altered by metamorphism, and is found in a distinct tectonic position. Commonly the formation is several thousands of meters thick and builds up vast areas in the Lower Himalayas.

In consequence descriptions of the formation are found in most papers dealing with the geology of the Lower Himalayas. But many local names have been introduced and different correlations made by various authors (see Pl. 4 and G. Fuchs 1967). Opinions of the age of the Chails are similarly diverse ranging from Precambrian to Jurassic. In the Hiunchuli area (West Nepal), where the Chails form part of a stratigraphic succession, conditions were very favourable for establishing the stratigraphic position of the Chails. There can be no doubt about the equivalence of Chails and Chandpurs. The geological age will be discussed on page 56.

The rock types are found to be very persistent throughout the Himalayas, but their relative proportions show lateral variations due to changes in facies.

A mixed schistose quartzitic facies is most common: grey, green, dark, or silvery sericitic schists and phyllites, often exhibiting crumpled s-planes, alternate with quartzitic schists, psammitic schists, schistose greywackes, grey, green, white, or yellow quartzites and conglomeratic schists. The psammitic schists show round granules of bluish quartz of several millimeters in diameter in a sericitic schistose matrix. Increase in grain size leads to the conglomeratic schists.

Coarse conglomerates with components up to 15 *cm.* diameter which consist mainly of quartz and quartzite are rather abundant in the area Mayang-Ranmagaon (G. Fuchs 1967, p. 54). The matrix is rich in feldspar. S and SE of Lawamjula the Chail schists contain sporadic cobbles (up to 20 *cm.*) of fine-grained grey dolomite and pebbles of medium-grained biotite-plagioclase gneiss, which have been derived from a crystalline complex.

The quartzites are partly arkosic quartzites. They show sedimentary structures such as ripple marks, cross-bedding, and clay galls, but these are less frequent than in the Nagthats.

There are areas, where the arenaceous and coarser clastic rocks are subordinate or missing, nearly all the Chail Formation then being phyllitic. Some phyllites are rather dark and grade into pyritiferous graphite schists.

In a few instances grey carbonate rocks, showing brown weathering colours, form layers up to some decimeters thickness in the basal beds of the otherwise entirely clastic formation. They possibly correspond to the Chail Limestone described from the base of the Chails in Simla (Pilgrim and West 1928).

In the facies described, basic rocks are rather rare. However, they become very important in the facies to be described next.

In some areas, e.g. W of Tibrikot, around Jumla, etc. part or all of the Chail Formation is composed of very pure quartzite and metadiabase. Phyllitic rocks are very scarce. The pure quartzites, less commonly arkosic quartzites, show white, yellow, green colours. They are thin- or thick-bedded and exhibit some sericite on the s-planes. Sometimes lenticular white or dark quartz components show that there were also conglomeratic layers in the quartzite. Cross-bedding, ripple marks etc. are not infrequent.

In the quartzitic facies minor or major masses of metadiabase are always found. They are fine- to coarse-grained rocks either massive or schistose and chloritic. In the massive types the primary ophitic structure is still recognizable though the rocks have undergone strong alteration (see G. Fuchs 1967, pp. 55, 90). Apparently the rocks have formed under subvolcanic to volcanic conditions, as indicated by tuff horizons in the phyllites (7 *km*. WSW of Dunaihi). Commonly the metadiabases form concordant bodies from a meter to several hundred meters in thickness. But dikes cutting the bedding of the quartzites have also been observed (e.g. in the Thulo Bheri gorge NE Palang).

There are chlorite schists representing thin layers of the amphibolite, which have become tectonized. But there are chlorite rich phyllites and quartzites which are apparently metamorphosed tuffites.

The frequency of these subvolcanic or volcanic rocks in the quartzites probably finds its explanation in the high porosity of the original sand accumulations. On their way to the surface the basic melts lost their content of fluids and gases and crystallized. Furthermore the arenaceous sediments might have facilitated eruption, the argillaceous beds providing less suitable ways for the melts.

Generally the Chail rocks are developed in one of the two facies described. However, we recognized a different facies in the Thulo Bheri valley, N of the Hiunchuli. In the cores of several anticlines, underlying the Nagthats, rocks are found, which are at first glance reminiscent of Simla Slates. Admittedly their strange appearance is enhanced by the fact that the metamorphism dies out almost entirely in the Thulo Bheri region (see B. IV. 1.), but certainly they differ from normal Chails in their original lithology. The rocks are finely laminated (millimeter to several centimeters). Dark grey to green slate layers alternate with siltstone and light quartzitic layers. Graded bedding is very common (Fig. 10). There are erosional channels, disturbed bedding and also cross-laminated layers. Intraformational breccias are frequent consisting of angular pieces of slate, siltstone etc., all rocks are of intraformational origin, up to decimeter sizes, which are embedded in mud- or siltstone. These features indicate a flysch like environment, turbidity currents and slumping seem to have been important factors. This facies was formed in deeper parts of the Chail basin.

Towards SW psammitic schists and quartzites, typical lithologies for the Chails, are found interstratified in the flysch-like rocks. This and their position in the section are evidence, that the-flysch facies is really a facies of the Chails, though an exceptional one.

There is also clear evidence that the mixed schistose-quartzitic facies and the complexes consisting of pure quartzite and greenstone are different lithologies of same age. This can be clearly seen in the Thulo Bheri valley between Tibrikot and Palang, where the thick quartzite succession of the W interfingers with the predominantly argillaceous rocks of the E. This explains the common but surprising observation, that evidently the same zone of Chails consists of phyllites with a few quartzite intercalations in one section while in another section only a few kilometers away, it is composed nearly entirely of pure quartzite and greenstone.

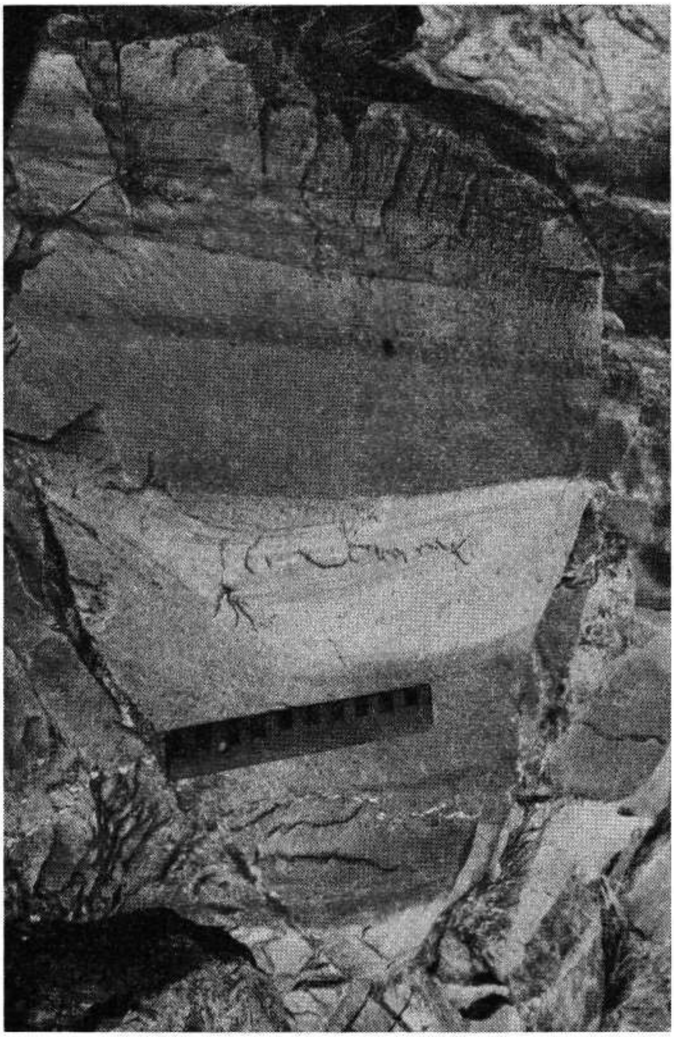

Fig. 10: Peculiar Chails typical for the Thulo Bheri valley N of Hiunchuli. The banded rock consists of quartzite (light) to siltstone (grey). Graded bedding and load deformations (lower and middle part), flaser bedding in layer in upper part of the outcrop.

As for the depositional environment of the Chails we conclude, that the dominant assemblage of phyllites and quartzites represents a deltaic facies; the phyllites, psammitic schists, quartzites, and coarse conglomerates are probably a deltaic to fluviatile facies. In more central and probably deeper parts of the basin, conditions prevailed which were controlled by slumping and turbidity currents. The very restricted distribution of this facies shows that such conditions were exceptional.

In the previous paper (G. FUCHS 1967) we stressed the molasse-like character of the Chails and have put forward the view that they were deposited in a continental basin at the southern foot of a Caledonian mountain range.

This hypothesis is also supported by the fact that the highest Chail Nappe, which was derived from the northern-most part of the Chail basin, closest to the Crystalline Ridge, shows no cover of younger sediments comparable to the successions of Chail Nappe 1 or 2. However Gondwana rocks were found in immediate contact with Chail rocks, S of Lawamjula. The tectonic position of the latter seems to correspond with Chail Nappe 3. This indicates terrestrial conditions in the N of the Chail basin in the succeeding Upper Palaeozoic times. Also the distribution of the finer-grained Chandpurs in the S, the coarser Chails in the N points to a landmass in the N.

Closely related to problems of metamorphism and palaeogeography is the question of the age of the Chails. A Jurassic-Cretaceous age (P. BORDET et al., 1964) is ruled out by the stratigraphic position of the formation between Simla Slates and Nagthat. Furthermore in the course of our expedition 1967 W. FRANK has discovered Gondwana beds lying on the Chails S of Lawamjula.

Many authors favour a Precambrian or at least Early Palaeozoic age mainly because of the metamorphism of the formation. Physical age determinations done by D. KRUMMENACHER (1966), one of the coworkers of BORDET, seem to support this view. However, there is only one measurement on an uralite and few determinations of detrital micas.

Based on palaeogeographical considerations and the stratigraphic position of the Chails G. FUCHS (1967) has suggested an Upper Silurian-Devonian age. The Chails would be the molasse deposited after the formation of a Caledonian orogen. The basic volcanic to subvolcanic rocks would represent outbursts of final basic magmatism in the sense of H. STILLE. Recently our view has been supported by a personal communication by B. N. RAINA (Geol. Surv. India); Mr. RAINA informed us that hystrichospheres of Lower Palaeozoic age have been found in carbonaceous rocks of the Ladhiya Formation (VALDIYA, 1963) in the Ladhiya valley, Almora. FUCHS regards this formation equivalent with Chail.

On the other hand we found that the metamorphism of the Chails is post-Shali (see p. 42). If the Krol-Shali-Productus Limestone correlation is accepted (FUCHS), it implies an Alpine age for the metamorphism, but this correlation is still in dispute. However, the rocks of the Chail Nappes gradually become more metamorphic towards their roots. This indicates that the metamorphism of the Chails is related to Alpine structures, though the metamorphism shows some independence and is not precisely restricted to the Chail- and Crystalline Nappes. It may alter the northernmost parts of the Tansing Nappe (e.g. Dhorpatan) or the successions in eastern parts of the Rukum Nappe, whereas the metamorphism of Chail Nappe I dies out towards the W (see pp. 41—42). We think that this could be explained by Alpine metamorphism, which altered the rock sequences already in an early stage of the thrust movements and which was concentrated to the root zone, where the thrust masses were squeezed out. There the metamorphism seems to have outlasted the main tectonic movements.

No final decision can be given, however, considering all the information available at present FUCHS would still favour the view that the Chails are an Upper Silurian to Devonian molasse.

3. Nagthat

In the Chail Nappes 1 and 2 the Chail Formation is overlain by a thick development of Nagthats (Fig. 11). Generally the thickness is variable but about 1000 *m.* occasionally reaching 2000 *m.*

In contrast to most other parts of the Lower Himalayas the Nagthats of the Hiunchuli area could be subdivided.

The lowest member consists of a varicoloured predominantly red alternation of quartzite, sandstone, slate, and subordinate pink dolomite. This sequence resembles the normal type of Nagthat met in the Tansing Unit. The thickness does not exceed 200 *m.*

In the main central part of the Nagthat thick-bedded quartzite predominates, slates are missing. The light coloured quartzites are white, greenish and less commonly red and contain granules of haematite and jasper. The thickness always attains several hundred meters.

The top member is formed again by an alternating sequence similar to that at the base of the formation. The thickness varies between 50 and 200 *m.*

Ripple marks and cross-bedding are abundant throughout the formation. In the lower and upper parts mud cracks and clay gall-breccias are also very frequent (Fig. 12, 13, 14).

These structures indicate very shallow water or even partly subaereal deposition. This is evidence that the rapid subsidence, which can be postulated from the great thickness, was compensated by rich supply of sediment.

Most probably the red quartzites S of Nuwakot are Nagthats of the Chail Nappe. It is a thick-bedded quartzite sequence of ca. 900 *m.*, without significant slate intercalations. Ripple marks and cross-bedding are frequent.

4. Blaini

It is not possible to find a sharp boundary between the Nagthats and the Blainis in the Jangla Bhanjyang section (G. FUCHS 1967, p. 57); the carbonate content increases towards the top of Nagthat, which grades into the Blaini. However, in the Thulo Bheri valley a zone of 100 to 250 *m.* of grey slate separates the two formations (Fig. 11). As discussed below we regard these slates as part of the Blaini rather than as part of the Nagthat.

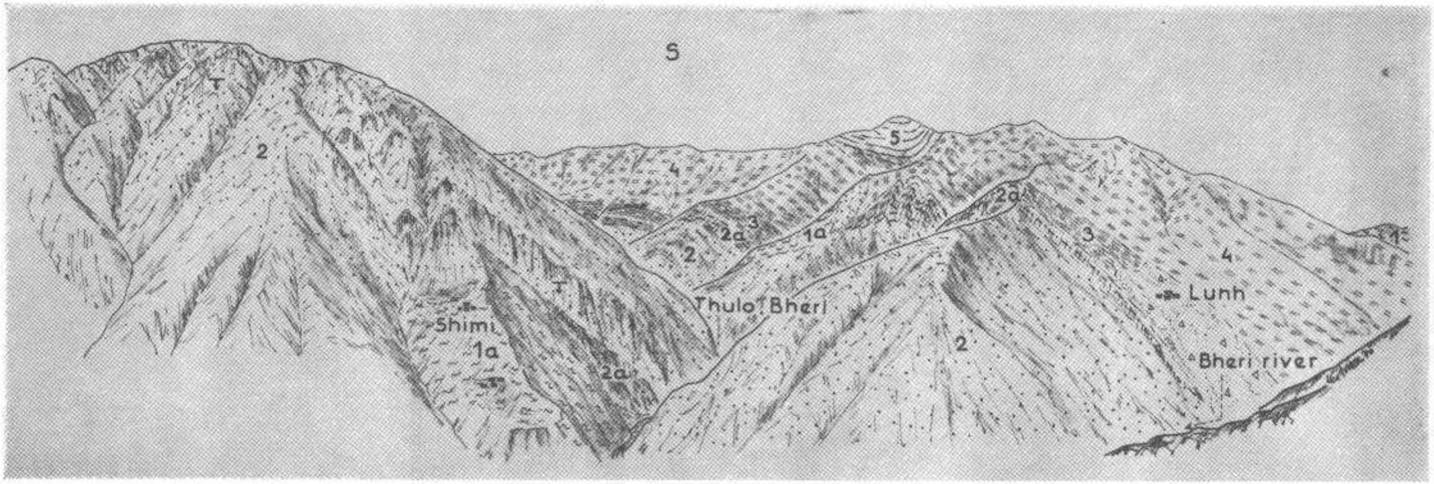

Fig. 11: View from SW of Palang down the Thulo Bheri valley, showing anticlines of Nagthat (Chail Nappe 1).

1. Chail

1a. Low grade metamorphic Chail schists

2. Nagthat, green to white quartzite

2a. Nagthat, red quartzite and slates

3. Riri Slates, grey to violet slates

4. Blaini, thin-bedded purple dolomite alternating with purple-green slates and quartzites

5. Shali Dolomite

The grey and violet slates, less frequently silky phyllites, are thin-bedded, fissile but not laminated. Occasional pinkish layers are slightly calcareous.

These grey slates seem to reflect a significant change in environment. There are no more arenaceous beds; the red colour of the Nagthat disappears; no sedimentary structures indicating shallow-water deposition are found. The slates therefore represent a somewhat deeper facies, probably marking the central parts of the basin. The shallower or marginal parts of the latter show an increase in carbonate, which makes the Blainis distinguishable from the Nagthats. Thus we think that the grey slates mark the beginning of a new cycle, which leads up to the Shali. Our opinion that the grey slates belong to Blaini is strengthened by the fact that the similar Riri Slates were found in association with the Blainis in other regions (e.g. Riri Khola, Thulo Bheri NE Jajarkot).

Fig. 12: Block of greenish white Nagthat quartzite showing oscillation ripple marks. The mountains of the northern Hiunchuli range (background) are composed of the Nagthat—Shali sequence. View across the Thulo Bheri valley towards E.

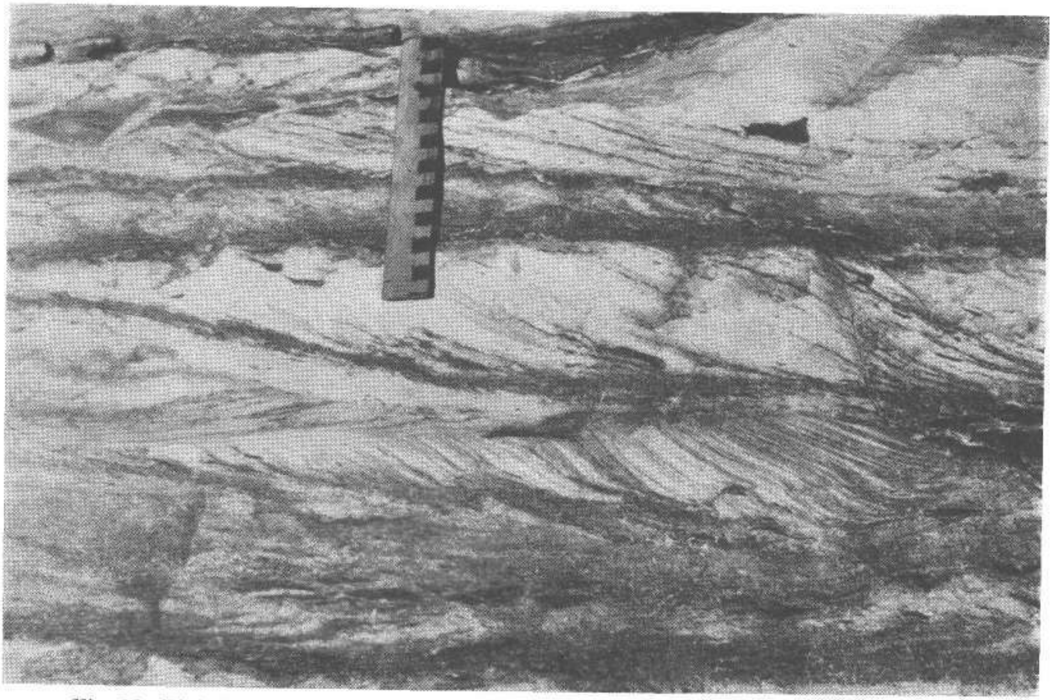

Fig. 13: Pink Nagthat quartzite of Chail Nappe 1 showing cross-bedding of various directions. Angular irregularly shaped red slate fragments (dark) are embedded in the quartzite. Blocks N of Gotam, Thulo Bheri valley.

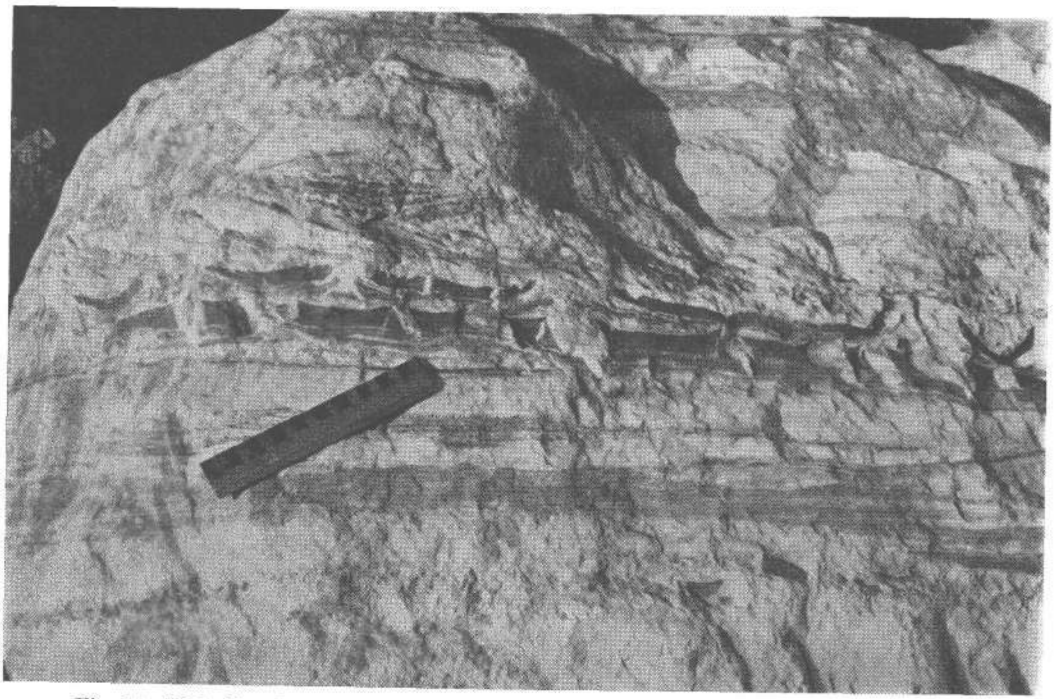

Fig. 14: Pink Nagthat quartzite with slate laminae and cross-bedding. The central slate layer is broken up by desiccation. The formation of mud curls is still recognizable (at left and right). Such layers yielded the material for the clay gall breccias (lower part). N of Gotam, Thulo Bheri valley.

On top of the grey slates and where they are missing immediately over Nagthat, we find the normal development of the Blainis 600 to 1000 *m* thick. Pink, white, green quartzites alternate with sandstone, purple and green slate and phyllite, pink, yellow, white, grey, or greenish commonly siliceous dolomite, and green to white lenticularly structered calc schists. A rough estimate of the relative proportions of these rocks at Gotam (Thulo Bheri valley) gave:

sandstone and quartzite	40%
slate and phyllite	40%
dolomite	20%.

In other areas, however, the carbonate content of the succession may be much higher. The rocks described are thick-bedded (e.g. sandstones) to finely laminated (dolomite-slate). Ripple-marks, mud cracks, washouts, intraformational breccias are common throughout the formation.

S of Barikot (or 29 *km.* N of Jajarkot) there are iron deposits in the lower part of the Blainis or uppermost Nagthat. We find chloritic haematite schists, itabirites and haematite-quartzites. These rocks apparently also contain some magnetite. They are interstratified with the rocks of the Blainis already described. This occurrence resembles the sedimentary iron ores in the Blainis of the Uttar Ganga, which, however, belong to the Tansing Unit. The iron ores of the Chail Nappes are more strongly metamorphosed.

The metamorphism shows much variation. Within the formation, at a given place, the sandstones and quartzites are less altered than the finely laminated alternations of dolomite and slate or fine-bedded calc schists. This is the reason for the common observation, that the Nagthats seem to be less metamorphosed than the Blainis.

But the degree of alteration of the rocks also varies laterally from place to place. For instance, the rather strong metamorphism of the upper part of the Jangla section (G. Fuchs 1967, pp. 57—62) becomes weak towards the W and almost dies out in the Thulo Bheri valley, (see Fig. 10 in Frank and Fuchs 1970). Generally the Chail Nappes are more metamorphosed towards their roots and the higher units (2 and 3) are more altered than the lower unit (1). Sandstone becomes quartzite, the slates are altered to phyllites, carbonate rocks become finely crystalline and the characteristic greenish-white sericitic calc schists form. Sometimes also the colours change from red to green, carbonate layers becoming white or yellow.

Metamorphic alteration is especially clear in those rocks which have been thrust far to the S (e.g. N Sallyana, SE Rukumkot). The younger formations (Nagthat, Blaini, Shali) are highly contorted near the boundaries of the Chail Nappes and are so tectonically disturbed, that they are not separable from each other. In such cases we have to use a common name. We suggest the term Jangla Group after the area of the Jangla Bhanjyang (82° 55′ E Greenw., 28° 50′ N), where the succession younger than Chail was first described (Fuchs 1967). Though this group comprises Nagthat, Blaini, Shali Slate, and Shali, the disturbed occurrences described above show predominately Blainis; Shalis are less common and Nagthat very rare.

5. Shali

The pink or varicoloured Blainis grade at their top into grey dolomite which is generally thick-bedded. In the area SW and W Tarakot this Lower Shali Dolomite has a thickness of 200 to 400 *m*. It is succeeded by 200 to 300 *m*. of black slate (Shali Slate), above which again dolomites and limestones follow with grey phyllitic intercalations in the lower part. The upper carbonate division is frequently altered to micaceous calc marble or calc schist in this area. The thickness of the Upper Shali Limestone is about 800 *m*.

As mentioned above the metamorphism of Chail Nappe 1 dies out towards the W. The dolomite-limestone complex of the Bhalu Lekh, which is at least 1500 to 2000 *m*. thick is not metamorphosed. Unaltered rocks can also be found in the dolomite mountains N of Jumla. Such unaffected dolomites and limestones show their original grey to bluish-grey colour, cherty laminae and nodules, and beautifully preserved algal structures and intraformational breccias (Frank and Fuchs 1970, Fig. 4). Though unmetamorphosed and resembling the normal Shalis of the Tansing Unit in their lithology, they are distinguished from the latter by their stronger deformation. s-parallel shearing combined with small scale folding is not infrequent.

In the first stage of metamorphism this may lead to the tectonic formation of laminae and to banded dolomite-limestone rocks. Dolomite layers are contorted to lenses surrounded by limestone which has undergone plastic deformation. The rocks become finely crystalline, partly change their colour by loss of pigment, sericite grows on the s-planes.

In successive stages crystalline carbonate rocks are formed: schistose limestones, dolomites or calc phyllites, calc-mica schists, banded marbles and massive, micaceous, medium-grained marbles. Besides sericite chlorite, muscovite and phlogopite also form. These strongly altered rocks were observed in the zones extending from the Jangla Pass to Tibrikot and to the Hiunchuli respectively.

6. Shali Slates

We have already mentioned the black slates intercalated in the Shalis of the Jangla section. There and in the area S of Dunaihi they have just the same stratigraphic position as the dark slates in the Shalis of the Surtibang Syncline, and the Shali Slates of the Simla-Sutlej area (compare W. D. West 1939, G. Fuchs 1967, pp. 113, 115, 119). This and the observations at the contacts with the carbonate rocks prove that the dark slates are a sedimentary intercalation.

The rocks are black or dark grey fissile slates, phyllites, with quartzitic and carbonate layers, generally thin-bedded. Light efflorescences are frequently observed on weathered surfaces of the bituminous and pyritiferous rocks.

Ecologically the Shali Slates indicate an anaerobic facies, which apparently prevailed at a certain stage in the Shali succession. This facies, however, is not represented everywhere.

7. Lower Gondwana Beds

On the trail from Lawamjula to Bijauri around the village Phalabang an argillaceous-arenaceous series, only slightly metamorphosed, was found overlying the Chails (Fig. 15). The palaeobotanical examination of the samples has shown that these beds resting on the Chails were Lower Gondwanas. As observations were made only along the trail it is difficult to give the precise areal extent of the sequence. From the morphology of the landscape it appears that the beds continue E of Phalabang but are eroded W of the village. The northern boundary against the Chails is concordant, the southern boundary abuts against thick Chail quartzites along a steep plane of tectonization. As the sequence was thought to be a slightly less metamorphosed and lithologically somewhat atypical part of the Chail Formation during field work, it is difficult now afterwards to give precise boundaries against the Chails. The rocks are predominantly slightly phyllitic slates of light greygreen colour, weathering yellow. They contain fine detrital micas and quartz, coarse clastic layers of some millimeters thickness are rather rare. Sporadically conglomeratic layers may occur, the components being quartzite and rare phyllite pebbles (!). Particularly in the N bleaching black slate layers up to 20 *m*. thick are characteristic. Macroscopically they appear to be unmetamorphosed.

The lithological distinction from the Chails is not very marked: Pure quartzites and coarse psammitic schists are missing in the Gondwanas; the alteration is more slight (recrystallization only of fine sericite and quartz).

The fossiliferous samples are from the black slates. Prof. Dr. W. Klaus (Vienna University) and Miss. I. Draxler (Geolog. B. A. Vienna) have kindly examined the material and found: reticulate and pitted tracheids (araucaroidal type), and a relatively well-preserved spore of the genus *Vittatina*. These fossils are the remains of land living plants and most probably belong to the Permo-Carboniferous Gondwana flora.

The palaeontologically proved occurrence of Gondwanas is of great importance. It shows that the underlying Chails must be older than Permo-Carboniferous. P. Bordet, for instance, has thought that his „série de Kunchha“ which is identical with Chail, was Jurassic-Cretaceous (1961, et al. 1964). Furthermore this seems to be another example that the Krols and Shalis may pass laterally into lithologically different Gondwanas (compare p. 57). The occurrence of Gondwanas lying on Chails without Shalis between proves the views of Fuchs concerning the palaeogeography. The underlying Chails are derived from the northernmost parts of the Lower Himalayan Basin. At the northern margins of that basin near the hypothetical Ridge (Himalayan Ridge) Gondwanas may be deposited again (see p. 36).

The somewhat lower metamorphic grade of the Gondwanas compared with the Chails still remains a problem. From the few samples taken, laboratory studies cannot establish whether there is a hiatus in metamorphism or not. We should emphasize the fact, however, that the Chails of the area in question are also less metamorphosed than elsewhere.

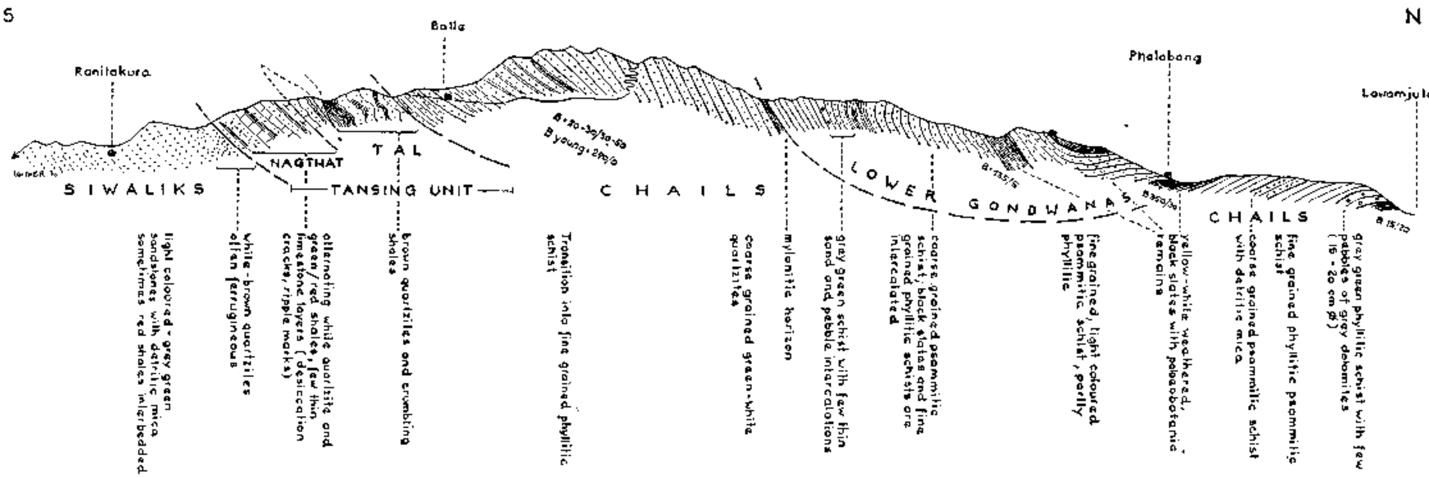

Fig. 15: Section from Lawamjula to the S, observed along the trail to Bijauri. Length of section 9 *km*.

IV. The Crystalline Nappes

No detailed descriptions of the thin sections are given, but the observations made on ca. 75 thin sections are included in the following descriptions and discussions.

From the rock assemblages, the grade of metamorphism, and tectonic considerations there are only two units distinguishable in the Crystalline of the area mapped. We use the terms Lower and Upper Crystalline Nappes. The name Kathmandu Nappes (T. Hagen and J. P. Hunger 1952) also found in G. Fuchs (1967) are abandoned as the Kathmandu Crystalline seems to be not quite identical with that of our area. Furthermore we do not accept the division of the Crystalline into a series of sub-units (T. Hagen 1959 a).

1. The Lower Crystalline Nappe

The unit is only a few hundred meters thick; we were, however, able to recognize it all along the root zone. An equivalent rock assemblage seems to be represented at the base of most of the Himalayan crystalline regions. Along the root zone we find a rather uniform assemblage: very fine-grained brown-grey biotite-muscovite-plagioclase gneisses are prominent and may contain phyllitic lenticles of *cm*-sizes more or less densely distributed. Very characteristic are also dark, graphite-pigmented garnet phyllites which accompany the described gneisses. The garnet reaches sizes of 5 *mm*. Furthermore there are calc-mica schists with phyllitic lenses containing both micas, coarse-grained thin-bedded mica quartzites with biotite up to 2—3 *mm*. on the s-planes. Fine-grained epidote amphibolite forms small bodies; however, these are not very frequent. They resemble the more strongly altered types of the Chail metadiabases.

The metamorphism of the Lower Crystalline Nappe corresponds to the albite-epidote-almandine subfacies of the greenschist facies. Thus it is markedly higher than that of the Chails, but much lower than that of the Upper Crystalline Nappe, which flanks with highly migmatitic gneisses the rocks described. Slight diaphthoresis is not infrequent in these rocks. It is more apparent in outcrop than in thin section. Near Kalgaon slightly diaphthoritic rocks have wide distribution; broken feldspars, unannealed deformed micas, and much mobilization of quartz were observed.

The Lower Crystalline Nappe is well developed S of Jajarkot. Above the Chail schists which contain fine biotite and garnet, the rocks of the Lower Crystalline Nappe show not much difference in respect to mineral facies. The mica schists, however, contain gneissic layers and are noticably coarser grained. There is growth of coarse garnet, biotite, chlorite, and hornblende, the latter may reach a length of 12 *cm*. In these rocks diaphthoresis is very rare. The thin sections show that crystallization continued after deformation of the rocks. In the above rock assemblage dark, thin-bedded fine-grained quartzites and schists rich in graphite and sulphides are not infrequent. They emphasize the similarity of the sequence with the Jutogh series of Simla.

N of the gneiss—mica schist series, where the trail starts to ascend the ridges of Jajarkot, we found light coarse augen gneiss with a pronounced

B-lineation and strongly tectonized after recrystallization. This rock may belong to the Upper Crystalline Nappe and may have been intercalated in the rocks of the Lower Crystalline Nappe by tectonics. The overlying quartzites are also much tectonized.

Further to the N garnet phyllites and some quartzite follow. They form the northern limb of the synclinal outlier of the Crystalline.

It is significant that the tectonic axes of the lower parts of the Crystalline, which are synchronous with the metamorphism, mostly show the same directions as those of the Chails. The axes are more or less horizontal and show much variation (WNW to NE). But the axes in zones of strong lineation and post-crystalline tectonization follow the general NW-strike.

The small wedge-like crystalline mass of the southern slope of the lowest Sani Bheri valley exhibits the strongest post-crystalline tectonization. The rocks are grey medium-grained, blastomylonitic augen gneisses. Tectonically they seem to be correlative with the augen gneiss S of Jajarkot (see above). In thin sections the deformation and chloritization of the former biotite, the mylonitization and deminution of grain size of feldspar and quartz are obvious. These observations can be made throughout the rock mass and therefore seem to be attributable not to local movements but rather to a regional tectonic event. *)

The metamorphism of the Lower Crystalline Nappe increasing towards the top and observations at the boundaries of the Crystalline (e.g. S Jajarkot) make it probable that Chail Nappe 3 and the Lower Crystalline Nappe have undergone metamorphism together and are now inverted. The connection may be preserved in a few rare occurrences (see also p. 576 in FRANK and FUCHS 1970).

2. The Upper Crystalline Nappe

This unit is much thicker than the lower one, but it can not be subdivided tectonically (compare FUCHS 1967, FRANK and FUCHS 1970, Fig. 9). The succession of rocks changes from the base upwards.

There is a lower gneiss complex partly migmatitic and containing calc-silicate rocks. The latter become more abundant towards the top and grade into the succeeding metamorphic carbonate complex. In the thick carbonate sequence the grade of metamorphism decreases towards the top and dies out in the basal parts of the Dhaulagiri Limestone. The total thickness of the Upper Crystalline Nappe including the Dhaulagiri Limestone amounts to 12 *km*. (Jagdula Khola).

The gneiss complex consists mainly of coarse-grained biotite-garnet-kyanite gneiss grading into mica schists and fine-grained grey biotite-garnet-(kyanite) gneiss. The first named show a typical alternation of flaky mica-rich layers with irregular locally folded lenticular quartz-feldspar-aggregates, which are the product of mobilization (Fig. 16). Muscovite is rare and potassium feldspar is missing. Kyanite reaches lengths of 4 *cm*. In these gneisses it is particularly evident that recrystallization continued after the intergranular movements.

*) After the experience of our 1969 expedition FUCHS points to the possibility that the augen gneiss forms part of the Chail Nappe.

The fine-grained grey migmatitic gneisses are apparently the homogenization products of the flaky gneiss described above. They alternate with the garnet-kyanite gneiss and still contain relict lenticles and layers of this gneiss. The fine-grained gneiss which is in some places layered shows the much stronger s-parallel orientation of the minerals.

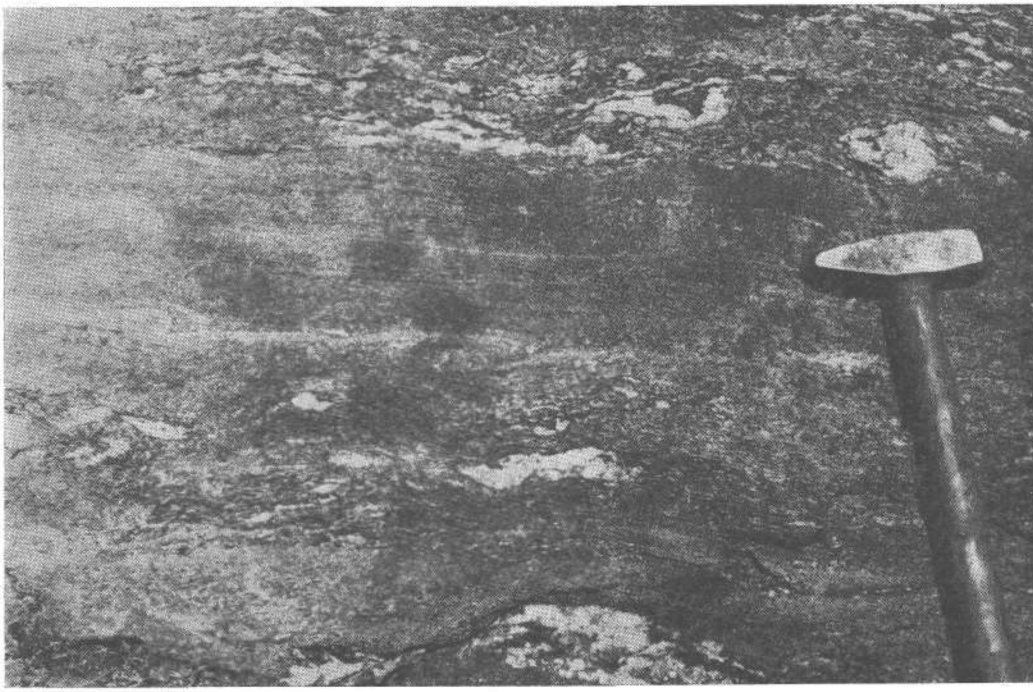

Fig. 16: Biotite-garnet-kyanite gneiss with layers of fine-grained migmatitic gneiss. Block at Rimi W of Kalgaon.

In the area SE of Talphi (see Pl. 1) light-coloured coarse-grained augen gneiss is abundant. Microcline forms the augen which may reach sizes of 5 *cm*. Muscovite is the main mica. This orthogneiss also contains layers of the middle- to fine-grained migmatitic gneiss. They have a similar relation to the augen gneiss as to the garnet-kyanite gneiss (see above).

Another type of gneiss is found in the Jagdula valley, immediately above the Lower Crystalline Nappe. There are middle- to coarse-grained two-mica gneisses with feldspar lenticles (plagioclase prevailes the microcline 1—5 *cm*.). They may be also garnetiferous. As in the flaky garnet-kyanite gneisses pegmatoid lenses and layers are characteristic. These are the products of a partial mobilization. The micas (muscovite and, in thin-slices, redbrown-coloured biotite) may reach sizes of several *cm*. In the lowest parts these rocks, which here form the base of the Upper Crystalline Nappe exhibit effects of strong post-recrystallizational deformation which are related to chloritization of biotite and garnet. In the rest of the Upper Crystalline Nappe such alteration is extremely rare.

Further, there are subordinate coarse-grained biotite-garnet quartzites, and amphibolites poor in plagioclase. They form small bandlike bodies.

Sporadic intercalations of limestone-marble, calc-silicate-marble, calc-mica schist, and fine-grained biotite-calc-silicate gneiss are found already in the gneiss complex described. These rocks build up a sequence often several thousand meters thick in the higher part of the crystalline unit. Within the latter a continuous decrease in metamorphic grade is observable towards the top, where it dies out in the nearly unmetamorphosed Dhaulagiri Limestone. From the rhythmic sedimentation, the composition and rare relict sedimentary structures, it may be concluded that the metamorphic carbonate complex was formed from the lower parts of the Dhaulagiri Limestone. Probably the enormous thickness is partly the product of tectonic reduplication.

The distribution of the various metamorphic minerals may be seen from W. Frank and G. Fuchs 1970 (Fig. 9).

Very interesting are fine-grained greenish calc-silicate layers which were observed in blocks derived from the lower gneiss complex. These rocks contain some wollastonite and vesuvianite. Near layers containing carbonate the wollastonite has reacted to calcite along fissures.

Coarse-grained calc-silicate marbles containing diopside (up to several *cm.* in size), hornblende, garnet, biotite, scapolite, microcline, and titanite are the most notable rocks.

The calc-silicate gneisses partly are monotonous, fine-grained, brown biotite-diopside-microcline gneiss, poor in carbonate, partly they are light banded carbonate gneiss containing biotite, diopside, hornblende, much microcline, scapolite, and quartz. The banding is caused by differences in composition as in the Dhaulagiri Limestone.

Scapolite, microcline, and biotite are abundant almost throughout the complex. Muscovite is less abundant towards the base, apparently it is replaced by microcline though reaction textures were not observed. Plagioclase is not abundant, in the lower part the An-contents are 40—45%, rarely they range to 80%.

That part of the section, where the metamorphism decreases, consists mainly of micaceous marble and biotite-muscovite-calc-mica schists. In the transition zone into the Dhaulagiri Limestone, formerly arenaceous rocks become abundant. They still show the sedimentary structures of the Dhaulagiri Limestone indicative of rather disturbed and cyclic sedimentation. In the basal beds of the Dhaulagiri Limestone in which the first lumachelle layers may be found silty layers were altered to fine-grained sericite phyllite with biotite porphyroblasts. The fossils indicate Ordovician age.

Tourmaline pegmatites forming oblique dikes up to several meters thick, are found throughout the Upper Crystalline Nappe particularly in the carbonate rocks. They have not been observed in the transition zone to the Dhaulagiri Limestone or in higher levels.

The metamorphism of the uppermost part of the section is not associated with deformation. The porphyroblasts are unorientated, whereas parallel orientation is well-pronounced in the calc-mica schists below. Where the two types of metamorphism are found together we observed an interference zone of B-axes parallel to the dip of the s-planes prevailing in the lower parts, and more or less horizontal NW to NNW-axes exhibiting a pronounced SW-vergence of movement. The latter structures are younger. Their Alpine age is evident as they are also found in the overlying Mesozoic beds of the Tibetan Zone.

In the Thabang section, which we have studied, the Crystalline N of Jaljala Dhuri consists entirely of calc-silicate gneiss containing hornblende, diopside, garnet, and biotite, calc-silicate marble, marble, and biotite-calc-mica schist. The type of rocks and the characteristics of metamorphism are identical with those of the root zone, e.g. the Garpung valley. The continuous decrease in alteration and the gradation into the Dhaulagiri Limestone, however, have not been observed there. We suppose that tectonic disturbances are responsible for the absence of intermediate members in the gradational series.

It is apparently impossible to elucidate the age of the Himalayan crystalline without systematic radiometric age determinations. From regional considerations we have come to the view that an old, —in the carbonate rocks not older than Caledonian—, metamorphism is also represented (G. Fuchs 1967, W. Frank and G. Fuchs 1970). The surprising rarity of retrogressive alteration in the crystalline, the radiometric age determinations hitherto published (D. Krummenacher 1961, 1966), and the continuous metamorphic section, which ends in the Dhaulagiri Limestone, the higher parts of which we think to be probably Alpine, indicate strong Alpine recrystallization. The geological fieldwork and study of thin sections have so far generally indicated only one metamorphism, which was only locally followed by later—certainly Alpine—deformation. The assumption that the observable metamorphism was largely Alpine has tectonic consequences which are not easy to explain (compare W. Frank and G. Fuchs 1970, p. 573, Fig. 11). If this is the case one must assume that the crystalline was metamorphosed at the beginning of the Alpine orogeny and that it was then thrust onto the Chail Nappes and that this caused the metamorphism of the latter. In a final tectonic event both units were thrust over the unmetamorphosed foreland of the Tansing Unit.

We do not want to give a final decision on this difficult problem at the present stage of the investigation.

3. Dhaulagiri Limestone

G. Fuchs (1967) introduced the name Dhaulagiri Limestone for a 2000 to 4000 *m*. thick formation of arenaceous-argillaceous limestone. It forms the lowest part of the sedimentary succession of the Tibetan Zone. The contact with the underlying crystalline complex is a gradational one. From place to place a varying volume of the Dhaulagiri Limestone seems to have been converted into calc schist and marble and is now part of the crystalline complex.

In the course of our 1967 expedition we have studied the Dhaulagiri Limestone in the southern Kanjiroba range which is W of the area investigated in 1963 and described in G. Fuchs 1967. It is very interesting that in several ways the formation is different from the eastern area suggesting change of facies.

The content of argillaceous-arenaceous matter, mainly silt, is much higher than in the E. We find an alternation of grey fine-grained calcareous sandstone to calcareous siltstone weathering in a characteristic reddish-brown to brick-red colour, grey silty limestone, bluish grey limestone, and silvery to greenish phyllitic-sericitic layers.

These rocks alternate in a rhythmic way. Most of the cycles start with arenaceous-silty-calcareous types (ripple cross-laminations) which pass upwards to argillaceous types. Many of the cycles are incomplete. Purer limestones are only found in the topmost parts of a cycle. Occasionally the cyclic units commence with a layer of intraformational breccia (Fig. 17). Graded bedding can often be observed (Fig. 17, 18). Though the mountain faces exhibit a thick-bedded, less commonly thin-bedded character, the rocks are often finely laminated. The described rocks show a cyclicity on a scale of decimeters up to some meters. Ripple-load convolutions, washouts, younger layers following unconformably over disturbed older ones, ripple cross-laminations, and cross-laminations are very frequent (Fig. 17—19). The angular fragments composing intraformational breccias may be densely packed or sporadically scattered. Burrow casts have also been observed on s-planes.

Fig. 17: Block of Dhaulagiri Limestone exhibiting rhythmic sedimentation. At the base an intraformational breccia. Between very disturbed limestone layers a lenticular body of calcareous siltstone (dark) showing extreme ripple-load convolutions. Subaquatic erosion and sediment flow responsible for the lenticular form? In upper part of the block the limestone is followed by calcareous siltstone (dark) with a sharp boundary. Upper Garpung Khola, Kagmara Lekh.

The sedimentary structures described have not been observed in the neighbouring areas in the E. They suggest an agitated environment of deposition. Ripple marks and mud cracks are missing, and we therefore think that the frequent erosional surfaces were formed subaqueously. Bottom currents, or turbidity currents could have been effective. The cyclic and graded character of the beds is suggestive of such an origin. Anyhow, the supply of silty matter was increased towards the W within the basin.

The Dhaulagiri Limestone had an original thickness of several thousand meters in the Kanjiroba range before the lower parts of the succession were altered to form part of the crystalline complex. The rhythmic monotonous sequence must have been deposited in a rapidly sinking trough with lime sedimentation. Along its strike the basin has received varying supply of clastic matter. These features indicate that the depositional conditions were those of a geosyncline.

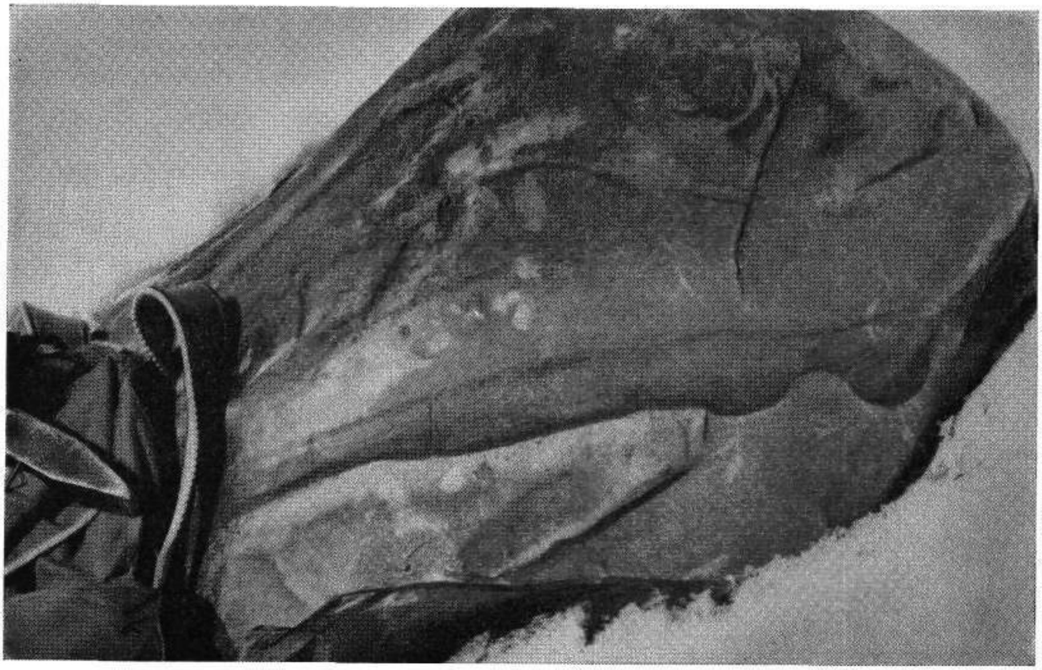

Fig. 18: Dhaulagiri Limestone. Sharp boundary between limestone (light) and overlying calcareous siltstone (dark) shows load convolution. Upper Garpung Khola Kagmara Lekh.

The facies changes described above are also reflected in the fossil content of the rocks. We found gastropods, low-spired flat forms and fragments of high-spired ones, brachiopods and lamellibranchs which form lumachelles, and crinoids. Prof. Dr. R. SIEBER has given the following determinations of some of the fossils found in the Kagmara Lekh:

Macluritina or *Pleurotomariina* (from Up. Cambrian on, in this case probably Ordovician—Silurian).

Poorly preserved *Orthida* and *Strophomenida* of post-Cambrian age.

A more detailed examination of the fossils shall be tried.

No orthoceratids could be found in the Kanjiroba Range, possibly because we did not cross the uppermost part of the formation from which we have found orthoceratids in more eastern areas (G. FUCHS 1967). Gastropods are not infrequent in the Kanjiroba region, but they were missing in the faunas we were able to collect in the Dhaula Himal and adjacent regions in 1963. However, gastropods are reported from the Nilgiri group (C. G. EGELER et al. 1964) and from the Garbyang Formation of Kumaon (A. HEIM and A. GANSSER 1939, A. GANSSER 1964 p. 117).

It is most important that we found Dhaulagiri Limestone also south of the Great Himalayan Range. When we crossed the Jaljala Dhuri, a mountain range almost 4000 *m*. high, on our way from Rukumkot to Piuthan we met a very thick development of Dhaulagiri Limestone overlying the crystalline rocks, mainly marble of the Crystalline Nappe. In the southern limb of this great syncline the underlying crystalline rocks are partly sheared off and the limestone comes into contact with the Chail rocks (Pl. 1, 3 [6—8]). Again we find the facies rich in arenaceous silty matter (Fig. 20).

Fig. 19: Blocks of Dhaulagiri Limestone showing ripple cross-lamination and unconformable contacts between calcareous (light) and overlying more silty layers (dark). Kagmara Lekh.

Purer limestones are exposed around the pass. On the southern slope of the mountain, quartzites containing some limestone laminae become important in the sequence. In the southernmost part of the Dhaulagiri

Limestone greenstone of volcanic origin appears. We find laminated rocks composed of alternating phyllite and chlorite-hornblende schists. Probably these rocks are altered tuffs and tuffites. There are also chlorite schists, chlorite phyllites with some quartzitic intercalations.

In the Thabang Valley we find a thick quartzite series at the base of the Dhaulagiri Limestone. The fine-grained rocks are grey mica quartzites, sometimes exhibiting lamination. The mica is greenish muscovite, but there is also brown, in thin section dark brown—dark green, biotite. The stratigraphic position of the series is somewhat doubtful as the zone of the Thabang Khola is rather disturbed. As the quartzites accompany the calc-mica schists we regard them as a local facies in the basal parts of the Dhaulagiri Limestone. There is no break in grade of metamorphism between these metasediments and the crystalline complex. Thin sections are identical with those from silty-arenaceous layers from the basal Dhaulagiri Limestone of the Garpung valley (Kanjiroba). They are similar also in structure, in as much as the micas show nearly no preferred orientation, which indicates relatively static conditions.

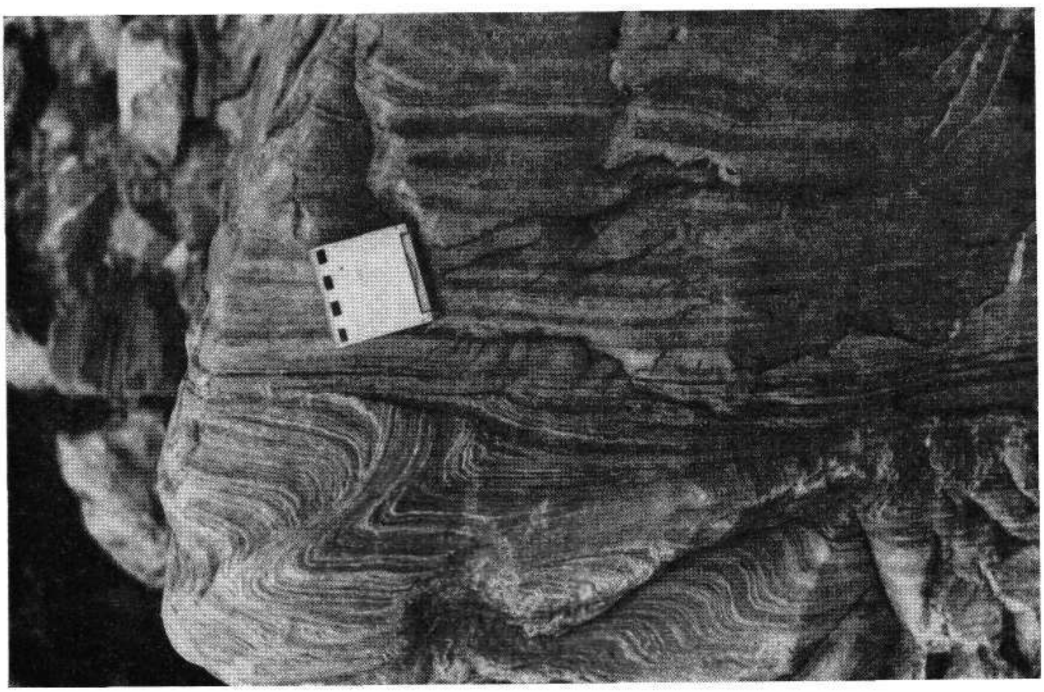

Fig. 20: Rhythmically laminated carbonate quartzite (Dhaulagiri Limestone) with ripple-load convolutions in basal part of the outcrop. Southern slope of Jaljala Dhuri.

The rocks of the Jaljala Range closely resemble those of the Kanjiroba area. The figures 17—20 show the similarity in lithology. Crinoids also are found in the Jaljala Range. But the occurrences of quartzites and the greenstones described above are confined to the Jaljala occurrence of

Dhaulagiri Limestone. However, they strengthen the correlation with the Garbyang Formation of the Kumaon Himalayas. Heim and Gansser (1939, p. 203) and Gansser (1964, p. 117) describe from Kumaon a rock assemblage exactly parallel to that which we found in Western Nepal. Thus the silty facies of the Dhaulagiri Limestone, found in the western part of the area mapped, forms a link between the typically developed Dhaulagiri Limestone and the Garbyang Formation. The correlation of these two formations was advocated by C. G. Egeler et al. (1964, Nilgiri Carbonate group) and G. Fuchs (1967).

It should be noted that the Dhaulagiri Limestone of the Jaljala Dhuri is one of the few occurrences of fossiliferous rocks S of the Great Himalayan Range (e.g. Phulchauki P. Bordet 1960, 1961). The metamorphic rocks of the Crystalline Nappe generally underlie the Jaljala rocks, as seems to be true also for the beds of Phulchauki.

The quartzites, phyllites, and tuffaceous rocks described by Gansser (1964, pp. 198—199, Figs. 68—71) from Bhutan (N of Sangsing La) exhibit a lithology very close to that of the silty Dhaulagiri Limestone, however, they are not calcareous. The regional position of these series seems to correspond to Phulchauki or the Dhaulagiri Limestone of Jaljala Dhuri. All these rock sequences are uninverted.

The age of the Dhaulagiri Limestone has already been discussed by G. Fuchs (1967, pp. 155—157, Pl. 4) and was given as Cambro (?)—Ordovician a conclusion which seems to be strengthened by the newly found fossils.

The formation commonly shows a slight metamorphism, which must be discussed in more detail especially with respect to the gradational contact with the crystalline complex at the base, and to the general problem of the metamorphism in the Himalayas.

V. The Distribution of Facies

When we described the stratigraphic developments in each of the tectonic units, problems of facies often had to be discussed. In this chapter we consider the facies distribution over all the mapped area.

One of the most significant differences in facies is between those of the Tibetan Zone and those of the regions S of the Great Himalayan Range, especially in the units underlying the Crystalline Nappe.

In the Tibetan Zone as well as in the Lower Himalayas the base of the succession is formed by thick geosynclinal deposits, the Dhaulagiri Limestone and the Simla Slates respectively. It is a surprising fact that neither in the Tethys Zone nor in the South an old crystalline basement is exposed below the sedimentary successions. Though the Crystalline Zone dips below the Tibetan Zone it does not represent a crystalline basement of that zone, for the metamorphism of the Crystalline is evidently younger than the overlying sedimentary rocks.

The Simla Slates are uniformly developed and show no facies differences, whereas the Dhaulagiri Limestone reflects a laterally varying supply of clastic matter (pp. 49—51).

Inspite of their uniform character the Simla Slates are thickly developed in some zones (Riri-Piuthan, Rukum Nappe, Andhi valley) and missing in others (e.g. Mahabharat Lekh and Surtibang Syncline). As the character of the overlying younger formations seems to vary with the thickness of the Simla Slates, we suppose that they were of palaeogeographic significance. In the zones with great thicknesses of Simla Slates the Jaunsars are more shaley and thinner, and the Blainis also are not very thick. In the Rukum Nappe the succession Jaunsar-Blaini-Shali seems locally not to have been deposited (see p. 28). On the other hand zones with insignificant Simla Slates exhibit a thick development of the younger formations. The Jaunsars are predominantly arenaceous. All the Jaunsar-Shali succession, except some black slate intercalations in the Blaini and Shali were deposited in very shallow water, whereas in the zones with a thin Jaunsar-Shali development shallow-water indications are less frequent. From these features follows that the areas rich in Simla Slates were stable zones with little or no subsidence and have received less sediment. Parts of these areas could have been above the level of deposition. Those poor in Simla Slates were areas of rapid subsidence, which was fully compensated by sedimentation.

This indicates that the basin was divided into zones of differential subsidence and sedimentary supply. It is most important that these zones seem to run along the strike of the Himalayas in a NW—SE direction. The best example is given by the Chail Formation; the very thick, locally rather coarse, deposits of the Chail zone correspond to the Chandpurs which are generally finer-grained and much thinner. The distribution of Chails in the NE, Chandpurs in the SW, can be observed all along the Himalayas. Thus the Himalayan strike is already reflected in the development of older Palaeozoic formations, as to the opinion of Fuchs, of Late Precambrian beds according to Frank. It should be noted, however, that Aravallis and Vindhyans of the adjacent Indian Shield exhibit SW—NE-respectively WSW—ENE trends.

From the above considerations the question arises, as to whether the various facies zones are confined to certain structural units of the Himalayan orogen ("facies-nappes"). The Chail Formation mentioned above, for instance, is restricted to the Chail Nappes. Also the succession of the Rukum Nappe shows individual features different from the adjacent zones. In other cases there are facies differences within one unit (e.g. Blainis, Riri Slates, and Infra Krols in the Tansing Unit). Apparently the thrusts did not always cut the basin precisely along facies boundaries, as they did not in respect to metamorphism (see p. 77). For instance the Shali Slates important in the Surtibang Syncline in the Thulo Bheri region, disappear towards SE, and possibly correspond to the black slates of the Bari Gad—lower Andhi valley zone, which belongs to another structural element. The zone rich in Simla Slates which is exposed in the middle course of the Andhi Khola (Tansing Unit) probably forms the continuation of the depositional area of the Rukum Nappe.

Though the structural units can not be defined by means of facies without further investigation, the thrusts bring into contact rock sequences, which were deposited in different areas. Therefore structural boundaries are very frequently also facies boundaries, which will be shown in the tectonic section.

VI. Discussion of the Ages of the unfossiliferous formations of the Lower Himalayas

In 1967 we did not hesitate to compare the formations found in Nepal with those of the Kumaon- and Punjab Himalayas. We have also found correspondence between the Outer and Inner Zones of the Lower Himalayas.

This view of an uniform stratigraphy for all the Lower Himalayas was substantiated by the work of our last expedition (1967). So there can be no doubt about the equivalence of Krol and Shali. Both carbonate formations are found as part of correlative successions, which have nearly identical lithologies and thicknesses of the constituent formations. There are even facies transitions. The carbonate rocks of the Tansing Syncline are very similar to the Krols of the Krol belt, where J. B. AUDEN (1934) did his classical studies. In the northern limb of the syncline mentioned we find the typical Krol rocks side by side with the stromatolite bearing shallow-water dolomites characteristic for the Shali Facies. Thus there is enough evidence now for the Krol-Shali correlation, which has been favoured already by J. B. AUDEN (1948, p. 79).

Nevertheless, there remains some doubt as to the age of the formations. We wish to emphasize that in discussing their ages Krols and Shalis must be considered together as they are equivalent.

At the present there are three main views, the arguments are given below.

A. The conservative view of an Upper Palaeozoic age of the Blaini-Krol sequence is the result of the careful studies of R. D. OLDHAM (1888), G. E. PILGRIM and W. D. WEST (1928), J. B. AUDEN (1934), and D. N. WADIA (1937). It is accepted by the Lexique Stratigraphique (1956) and by A. HEIM and A. GANSSER (1939), and by A. GANSSER (1964). This view was extended to the Shali Facies by W. D. WEST (1939, p. 138), J. B. AUDEN (1948), G. FUCHS (1967), I. C. PANDE (1967), and I. C. PANDE and M. N. SAXENA (1968). The arguments are:

1. In the Lower Himalayas as well as in the Tibetan Zone thick geosynclinal deposits form the lower parts of the stratigraphic successions. In the southern and western parts of the Himalayas they are clastic mainly of a slate-greywacke type. They are described as Simla, Hazara-, Attock-, and Dogra Slates and most probably correspond to the Haimantas, Martolis etc. of the Tethys Zone. From the Hazara Slates ill-preserved fossils have been recorded by R. G. DAVIES and RIAZ AHMAD (1963, p. 29). D. N. WADIA (1934) described a gradation of the Dogra Slates into younger beds of similar lithology, which have yielded Cambrian, Ordovician to Silurian fossils in Kashmir. It seems reasonable therefore to regard the basal slate formations as Late Precambrian to Lower Palaeozoic. As they are followed by thick clastic formations, the Chandpurs, respectively Chails, the Nagthats, and then by the Blaini-Krol succession, we conclude that the latter cannot be of the same age as the basal slates. Furthermore we emphasize that the slate formations mentioned are restricted to the Himalayan region and apparently have no parallel in the Precambrian or Purana rocks of the peninsular area. Their equivalents, though in a different facies, seem to be the Vindhyans.

2. The correlation of the Blaini-Krol sequence with the fossiliferous succession Talchir-Productus Limestone of the Salt Range: Besides lithologic analogies the proved glacial boulder beds of the Blainis are strong evidence. T. H. HOLLAND (1908) suggested a Precambrian age for this tillite but it appears much more probable that it corresponds to the Talchir Boulder Bed which forms a significant horizon widely developed at the base of the Gondwanas of northern India. Though there are Precambrian tillites known from many places all over the world, no proved occurrences are reported from the Indian Precambrian by E. H. PASCOE (1950, 1959). Contrary F. AHMAD (1960) refers to several conglomerates supposed to be glacial.

The points 1 and 2 together are convincing evidence for a Late Palaeozoic age.

3. Tracing the carbonate zone of the Krols to the NW one finds increasing influence of the Panjal Trap until in the Autochthonous Fold Belt of Kashmir (D. N. WADIA) the bulk of that zone is composed of that volcanic formation. If one goes to the ESE, instead of the carbonate rocks, Lower Gondwanas are commonly found in the eastern Himalayas. In those cases FUCHS thinks that these formations, though being of different facies, are of about the same age and substitute for each other. Nowhere the formations mentioned were observed together in one original sequence.

4. For oil exploration a well was sunk at Ujhani (India). Between the basement consisting of Vindhyan rocks and the Tertiary formations ca. 1000 *m*. of dolomitic limestones, mudstones, and subordinate siltstones and tuffaceous material, overlain by 70 *m*. of orthoquartzite were penetrated (L. P. MATHUR and P. EVANS, 1964, pp. 71—72). No animal fossils were found, but there was palaeobotanic evidence for a "late Palaeozoic age for the oldest sediments and a Mesozoic age for the rest of the sediments found beneath the (Tertiary, remark of the author) unconformity". A correlation with the Krol Formation was suggested. In addition we would point to the possibility that the orthoquartzite at the top of the succession corresponds to Tals.

R. N. LAKHANPAL, S. C. D. SAH, and S. N. DUBE (1958) have found palaeobotanic evidence for a Permian age of the Krol series of Naini Tal. Their samples are from the lower part of the formation. Also on palaeobotanic evidence A. K. GHOSH and S. K. SRIVASTAVA (1962) suggest a Permian age for the Infra Krols, and a Triassic age for the Krols.

5. Dr. B. N. RAINA kindly informs us that hystrichospheres of Lower Palaeozoic age were found in the Ladhiya Formation (VALDIYA) of the Kumaon Himalayas (Ladhiya valley). The Ladhiya Formation is regarded as Devonian and thought to be probably equivalent to the Jaunsars. These new data strengthen our view that the Chails, which are identical to the Ladhiya Formation, are Devonian (G. FUCHS 1967, Pl. 4). It has been shown in the Hiunchuli region, that the Chails are succeeded by the Nagthats and the Blainis, and these in turn by the Shalis (Pl. 1, 3). So this is further evidence for the Upper Palaeozoic age of Krol-Shali.

6. If we try to correlate the formations of the Lower Himalayas with the Precambrian or Purana rocks of peninsular India, we will find several rock units of analogous lithology, e.g. to Nagthat or Blaini. But if we

search for equivalent sequences for the succession Simla Slate to Shali we find none. Furthermore there are no geosynclinal formations in the Peninsula which could correspond to the Simla Slates.

B. Objections were raised against the theory discussed above first by T. H. Holland (1908) and recently by R. C. Misra and K. S. Valdiya (1961), K. S. Valdiya (1962 a, b) and A. Gansser (1964). We should like to stress that only Holland contested the Upper Palaeozoic age of the Krol, whereas the other workers accept the young age of the Krol, but suggest a Late Precambrian to Lower Palaeozoic age for the carbonate rocks of the Inner Zones (Shali, Tejam, Deoban etc.).

1. The strongest argument against an Upper Palaeozoic age of Krol-Shali is the absence of fossils. Near the Salt Range, where beds rich in fossils were deposited, we must assume a basin with an area of ca. 2000 × 400 *km.*, the deposits of which are completely devoid of animal fossils. There are unmetamorphosed carbonate rocks, shales etc., which seem quite appropriate for the preservation of fossils. To explain these facts we must assume "unfavourable conditions of life", "isolation of the basin" etc.

In addition stromatolites are very frequent in the carbonate rocks of the Shali Facies. Such algal structures have a wide distribution in Late Precambrian—Early Palaeozoic formations all around the world. So the assumption of a Late Precambrian age could explain for the lack of fossils.

2. There are a few physical age determinations (P. Bordet et al. 1965, D. Krummenacher 1966) suggesting a Precambrian age of the Chails (Series of Kunchha). Only two samples, however, have been examined. A detrital muscovite from a micaceous sandstone (KA 103) may be derived from a Precambrian area. KA 104, the determination of an uralite from a gabbroid rock appears to be rather unreliable. So few determinations are not conclusive until more data are available, and the French authors doubt by themselves that the series of Kunchha should be considered Precambrian. Bordet (1961, et al. 1964) had estimated that the formation was Jurassic-Cretaceous.

A difficulty with theory B. is that it is inconsistent with arguments 4. and 5. advanced in support of A., it is also necessary to assume an enormous stratigraphic gap between the Early Palaeozoic and the Jurassic. Not even Gondwana beds could have been deposited, as no occurrence of Gondwanas is known overlying Krol or Shali and overlain by Tal beds.

C. There is a third group of workers who favour a Devonian age for Krol-Shali.

Geologists of the Nepal Bureau of Mines (e.g. C. K. Sharma, unpublished reports) think that their Mahabharat Limestone Group, which corresponds to Krol, is Devonian in age. Their estimate is based on the occurrence of *Chonetes*. As they mention no fossil locality, they seem to refer to the fossil found by Das-Gupta in the Simla Hills. J. B. Auden (1932) has shown, however, that the fossil was not derived from Krol, but Subathu, and that it was too ill-preserved for determination. Furthermore, it should be stressed that the genus *Chonetes* ranges from Middle Silurian to Permian.

P. BORDET et al. (1964) think that the rock series of the Nepalese Midlands represent a stratigraphic succession, and that the dolomitic limestones containing *Collenia* (= Shali) are Devonian. No further reasons for that view are given. We found, however, that the rock sequences of the Nepalese Midlands do not form a stratigraphic succession, but belong to the Tansing Unit and the Chail Nappe. So, in our opinion, there is no sound basis for the stratigraphical scheme of the French geologists.

Of much interest, however, are findings of fossils in West Pakistan (in Swat W of the Indus River) (N. R. MARTIN, et al. 1962). R. G. DAVIES and RIAZ AHMAD (1963) described and discussed the fossils (orthoconic nautiloids). A Middle Palaeozoic, most probably Silurian to Devonian age is given for the Kala Limestone, from which the fossils were derived. MARTIN et al. (1962, p. 12) suggested a correlation of the rocks from Swat with the Abbottabad Formation (CH. MUHAMMAD ALI 1962) of Hazara. This correlation is also favoured by M. A. LATIF (1970, and personal communication). The Abbottabad Formation (the former "Infra Trias") corresponds very probably to the Blaini-Krol sequence of the Lower Himalayas, so a Middle Palaeozoic age follows from that correlation. However, further investigation appears to be necessary to prove the equivalence of the rocks of Swat and Hazara. Thus it seems necessary to wait until further information is available, but the importance of the occurrence of fossils in West Pakistan is beyond doubt. [1])

The arguments advanced by the supporters of theory B. against A. are also valid against theory C. The question, why all the equivalents of the fossiliferous beds W of the Indus are unfossiliferous towards E and SE remains.

Evaluating the theories discussed, we must admit that no definite decision can be made at the present. One of the writers, G. FUCHS, feels that the arguments are in favour of theory A., whereas W. FRANK thinks the problem to be still unsolved.

As the next step in the clarification of this fundamental problem we plan further investigations in the area mapped by our expeditions in West Nepal, and comparative studies in the Indian and Pakistan Himalayas.

During our investigations 1969 in the Northwest-Himalayas FRANK has firmed his view of a Late Precambrian age of the sequence Simla Slates—Krol (Shali). It should be stated that the different views of the authors only concern the age of the unfossiliferous sequence. There is full accordance about lithology, tectonics and especially the sequence of lithostratigraphic units described in this paper.

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[1]) In 1969 a joint excursion of Dr. M. A. LATIF and G. FUCHS has substantiated the equivalence of the Abbottabad Formation and the Blaini-Krol (Shali) sequence. FUCHS, however found carbonate rocks which he correlates with the fossiliferous Swabi- and Nowshera rocks (Silurian-Devonian) interfingering with the Tanol (= Chail) Formation at Tarbela. Not far from that locality, at Kachhi, the Abbottabad Formation overlies the Tanols with a zone of reworking at the base. Though further investigation is desirable these observations suggest an Upper Palaeozoic age for the Abbottabad Formation.

As to the arguments of view A [Nagthat—Blaini—Krol (Shali) of Late Palaeozoic—Early Mesozoic age], FRANK wants the following to be taken into consideration:

Ad view A, point 1 (Kashmir—Hazara): We admit that in Kashmir the uppermost part of Dogra Slates (equivalent of the Simla Slates) are of Early Palaeozoic age. But this does not mean that the Simla Slates of the Lower Himalayas are of the same age. There are too many differences in the sequence of Kashmir and the Lower Himalayas. For instance the characteristic Nagthat—Shali sequence is completely lacking in Kashmir.

There is also no evidence for Palaeozoic age in the Hazara Slates. The only fossil mentioned by R. G. DAVIES and RIAZ AHMAD (1963 b) is very doubtful and even its organic origin can not be proved. FRANK came to this conclusion after investigating the samples in Lahore.

Ad view A, point 2 (Salt Range): We do not doubt that there is a lithological resemblance between the Talchirs (also with certain layers in the Agglomeratic Slate) and the Blaini Boulder Bed, but this can not be used as a stratigraphic argument. It is simply the result of their common glacial origin. The nature of the boulders is different: local material of Simla and Tanol type in the Tanakki and Blaini Boulder Beds and a high percentage of exotic crystalline boulders in the Talchirs (PASCOE 1950). The overlying sequence has really nothing in common except the fact that they are clastic in the lower and calcareous in the upper part.

The Chails are a very characteristic formation represented throughout the Lower Himalayas from the Dalings in the E to the Tanols of Hazara in the W. In the course of our recent investigations FUCHS was able to prove that Chail-type formations of SW-Hazara, Kashmir, and Chamba are of Lower Palaeozoic, locally even of Carboniferous age. They follow the Dogra Slates, may pass laterally into Muth Quartzite, and locally replacing the Syringothyris Limestone (Chamba). Following view B, FRANK is convinced to assume the existence of two Chail-Tanol-type formations, one of Algonkian and one of Palaeozoic age. In SW-Hazara these two "Tanol Formations" are observed close together, however, nowhere they hitherto have been observed in one section.

Contrary to this observation strengthening view A, FRANK emphasizes that he has found a thick sequence of Chail-type rocks in the low grade metamorphic part of the Crystalline in the Chandra valley of Lahul-Kulu area. He does not doubt their correspondence with the Middle Haimantas in the immediate neighbourhood of the upper Chandra valley.

The Haimantas of Spiti are overlain by fossiliferous Lower Cambrian (CHATTERJEE 1966) of the Parahio group (in the Pin Valley). According to FRANK Chail type rocks exist definitely in very different stratigraphic levels. Thus there is no evidence which of them is the equivalent of the Chails in the Lower Himalayas.

However, FUCHS advances a strong argument against this view: In the Sach Pass area (Chamba) adjacent to Lahul and very probably in the same structural position he found a sequence resembling the Dogra Slate—Tanol (Chail type rocks, mainly Devonian)—Syringothyris Limestone—Fenestella

Shale—Agglomeratic Slate succession of Kashmir (Late Precambrian to Up. Carboniferous). He therefore doubts the Precambrian age of the Chail type rocks referred by FRANK.

Ad view A, point 4, 5 (microfossils): A strong argument for the Upper Palaeozoic age of the sequence in question is based on the few reports of microfossils. But it is necessary that these findings can be proved in more localities and that errors are excluded in every case. Current investigations from our side are concerned with this problem.

Again there are some more arguments in favour of view B. The sequence Nagthat—Blaini—Krol (Shali) was deposited within characteristic environments. Highly oxydized red sediments of arid climate (partly also pyritiferous and carbonaceous sediments) pass upwards into shallow water carbonates with stromatolites. There exists no similar sequence within the fossiliferous Upper Palaeozoic of the Himalayas. The Late Palaeozoic Gondwanas of the Peninsula consist of glacial sediments at the base, grading upwards into grey continental deposits with plant fossils. They represent a humid moist climate, very different from the arid environments of the Nagthat-Blaini sediments. No references from the field are known to explain this exception and the lack of macrofossils.

In contrast to the missing similarities between Lower Himalayas and the proved Late Palaeozoic sequence there exist lithological resemblances to the Vindhyans. It is not an identical sequence, but the single members show strong lithological similarities, especially to Nagthat and also to Blaini-Shali carbonate rocks. F. AHMAD (1955) reports also glacial boulder beds from the Vindhyans. In his detailed, recent paper K. S. VALDIYA 1969 describes several stromatolite assemblages which are common to both the Vindhyans and the Shali carbonate rocks. He thinks that these stromatolites indicate an age of 1000—1260 *m. y.* However, there are some doubts about the stratigraphic value of the stromatolites, nevertheless, the mentioned fact is a strong indication of contemporaneous rock formations in the Vindhyans and the Lower Himalayas.

A very important observation is reported by K. S. VALDIYA (1964, p. 25) and was made again by FRANK and SCHLAGER 1969 at the type locality of the Blaini Boulder Bed in Simla. They proved that the glacial sediments follow above the Simla Slates without an unconformity or major time gap and sometimes these beds even alternate with their topmost layers. In this sections the thick Jaunsars of other areas are represented only by *dm*- to few *m*-thick layers of red quartz conglomerate of Jaunsar type within the Simla Slates. Only two explanations are possible in this case: 1. The Simla Slate type sediments pass upwards also into the Late Palaeozoic, or 2. The Blaini Boulder Bed is not of Late Palaeozoic age, but older. As from climatological consideration a Lower Palaeozoic glaciation is very unprobable and hitherto unknown in this area, it represents most probably the widespread Late Algonkian-Eocambrian glaciation. The small unconformities below the Blaini Boulder Bed in other areas do not depreciate the above mentioned observation. The best argument in the same direction is that no stratigraphic gap within the sequence Simla Slates—Krol-Shali is developed in W-Nepal. There exists only a pronounced change in deposition from geosynclinal slate sediments to shallow water sediments. In any case the mentioned fact is a strong argument against the comparison of Blaini Boulder Bed and Talchir Tillite, on which the hypothesis of view A was mostly based.

Discussing also view C, we can state the following now: During our 1969 field work in W-Pakistan Frank and Fuchs found no evidence for a comparison of the Abbottabad Group (equivalent to Blaini-Krol [Shali] of the Lower Himalayas in the SE) with the Silurian-Devonian Nowshera Formation (Stauffer 1966).

Summarizing Frank concludes: Although it is not sufficiently proved until now, the unfossiliferous sequence of the Lower Himalayas is most probably of Algonkian age. This view is also in best agreement with the palaeogeographic—lithological history of the neighbouring areas of the Asian continent during Late Algonkian times (cf. Stöcklin, 1968, Biq Chingchang 1966).

He is not able to decide exactly to which Algonkian time interval the Lower Himalayan sequence corresponds and whether the topmost formations pass into the Early Palaeozoic. But he supposes that the Blaini Boulder Bed corresponds to the Late Algonkian-Eocambrian glaciation (Holland 1908).

Concerning the age of metamorphism in the axial crystalline zone new evidence could be found in the course of our most recent expedition. Fuchs (1967) has stressed the existence of post-Precambrian metamorphism particularly of Caledonian age for reasons given on pp. 20, 78, 134, 151. Fuchs also has pointed to the presence of Alpine metamorphism in the Himalayas, however, he was not able to make a distinction between the various metamorphic acts in the crystalline complex (pp. 78, 151). Also in our paper (Frank and Fuchs 1970, p. 573) we could not give a definite decision of the problem of metamorphism. In the course of recent work Frank has shown that Alpine metamorphism is far predominant in the Himalayas (cf. P. Misch 1949, Krummenacher 1966).

During his 1969 studies in the Crystalline of Kulu—Chandra region (NW-Himalayas) Frank was able to prove the Alpine age also of the high grade metamorphism. There are no signs of older metamorphism in the Precambrian to Late Palaeozoic series. He has no doubt that this picture is also true in other areas where the characteristics of metamorphism are the same, especially in W-Nepal. A striking argument for this view is that, in the area described in this paper, the thickness of sediments upto the Silurian is not sufficient to explain the high grade metamorphism of the lower parts of the Dhaulagiri Limestone. Further there is no sign of such a strong Caledonian orogeny in the sedimentary sequence of the Tibetan Zone.

Thus Frank came to the result that there is not enough evidence for a Caledonian metamorphism, which does not mean that there is no pre-Alpine crystalline in the Himalayas at all.

After all Frank's view of the history of the Himalayas (excluding the Tibetan Zone) is the following: The material of the unfossiliferous sequence is mostly of Late Algonkian age, deposited in the immediate neighbourhood of the Indian shield. The pronounced facies belts were parallel to the later strike direction of the mountain range. This mass of sediments remained undisturbed until it was involved in the great Alpine revolution. In the course of this orogeny the Crystalline Axis was formed along the border zone of the old sedimentary plateform and the Tibetan Zone.

B. Tectonics

T. HAGEN (1959 a) has given the first structural outline of the whole of Nepal. He found a multitude of structural units. Their continuation along the strike of the mountains appears to be rather restricted. Contrary to this view G. FUCHS (1967) favoured a more limited number of units and emphasized their great lateral extent along the axis of the Himalayas. Even though this holds true for the main units, the detailed investigations of the last expedition have shown greater complications within some areas, e.g. the division of the Chail Nappe into three nappes in the Thulo Bheri region, and the regional importance of the Rukum Nappe, which was previously thought to be merely a local scale between Tansing Unit and Chail Nappe.

In the course of the expeditions 1963 and 1967 we were able to gain a fair knowledge of the tectonics of the area under consideration. Of special interest is the information about the constancy of some tectonic features and variation of others along the strike of the mountains. In this way we get an impression of the tectonic style.

The main structural units of W-Nepal are from S to N:

1. The Tertiary Zone (Siwaliks)
2. The Tansing Unit
3. The Rukum Nappe
4. The Chail Nappe, splitting into three nappes in the W
5. The Lower and Upper Crystalline Nappes (Kathmandu N., HAGEN)
6. The Tibetan or Tethys Zone.

The present paper deals with the units 2 to 5 which are described in the following chapters.

I. The Tertiary Zone

In Nepal the Tertiary Zone is built up entirely of rocks of the Siwalik formations. As we did not make any detailed investigations in that unit, we refer to T. HAGEN (1959 a).

II. The Tansing Unit (see p. 8)

The Tansing Unit shows a thrust contact against the Tertiary Zone all along its southern boundary (Main Boundary thrust). The tectonic style of the Tansing Unit which contrasts with that of the higher nappes, led FUCHS (1967) to assume a parautochthonous character for that unit. A combination of folding, thrusting, and faulting is characteristic for the Tansing Unit.

In our description of the tectonic elements represented in the mapped area, we start with the outer structures (in the southwest) and go through to the inner zone (in the northeast).

1. The Syncline of Daban

A wide syncline marked by a thick development of the Tal Formation forms the southern parts of the Tansing Unit in the area NE of Bijauri. In the core of the syncline some outliers of the Chail Nappe are found.

In the W the Siwaliks are overthrust by the southern limb of the Daban Syncline. This syncline is overthrust in turn by the Chail Nappe, which is of enormous thickness. As can be seen at the trail from Bijauri to Lawamjula the southern limb of the Daban Syncline is highly reduced (Pl. 1, 3 [2, 3] Fig. 15). A zone of Nagthat (250 *m.*), which follows above the Siwaliks, is overlain by Tal beds. The succession Blaini-Krol is missing. As observed through the binoculars the Krol rocks come in towards SE. This complication seems to have been caused by the Chail Nappe, which sheared off the Krol rocks and dragged the Tals onto the Nagthats.

The Chail outlier shows a very steep northeastern boundary, the effect of secondary faulting. The rocks of the Tansing Unit form a small anticline near the Chail thrust (ESE of Lawamjula, Pl. 3 [3]). The thick development of Shali Dolomite NE of Lawamjula, however, belongs mainly to the Piuthan—Riri-Anticline. These rocks are thrust over the northern limb of the Daban Syncline, and this caused much shearing in the northern part of the latter (Pl. 1, 3 [4, 5]). Thus Blainis are found within the Tal rocks NW of Daban. Also the lenticular masses of Shali Dolomite and Blainis (up to 100 *m.* thick) found at the base of the Chail outliers, apparently are sheared off rocks of the northern limb of the Daban Syncline, e.g. at Saki (Figs. 21, 22), Libang Liga (Fig. 23). At the last named locality the Blainis are still in connection with the Blainis and Nagthats of Swargdwar, which represent the overturned northern limb of the Daban Syncline. These rocks show a rather complicated internal structure, normal and inverted beds are found. The Blainis and Nagthats have been moved onto the Tal beds and are overthrust by the Simla Slates of the Piuthan—Riri Anticline.

We were not able to investigate the southern limb of the Daban Syncline in the area E of Bijauri. As seen with binoculars the Tal Formation seems to be underlain by N dipping carbonate rocks of the Krol.

Towards SE the Daban Syncline becomes increasingly reduced and is replaced by the Tansing Syncline. The latter structural element, however, is moved over the first: The sequence black shale—Tal Formation—Dagshai, found between the Siwaliks and the Nagthats of the lower Immrun Khola, seems to represent the easternmost parts of the Daban Syncline (Pl. 1, 3 [12]). The Nagthats of the Immrun Khola clearly belong to the Tansing Syncline, but they seem to continue towards NW and connect with the Nagthats of Swargdwar. This means that the Tansing Syncline develops from the northern limb of the Daban Syncline.

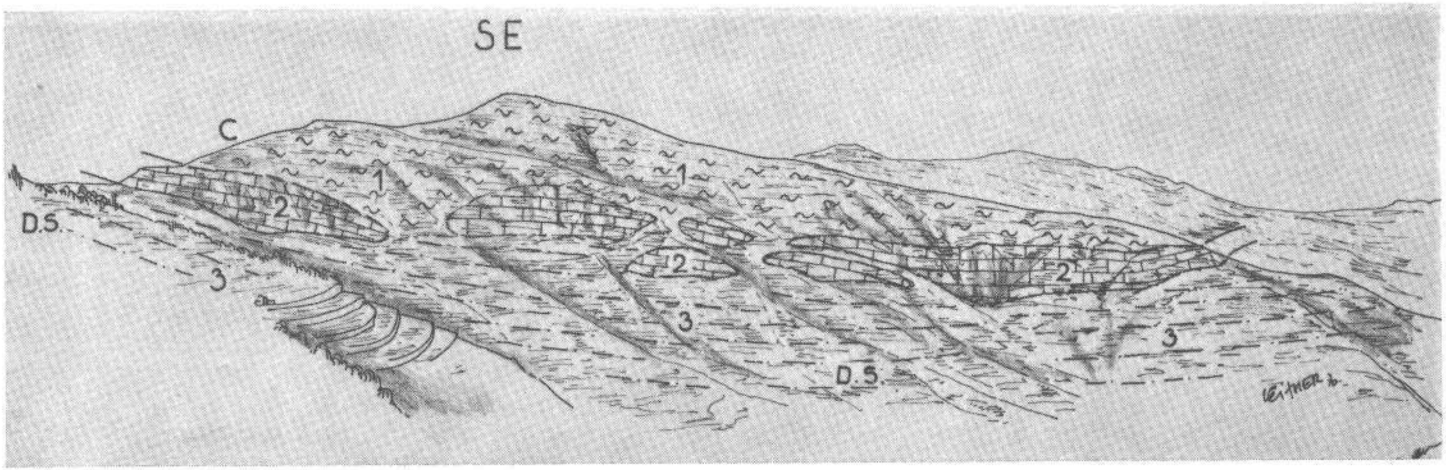

Fig. 21: Outlier of Chail Nappe (C) resting on the core of Daban Syncline (D. S.), W of Saki.

1. Chail
2. Shali (partly + Blaini)
3. Tal

2. The Syncline of Tansing

As described above the Daban Syncline is replaced by the Tansing Syncline towards the E. This syncline makes its first appearance in the uninverted succession Nagthat—Blaini—Infra Krol—highly reduced Krol—Tal, found overthrust by the Simla Slates of the Piuthan-Riri Anticline SE of Swargdwar (Fig. 24 Pl. 1, 3 [9]). The Nagthats of the Immrun Khola form the basal parts of the Tansing Syncline. Younger beds are exposed in the high mountains E of the valley and in moderate thickness (280 *m.*) along the thrust against the Simla Slates. The latter occurrence consists of vertical Blainis and Shalis; stromatolites show that the succession becomes younger towards the N (Pl. 3 [11]). These beds are the eastern continuation of the Nagthat-Tal sequence found below the Simla Slates 8 *km.* SE Swargdwar.

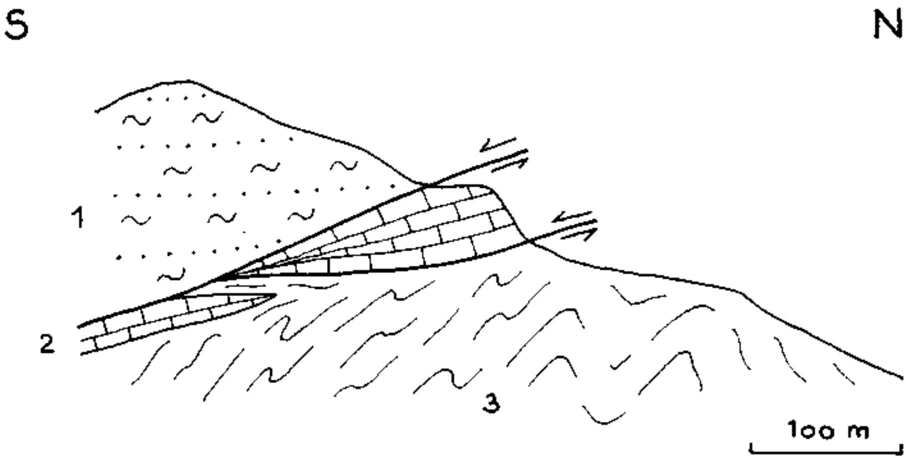

Fig. 22: The northern edge of the Chail outlier at Saki.
1. Chail
2. Shali-Krol
3. Tal

In the area between Khanchikot and Tansing we find a wide syncline formed by rocks ranging from Nagthat to Dagshai. The deepest axial depression lies SSW of Tansing where the youngest formations and the outlier of older rocks are found.

In the southern limb of the syncline the Nagthats seem to be squeezed out, as in the traverse from Butwal to Tansing (G. Fuchs 1967, p. 27). Infra Krol shales are the oldest rocks of the syncline along the Main Boundary Thrust (Pl. 1, 3 [17, 18]). Fig. 6 shows that the succession Infra Krol—Krol—Tal—Dagshai is steeply dipping, partly inverted.

The northern limb is highly complicated. Imbrications and inversion of the beds are rather frequent (Pl. 3 [14—19], Figs. 2, 6, 25). Parts of the northern limb apparently are sheared off and are found as a large outlier in the central parts of the syncline. This outlier is formed by Simla Slates, Nagthats, and Blainis, showing an internal structure unrelated to the underlying Tal beds. These complications are caused by the Piuthan—Riri

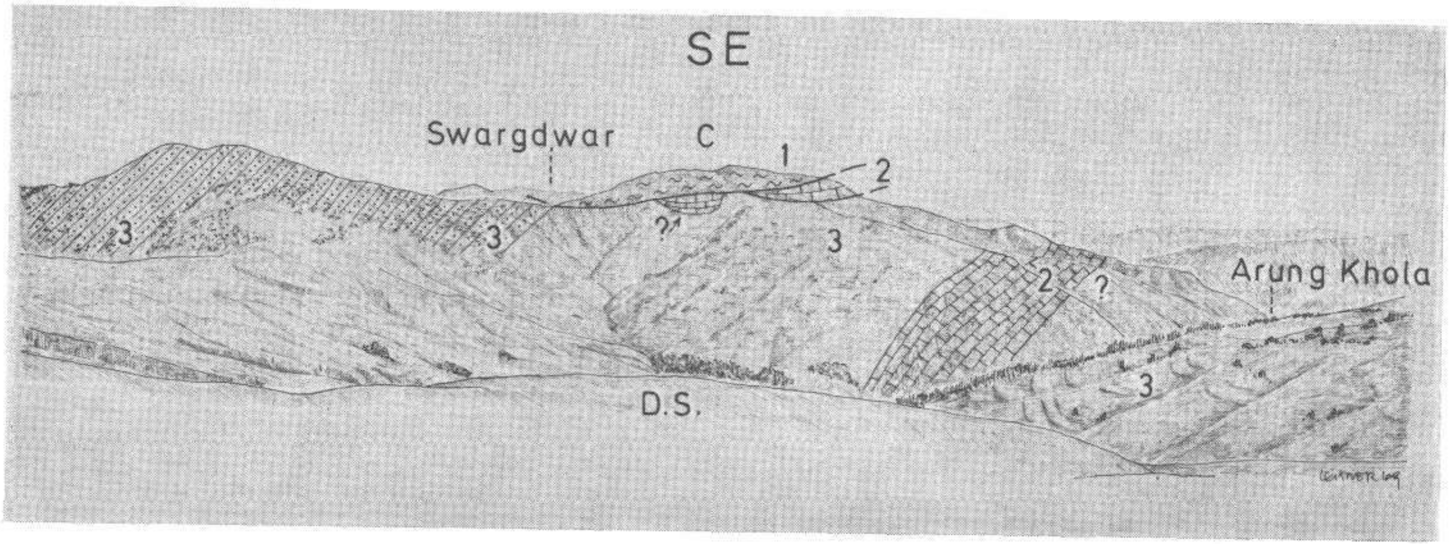

Fig. 23: The Chail outlier of Libang Liga seen from the NW.
1. Chail of Chail Nappe (C)
2. Blaini-Krol } of Daban Syncline (D. S.)
3. Tal

Anticline, which was pressed against the Daban- and the Tansing Synclines along a steep thrust. The Simla Slates of this anticline come into tectonic contact with different beds of the Tansing Syncline. It should be noted, however, that some of the faults and imbrications dip to the S and show movements towards N. They may be the result of late orogenic compression.

Structures such as those described above are typical for the Tansing Unit but absent in the nappes.

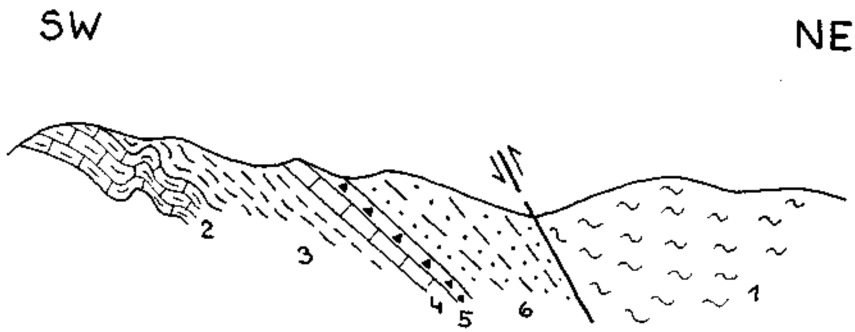

Fig. 24: Section across the westernmost continuation of the Tansing Syncline, 12 *km*. WSW of Piuthan.
1. Simla Slates
2. Blaini
3. Infra Krol and Riri Slates
4. Krol Limestone (tectonically reduced)
5. Shali Quartzite
6. Tal Formation

Length of section ca. 2 *km*.

3. The Piuthan—Riri Anticline

The anticline is marked by a continuous zone of Simla Slates, which can be seen in Pl. 1. The soft rocks are readily eroded, and the zone is one of low terrain, gentle hills and depressions, often followed by the rivers (e.g. Mari Khola, Riri Khola, Kali Gandaki, and lower Andhi Khola).

In the E in the region of the Kali Gandaki knee the Simla Slates border with a steep tectonic contact against the various formations of the Tansing Syncline and against the younger rocks in the N. The thrusts and imbrications cut the rocks discordantly, a feature often found in the Tansing Unit.

From Riri Bazar towards the W the Simla Slates are overlain by Jaunsars and Shalis in the N. These rocks form a stratigraphic sequence. Near Piuthan a syncline of Jaunsars is found in the zone of the Simla Slates (Pl. 3 [9—11]).

In the Piuthan—Swargdwar area the Simla Slates are thrust towards SSW onto the successions of the Tansing- and Daban Synclines (Pl. 3 [8, 9]). Toward NE they dip below their sedimentary cover. The structure of the latter is complicated only by some minor imbrications (Pl. 3 [8, 10]). The succession ranges from the Simla Slates up to Tal. The Tal beds dip towards NE below the overriding Rukum Nappe.

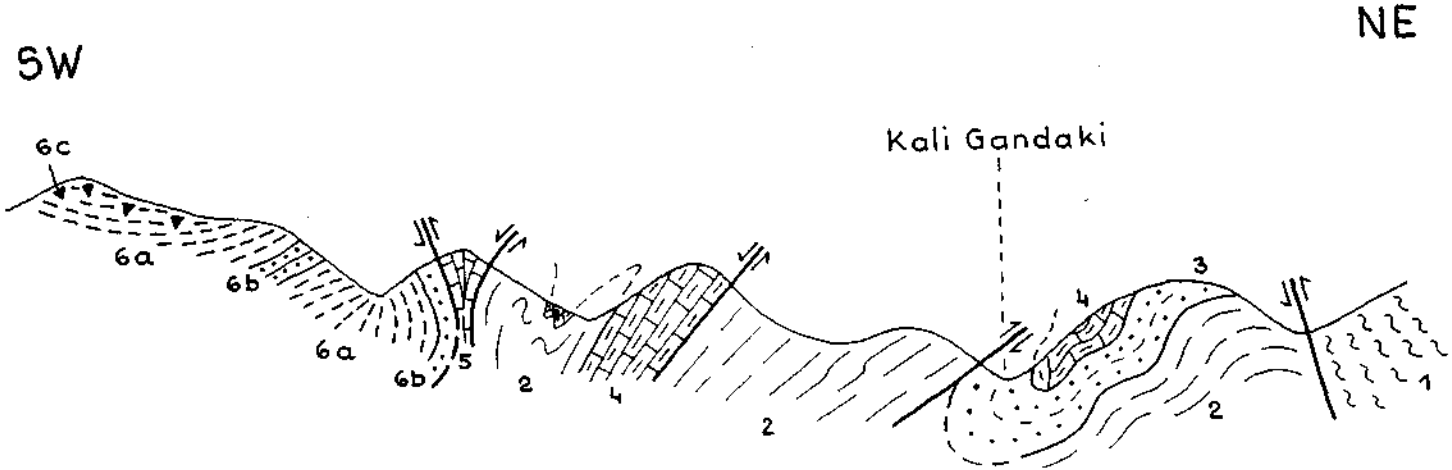

Fig. 25: Section of the northern limb of Tansing Syncline, NE of Tansing.

1. Simla Slates
2. Chandpur
3. Nagthat
4. Blaini
5. Shali-, Krol Dolomite
6. Tal Formation
   a. Shales
   b. Sandstone and quartzite
   c. Greywacke

Length of section ca. 7 *km*.

The continuation of the Piuthan—Riri Anticline towards WNW was not investigated. However, the Simla Slates and Jaunsars seem to dip below younger beds. This means that the anticline shows an axial dip towards WNW. The same axial dip was observed in the Daban Syncline, and the axial depression in the region of Sallyana causes the vast area of outcrop of the Chail Nappes. In section 4 (Pl. 3) the Riri Slates are the oldest rocks of the Piuthan—Riri Anticline. They are thrust over the Tals of the Daban Syncline and dip NNE below Blainis and a thick sequence of Shali Dolomite.

The overturned anticline NW of Lawamjula is the westernmost part of the Piuthan—Riri Anticline before it disappears below the Chail Nappe (Pl. 1, 3 [2], Fig. 26). The thick dolomites, which dip gently to the N, form the northern limb of the anticline.

4. The Structures of the area Andhi Khola—Kali Gandaki

Before we discuss the highly complicated zone Bari Gad—Rukumkot, we shall describe the eastern areas which are less disturbed and not covered by outliers of nappes.

The Simla Slate anticline described on the last pages has a steep tectonic contact against Shali and Tal rocks of a syncline in the N. The southern limb of this syncline is cut off by the fault, but the northern one shows a sequence from Chandpur to Tal (Pl. 3 [19, 20]). The dolomites of this syncline form a barrier, which is crossed in gorges by the rivers Andhi and Kali Gandaki. In the Kali Gandaki valley minor anticlines of Nagthat-Blaini rocks are exposed (Pl. 3 [13, 17]), and were described in G. Fuchs (1967, pp. 83—84). The syncline continues towards NW in the dolomite mountains NE of the Bari Gad.

In the valley of the Andhi Khola this syncline has been moved onto Shali Slates and Shali Dolomite along a reverse fault (Pl. 3 [18—20]). This fault separates successions of different facies. The syncline in the S shows a gradation from pinkish Blainis into the Shali Dolomite, whereas Blainis are missing N of the fault where we find a thick development of Shali Slates. These rocks show minor folds and form an anticline which is truncated by another fault towards the N (Pl. 1, 3 [19, 20]).

A corresponding anticline is found in the Kali Gandaki valley at Behadi (Pl. 3 [16, 17], see also G. Fuchs 1967, pp. 82—83). N of that structure follows a syncline marked by a thick succession of Shali Dolomite (Pl. 3 [19, 20]). In the Andhi valley these rocks are rather flat-lying. An anticline brings up Simla Slates, but the higher parts of the mountains are made by Shali Dolomite. Up river again a syncline follows. Only on the E-side of the valley does the Shali Dolomite reach the bottom of the valley.

In the region of Syangja the Jaunsars and Simla Slates, which represent the northern limb of the syncline mentioned above, show steep to vertical dips. This northern limb is rather disturbed. The Nagthats which follow N of the Simla Slates apparently belong to the Chail Nappe. They overlie the Chails showing a southern dip. Just before they reach the thrust against the Simla Slates their bedding planes become horizontal. The thrust which brings the Nagthats upon the Simla Slates dips to the N at a moderate angle. It can be seen from the map (Pl. 1) that the Shali Dolomites strike from the

Andhi Khola to the W, where they cross the Kali Gandaki. Their continuation farther to the W has hitherto not been investigated.

We should like to stress, that the northernmost structural elements of the Tansing Unit do not continue from the Andhi valley to the Kali Gandaki valley. They are burried below the Chail Nappe.

A characteristic feature of the Tansing Unit is, that it is not the youngest beds which come into contact with the Chail Nappe, but Jaunsars or Simla Slates. This suggests that there was a dragging effect below the Chail thrust, but seems also to indicate that the nappe structures developed from folds.

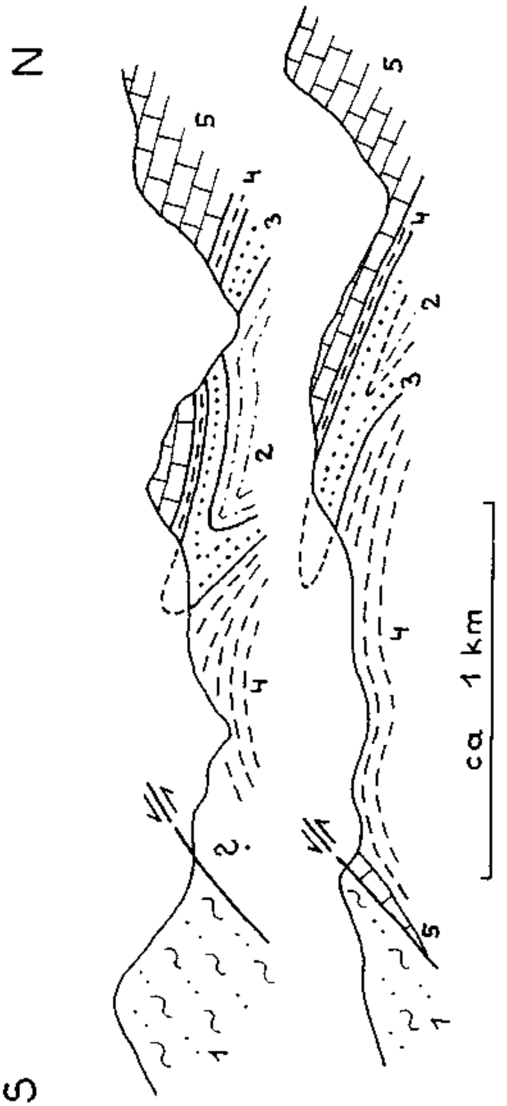

Fig. 26: Sections across the anticline 4 *km*. NW of Lawanjula. Note the unconformable tectonics of the Tansing Unit and Chail Nappe.

1. Chail
2. Chandpur
3. Nagthat
4. Riri Slates
5. Shali Dolomite

5. The Bari Gad Anticline

Outliers of the nappes have extensive outcrop W of the Bari Gad (Pl. 2). This has already been observed by T. HAGEN, who suggested the term Jaljala Syncline for that area (1959 a). NE of these outliers an anticline brings up again the rocks of the Tansing Unit, which form a semi-window in the area Bari Gad—Sani Bheri—Thulo Bheri. This zone shows very complicated structures, and there are still problems to be solved. Even so this zone is very instructive; it shows the distinctness of the structures of the Tansing Unit from those of the overthrust nappes, and is very important for the understanding of the Himalayan tectonics.

The Bari Gad Anticline branches from the Piuthan—Riri Anticline at the junction of the Bari Gad and the Kali Gandaki. The Bari river has cut its bed along the axis of this anticline. From Pl. 1 it can be seen that dolomites form the higher parts of the slopes on both sides of the valley. But Pl. 2 and the sections 11—13 of Pl. 3 show that the two sides of the valley are different. The Shali Dolomites NE of the valley are the northwestern continuation of those already described from the lower Andhi Khola and N of the Kali Gandaki bend. These dolomites are underlain by black shales (Infra Krol) and Chandpurs in the lower Gari Gad. The missing Nagthats and the discordance of dip between the dolomite and the underlying rocks (G. FUCHS 1967, pp. 35—37, Figs. 2, 3) point to the existence of planes of movement within that sequence; thus the original sequence is somewhat disturbed.

Between the junctions of the Hukdi Khola with the Bari Gad and that of the Londi Khola and the Bari Gad Simla Slates form the bottom of the valley. Within these slates rocks of the Tal Formation are found pushed up from below. On his first traverse in the Himalayas in 1963 G. FUCHS mistook the Simla Slates for Jaunsars and the Tals for Nagthats (1967, Pl. 2). From our present knowledge of the lithology of the Tal Formation and of the structure of the Rukum area we offer the interpretation seen from Pl. 1, 2, 3 (11—13). All the Simla Slates, and the black slates and slightly metamorphosed carbonate rocks SW of the river belong to the Rukum Nappe—they generally dip towards the SW. They are thrust over both the Tal rocks and the Jaunsar-Shali sequence NE of the Bari Gad. The latter sequence in its turn has overthrust the Tals. In the Bari Gad the already rather complicated structure has suffered further disturbance by younger movements. Such late movements, younger than the main thrusts, are responsible for the form and probably also for the direction of the Bari Gad Anticline.

The tectonics of the Kutharpekot area are of particular interest (Pl. 3 [11, 12]). Below the SW dipping carbonate rocks and black slates of the Rukum Nappe we find the Tal beds (in FUCHS 1967, Fig. 6: 3—7). The black slates N of the Tal may belong to this formation; they may be parts of the Rukum Nappe, or may belong tectonically to the Shali Dolomite sequence N of the river. To the N the Shalis are underlain by a thick development of Nagthat (in G. FUCHS 1967 mistaken for Tal) and below these we find a doming up of Shali Dolomite. The dolomite is surrounded by overlying Nagthats. Towards NW the Nagthats dip below Shali Dolomite and then follows a tectonic break.

Our interpretation is, that below the SW-dipping thrust of the Rukum Nappe there were thrust movements within the Tansing Unit. The Tals and the dome of Shali Dolomite form one structural unit. This unit is overthrust by the Nagthat-Shali succession. The minimum displacement on this thrust is 6 *km.*, an amount that is rather small. Again the influence of later compression on the thrust structures is apparent.

At the thrust of Dogadi we enter a new tectonic element of the Tansing Unit, the Surtibang Syncline, which continues towards NW to the Thulo Bheri area.

At Rukumkot and along the Sani Bheri we again find structures quite similar to those described from the Bari Gad (Pl. 1, 2, 3 [4—7]): along a NE-dipping thrust plane the Surtibang Syncline is displaced over a lower structural element consisting of Shali Dolomite and Tal Formation. This is a structural complication within the Tansing Unit, but its continuation from the lower Bari Gad to the Thulo Bheri indicates that it is of more than local importance. The thrust described within the Tansing Unit is cut approximately at right angles by the thrust, which has brought the Rukum Nappe from the N over the Tansing Unit. The area around Rukumkot is especially instructive for interpreting the structures described (Fig. 7). The Serpo lake section (Figs. 27, 28) is even more disturbed, but offers the same general picture.

It should be emphasized that this is again an example of the discordance tectonic style between the Tansing Unit and the nappes. The sections of Pl. 3 show this very clearly.

The Chail- and Crystalline Nappes are concordant with each other, whereas the structural pattern of the Tansing Unit is cut discordantly by the nappes.

At Dali in the Thulo Bheri valley the Tal rocks, which form a continuous zone from Rukumkot to the Thulo Bheri, disappear below Shali Slates or Shali Dolomite belonging to the Surtibang Syncline. However, both the formations of the Surtibang Syncline and those of the Bari Gad Anticline, dip below the Simla Slates, which form the base of the Rukum Nappe (Pl. 1).

From sections 2 and 3 (Pl. 3) it is apparent that movements younger than the thrusts have deformed the preexisting structures to produce such complicated tectonics.

6. The Surtibang Syncline

The name has been taken from the Surtibang Lekh W of Dhorpatan, where the synclinal character of this structure was first recognized (G. Fuchs 1967, pp. 44, 47). The tectonic element is characterized by a thick development of the Nagthat-Shali succession.

The Surtibang Syncline sensu stricto starts with the Chandpurs at the Dogadi thrust. However, this seems to be a local imbrication and the Shalis and Nagthats SE of Dogadi, which were thrust over the dome of Shali Dolomite and the Tal beds of the Bari Gad, most probably form a basal wedge in the Surtibang Syncline (see above). In this case the dolomite

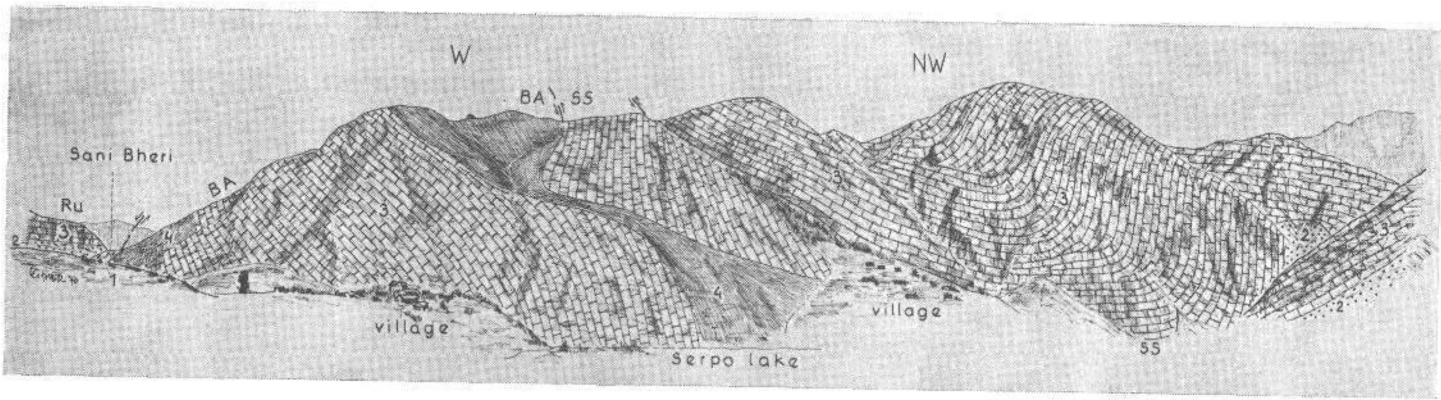

Fig. 27: View from the Serpo lake towards W.
1. Simla Slates
2. Nagthat
3. Shali
4. Tal
B. A. = Bari Gad Anticline
S. S. = Surtibang Syncline
Ru = Rukum Nappe

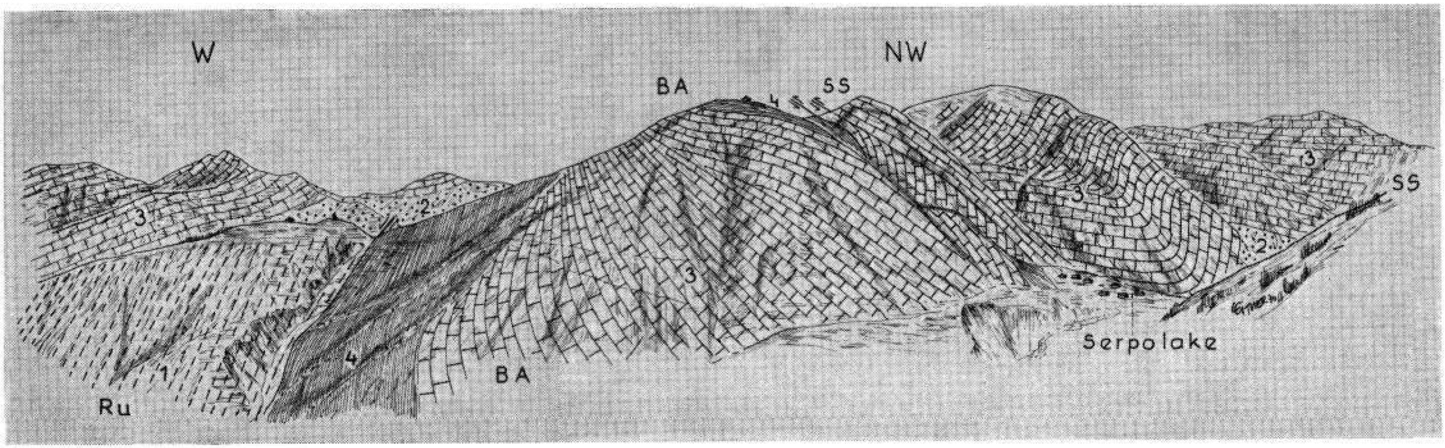

Fig. 28: The Serpo lake area, view towards WNW. The Surtibang Syncline (S. S.) is thrust to the Bari Gad Anticline (B. A.) both units are unconformably overthrust by the Rukum Nappe (Ru).

1. Simla Slates
2. Jaunsar
3. Shali (partly also Blaini)
4. Tal

zones of the Kali Gandaki—Andhi Khola area would be the southeastern continuation of the Surtibang Syncline. But we do not wish to emphasize such correlations of minor structural elements over such long distances, as this seems to be of little value.

In the E, in the area S of Dhorpatan, we find the Surtibang Syncline thrust over the rocks of the Bari Gad Anticline (see above). The northern limb of the syncline is overturned towards SW (Pl. 3 [8—10]).

S of Takbachhigaon there are several small anticlines of Blainis steeply folded within the Shali Dolomite. In the northern limb of the Surtibang Syncline imbrications are found. At the village mentioned a plane of movement cuts the Shali Dolomite and brings it into contact with overthrust Chandpurs. The local structure and the iron ore deposits are described in G. Fuchs (1967, pp. 48—53). N of Rukumkot the Surtibang Syncline again shows much internal folding and it is thrust towards SW onto the Tal beds and Shali Dolomite of Rukumkot (Pl. 1, 3 [6, 7]). Again the northern limb of the syncline is inverted. Thus if we walk from Tubang to the N we come from the Blaini into Nagthat, Chandpur, and Simla Slates. The Simla Slates probably form the root of the Rukum Nappe (Pl. 1, 2, 3 [6—9]).

The northwestern part of the Surtibang Syncline is formed entirely by the younger formations, Blaini, Shali Slates, and Shali Dolomite. The black slate facies is missing in the southeastern parts of the Surtibang Syncline, an example of facies differences within one structural unit. Shali Slates are found at the base of the dolomite in the Thulo Bheri valley, within the dolomite (e.g. NNW of Serpo lake), and above the dolomites immediately below the overthrust Simla Slates along the Barikot Khola. This shows that the succession is highly disturbed (see Pl. 3 [2, 3]). In particular the Shali Slates of the Barikot Khola seem to be dragged over the dolomite by the overriding Rukum Nappe. Transitions from the slate to the dolomite and the association of the dark slates with the small zone of Blainis at Aurali indicate that the black shales belong to the succession of the Surtibang Syncline and not to the overthrust Simla Slates.

It is very interesting that the Surtibang Syncline is in contact with Chail Nappe 1 in the Thulo Bheri valley without the intervening Rukum Nappe. A comparison of Pl. 1 and 2 shows, that the boundary between the Chail Nappe and the Surtibang Syncline (Tansing Unit) is drawn between the Shali Dolomite and the Blainis of Gotam. Any geologist who studied only the section along the Thulo Bheri would think, that these rocks formed a stratigraphic succession. The tectonic contact becomes apparent, however, if we consider the geology of the adjacent areas in the W and in the E. In the W the Simla Slates of the Rukum Nappe surround the Surtibang Syncline always overlying the latter. The Simla Slates for their part dip below the Shali Dolomite of the Bhalu Lekh (Chail Nappe 1) and seem to strike into the junction between Chail Nappe and Surtibang Syncline.

Going ESE we find that below the Blainis of Gotam, Nagthats and the Chails come in. Thus the Blainis which continue towards the Jangla Bhanjyang certainly belong to the Chail Nappe. The dolomites which were in contact with those Blainis in the Thulo Bheri valley strike SE forming the core of the Surtibang Syncline, which is overthrust by Simla Slates and by the Chails in the Sisne Khola. We may explain this structural relationship if the roots of the Rukum Nappe and the lower stratigraphic units of Chail Nappe 1 are cut off by late-orogenic movements. The carbonate complex of Chail Nappe 1 was moved towards the S on near-horizontal shearing planes. Evidence for such movement planes is found in the south-face of Hiunchuli (Fig. 29, Pl. 3 [5 a]).

This instructive example shows what problems arise if only one section is investigated, even if it is studied in great detail, and the advantage of a regional reconnaissance survey.

On page 11 we have already pointed to the great facies similarities of the Surtibang Syncline and Chail Nappe 1 (e.g. thickness, lithology, sedimentary structures of Nagthat and Blaini, abundance of stromatolites in the Shali etc.). Today, these units are adjacent over long distances (see Pl. 1 and 2). But from tectonic considerations we see no alternative to the deposition of the Rukum Nappe with its very different facies between the Surtibang Syncline and Chail Nappe 1.

III. The Rukum Nappe

In the earlier publication (G. Fuchs 1967), which was based on our knowledge of the traverse Uttar Ganga—Jangla Bhanjyang and our studies in the Simla area, we drew attention to the similarity between the thrust masses, consisting mainly of Simla Slates found in both areas. However, we thought them to form wedge-like thrust sheets, resulting from local complications at the junction between the Tansing Unit and the Chail Nappe.

Our 1967 expedition has given further information about this structural element. It is not merely a wedge, but has distinct nappe character. It consists of a sedimentary succession which exhibits characteristic features and seems to have a somewhat reduced stratigraphic thickness (see pp. 25, 28). Whereas the Tansing Unit is nearly unmetamorphosed, the areas of Dhorpatan and N of Tubang excepted, the rocks of the Rukum Nappe frequently show a grade of alteration similar to that observed in the Jangla Group of the Chail Nappes S of the root zone.

We came to the conclusion that the Rukum Nappe forms the lowest nappe of the Lower Himalayas. It was thrust horizontally over the Tansing Unit and is overthrust by the Chail Nappes. The occurrence of a similar unit in Simla indicates that it has regional significance. The areas of outcrop of this nappe are relatively small, however, and it seems discontinuous along the strike, being absent in some areas.

The southernmost outcrops of the Rukum Nappe were found in the area NW of Piuthan (Pl. 1, 2, 3 [8—10]). The Lungri Khola section (Pl. 3 [8]) shows the tectonic relations. The Tal Formation of the northern limb of the Piuthan—Riri Anticline dips NE under Simla Slates. These are overlain by ca. 150 *m.* of Shali Limestone containing some layers of dark slate. The bluish limestone is banded to laminated, partly recrystallized, particularly the light layers. The internal deformation of the rock has led to flowage. Thus the slight alteration gives the limestone an appearance distinct from that of the nearby Shalis, which belong to the Tansing Unit.

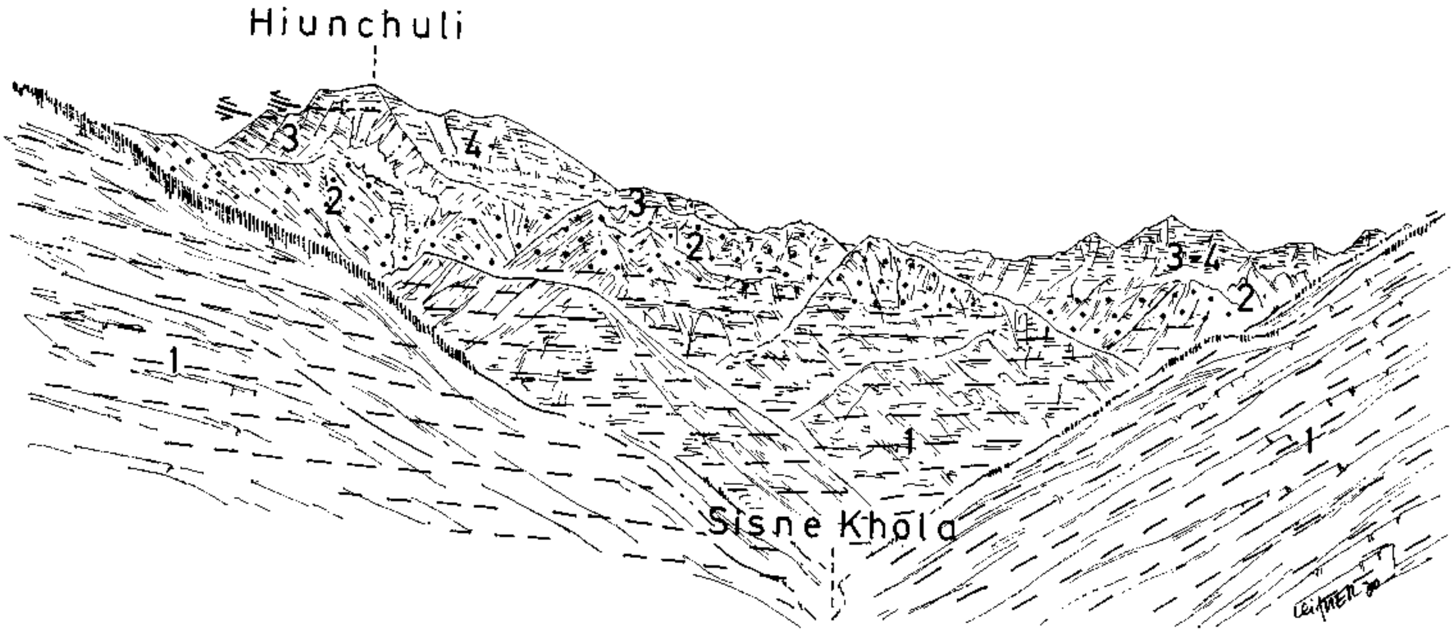

Fig. 29: View from the Sisne valley towards NNW to the Hiunchuli.
1. Chail
2. Nagthat
3. Blaini
4. Shali

Again Simla Slates follow grading at their top into grey slates and phyllites, probably Chandpurs. The total thickness of all these slates is about 500 *m*.

Above the slates there follows ca. 300 *m*. of slightly altered limestones, similar to those already described. Argillaceous intercalations in the highly deformed rock are partly phyllitic.

The limestone is overlain by quartzites and schists of the Chail Nappe.

The sequence between the Tal beds and the Chails belongs to the Rukum Nappe. It represents a normal succession, however, repeated by imbrication.

Pl. 1 shows that the great syncline (Jaljala Syncline, HAGEN 1959 a), which is occupied by the outliers of the nappes, borders against the Bari Gad Anticline. In the NE-limb of the Jaljala Syncline the Rukum nappe is again exposed. The slope SW of the Bari Gad is made by dark to bluish schistose limestones and dark phyllites which dip SW (G. FUCHS 1967, pp. 38—39). Most probably the Simla Slates, which are found in the bottom of the valley surrounding the occurrences of Tal, also belong to the Rukum Nappe.

The Rukum Nappe was studied again farther NW in the vicinity of Rukumkot. The tectonic situation is similar to the Bari Gad but in the mountain W of the village we have an undisturbed stratigraphic section from the Simla Slates up to the Tal Formation (see p. 25, Fig. 7, Pl. 3 [6]). This uninverted sequence of the Rukum Nappe lies upon the Tals of the Bari Gad Anticline, which is best exposed at Rukumkot. Above the Tal Formation of the Rukum Nappe follow Chails of Chail Nappe 2.

At Ratam, where the Sani Bheri crosses the range formed by the rocks of the Rukum Nappe, we find generally the same relations (Pl. 1, 3 [4]). The Tals of the Bari Gad Anticline are overthrust by the SW-dipping Simla Slates. However, the succeeding younger formations are more disturbed than at Rukum: The Tal Formation is overlain by the Blaini-Shali sequence which is already rather disturbed. Such internal imbrications become even more important at the western end of the Rukum Nappe in the Thulo Bheri region. It is not easy to give a definite picture of the very complicated structure from only a few traverses. Three wedges are discernible (Pl. 1, 2, 3 [2, 3] see also p. 27).

The Rukum Nappe again commences with the Simla Slates in the N, which have overridden the Tals of the Bari Gad Anticline. Probably this has caused the dragging of Shali Slates of the Surtibang Syncline over the Tals of the Bari Gad Anticline. Within the Jaunsars, which follow the Simla Slates, there is a SW-dipping wedge of Shali Dolomite in contact with a plane of movement, which dips WSW. The rocks following form a syncline. The Shalis W of the valley lie horizontally or dip gently W. Going SW in direction to Jajarkot we cross Shalis and Riri Slates which dip N and form imbricate structures. Within these highly disturbed rocks we even find a wedge of Tal quartzite.

These imbrications which we have described are directed SW and moved over the partly inverted Tal zone, which is the continuation of that observed SW of Rukumkot and at Ratam. Just N of Jajarkot the steeply dipping Tals are overthrust by the Chail Nappe (Pl. 1, 3 [1, 2], Fig. 39).

Without a detailed areal survey of so complicated a region it is impossible to give a definite explanation of the structure. But from what we know at present it seems that here too the Rukum Nappe consisted of a succession from Simla Slate to Tal like at Rukumkot when it was thrust over the Tansing Unit. Later strong compression would have forced the succession of the Rukum Nappe to become folded and would finally sheared it into wedge-like bodies. These movements were directed towards S and apparently also to the N. Probably the semi-window of the Bari Gad—Bheri region was produced by the late-orogenic movements. We think that the structures described are related to the upwarping, which has brought lower tectonic units to the present level of erosion (see Pl. 2).

To continue the description of the Rukum Nappe it should be noted that the Tal zone ends N of Jajarkot (Pl. 1), and the Chails immediately overlie the Shali Dolomite.

In the region of the Barikot Khola the general dip is W. The Simla Slates which form the base of the Rukum Nappe attain great thickness. They are immediately overlain by the Tal Formation. On p. 28 we have given reasons, why we think that this is an original unconformity.

NE of Khurpa the Tals are overthrust by metamorphic carbonate rocks of the Jangla Group (Chail Nappe 2). In the region of Barikot Fuchs found a succession of unmetamorphosed and fossiliferous Tertiary beds between the Tal Formation and the overthrust metamorphic rocks of the Chail Nappes (Figs. 30, 31, 32). The youngest beds, the Dagshais (Lower Miocene), indicate that the Chail Nappes were overthrust no earlier than the Lower Miocene. Furthermore the Tertiary rocks establish a thrust displacement of at least 90 *km.* for the Chail Nappe.

From the Barikot Khola to the area N of Jumla we were able to trace a young fault line, along which the eastern block was lifted relative to the western one. From S of Maina to Ranga Chauthaka this fault forms the boundary between the Rukum Nappe and the higher Chail Nappes (Fig. 31, 32). NE of Ranga Chauthaka the Tals and Tertiary rocks disappear, and the dolomites of the Bhalu Lekh (Chail Nappe 1) come in contact with the fault.

The Simla Slates, which evidently overlie the Shali Slates and Shali Dolomites of the Surtibang Syncline, dip under the Shali Dolomite of the Bhalu Lekh (Chail Nappe 1).

In the inner Ranga Gad the Simla Slates of the Rukum Nappe and the Shalis of Chail Nappe 1 are folded together along an axis (10/35) which lies across the regional strike. This folding locally brings the Simla Slates on top of the Shali Dolomite. But in the Thulo Bheri valley the roots of the Rukum Nappe are completely cut off (see p. 76). We think that the zone of Simla Slates which was crossed in the Sisne valley and S of Mayang (G. Fuchs 1967, p. 53), represents the root zone of the Rukum Nappe. On p. 32 we discuss the possibility that the Rukum Nappe developed from a fold.

We have no evidence for the existence of the Rukum Nappe in the eastern part of the mapped area (Pl. 1).

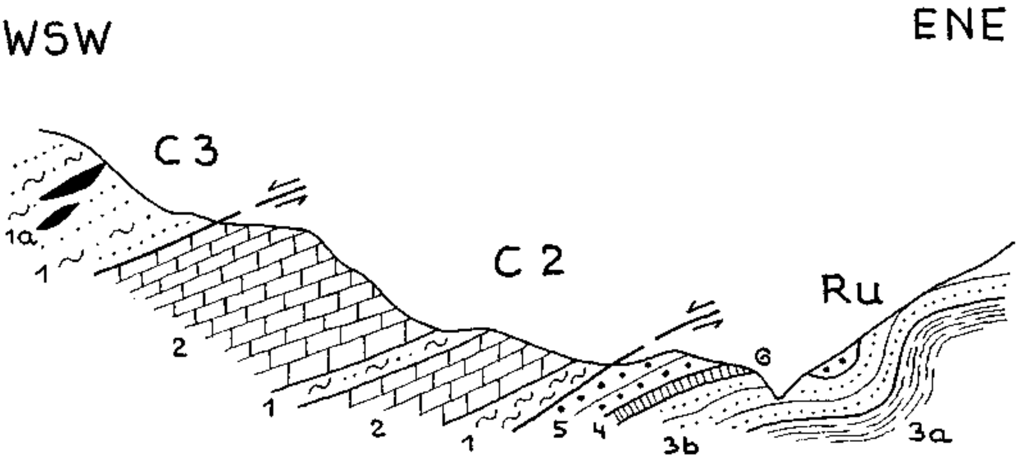

Fig. 30: Section across the Barikot valley showing the Chail Nappes (C 2, C 3) overthrust to the Tertiary beds of the Rukum Nappe (Ru).
1. Chail
1a. Metadiabase
2. Jangla Group (Nagthat-Blaini)
3a. Tal shales
3b. Tal quartzites
4. Subathu (Eocene)
5. Dagshai (Lower Miocene)
Length of section ca. 3·5 *km*.

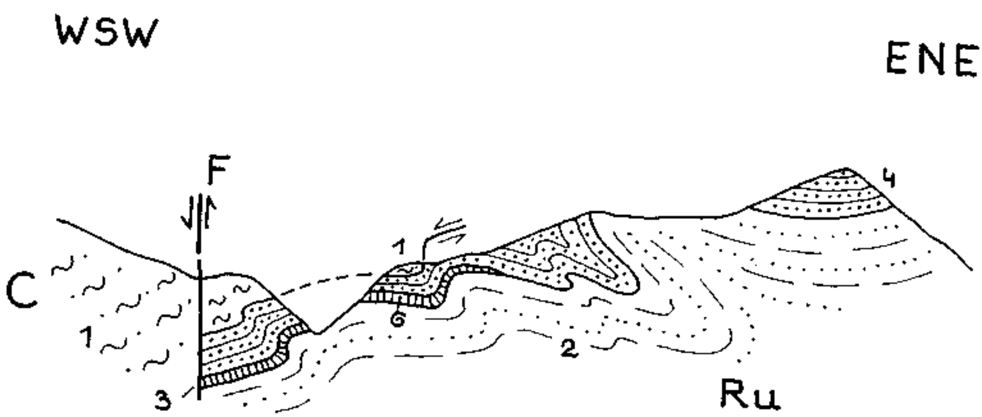

Fig. 31: Section N of Maina, showing the thrust contact of the Chail-(C)-and Rukum Nappes (Ru).
1. Chail
2. Tal
3. Subathu (Eocene)
4. Dagshai (L. Miocene)
F = Faults

IV. The Chail Nappes

G. Fuchs (1967) emphasized that the Chail Nappe, found by G. E. Pilgrim and W. D. West (1928) in Simla, is represented nearly throughout the Himalayas. Our 1967 expedition has shown that the Chail Nappe splits into three subsidiary thrust sheets in the Thulo Bheri—and Jumla regions of West Nepal. From our present, admittedly incomplete knowledge of the geology of the Himalayas, this seems exceptional. It is possible that the splitting into three nappes is related to the exceptionally thick development of the Jangla Group in the area mentioned (Nagthat-Shali). The succession of ca. 4000 *m.* which contains a number of rather rigid rock units, overlying the Chails in that area, has certainly influenced the tectonics.

The Chail Nappe has a large area of outcrop in the eastern part of the mapped area. It appears as an uniform nappe composed entirely of the Chail Formation. The zone of ca. 35 *km.* breadth, consisting only of Chails in the Pokhara-Kali Gandaki region, is strikingly monotonous. However, there is one exception. At Nuwakot at the southern boundary of the Chail Nappe we find a succession of 800 to 1000 *m.* of Nagthat quartzite lying on the Chails (Pl. 1, 3 [20] see also p. 70).

Pl. 1 and the sections 14—17 (Pl. 3) show that the rocks dip below the Crystalline Nappe at a moderate angle, but further south their bedding planes are horizontal or show variable, predominantly gentle dips.

The Chail Nappe has not been examined between the Kali Gandaki and the section Mayang—Jangla Pass (G. Fuchs 1967).

The Chail Formation still has an enormous thickness in the latter section (Pl. 1, 3 [8]). On our traverse in 1963 we first met the younger formations overlying the Chails (G. Fuchs 1967, pp. 57—59). In this region also the splitting into three nappes can be well studied.

Overlying the thick Chail Formation we find the sequence Nagthat—Blaini—Shali Dolomite—Shali Slate—phyllites and calc schists—calc-mica schists. The latter represent the Upper Shali Limestone (see G. Fuchs, 1967, pp. 57—59).

A few meters of quartz phyllite (Chail) mark the beginning of Chail Nappe 2. Again thick calc-mica schists follow.

At the Jangla Pass Chail quartzite overlies the calcareous rocks. It represents Chail Nappe 3 which is overthrust by the Lower Crystalline Nappe.

Pl. 1 shows that the succession of Chail Nappe 1 attains an enormous outcrop area towards the W forming all the southern and central parts of the Hiunchuli range and the Bhalu Lekh.

Chail Nappe 2 continues NW. In the area S of Dunaihi it shows a complete stratigraphic succession from Chail to Shali, which is identical to that of Chail Nappe 1.

Chail Nappe 3 consists only of the Chail Formation.

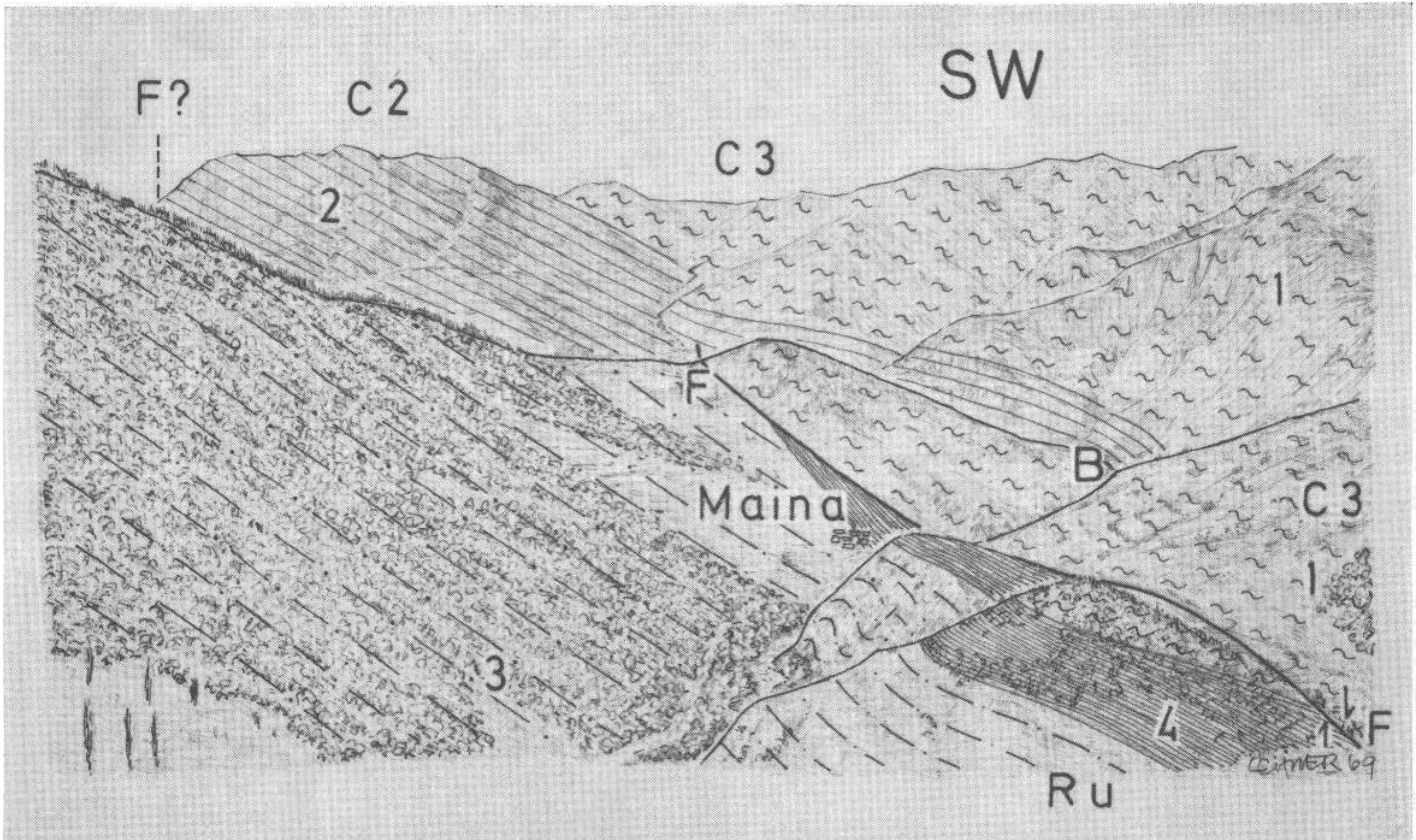

Fig. 32: The area Maina-Barikot seen from NE. Along the fault (F) the Rukum Nappe (Ru) abuts against Chail Nappe 2 or 3 (C 2, C 3). 1. Chail, 2. Jangla Group (mainly Blaini), 3. Tal, 4. Subathu (Eocene) and Dagshai, B = Barikot

It can be seen from the map (Pl. 1) that the sedimentary successions of these tectonic units become reduced in the Jangla area (e.g. Chail Nappe 2). The younger formations show easterly dips, whereas the Chails of Chail Nappe 1 exhibit the normal NNE-dips. These features make it probable, that both the younger formations and the well-defined separate nappes do not continue ESE. In the E only one uniform Chail Nappe is to be expected. *)

1. Chail Nappe 1

By comparison with the higher nappes the lowest unit seems to have been thrust no great distance and therefore has a more parautochthonous character. It may therefore be disputed, whether it should be termed a nappe. We could call it a wedge, but as it becomes a part of the uniform Chail Nappe towards the E, it appears to be simpler to use the terms Chail Nappe 1, 2, 3 for the subsidiary sheets of the Hiunchuli area.

We have already mentioned that Chail Nappe 1 outcrops over a wide area towards the W. It is very interesting that the lower formations disappear if we follow the southern boundary of the nappe to the W. The Chails must end somewhere W of the Sisne valley. The Nagthats disappear in the Jaldi Gad. Whereas the Blainis are very thick in the Thulo Bheri valley, Blainis are virtually absent in the detritus along the Shib Khola, separated from the other valley by only one ridge.

Also along the Ranga Gad SW of the Bhalu Lekh, only Shali Dolomite comes into contact with the underlying Simla Slates and the rocks are locally folded together (Fig. 8, see p. 80).

As no lithologic changes are visible westward within the formations, we think that the lower formations of Chail Nappe 1 are cut off by tectonics. This means that the thrust plane at the base of the nappe has cut the sedimentary succession obliquely to the stratigraphic boundaries, and the stratigraphic units were cut by a movement plane dipping to the E. In this connection we have already noted the shearing planes in the S-face of Hiunchuli (see p. 77). Late-orogenic movements along the base of the Shali Dolomite were effective too. They could explain these observations and the disappearance of the roots of the Rukum Nappe.

The Pls. 1 and 3 (3—6) show that the sedimentary sequence in Chail Nappe 1 is not much disturbed. This is especially true of the younger formations which form the high ranges E and W of the Thulo Bheri valley and are only slightly folded. There is a little bit more folding and some imbrication in the deeper part of the nappe exposed along the Thulo Bheri river (Fig. 11). We find one large culmination with several smaller anticlines, the cores of which are composed of Chails. The vergence is clearly directed towards SW.

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*) W. Müller-Jungbluth, geologist of the Austrian Dhaulagiri Expedition 1969, has found a reduced continuation of carbonate rocks in the area 20 *km*. NE of Dhorpatan. This is indicated in Pl. 1 and 2.

In the N Chail Nappe 1 generally dips beneath the Chail rocks of Chail Nappe 2. This tectonic boundary can be followed from S of the Jangla Bhanjyang across the Tali valley at Taligaon (Fig. 33, Pl. 6); at Palang it crosses the Thulo Bheri valley and was observed N of the villages Ila and Ukta (Fig. 34).

Chail Nappe 1 is terminated in the W by the young fault already mentioned on p. 80.

From the area of Jumla and Galwa T. HAGEN (1959 a) has reported windows of lower structural units surrounded by the crystalline rocks of the Kathmandu Nappes. He correlates the rocks of the windows with his Bajang Nappes and also with the Hiunchuli Zone (see HAGEN 1959 a, Fig. 3). The Bajang Nappes are identical to the Tejam Zone of HEIM and GANSSER (1939). From our recent observations in the Hiunchuli and Jumla regions it is clear, that even the lowest parts of the windows belong to the Chail Nappes. *)

In the Jumla window the division into three Chail Nappes was observed again. The conspicuous mountain range N of Jumla, composed of a thick succession of dolomites and limestones, represents Chail Nappe 1. The southern boundary is marked by the fault which we have observed in the Maina area. It brings the carbonate rocks of Chail Nappe 1 into contact with the Chail Formations of Chail Nappes 2 and 3 (Fig. 35). In the E, in the area of Lorpa, it can be seen that the carbonate rocks dip towards the E beneath Chails and rocks of the Jangla Group of Chail Nappe 2.

The southwestern parts of Chail Nappe 1 are virtually unmetamorphosed, but even there the stronger internal deformation, particularly of the carbonate rocks, indicates shearing and flowage to a degree not found in the Tansing Unit. To the E and towards the root zone metamorphism increases (see p. 41). In the Jumla window the carbonate rocks of Chail Nappe 1 are only slightly metamorphosed in contrast to the overlying rocks of Chail Nappe 2.

2. Chail Nappe 2

If again we start our description in the E, in the Jangla section, we find Chail Nappe 2 highly reduced, consisting of a few meters of Chail phyllite and some hundreds of meters of calc-mica schists (Shali; Pl. 1, 3 [8]). However, not far to the W, in the area S of Dunaihi we meet a complete stratigraphic succession from Chail to Shali (Pl. 1, 3 [7], 5).

Farther to the NW the younger formations become much reduced and disturbed (Pl. 3 [3—6] Figs. 36, 37). The Chail Formation is very thick.

Though disturbed, the section Ukta—Chaurkot still shows an unbroken sedimentary sequence from Simla Slate to Shali Dolomite (Pl. 3 [3], Fig. 34).

*) In 1969 on a traverse from Almora to Bageshwar and Baijnath G. FUCHS found that the carbonate zone of the Sarju Valley belongs to the Chail Nappes. As the named zone continues to Pithoragarh, there is the possibility that all the carbonate rocks of the Pithoragarh-Tejam region are part of the Chail Nappes. In this case T. HAGEN would be right in his correlation.

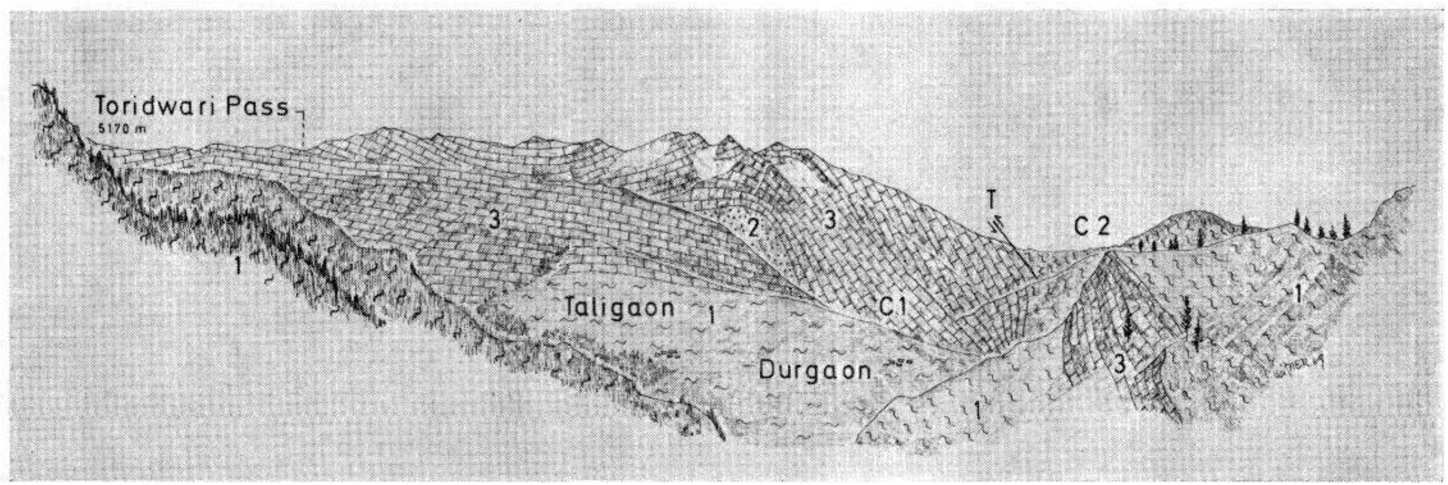

Fig. 33: The northeastern Hiunchuli group seen from the Tali valley. Chail Nappe 1 (C 1) dips beneath Chail Nappe 2 (C 2).

1. Chail
2. Nagthat
3. Blaini-Shali

T = Thrust

Along the Maina-Jumla fault the Chails abut against the rocks of the Crystalline Nappe. The younger formations, mainly Blainis and some calc schists, form distorted lenses between the Chails of Nappe 2 and those of Nappe 3. They can be traced through Munigaon to the area E Lorpa where they become thicker again (several hundred meters). Fig. 35 shows the Chails overriding the Shalis of Chail Nappe 1, and overlain by the rocks of the Jangla Group. These in turn are overthrust by the Chail Formation of Chail Nappe 3.

From Munigaon to Lorpa the Chails at the NE and N of the fault belong to Chail Nappe 2.

Near the roots of the Chail Nappes we were able to establish with a high degree of certainty to which of the nappes a given rock assemblage belonged. This is much more difficult in the outliers in the SW. But even there the subdivision of the Chail Nappes is evident.

Chail Nappe 1 seems to have moved over the root zone of the Rukum Nappe but not very far, and it thus appears to be parautochthonous.

Rocks of the Jangla Group are known from several localities; there make it possible to subdivide the Chail Nappe. Apparently all these occurrences belong to Chail Nappe 2 and are overthrust by Chails which are followed by the rocks of the Crystalline Nappe without beds of the Jangla Group between. This seems to be characteristic of the highest Chail Nappe (see pp. 90—93).

In the Barikot-Khurpa area the Tertiary and Upper Mesozoic beds are overthrust by rather disturbed rocks of the Jangla Group, mainly Blainis and Nagthats, and some intercalated Chail phyllites. The overlying Chails belong to Chail Nappe 3 (Fig. 30—32).

Within the Chails we found a zone of Jangla Group in the area S of Rukumkot. These rocks together with the underlying Chails represent Chail Nappe 2. They reappear S of the Jaljala Syncline (Pl. 1, 3 [6—8]).

The area N of Sallyana is of particular interest (Pl. 1, 2, 3 [1]). In an anticlinal structure which was subject to minor folding, a great thickness of carbonate rocks appears below the Chails of Chail Nappe 3. The core of the anticline is formed by pure quartzite, and altered tuffs and volcanic rocks (Chail). These are overlain by Blainis, and some intercalated Chail schists, then Shali Dolomite follows. The Shalis attain a great thickness N of Sallyana and at the mountain Kumak. They thin again within a short distance and apparently form distorted lenticular or block-like bodies. They dip beneath the Chails of Chail Nappe 3. The latter form synclines folded into the underlying younger rocks of Chail Nappe 2 (Fig. 38).

The eastern and western continuations of this tectonic window are not explored.

As for the metamorphism of Chail Nappe 2, the differences are less than in Chail Nappe 1; however, in this case too there is an increase in metamorphism near the root zone. The metamorphism is generally higher than in Chail Nappe 1.

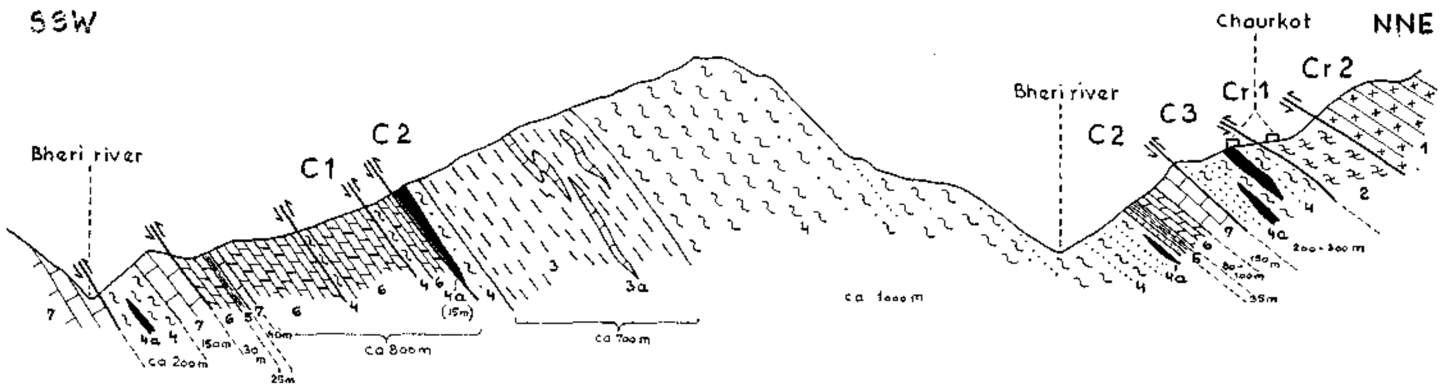

Fig. 34: The section Chaurkot-Ukta shows the roots of the Chail- und Crystalline Nappes.

1. Garnet-kyanite gneiss, migmatites, and marble of Upper Crystalline Nappe (Cr 2)
2. Phyllite, mica schist, paragneiss, and quartzite of Lower Crystalline Nappe (Cr 1)
3. Simla Slates

3a. Layers of limestone

4. Chail: phyllite, arkose schists, and quartzite

4a. Metadiabase

5. Dark slates and phyllites
6. Varicoloured series of calc phyllites, dolomite, limestone, and quartzite (Blaini)
7. Shali Dolomite

Where possible thicknesses are given in brackets. Length of section ca. 9 *km*.

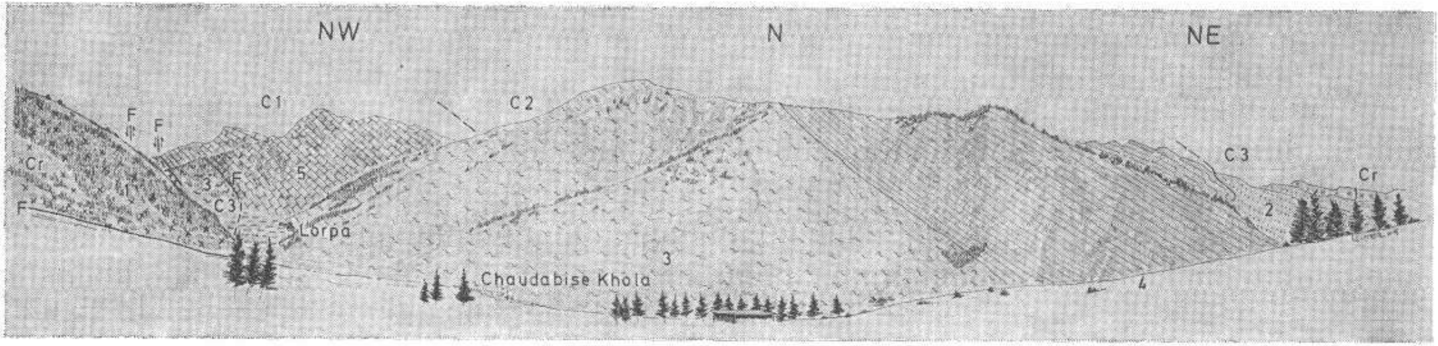

Fig. 35: The eastern end of the Jumla window in the Chaudabise valley at Lorpa. The Chail Nappes (C I, 2, 3) dip beneath the Crystalline Nappe (Cr). The Maina-Jumla fault (F) displaces the rocks of the Chail Nappes against those of the Crystalline.

1. Crystalline
2. Chail, quartzites
3. Chail, phyllites
4. Jangla Group, mainly Blaini
5. Shali carbonate rocks.

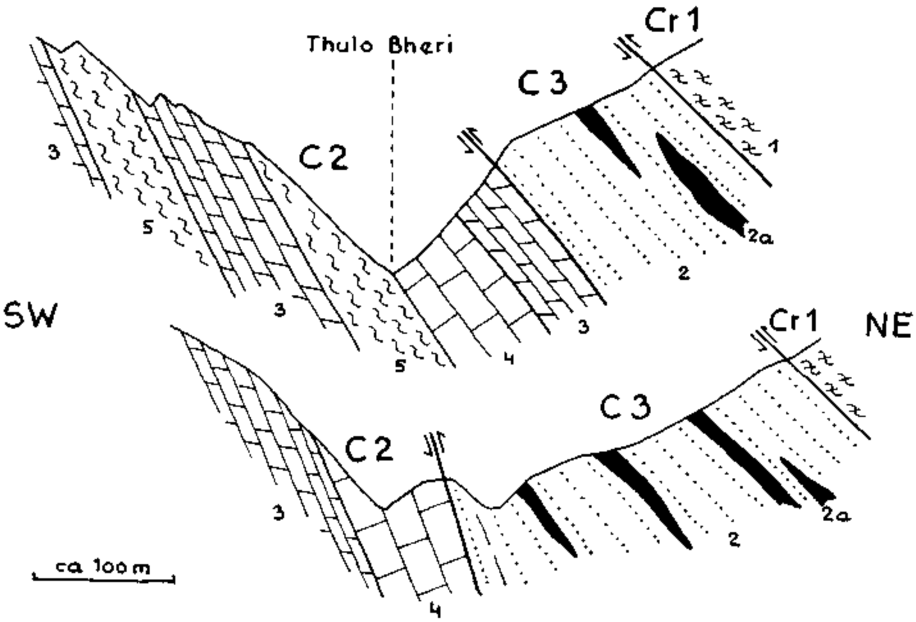

Fig. 36: Sections across the Thulo Bheri valley, NW of Dunaihi. Chail Nappes 2 (C 2) and 3 (C 3) dip beneath the Lower Crystalline Nappe (Cr 1).

1. Phyllites, mica schists, quartzite etc.
2. Chail quartzites
2a. Metadiabase
3. Calc-mica schist
4. Dolomite
5. Dark phyllites and slates

3. Chail Nappe 3

In contrast to the lower Chail Nappes which consist of uninverted stratigraphic successions the highest Chail Nappe is composed entirely of the Chail Formation with the exception of the Gondwanas S of Lawamjula.

In the Jangla area Chail Nappe 3 is represented by the quartzites of the pass and NE from it. Above the quartzites follow paragneiss and mica schists of the Lower Crystalline Nappe (see G. Fuchs 1967, pp. 59—61). Towards NW the quartzites are cut off in the lower Jairi valley. There the calc-mica schists of Chail Nappe 2 come into contact with the Lower Crystalline Nappe. Near Dunaihi, however, the Chail Nappe 3 comes in again and may be traced via Tibrikot—Balangra Pass—Kalgaon—Chaurkot to the area of Talphi. Thus the Chails of this nappe form a nearly continuous zone overlying the Jangla Group of Chail Nappe 2 and dipping beneath the Lower Crystalline Nappe.

The Chail Formation at and around Jumla belongs to Chail Nappe 3. It is found immediately below the Crystalline. In the N and E it is terminated by the Maina-Jumla fault. Situated at the downthrown side it abuts against carbonate rocks of Chail Nappe 1 or Chails of Chail Nappe 2 respectively.

From S of the Chakhure Lekh to the region of Khurpa probably all the Chails belong to Chail Nappe 3. At Jajarkot (Fig. 39) no division can be made, but S of Rukumkot Chail Nappe 3 is represented by the Chails overlying the band of Jangla Group.

S of the Jaljala Syncline the Chails immediately underlying the Dhaulagiri Limestone down to the top of the Jangla rocks are Chail Nappe 3.

Going to the W, all the Chails of the Marma Khola region and of the area Sallyana—Lawamjula represent Chail Nappe 3. They surround the tectonic window N of Sallyana, where Chail Nappe 2 is exposed (Fig. 38).

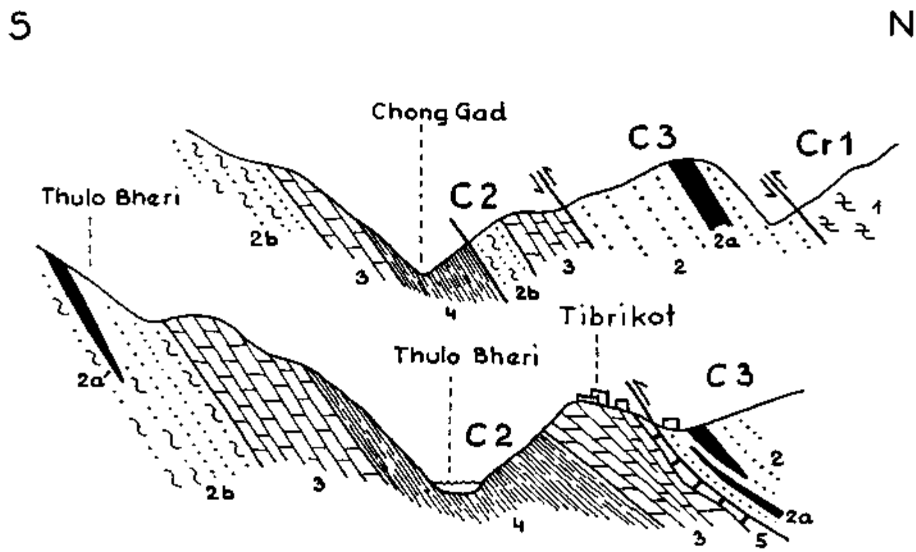

Fig. 37: Sections at Tibrikot, Chail Nappes 2 (C 2) and 3 (C 3) dip beneath the Lower Crystalline Nappe (Cr 1).
1. Crystalline
2. Chail quartzite
2a. Metadiabase
2b. Chail phyllites and quartzites
3. Calc phyllite, limestone, and dolomite (mainly Blaini)
4. Black phyllites and slates
5. Dolomite

Length of sections ca. 2·5 *km*.

The Gondwana rocks S of Lawamjula seem to belong to Chail Nappe 3 or a subsidiary unit in this position. This unit was thrust from the northernmost part of the Lower Himalayan Basin, from an area very near to the Crystalline, and was possibly deposited on the latter. The terrestrial Gondwanas are additional evidence for a land barrier separating the Lower Himalayas from the Tethys.

As to the metamorphism, the rocks of appropriate composition, are generally in a phyllitic state. However, there are slight regional differences. S of Lawamjula the beds are less metamorphosed, whereas S of the Jaljala

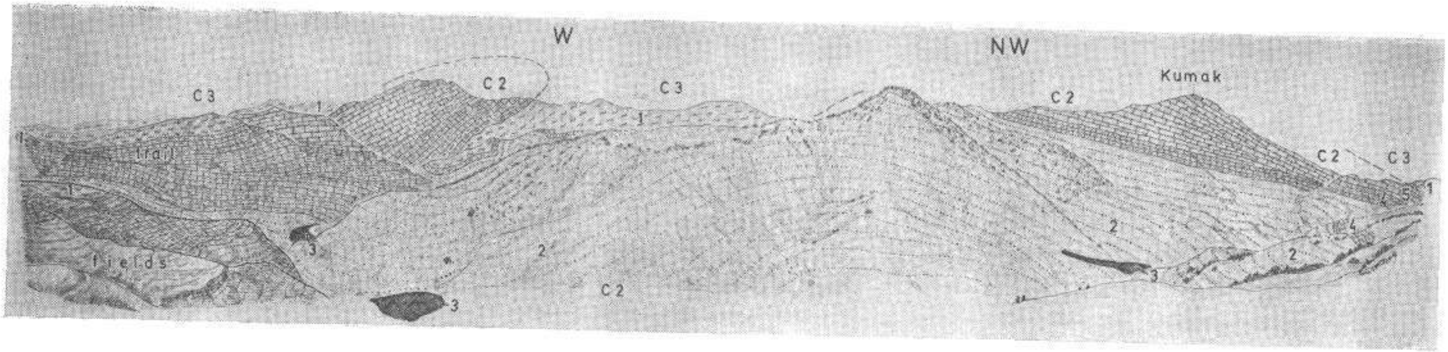

Fig. 38: View of the Kumak area, N of Sallyana. Chail Nappe 2 (C 2) forms a tectonic window, surrounded by Chail Nappe 3 (C 3).

1. Chail, phyllites and quartzites
2. Chail, quartzite
3. Metadiabase and greenschist
4. Blaini
5. Shali

Syncline or in the Marma Khola area stronger metamorphism of the rocks is indicated by growth of garnet, hornblende, and small biotite. In the last mentioned region the metamorphism appears to increase upwards into the overlying Lower Crystalline Nappe.

In our paper 1967 we rejected the idea of a gradation from the Daling (Chail) phyllites into the gneisses of the overlying Crystalline. The uninverted stratigraphic sequences of Chail Nappes 1 and 2 are evidence against a huge recumbent fold comprising the whole Chail complex. Chail Nappe 3, however, is composed entirely of the Chail Formation, but for the Gondwana rocks mentioned above; thus an inversion of this thin structural unit cannot be excluded. The possibility exists that the Chails of Chail Nappe 3 were originally in connection with the rocks of the Lower Crystalline Nappe. Locally such connections could have been preserved and could explain the observed gradations. In most cases the connection has been lost and we are still of the opinion that Chail Nappe 3 and the Lower Crystalline Nappe should be considered as two separate structural units.

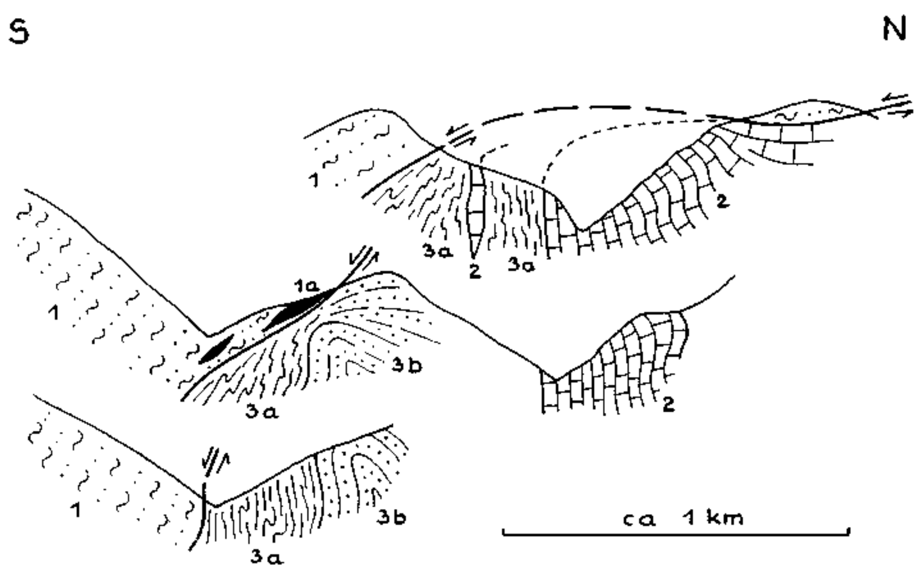

Fig. 39: Sections through the area N of Jajarkot. The northern thrust contact of the Chail outlier of Jajarkot; Tals and Shalis of the Rukum Nappe are exposed in a semi-window.

1. Chail

1a. Metadiabase

2. Shali Dolomite

3. Tal
   a. shales, greywacke
   b. quartzite predominating

V. The Crystalline Nappes

In 1967 we introduced the name Crystalline Nappe to stress the regional character of that unit. It is found throughout the Himalayas. The crystalline complex was thrust over the units of the Lower Himalayas. The roots of this nappe form a continuous zone, the Central Crystalline Zone as termed by HEIM and GANSSER (1939). The southern parts of the nappe were subject to erosion, and are missing in areas of axial culmination. In synclines detached outliers are preserved. But the Crystalline Nappe may protrude to the S, close to the Tertiary Zone, in regions of axial depression (e.g. Kathmandu and East Nepal).

In contrast to T. HAGEN (1959, 1969) who divided the Crystalline complex into 5 Kathmandu Nappes and 3 Khumbu Nappes and even more structural units in NE-Nepal, we were able to distinguish only two units (1967).

The lower nappe is composed of a characteristic rock assemblage, its metamorphism is of a lower grade, and evidence of retrogressive metamorphism is common (see pp. 45—46).

The upper nappe is quite distinct from the lower, migmatites, and garnet and kyanite bearing rocks are predominant. Marbles containing calc-silicates are very important. Diaphthoritic reactions are not observed. This higher complex is much thicker than the lower unit. The metamorphism dies out in the overlying basal formation of the Tibetan Zone.

FUCHS thinks that these two units are represented all along the Himalayas.

1. The Lower Crystalline Nappe

The easternmost section along which we have crossed this unit is that along the Kali Gandaki (G. FUCHS 1967, p. 75). At Tatopani the quartzites and basic rocks of the Chail Nappe dip beneath phyllitic mica schists, which contain layers of carbonate rocks, quartzite, and gneiss. This unit represents the Lower Crystalline Nappe. The upper boundary of the thrust sheet crosses the valley at Dana, where higher metamorphic gneisses follow.

To the NW the Lower Crystalline Nappe was studied in the surroundings of Tarakot (G. FUCHS 1967, pp. 59, 62—66). It is of interest that overlying the mica schists, quartzites, and gneisses, a sequence of carbonate rocks forms the top of the Lower Crystalline Nappe (1967, Fig. 24). Within these carbonate rocks the metamorphism increases towards the top.

From Tarakot the Lower Crystalline Nappe continues via Tibrikot—Balangra Pass—N of Kalgaon to Chaurkot. It is much tectonized and forms a thin basal sheet to the crystalline complex (Fig. 34, Pl. 1, 3). The nappe was traversed again 4 *km*. ENE of Munigaon. At Talphi it forms the basal parts of the Crystalline.

Also SW of the Maina-Jumla fault the Lower Crystalline Nappe is well-exposed from Munigaon to Jumla. WSW of Jumla its top, just below the Upper Crystalline Nappe, is formed by calc schists (10 *m*.) as at Tarakot.

When we climbed the Chakhure range from the S, we found the less metamorphosed rocks, typical of the lower unit of the Crystalline, overthrust onto the Chails.

Farther in the S in the Thulo Bheri section the outlier of the Crystalline Nappe of Jajarkot seems to consist entirely of the lower unit. The rocks, especially the black bituminous rocks, are reminiscent of the Jutogh series of Simla, which are equivalent in respect of lithology and structure.

The existence of the Lower Crystalline Nappe in the Jaljala section is doubtful; however, the Crystalline appears to be tectonically reduced.

Where the Sani Bheri river reaches the Thulo Bheri we found a wedge of crystalline rocks between the Tals of the Rukum Nappe and the Chails. The nature of this outlier is not quite clear; however, it seems to be a part of the nearby Crystalline Nappe, which was brought into its present position by later faulting.

2. The Upper Crystalline Nappe

The main part of the Central Crystalline Zone of the Himalayas is formed by the rocks of the Upper Crystalline Nappe. We take this unit as one complex. From our knowledge of numerous sections across the crystalline, we consider, that the carbonate rocks, which form bands within the gneiss, cannot be used as a basis for subdivision. We think that the subdivision given by Bordet et al. (1967) is of merely local significance.

We have described the sections along the Kali Gandaki, the Barbung Khola, and the Tarap Khola in G. Fuchs 1967 (pp. 73—78; 66—71; 71—73) to which we refer. For the most part the same relations were found in the section from Kalgaon along the Garpung Khola to the Kagmara Lekh (Pl. 1, 3 [4—6], Frank and Fuchs 1970, Fig. 9).

In the Chaurkot—Jumla—Chakhure Lekh area parts of the Upper Crystalline Nappe were studied, but not sections extending from the base up to the transition zone into the Tibetan Zone, as in the sections mentioned above. The superposition of the Crystalline Nappe upon the rocks of the Chail Nappes is very clear in that region (Pl. 1, 3 [1—2]).

The core of the Jaljala Syncline is occupied by an outlier of the Upper Crystalline Nappe, which directly overlies the Chails. The crystalline rocks of the Upper Crystalline Nappe are tectonically reduced, particularly in the southern limb of the syncline. But there is a thick development of Dhaulagiri Limestone, which belongs tectonically to the Upper Crystalline Nappe. This occurrence is of great importance as it shows that the Cambro-Ordovician formation which forms the base of the Tethys Zone may also be found far S of the Great Himalayan Range, overlying not the roots, but advanced parts of the Crystalline Nappe. The occurrence in the Jaljala region is about 60 *km*. SW from the southernmost parts of the Dhaulagiri Limestone of the Tibetan Zone in the Great Himalayan Range. However, the stratigraphic transition from the Crystalline to the overlying Dhaulagiri Limestone seems not to be preserved in the Jaljala Syncline; apparently it has been lost by differential movements. Pl. 1 and 3 (8) show that there is another smaller syncline SW of the main Jaljala Syncline. It consists only of Dhaulagiri Limestone. In the area mapped there are no other outliers of the Crystalline Nappe, but from Garhwal or Simla in the NW, and eastern Nepal, Sikkim, and Bhutan in the E we know that the Crystalline Nappe extended far to the S, it may even have reached the zone of the Siwaliks.

VI. Tectonics and Fabric

The measurements taken along our routes are not sufficiently numerous to give a structural map without gaps. Nevertheless, there are some general features which emerge from this preliminary survey. In contrast to the lower tectonic units *), in the Chail Nappes the B-axes which are associated with metamorphism (folds, lineations, preferred orientation of minerals etc.) show predominantly NE-directions, that is across the regional strike. These transverse structures are older than the large anticlines and synclines following the regional NW—SE strike. The interference of older NE-axes with younger NW-axes has been often observed in the outcrops. It is remarkable that the younger folds already have the appearance of chevron folds which indicates lower hydrostatic pressure. The chevron folds have also caused slight post-recrystallization deformation in the fine structure of the rocks. The transverse structures are particularly frequent (see Pl. 1): S of Lawamjula, in the Chails S of Jajarkot, of the Thulo Bheri valley, and of the valleys S of Dunaihi. Only exceptionally are these structures of mappable dimensions, e.g. the quartzite fold in the Chail schists S of Tibrikot in the Thulo Bheri valley.

We think that the cross structures described above, which are also found in the Crystalline, are transported structures. They came into existence when the Chails became metamorphosed under the load of the overthrusting Crystalline Nappes. As their formation was synchronous with the nappe movements it may be assumed that they were formed further in the N. The structures seem to be caused by compression along B which becomes effective during the deformation of deeply buried parts of an orogen ($B \perp B'$ compare Plessmann 1962). The compression along B is compensated by the formation of transverse axes which are frequently observable in the outcrop, but insignificant for the large scale structures. This phenomenon is a characteristic of the metamorphic, deep-seated parts of an orogen and is also known from the Alps.

VII. Faults

In the previous chapters we had occasion to refer several times to younger movements which had deformed the nappe structures and are responsible for many tectonic complications. These younger movements were, however, still related to thrusting and therefore have been discussed above. However, there are dislocations which show no relation to the structure of the adjacent rocks and no dependence on the tectonic units. These are mostly steeply dipping disturbances and will now be described.

A most important fault line is that which we were able follow for 70 *km*. from S of Maina to N of Jumla (Pl. 1, 2, 3 [1—2]; Figs. 31, 32, 35). As it brings into contact rocks of very different resistence to erosion, it is a marked feature in the landscape. The fault was first encountered in the Barikot valley; however, it may continue towards the S. To the NNE it brings the Chails of Chail Nappe 3 in contact with the Tertiaries of the Rukum

*) The root zone of the Rukum Nappe seems to be an exception as in the Simla Slates of the Sisne valley older NE-axes interfered with younger NW—SE folds in the same way as in the Chail Nappes above.

Nappe and the dolomites of the Bhalu Lekh. The fault crosses the eastern Chakhure Lekh and turns to the NNW. There rocks of the Crystalline Nappe abut against the Chails. At Lorpa the fault splits into two. One fault continues in a western direction and dislocates Shalis of Chail Nappe 1 against Chail Nappe 3. The other swings to the SSW at Uthagaon. It brings into contact Chails of Chail Nappe 3 and rocks of the Upper Crystalline Nappe.

It may be clearly seen from Pl. 1 that the rocks to the W of the fault were thrown down. The amount of the displacement lies between 1000 and 2000 *m*.

Another system of transverse faults, although of much less importance, is found at Rukumkot (Fig. 7). The displacement is not so great here, but again the rocks W of the fault are moved down. Various rocks of the Rukum Nappe abut against the Tals or Shalis of the Bari Gad Anticline exposed around the village Rukumkot.

There are also some faults parallel to the strike of the rocks, e.g. SW of Riri Bazar, and in the middle course of the Andhi Khola.

The great transverse faults of the Thakkhola graben in the NE of the mapped area are described by T. Hagen (1959 b, 1968), C. G. Egeler et al. (1964), Bordet et al. (1964, 1967) and G. Fuchs (1964, 1967).

VIII. Review of the Tectonics

In our description of the tectonics of the mapped area in the previous chapters, we have made already some tentative remarks concerning the origin of certain structures. We now wish to interpret the tectonic pattern and to try to gain a general picture.

It now seems accepted, that thick rock units were thrust over considerable horizontal distances in the course of the Himalayan orogeny. The existence of nappes is not doubted but views concerning the style of deformation, the character and number of structural units are rather diverse. Hagen's (1959 a) nappe systems are very dissimilar to the tectonic pictures given by P. Bordet (1961, et al. 1964), or C. G. Egeler et al. (1964) who think that the formations of the Lower Himalayas belong to more or less one structural unit. K. S. Valdiya (1962 a) suggests the idea of one gigantic recumbent anticline, which was thrust over an unknown autochthonous basement. According to him the successions of the Lower Himalayas are all inverted, in contrast to the views of G. E. Pilgrim and W. D. West (1928), J. B. Auden (1934, 1937), W. D. West (1939), A. Heim and A. Gansser (1939).

We consider that only combined stratigraphic and structural investigations can solve the tectonic problems. Excellent work has been done by the geologists of the Geological Survey of India (Auden, Pilgrim, West) and Heim and Gansser (1939). We think that those workers on Nepal, who have neglected the geological results from the Central and NW-Himalayas were misguided and we disapprove of their hypotheses (Hagen, Bordet). We found that the stratigraphic and in part also the tectonic nomenclature from the NW-Himalayas can be used in Nepal very well (G. Fuchs 1967).

Inspite of local complications the structural units of the Himalayas can be traced laterally over enormous distances. The structure of Nepal is therefore in the main the same as that of the areas in the NW and in the E from that country. The tectonic units are discernible by means of their style of deformation and metamorphism, and their stratigraphic features; all these are very uniform in lateral direction. This reflects a pretectonic zonal arrangement parallel to the axis of the Himalayas. We have pointed this out in the Stratigraphic Part. This shows that it is rather unlikely that structural elements of the Indian Shield continued into the Lower Himalayas, as supposed by J. B. AUDEN (1935, 1937 a, 1951) and A. GANSSER (1964, pp. 248—249).

It should be stressed that the palaeogeographic history of an area, reflected by its stratigraphic record, is a most important influence upon tectonics.

According to FUCHS the southern parts of the Himalayas show a long continued continental (s. l.) history. Whatever the age of the formations may be, the basin of deposition was under the influence of the Indian Subcontinent for at least the main part of the Palaeozoic and all the Meso- and Cenozoic. The few marine incursions (Tal, Subathu) have deposited beds which are insignificant by comparison with the volume of the rest of the sequence.

The barrier which has protected the cratonic basin against transgressions from the Tethys and which is apparent from the distribution of the sedimentary rocks already showed the NW—SE direction of the much later Himalayas. Certainly this barrier was a significant structural element when it was involved in the Himalayan orogeny.

Naturally the formations of the Tibetan Zone, which were deposited in a marine environment, show tectonics different from the old consolidated barrier and the deposits of the Lower Himalayas. In the geosynclinal region of the Tethys a flysch zone was able to be formed when the movements of the Himalayan orogeny started. In the continental basin in the S a flysch trough apparently could not develop.

These few examples show that the palaeogeographic situation of the Himalayas was quite different from the Alps. Therefore attempts to correlate the tectonic zones of the Alps and the Himalayas as made by Ch. BIQ (1968) are regarded as rather fruitless. Better the Himalayas should be considered as a mountain range with an individual history and individual structure.

In 1967 we argued that the structural development during the Himalayan orogeny was determined by the former history of the region. This view was strengthened by our further work. We will try to give a tentative picture of the development of the Himalayan structures (see also FRANK and FUCHS 1970, Pl. 1, p. 576).

By comparison with the Alps the orogenic movements started rather late in the Himalayas. The break between the Eocene Subathus and the Lower Miocene Dagshais seems to mark the beginning of the Himalayan orogeny. However, the brackish Dagshais are found 90 *km*. N from the

Tertiary Zone in tectonic windows, which indicates that the main thrust movements did not occur before the Middle Miocene. At this time the molasse sedimentation of the Siwaliks started.

The barrier between the Lower Himalayas and the Tibetan Zone becomes one of the most significant and active structural elements, the Crystalline Nappe. Under the tectonic compression the thick sequences deposited S of the barrier were squeezed out to form the Chail Nappes. At the base of the Crystalline Nappe the Chail Nappes are passively dragged to the S. Chail Nappe 1 the lowest of these nappes seems to have been transported only a short distance, and therefore has a more parautochthonous character.

The depositional area of the Rukum Nappe shows stratigraphic features different from those of the Chail area in the N, and the northern parts of the Tansing Unit in the S. These differences in composition are probably why it was squeezed out to become a separate unit, which was dragged to the SW by the overriding higher nappes.

From its structural pattern, which is quite different from that of the nappes we conclude that the Tansing Unit is parautochthonous. It reacted to the compressive forces by folding and imbrication. However, some parts of the Tansing Unit were also dragged by the overriding nappes to the S, and so are allochthonous (e.g. parts of the Piuthan-Riri Anticline and of the northern limb of the Tansing Syncline were thrust to the centre of this syncline). The southern, frontal parts of the Tansing Unit are thrust onto the Tertiary Zone.

The Siwaliks, the molasse deposits of the Himalayas, are overriden by the inner zones of the orogen (see above). Their rocks lie in folds, which become more and more gentle towards the plains.

After the main thrust movements compressive forces were still effective. The nappes and their parautochthonous substratum were subject to folding, wedge-like deformation and the formation of reversed faults. The Jaljala Syncline, and the complicated structures along the Bari Gad Anticline, particularly in the Thulo Bheri valley, were formed then. The Piuthan-Riri Anticline and the synclines of the Mahabharat Range were further accentuated in this phase of deformation. In the synclines formed at that time we find the outliers of higher nappes, and in zones of upwarping the tectonic windows. It should be noted, that the movements were directed both towards the S and to the N as a simple response to compression, whereas the earlier movements were generally directed towards the S.

The tectonics of the Tibetan Zone in Nepal also show the peculiarity that structures are directed both towards S and N (see G. Fuchs 1967, Pl. 8). By comparison with the southern zones the Tibetan Zone is much less intensely deformed. However, according to A. Heim and A. Gansser (1939), and A. Gansser (1964) there are again highly deformed zones farther N (Indus suture line).

In the Plio-Pleistocene the Himalayas were lifted and became a mountain range. This is documented by the coarse detritus accumulated in the Upper Siwaliks. Differences in the amount of uplift led to the formation of axial culminations and depressions. But the deformation could also be disruptive and gave rise to faults. The amounts of vertical dislocation along such tectonic lines may be several thousand meters (e.g. Maina-Jumla fault, Thakkhola graben).

According to T. HAGEN (1959 a, 1960) the northern regions of the Himalayas were elevated first. The rivers made their way to the S and were dammed up to form lakes (Thakkhola, Kathmandu), when the southern ranges were lifted. They have since cut their way through the rising mountain ranges. So most of the great rivers of the Himalayas have their source in the Tibetan Zone and have to cross the Great Himalayan Range in deep gorges.

Earthquakes, raised river terraces etc. show that the Himalayas, the youngest and highest mountain range on earth, are still in motion.

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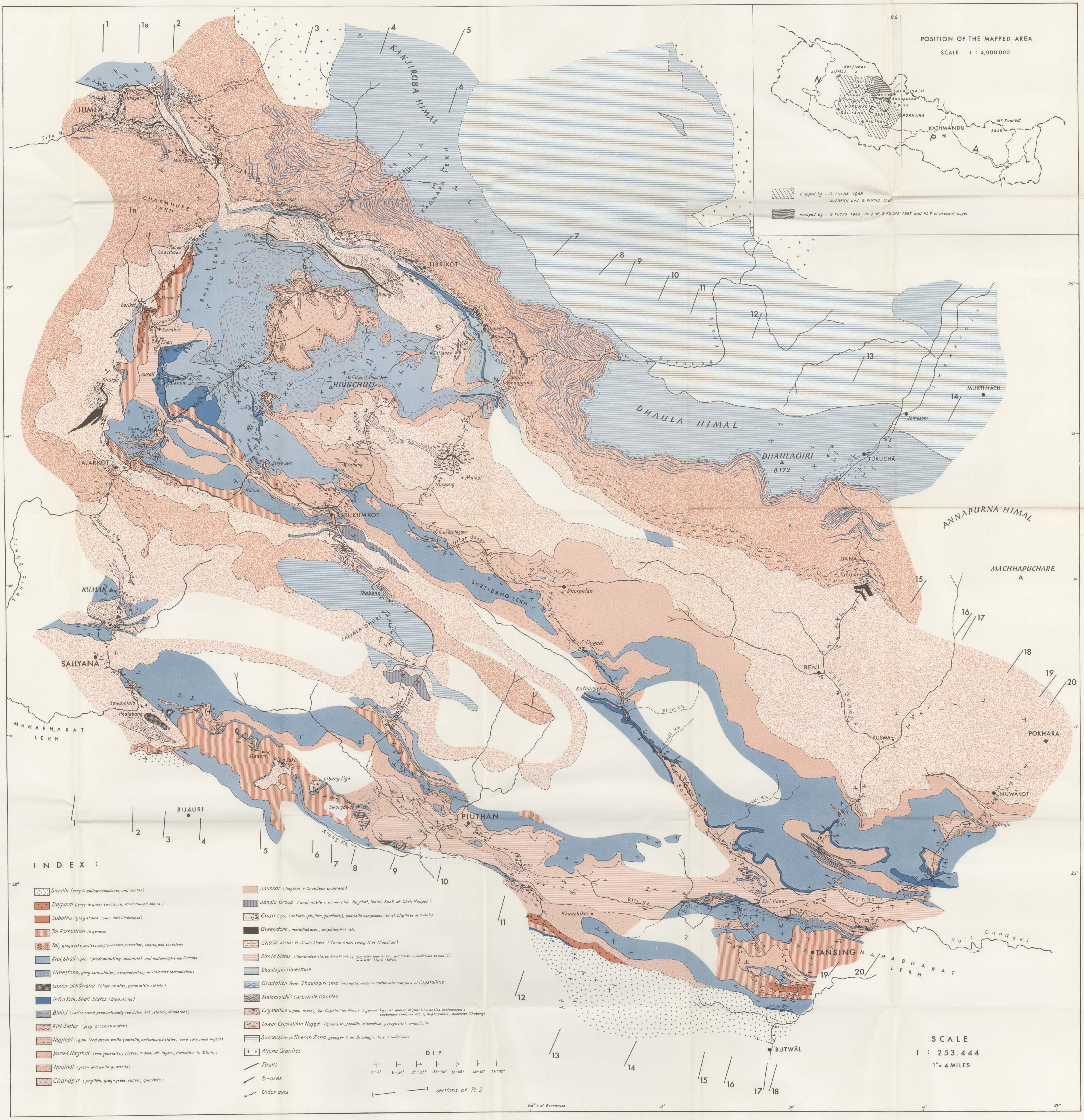
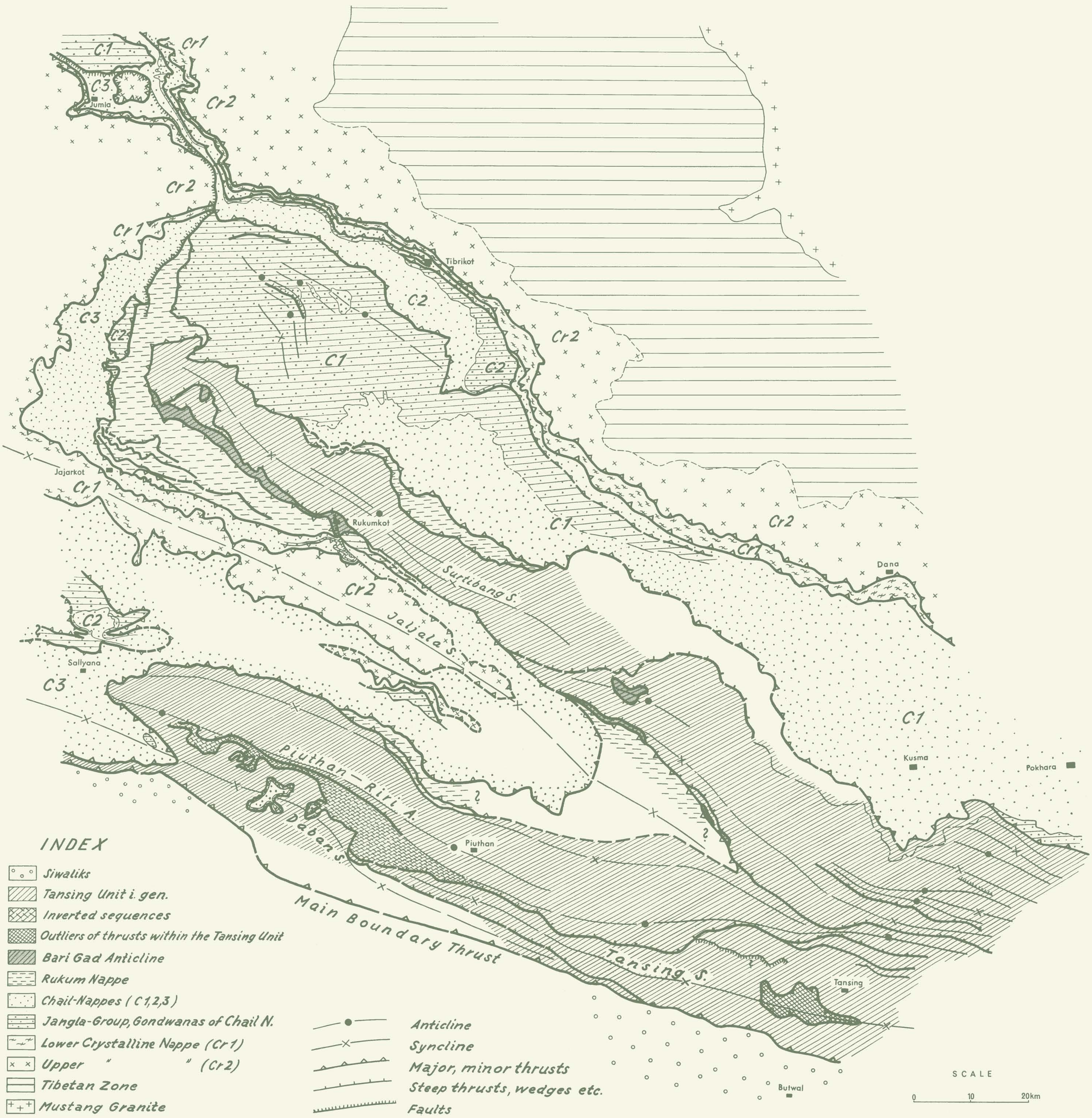
GEOLOGICAL MAP OF WEST-NEPAL BETWEEN THE RIVERS KALI GANDAKI AND THULO BHERI

mapped by G. FUCHS 1963, and W. FRANK and G. FUCHS 1967



Druck: Bundesamt für Eich- und Vermessungswesen (Landesaufnahme) in Wien

TECTONICAL MAP OF THE AREA STUDIED



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SECTIONS ACROSS W-NEPAL BETWEEN THE RIVERS KALI GANDAKI AND THULO BHERI

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Stratigraphische Tabelle des Himalaya – Stratigraphic Table of the Himalayas G. FUCHS, 1966.

Tafel 4

Denkschriften der Akademie d. Wissenschaften Band 113, 1967

ABKÜRZUNGEN		ABBREVIATIONS
Farben		**colours:**
bl.	blau	blue
d.	dunkel	dark
g.	grau	grey
ge.	gelb	yellow
gr.	grün	green
l.	licht	light coloured
r.	rot	red
schw.	schwarz	black
w.	weiß	white
Eigenschaften		**properties:**
bit.	bituminös	bituminous
dol.	dolomitisch	dolomitic
gli.	glimmerig	micaceous
k.	kalkig	calcareous
kiesel.	kieselig	cherty
m.	mergelig	marly
qzt.	quarzitisch	quartzitic
phyll.	phyllitisch	phyllitic
s.	sandig	arenaceous
schf.	schiefrig	shaly
ton.	tonig	argillaceous
Minerale		**minerals:**
Bi.	Biotit	biotite
Chlor.	Chlorit	chlorite
Disth.	Disthen	cyanite
Gr.	Granat	garnet
Hb.	Hornblende	hornblende
Mu.	Muskovit	muscovite
Ser.	Serizit	sericite
Staur.	Staurolith	staurolite
Gesteine		**rocks:**
Ark.	Arkose	arkose
Brekz.	Brekzie	breccia
C.	Kohle	coal
Congl.	Konglomerat	conglomerate
Dol.	Dolomit	dolomite
Gn.	Gneis	gneiss
Gra.	Granit	granite
Grw.	Grauwacke	greywacke
K.	Kalk	limestone
Kglschf.	Kalkglimmerschiefer	calcareous schists-micaceous marble
Ksil.	Kalksilikatgest.	limesilicate rocks
lms.	Kalk	limestone
M.	Mergel	marl
Ool.	Oolith	oolite
Phyll.	Phyllit	phyllite
Qzt.	Quarzit	quartzite
Schf.	Schiefer	shale, slate
sh.	Tonschiefer	shale
sl.	Schiefer	slate
Sst.	Sandstein	sandstone
Vulk.	Vulkanit	volcanic rock
B.	Schichten	beds
F, fn.	Formation	formation
S, s.	Serie	series
st.	Stufe	stage
Z.	Zone	zone
	Pflanzen	plant fossils
	Fossilien	animal fossils
	Stromatolithe	stromatolites
	Schichtlücken	stratigraphic gaps
	Transgressionen, Diskordanzen	transgressions, unconformities

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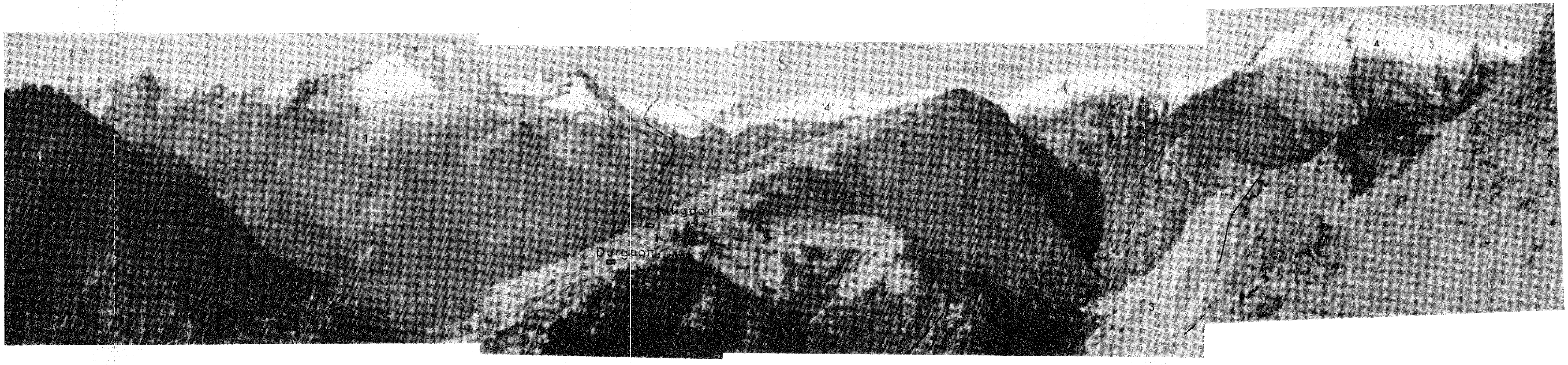
Pl. 5: Panorama view from SE of the Toridwari Pass towards Hiunchuli (in the W) and the Kanjiroba Himal (in the N).
1. Chail
2. Nagthat
3. Blaini
4. Shali

C 1, 2 = Chail Nappes 1, 2
Cr = Crystalline Nappe
D = Dhaulagiri Limestone



Pl. 6: The Tali valley seen from the N. Chail Nappe 1 dips beneath Chail Nappe 2.
1. Chail
2. Nagthat
3. Blaini to Shali
4. Shali

GEOLOGISCHE KARTE VON DOLPO UND DHAULA HIMAL Geological Map of the Dolpo region and the Dhaula Himal G. FUCHS, 1964

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Profile durch Dolpo und den Dhaula Himal

G. FUCHS 1966

Tafel 8

Sections through the Dolpo region and the Dhaula Himal

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Fig. 3: Outcrop of Infra Krol in the Andhi valley 14 *km*. SW of Syangja. Black shales and slates (1) alternate with marly shales and dolomitic marls weathering yellow (2). The Krol Dolomite (3) follows with a sharp sedimentary contact. It is partly laminated and shows karst weathering.