Jahrb. Geol. B.-A.	Band 120, Heft 2	S. 165—217	Wien, Dezember 1977

The Geology of the Karnali and Dolpo Regions, Western Nepal

By Gerhard FUCHS *)

With 13 plates and 36 figures

Schlüsselwörter
Tectonics
Stratigraphy
W-Dolpo
Karnali area
W-Nepal

CONTENTS

*) Address of the author: Dr. Gerhard FUCHS, Geologische Bundesanstalt Wien A-1031, P. O. B. 154.

Abstract

The traverse Surkhet—Dailekh—Mabu Pass—Tila Valley—Sinja Valley is described: The Tansing Unit overriding the Siwaliks along the Main Boundary Thrust, is rather reduced and the Chail Nappes, particularly the Crystalline Nappes are very much extended. The latter form a wide synclinorium. N of it the Chail Nappes are exposed in the Galwa Window. Within that window there are three or four subsidiary units, which correlate to those of the Hiunchuli area (FUCHS & FRANK, 1970).

The Central Crystalline is crossed along the Mugu Karnali on the approach to Dolpo.

In continuation to my previous work in the Tibetan Zone of eastern Dolpo (FUCHS, 1967), the western portions of the Dolpo Synclinorium have been investigated. A geological map and sections are presented as result of this first survey of this region. The Palaeo-Mesozoic succession of western Dolpo is very interesting, inasmuch as the area forms a link between Central Nepal and Kumaon. Several changes of facies within the Tibetan sequence may be traced along the strike, which is of great palaeogeographical interest. Generally the facies was shallower in western Dolpo and Kumaon than in the Thakkhola-Annapurna region. As to tectonics the Dolpo Synclinorium, which strikes NW-SE, shows folds along WNW-ESE-axes. The vergency of the folding may be NNE or SSW. Due to the rigid character of certain formations we find folds combined with reverse faults, wedge structures, and small-scale thrusts.

Zusammenfassung

Das Profil Surkhet—Dailekh—Mabu-Paß—Tila-Tal—Sinja-Tal wird beschrieben: Die Siwalik-Zone wird an der „Main Boundary Thrust" von der Tansing-Einheit überschoben, die stark reduziert ist. Die Chail-Decken, besonders aber die Kristallin-Decken besitzen hingegen große Ausdehnung. Letztere bilden ein weites Synklinorium. Nördlich desselben tauchen die Chail-Decken wieder empor und bilden das Galwa-Fenster. Innerhalb des Fensters sind drei bis vier Teil-Einheiten zu unterscheiden, die denen des Hiunchuli-Gebietes entsprechen (FUCHS & FRANK, 1970).

Die Kristalline Zentralzone wird beim Anmarsch nach Dolpo entlang des Mugu Karnali gequert.

Im Anschluß an meine frühere Arbeit in der Tibetischen Zone des östlichen Dolpo wurde nun der westliche Teil des Dolpo-Synklinoriums aufgenommen. Eine geologische Karte und Profilserien sind das Ergebnis dieser ersten geologischen Bearbeitung West-Dolpos. Die Schichtfolge dieses Gebietes ist insoferne sehr interessant, als West-Dolpo ein wichtiges Bindeglied zwischen Zentral-Nepal und Kumaon darstellt. Eine Reihe von paläogeographisch interessanten Faziesveränderungen lassen sich entlang des Streichens feststellen. Im allgemeinen ist die Fazies von West-Dolpo und Kumaon seichter als die des Thakkhola-Annapurna-Gebietes. Bezüglich der Tektonik zeigt das Dolpo-Synklinorium, das selbst NW-SE streicht, einen WNW-ESE-orientierten Faltenbau. Die Faltenvergenz ist entweder gegen NNE oder SSW gerichtet. Durch den starren Charakter bestimmter Formationen bedingt, begegnen wir einer merkwürdigen Kombination von Faltung, Aufschiebung, Schuppung und kleinräumigen Überschiebungen.

1. Introduction

In 1963 I started to work on the geology of the Himalayas in the region Kali Gandaki — eastern Dolpo of western Nepal (FUCHS, 1967). The Lower Himalayan area between the Kali Gandaki and the Thulo Bheri was studied in the course of my expedition in 1967 (FUCHS & FRANK, 1970). The Austrian Geological Himalayan Expedition 1973 had the aim to extend my geological work towards the W. In the Lower Himalaya the Galwa Window and the areas E of the Karnali were studied. In the Tibetan Zone the western part of the Dolpo Synclinorium was investigated, in continuation to my earlier mappings (FUCHS, 1967, Pl. 7, 8).

The Austrian Geological Himalayan Expedition 1973 was sponsored by following institutions: „Fonds zur Förderung der wissenschaftlichen Forschung“, „Bundesministerium für Wissenschaft und Forschung“, „Kulturamt der Stadt Wien“, „Österreichische Akademie der Wissenschaften“, „Österreichischer Alpenverein“, and „Rohöl-Aufsuchungs GmbH“. Their aid has made possible our research programme, for which I am very much grateful. To Hofrat Dr. A. RUTTNER, former head of the Austrian Geological Survey, I am highly indebted for giving me leave for my Himalayan studies.

Further I owe thanks to Mr. Herwig LECHNER (Vienna), who did the organization during field work, thus enabling Prof. Dr. J. B. WATERHOUSE (Toronto at that time) and me to concentrate on our scientific work. Miss E. KOHLMANN did the typing and the ladies and gentlemen of the „Zeichenabteilung“ of the „Geologische Bundesanstalt“ did the graphical work of this paper. To all of them I am very much obliged for their useful work. I am very much grateful to the anglist Dr. F. STEFAN (Vienna) for reading this paper.

2. The Lower Himalaya

The complicated structure and the barrenness of fossils make the Lower Himalaya one of the most problematic, but also most challenging regions.

I found that the sequence of litho-units worked out by AUDEN, PILGRIM and WEST and adopted in hand books of the Geology of India (PASCOE, 1959) may be applied for Nepal as well. The stratigraphy of the area recently investigated is principally the same as that described from the adjoining region (FUCHS & FRANK, 1970). Therefore I refer to this paper starting immediately with the description of the geology along the route Surkhet—Dailekh—Jumla and of the Galwa Window (Pl. 1, 2). The succession of rock units as well as the structure found in that region allow to correlate Western Nepal with the Kumaon Himalaya.

2.1. The Surkhet—Dailekh—Jumla Traverse

Along the footpath from Surkhet to Ranimatta first the rocks of the Siwaliks crop out. Green-grey, less frequently reddish, fine- to medium-grained, micaceous sandstones alternating with green, grey, or red shales and silty shales. These beds dip NNE to NE at medium angles.

After crossing the Main Boundary Thrust, which is not well-exposed there, Krol rocks follow the Siwaliks at an altitude of ca. 1250 m. The thickness of the Krol, 10 to 15 m, is very much reduced. They consist of blue to light grey, cherty limestones and dolomites, frequently laminated. Wavy laminations seem to reflect algal mats.

The Krols are succeeded by the Tal Formation comprising white, grey, green, unstratified or rather thick-bedded quartzites and quartzitic sandstones with shaley intercalations. The arenaceous rocks are fine-to coarse-grained and show brecciated layers. Some haematitic impregnations have been observed. The series, ca. 200 m thick, reveals lithology common in the upper portions of the Tal Formation.

The Tals dip towards NNE at an angle of 30—40° and are overlain by grey-green, fissile shales, which are 150 to 170 m thick. At the top of that series there is a 0.1 m thin earthy limonitic layer full of casts of gastropods and bivalves. Doz Dr. F. Steininger (Palaeontological Institute, University of Vienna) kindly has examined these fossils together with those collected from an equivalent horizon N of Masjem. In Fuchs & Frank (1970, p. 21, Fig. 6) this latter horizon was regarded as belonging to the Upper Tal Formation. The re-examination of the fossils, however, makes it more probable that these beds represent the Subathu.

Doz. Dr. F. Steininger gave the following determinations:

Gastropoda:

Turritellidae: Small to medium size forms showing 3 main revolving ribs and 1—2 secondary ones. There are two forms, one with smooth ribs probably belonging to *Turritella* and another with granulated ribs, which seems to belong to *Mathilda*. Both genera appear in the Cretaceous, the above forms are comparable to Palaeogeneous species.

Cerithidae: Moulds of whorl fragments of two forms: One probably belonging to the genus *Potamides*, which is known since the Eocene, and the other probably belonging to the genus *Tympanotonos* or *Ptychopotamides*, which commence in the Upper Cretaceous respectively in the Paleocene.

Muricidae: A steinkern of a small form showing 4 whorls, the last is large with traces of varices and a clear siphonal canal. Siphonostome forms generally appear in the Upper Cretaceous, small Muricidae are freqent in the Paleocene-Eocene.

Bivalves: Difficult to determine as neither the outer ornamentation nor the hinge are observable. Steinkerns of *Chama* sp. are frequent and allowed definite determination. The genus *Chama* begins in the Upper Cretaceous and is common in the Paleocene — Eocene.

Also freqent are moulds of sculpture fragments of a Mytilid either belonging to *Brachiodontes* (Jurassic — Recent) or *Arcomytilus* (Jurassic — Eocene).

Further were determinable: a medium size, distinctly costate *Cardium*, and internal moulds of Arcidae and various Veneridae.

As to stratigraphic position the composition of the fauna excludes a pre-Upper Cretaceous age and makes probable an Upper Paleocene — Eocene age.

This age of the fossil horizon makes it probable that the underlying shales also represent the Subathus. Lithologically they might be Lower Tals, but as they overlie the typical quartzites of Upper Tal, a Subathu age is more suggestive.

Above the fossil horizon follows the Dagshai Formation (Lower Miocene), about 500 m thick. It consists of thick-bedded, medium-grained, compact, grey-green sandstone regularly alternating with purple, silty and micaceous shales or shaley sandstones. The sandstones may contain also felspar. Argillaceous-calcareous patches, leaving holes in the sandstone after weathering, represent concretions or intraformational breccias.

The Krol—Dagshai succession is a normal stratigraphic sequence representing the Parautochthonous Unit (Tansing Unit).

After a few meters of mylonitized rocks a complex consisting of *basic metavolcanics* and predominating white, but also pink *quartzites* overlies. The basic rocks are medium- to coarse-grained and still show ophitic structure. They consist of euhedral and twinned augite, slender pseudomorphs of sericite-albite aggregates after former more basic plagioclase and secondary sphene, chlorite, and ore; albite and rare quartz fill interstices. In certain zones the schistosity is well-developed and the basic rocks are altered to chlorite schists. The quartzites connected with the metavolcanites are medium- to coarse-grained with local pebbly layers (components up to 8 cm), and current bedding. Sericite on the s-planes indicates that the metavolcanite-quartzite complex has undergone phyllitic alteration, whereas the underlying formations did not show metamorphism. The lithology resembles the Nagthats, particularly those of the Bhowali—Bhim Tal area (Kumaon), where the quartzites are similarly associated with basic volcanites (FUCHS & SINHA, 1974). There the Nagthats. however, belong to the Naini Tal Syncline of the Parautochthonous Unit, whereas the Ranimatta Nagthats, judging from their position and the phyllitic metamorphism, from part of the Chail Nappes.

The thickness of the quartzite—metavolcanic series is approximately 5000 m. They dip NNE at medium to steep angles and are followed by typical Chails.

The Chails comprise white to green, massive, or schistose quartzites, psammite schists, sericite-chlorite schists, silvery, grey, or green phyllites, and a few small boddies of basic metavolcanics.

Descending to the Kotila Khola one crosses intercalations of coarse-grained augen granite-gneiss. Thick granite-gneisses are exposed in the Kotila Valley in a synclinal position. These coarse-grained, porphyric rocks are foliated at varying degrees, thus the microcline phenocrysts commonly are deformed to augen.

Under the microscope the gneisses consist of perthitic microcline, plagioclase (6—10% An) *) the central parts of which are full of microlites of sericite and clinozoisite, quartz, muscovite, green-brown biotite, tourmaline, apatite, zircon, and ore. Chlorite, sericite, epidote-clinozisite, and sphene have grown during the alteration in greenschist facies, which both the Chails and the intrusive granites have undergone.

Veins of aplite or augen granite-gneiss penetrating the greenish phyllites and metasiltstones of the Chails show the intrusive character of the granites (Fig. 1, 2).

Fig.1: Dikes of pegmatites and granitoids penetrate the silty phyllites of the Chail Formation. Kotila Khola, S of Dailekh, Nepal.

From the Kotila Khola to Dailekh phyllites containing layers of metasiltstone predominate. There are rare and small lenses of greenstone or veins of aplitoid or pegmatoid rocks bearing tourmaline. S of Dailekh there is a body of pure quartzite in the Chail phyllites. All the rocks are horizontal or dip gently towards the S to SW.

N of Dailekh phyllites and intercalations of pure orthoquartzites alternate. The rocks are strongly deformed along N—S axes. Intercalations of graphite schist and blue crystalline limestone, a few meters thick only, may indicate a tectonic line separating individual units of the Chail Nappes. The dip is NE at medium angles.

*) All the plagioclase determinations were kindly done by Dr. A. Daurer (Geol. B.-A., Vienna), which enabled me to publish the paper without further delay.

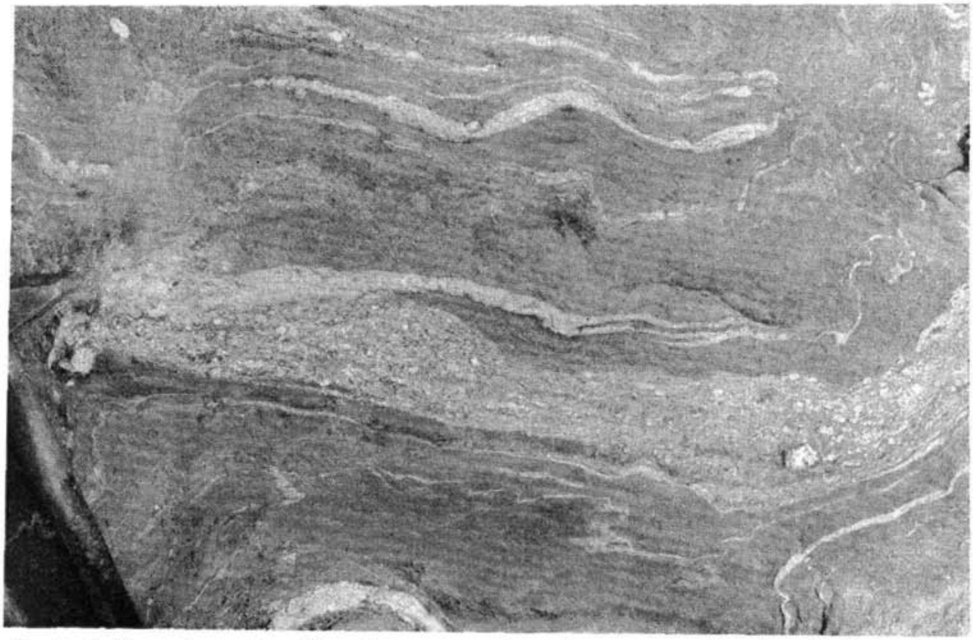


Fig. 2: Aplite veins and a dike of augen granite-gneiss penetrate the silty phyllites of the Chail Formation. Kotila Khola, S of Dailekh, Nepal.

To the N the Chails are succeeded by the typical assemblage of the Lower Crystalline Nappe: Black graphite schists, dark grey garnet phyllites, medium- to coarse-grained mica schists (± garnet, 1—3 mm), and light quartzites. These Jutoghs are approximately 700 m thick and are followed by 250—300 m of calc-mica schist and micaceous marble. The rocks contain phlogopite, muscovite, and biotite. The mineralogy and the content of garnet indicates a hiatus in grade of metamorphism between the Chails and the rocks of the Lower Crystalline Nappe.

Above the carbonate rocks again quartzites, mica quartzites, and coarse-grained, garnetiferous mica schists follow. Then augen granite-gneiss and garnetiferous two-mica paragneiss (ca. 150 m) signal the Upper Crystalline Nappe. An intercalation of Jutogh, 150—200 m thick, shows repetition in form of a scale.

Platey, banded, fine-grained gneisses, medium- to coarse-grained two-mica gneisses (± garnet) pass upwards into a series of carbonate gneisses and calc-mica schists. Besides prevailing carbonate this rocks contain plagioclase (23—29% An), quartz, phlogopite, muscovite, sphene, clinozoisite, tourmaline, apatite, zircon, and opaques.

These carbonate series dip steeply beneath a 500—600 m succession of thin- to thick-bedded, light grey quartzite to micaceous quartzite. Then mica schists, kyanite bearing paragneisses with pegmatoid lenses and aplites, and rare graphitic rocks follow. On the ascent to the Mabu Pass one crosses these paragneisses and migmatites, the quartzites, the platey laminated paragneisses to carbonate gneisses, and the metamorphic carbonates several times. The way of repetition of these rock units suggests SW-directed folding of a stratigraphic sequence (Pl. 2). The metamorphic grade of these rocks, however, increases in direction to the Mabu Pass. Kyanite, garnet, and pegmatoid lenses are frequent in the gneisses; the marbles and carbonate gneisses contain diopside, colourless hornblende, scapolite, phlogopite, zoisite, and epidote-clinozoisite. Veins of pegmatite are frequent.

The steep slope immediately S of the pass consists of augen granite-gneiss, garnet-kyanite gneiss, two-mica gneiss, and rare intercalations of graphite quartzite. Thick-bedded augen granite-gneiss overlies these rocks at the top of the Mabu Pass.

Descending to the N of the pass one finds augen granite-gneiss, migmatite, kyanite gneiss, and graphite quartzite. It is interesting that the graphite quartzites contain andalusite, porphyroblasts up to 4 cm long, which along their margins are altered to fuchsite.

In the area around Dillikot rather homogeneous, medium- to coarse-grained two-mica granite-gneiss crops out. Muscovite prevails in the light rock. Generally the granite-gneiss is non-porphyric, but sporadic phenocrysts of microcline (up to 8 cm) have been observed. Locally one finds some garnet or tourmaline.

The north-eastern dip S of Dillikot turns to E, so the underlying paragneiss — migmatite series crops out several times beneath the granite-gneiss or augen gneiss along the trail from Dillikot to the N.

Fig. 3: Augen granite-gneiss. Ruru Khola, Nepal.

Up the Ruru Khola towards the village Chilkha one crosses a 1500 m complex of augen granite-gneiss (Fig. 3).

The thick-bedded granite-gneiss is rather homogeneous. The phenocrysts of microcline (up to 10 cm) are generally lenticular, locally their idiomorphic form has been preserved. Essential minerals are microcline, attacked by myrmekite and muscovite, plagioclase (16—23%, mainly 21% An), quartz, red-brown biotite, and muscovite. Accessories are apatite, rutil, zircon, and zoisite.

Aplite-gneiss and medium-grained tourmaline and garnet bearing two-mica granite-gneiss penetrate the augen-gneiss. These younger granitoids become important around Chilkha. From here up the Tila Valley to the confluence of the Tila and Sinja Valleys and further N and E we find a complex of granite-gneiss, and migmatites. There are augen gneisses of the type described, nebulitic gneisses, and rather homogeneous, medium-grained two-mica granite-gneisses.
The latter seem to be related with the granite-gneiss of Dillikot. They are richer in muscovite, garnet, and tourmaline than the augen gneisses. Observations at the contacts show that the augen gneisses are the oldest. In a process of disintegration they were altered to nebulitic migmatites and finally were homogenized to the medium-grained granite-gneiss. Relics of augen-gneiss drifting in the homogeneous granite-gneiss often show discordant contacts (Figs. 4—6). Locally the medium-grained granite-gneiss reveals light-coloured selvages a few cm thick against the augen gneiss. Pegmatites bearing tourmaline penetrate the gneisses as unfolded dikes.

Fig. 4: Coarse-grained augen granite-gneiss forms relictic bands (left) and lenses (right) in evidently younger, medium-grained homogenized granite-gneiss. Tila Khola, NE of Chilkha, Nepal.

Fig. 5: Coarse-grained augen granite-gneiss penetrated by younger, homogenized, medium-grained granite-gneiss. Tila Khola, ca. 5 km NE of Chilkha, Nepal.

The thick complex of granitoid gneisses forms the core of a wide syncline in which the Upper Crystalline Nappe is preserved from erosion. It is the western continuation of the Jaljala-Jajarkot Syncline (FUCHS & FRANK, 1970). The SSE-dip in the lower Sinja Khola and in the Tila Nadi, WSW of Jumla, brings up the lower units of the Crystalline. At the confluence of the Sinja Khola and the small river coming from Banjgaon intercalations of the kyanite-two-mica gneisses appear. Farther on fine-grained, banded gneiss, carbonate-gneiss, and calc-silicate marble underlie, followed by paragneisses with beds of banded and cross-bedded, light grey to green quartzite (20 m). These are underlain by metamorphic carbonates. Beneath them garnet-kyanite-two-mica gneiss, mica schists, and quartzites are observed, all penetrated by tourmaline pegmatite. The gneisses apparently form the core of an anticline. To the N metamorphic carbonates and after them migmatitic gneisses and augen gneisses follow again. The latter series form a syncline, N of which micaceous quartzites and the underlying carbonates come up again. The latter consist of banded calc-silicate marbles and calc-mica schists. They are underlain by laminated, grey, fine-grained two-mica gneisses, which soon give way to an alternation of quartzite, quartzitic gneiss, paragneiss, garnet-mica schist and rare beds of augen gneiss. This series is much folded.

Dipping NNE two-mica schists and light quartzites, and then steep, medium-grained calc-mica schists follow. These rocks belong to the Lower Crystalline Nappe. The calc-mica schists are underlain by garnetiferous mica schists, dark grey, phyllitic mica schists, alternating with quartzite of white, beige, green, or grey colour, and paragneiss. There is also a 20 m intercalation of graphite schist. This rock association corresponds to the Jutoghs. It is underlain by thick quartzites of the Chail Formation. They belong to the Chail Nappes of the Galwa Window to be described in the following chapter.

Review:

The traverse from Surkhet to the boundary of the Galwa Window crosses the following zones:

The Siwalik Molasse

The Tansing Unit, which in Western Nepal represents the Parau-

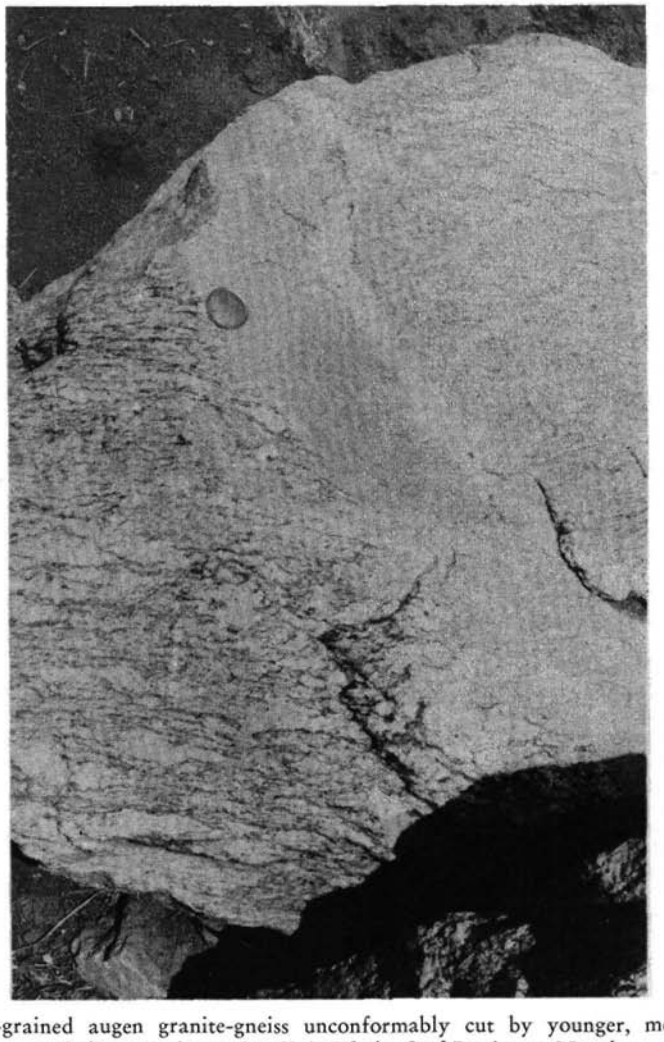


Fig. 6: Coarse-grained augen granite-gneiss unconformably cut by younger, medium-grained, nebulitic granite-gneiss. Sinja Khola, S of Banjgaon, Nepal.

tochthonous Unit. It is much reduced, the lower formations being missing, but the Krol—Tal—Subathu—Dagshai succession shows the normal stratigraphic sequence. The Nagthats and metavolcanics of Ranimatta might represent a detached northern portion of the Tansing Unit, which is suggested by their similarity to the Nagthats of the Naini Tal Syncline in Kumaon (FUCHS & SINHA, 1974). From the hiatus in metamorphism between the Dagshai and Nagthats and the same metamorphic grade of Nagthats and Chails it seems more likely that the latter belong to one unit, the Chail Nappe.

The Chail Nappes contain granite-gneisses, intrusiva in the Chail Formation like in Kumaon (Ramgarh Granite, RAINA & DUNGRAKOTI, 1975) or in the NW- Himalayas (Dalhousie granite, granites N of Kishtwar, FUCHS, 1975). The carbonates in the Chails (N of Dailekh) probably separate individual Chail Nappes like in the adjoining region in the E (FUCHS & FRANK, 1970). From the recent survey it is quite clear that the series of the Dailekh area do not form parautochthonous "schuppen" as suggested by HAGEN (1969). They continue beneath the syncline of the Crystalline Nappes and come up again in the frame of the Galwa Window. HAGEN, who discovered the Galwa Window, did not realize that his various schuppen zones of SW Nepal (e. g. Dailekh Zone, Dullu Zone) are indentical with the units of the Galwa Window or the Hiunchuli Zone. They do form nappes (Chail N.) and have their roots in the northern portions of the Galwa Window. An autochthonous massif (Dandeldhura Zone), as envisaged by HAGEN, does not exist. This zone either forms part of the Chail Nappes or the Crystalline Nappes (HAGEN's Kathmandu Nappes). In the same way my observations do not support the stratigraphic-structural scheme given by ANDO & OHTA (in HASHIMOTO, 1973; compare their Fig. 5 with Pl. 1, 2 of this paper).

The Crystalline Nappes, as in other parts of the Himalayas, consist of two units. The Lower Crystalline Nappe, a thin thrust sheet, is characterized by the Jutoghs. The Upper Crystalline Nappe shows the sequence from bottom to top:

1. mica schists, paragneisses, and quartzites
2. laminated fine-grained paragneisses passing into
3. carbonate gneiss, calc-mica schist, and marble
4. garnet-kyanite-two-mica gneisses and augen gneiss
5. coarse-grained augen granite-gneisses and younger, nebulitic and medium-grained granite-gneisses.

Thus the grade of metamorphism and of migmatization clearly increases upwards, which is a general phenomenon in the Himalayas.

Pl. 1, 2 show the symmetry of the Tila Syncline. In the way the various units of the Crystalline dip towards the axis of the syncline, they reappear in the same order towards the Galwa Window.

2.2. The Galwa Window

The Chail Nappes, so well-developed in the Hiunchuli area, are generally covered by the Crystalline Nappes towards the W. But, due to vertical displacement along a fault, the rocks of the Chail Nappes are connected with those of the Jumla region by a narrow corridor (FUCHS & FRANK, 1970). From there to the NW, the area formed by the rocks of the Chail Nappes widens to an extensive window zone, exposed in the region of the lower Mugu and Humla Karnali and quite a bit down stream the main Karnali River. This Galwa Window is surrounded by the overlying Crystalline Nappes. Its internal structure is rather complicated, but distinct structural units are discernible. This is evident from the fact that the typical Lower Himalayan succession, though being reduced, is repeated several times. Regional mapping revealed the existence of at least three structural units, the lowest of which is exposed in the central parts of the window.

As the following treatment of the Galwa Window is based on a regional survey and not on a single traverse, it seems appropriate to describe individual structural units. Before this some remarks shall be given concerning the litho-units found in the Galwa Window:

Simla Slates (?): A flyschoid series reminiscent of Simla Slates is found around Galwa. It is composed of blue-grey to green-grey, also dark grey slates, phyllites, silty slates, and siltstones. The silty rocks form cm-to dm-layers alternating with the slates. They are finely laminated (mm) and exhibit graded bedding. Current bedding, current ripple cross-lamination, and load casts underline the flysch character. There is no sharp boundary between this series and the surrounding Chails. It is difficult to decide whether these rocks are Simla Slates exposed in an anticline or whether they just represent a flyschoid development within the Chail Formation as observed in the Hiunchuli area (FUCHS & FRANK, 1970, p. 34).

Chail Formation: Thick-bedded, pure, white, green, grey quartzites with cross-bedding and ripple marks; schistose conglomerates, the rounded to angular components (up to dm-sizes) consisting of quartzite, quartz, aplite, and phyllite are elongated in B (Fig. 7); psammite schists; quartzitic schists; sericite-chlorite schists; silvery, green, grey also blackish phyllites with flasery, wavy s-planes; basic metavolcanics, medium-to coarse-grained, with relictic ophite structure and amygdales, they are partly altered to chlorite schists or amphibolite (Fig. 8); two-mica granite-gneisses, generally coarse-grained, the augen of microcline may reach sizes of 7 cm; these granite-gneisses as well as the associated aplite-gneisses, are often containing tourmaline.

Under the microscope the augen consist of microcline (Karlsbad twins, perthitic, myrmekites), other essential minerals are plagioclase (oligoclase — andesine), quartz, green-brown biotite, sericite, and muscovite. Chlorite, epidote — clinozoisite, and sericite are of secondary origin; mortar zones are generally healed.

The facies of the Chails may change from arenaceous over mixed to argillaceous facies, which is a characteristic of the formation.

Like the entire rock series of the Chail Nappes the Chails, sedimentary as magmatic rocks, have undergone alteration of greenschist facies. Locally, however, the metamorphic grade increases to amphibolite facies, such as near Una-

Fig. 7: Schistose conglomerate of the Chail Formation. Many of the components show angular shapes and are elongated parallel B. Note the poor sorting. Humla Karnali, NE of Galwa, Nepal.

pani in the Humla Karnali Valley. There garnet-mica schists are formed, which contain fine biotite and hornblende porphyroblasts, the garnets reaching 1 cm sizes. Generally the alteration is stronger in the higher Chail Nappes and in the northern limb of the anticlinorium that is near the root zone. Further the haematite-magnetite-quartz mineralizations in the Chail quartzites, SE of Unapani, must be mentioned. W of the Rara Lake, at Murma, a Chail outlier resting on the Blaini carbonates of Chail Nappe 2 contains chlorite schists with iron and copper mineralization. Prof. W. Siegl (Montanistic University, Leoben, Styria) kindly identified magnetite, haematite and some secondary limonite. Besides the rock shows traces of chalcopyrite and secondary copper minerals.

Fig. 8: Basic metavolcanite of the Chail Formation. The rock is full of amygdales (light dots) and shows chilled margins against an enclosed band of Chail siltstone. Humla Karnali, NE of Galwa, Nepal.

Nagthat (found only in the Karnali Valley near Riga): Thick-bedded, fine-to coarse-grained quartzites of red, white, and green colour. Sporadic conglomeratic layers show quartz pebbles, up to several cm sizes. Cross bedding and ripple marks are frequent. Green and grey phyllites occur as very subordinate intercalations in this quartzite series of ca. 1200 m thickness.

Blaini: Thin-bedded alternation of white, pink, and grey, partly cherty, fine-crystalline dolomite, grey calc marble, red carbonate quartzite to sandy carbonates, red, grey, and green quartzites, calc-mica schists *), calc-phyllites of green, grey colour and grey, green, purple, and also rather dark phyllites. It is typical that the carbonates contain lenticles or layers of phyllite, and the phyllites show strewn- in carbonate, sandy, or arkosic matter. A conglomeratic rock, interfingering with pink dolomite, is found in the Karnali Valley SE of the Kuwari Khola confluence (Fig. 9, 10):

In phyllitic or fine-conglomeratic matrix there are augen of calcite, angular or rounded boulders (up to 25 cm) of quartzite, quartz, dolomite, and argillite. The completely unsorted character of this bed is highly reminiscent of the Blaini Boulder Beds or particular layers of the Agglomeratic Slate of Kashmir-

*) It is noteworthy that plagioclase in calc-silicate bearing rocks shows An-contents of 28—50%, with average around 32%.

Chamba. A volcanogeneous component in the conglomerat is indicated by euhedral quartzes, exhibiting zonar inclusions and corrosional channels. This is the first instance of boulder beds in the Blainis of Nepal, supporting my former tentative correlation based on the pink dolomites and multicoloured argillites.

The Blainis NW of Sinja contain cm- to dm- beds of haematite schists or haematite quartzites. They seem to be the source rocks for the haematite found in quartz veinlets in that area. The sedimentary haematite rocks along with the primary dolomites of red colour, the desiccation cracks etc. indicate deposition in shallow water in an oxidizing environment.

Fig. 9: Schistose tilloid conglomerate of the Blaini Formation. Angular and rounded boulders embedded in unsorted way in a fine-brecciaceous matrix. Karnali, S of Kuwari Khola confluence, Nepal.

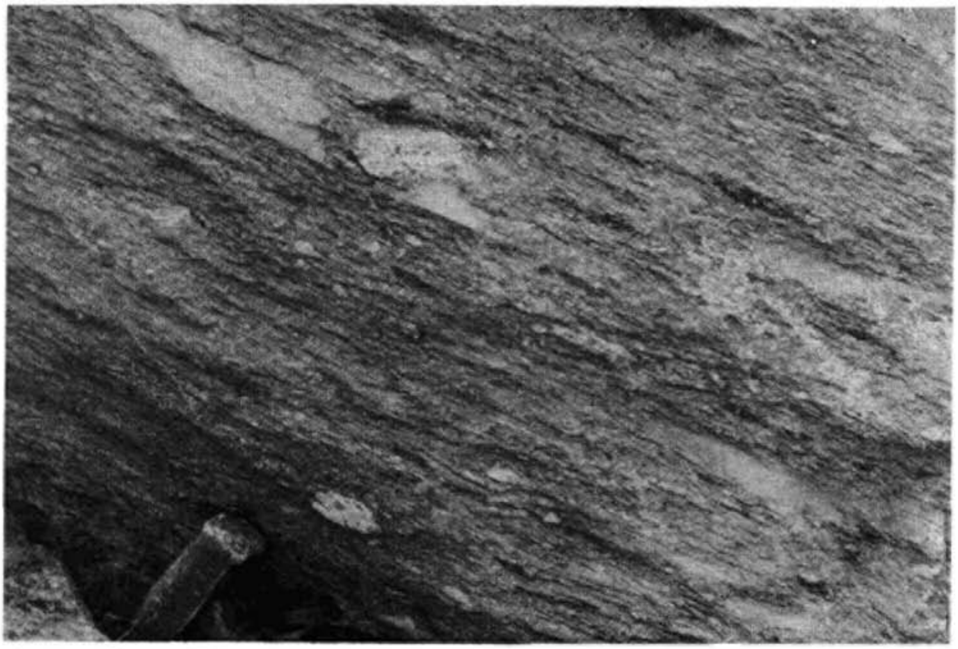


Fig. 10: Schistose tilloid conglomerate of the Blaini Formation. Karnali, S of Kuwari Khola confluence, Nepal.

Shali Slates: Associated with the Blainis or the Shali Dolomites are a series of black to dark grey, or green argillites. They are in the state of slates or phyllites. Silty, quartizitic, or carbonate layers locally give the series a thin-bedded to laminated character. The argillites are frequently interbedded with Shali Dolomites, making the boundary between Shali Slates and Shali Dolomite doubtful. These beds represent an euxinic facies in the stratigraphic range of Blaini-Shali.

Shali Formation: White, grey, blue dolomites and limestones. Cherty nodules are common; intraformational breccias and stromatolites stress the shallow-water origin of the carbonates. The algal structures are frequently of LLH-C, SH-V, and SH-C type (Fig. 11, 12). Due to the metamorphism of the Chail Nappes the rocks are finely crystalline. Tectonic flow in laminated rocks has caused a boudin-like breaking up of dolomite layers, the pieces being pulled apart in the neighbouring limestone. The stromatolites are frequently sheared parallel to their flanks and have been rotated to lie subparallel to s. The former argillaceous matter has become altered to phyllite, being found as fine lenses or coatings on s. The thickness of the formation may attain 2000 m.

No younger beds than Shalis were found in the Galwa Window.

In chapter 2.1. we approached the Galwa Window describing the Crystalline series S of it, and it seems best, therefore, to continue with the adjacent uppermost and pass down to the lowest structural unit of the window.

2.2.1 Chail Nappe 3 (C 3)

The uppermost Chail Nappe is identical with Chail Nappe 3 of the Hiunchuli area. Likewise it is composed merely by the Chail Formation consisting of quartzites, conglomeratic or psammitic schists, phyllites, and basic metavolcanic rocks. There are also granite-gneisses intrusive in the Chails.

The Chails around Jumla are mainly quartzitic, only the lowest portions are argillaceous. SE of Uthugaon, an outlier of the Crystallines rests on these Chails. To the NW, the Chail Nappe 3 may be traced to the Sinja Khola and the Karnali. Also in the north-eastern limb of the updoming the unit is well represented. From Talphi it strikes via Mandhara to the Nyor Gad, and further to the Rara Lake and Mugu Karnali. The upper portions of Chail Nappe 3 are particularly quartzitic, and we find large bodies of granite-gneiss. The latter consist of coarse-grained, porphyric two-mica granite-gneiss with phenocrysts frequently deformed to augen, and of aplitic gneiss. These intrusive rocks are foliated and obviously have undergone the same metamorphism as the surrounding Chails. Smaller bodies of granite-gneiss may be observed in Chail Nappe 3 also N of the Mugu Karnali in the region E of the Chankheli Pass. Along the Rawli Khola the lower boundary of Chail Nappe 3 is marked by lenses of crystalline dolomites and phyllitic rocks (Blaini, Shali). At Darma, the structure is complicated by faults parallel to the strike. So the phyllitic Chail rocks of Chail Nappe 3, SE of Darma, abut along the faults against quartzitic Chails of Chail Nappe 2

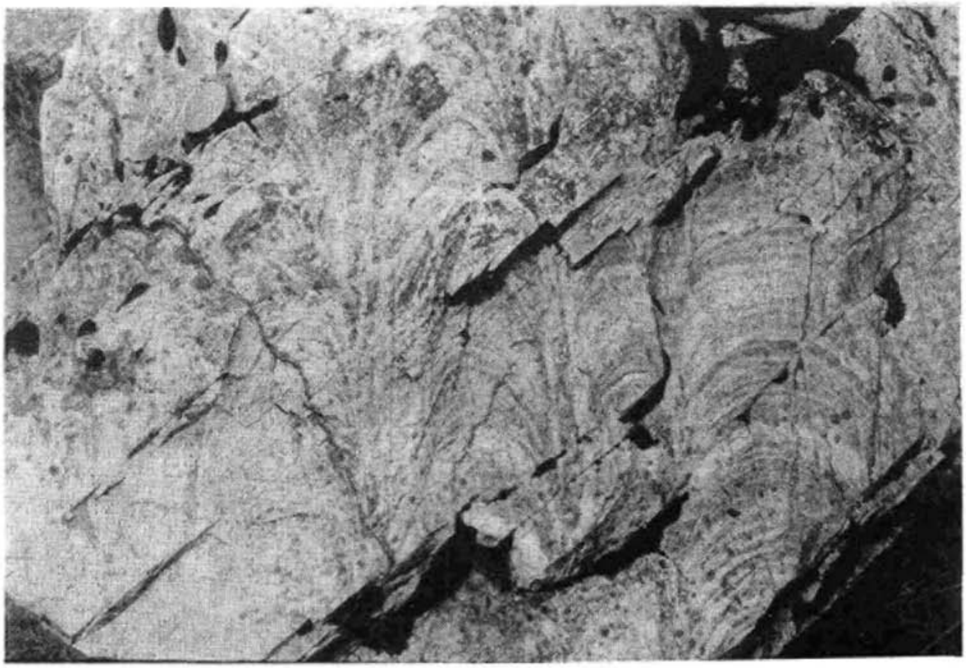


Fig. 11: Stromatolites in the Shali Dolomite. Approximately 7 km NW of Uthugaon, N of Jumla, Nepal.

Fig. 12: Stromatolites in Shali Dolomite. There are various forms of growth: SH-V, SH-V → LLH-C, SH-C; approximately 7 km NW of Uthugaon, N of Jumla, Nepal.

and rocks of the Upper Crystalline Nappe respectively. The boundary against the underlying Blainis of Darma ist the thrust contact at the base of Chail Nappe 3. W of Darma along the Humla Karnali, it is difficult to distinguish between Chail Nappes 2 and 3. The Chails of the Mehta Lagna and part of the Chail quartzites of the Humla Karnali definitely belong to the lower unit. But I assume that the upper portions of the Chails, directly underlying the rocks of the Lower Crystalline Nappe, represent Chail Nappe 3. Shali or Blaini rocks separating them, however, are missing.

The western margin of the Galwa Window is not mapped, but the general structure suggests that Chail Nappe 3 of the northern parts of the window joins up with that of the southern limb of the anticlinorium.

2.2.2. Chail Nappe 2 (C 2)

Chail Nappe 2 consists of Chails, Blainis, and a few intercalations of Shali Slates. The Chails are predominately argillaceous, except in the N (e. g. Rawli Khola, Unapani). This and the argillaceous-calcareous character of the younger formations seems to be the cause for the squeezed nature of the unit.

In the south-western limb of the Galwa anticlinorium the Chail Nappe 2 is cut off by a fault in the area of Uthugaon. Lenses of Blaini may belong to Chail Nappe 2, which is otherwise squeezed. As a continuous band Chail Nappe 2 commences NW of Jumla, and may be traced as a narrow zone between the Chails of Chail Nappe 3 and the dolomites of Chail Nappe 1 to the village Sinja.

The reduction of the unit and its missing in the region N of Jumla is due to vertical displacement along a fault belonging to the system described in FUCHS & FRANK (1970, p. 96) N of the Sinja Valley the Blaini Formation attains large thickness, whereas the Chails remain rather reduced. Towards the W Chail Nappe 2 seems to pinch out, as J. B. WATERHOUSE on his traverse along the Karnali SW of Riga did not report having observed this unit.

In the north-eastern limb of the Galwa anticlinorium Chail Nappe 2 has been recognized already in course of our 1967 expedition (FUCHS & FRANK, 1970). W of Talphi a Chail—Shali Slate—Blaini belt underlies the Chail quartzites of Chail Nappe 3 and succeeds the thick Shali Dolomite of the range which separates the Chaudabise Khola from the Nyor Gad. The rocks of Chail Nappe 2 dipping NE, cross the Nyor Gad and follow the upper course of the Mandu Khola. They buid up the crest and the northern slope of the range S of Rara Lake. This lake is situated in a syncline. Thus the Chails and overlying Blainis are rathere horizontal WSW of the lake and dip towards the S or SSE in the mountains N of the Rara Lake. The overthrust Chails of Chail Nappe 3 outcrop along the south-eastern and eastern shores of the lake. A few outliers of that mass rest upon the Blainis W of the lake (Fig. 13). Towards the Mugu Karnali the Blainis are reduced to a few thin bands, and so Chail Nappe 2 is composed mainly of Chails, which become quartzitic N of that river. These quartzites dip to the ENE or NNE at medium to steep angles, and are a significant feature in the landscape of the Rawli Khola and along the Humla Karnali up to Unapani. The quartzites are underlain by a phyllitic development of the Chails (e. g. Mehta Lagna) and are followed by lenses of Shali and Blaini rocks mentioned in connection with Chail Nappe 3. This series of carbonate lenses ends with the Blainis of Darma. Thus it is doubtful what proportion of the quartzites, which outcrop along the Humla Karnali W of that village, belongs to Chail Nappe 2 or 3. N of Mehta Lagna and near Unapani there are small intercalations of granite-gneiss in the Chails.

2.2.3. Chail Nappe 1 (C 1)

Whereas Chail Nappes 2 and 3 of the Galwa Window are still in a surface connection with the corresponding units of the Hiunchuli area, Chail Nappe 1 plunges SE beneath the higher units in the Chaudabise Khola. From there towards NW Chail Nappe 1 forms the core of the anticlinorium. It consists of rather thick Shali Dolomite dipping beneath the surrounding higher units. In the lowest parts of the dolomites in the Nyor Gad, there are thick intercalations of Shali Slates and also some Blainis. The black slates striking SE in direction to Uthugaon are partly faulted against the dolomites. Whether the Shali Dolomites underlying these beds in the Nyor Gad belong to the same rock complex or represent a still lower structural unit (C 1 a, see chapter 2.2.4.) is ambiguous.

The synclinal structure of the Rara Lake area crosses the NW-SE-striking anticlinorium in a WSW-ENE direction. In this structural depression Chail

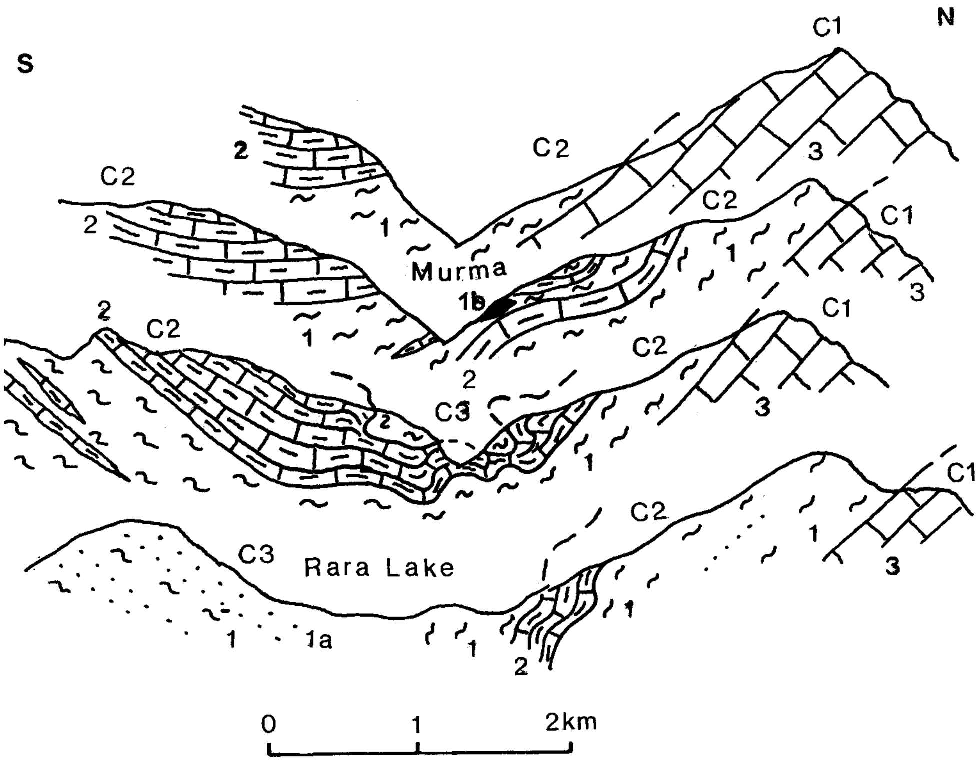


Fig. 13: Sections across the Rara Lake and the area W thereof.

1	Phyllites	Chail Formation	2	Blaini Formation
1 b	Iron ore body		3	Shali Dolomite
1 a	Quartzites		C 1, 2, 3	Chail Nappe 1, 2, 3

Nappe 1 is largely covered by Chail Nappe 2, but gains extention again in the Khatyar Khola. From there the Shali Dolomites with intercalations of Shali Slates and Blainis may be followed into the northern and southern limbs of the anticlinorium respectively. It is important that in the southern slope of the Khatyar Dara (Range) and at Riga in the Karnali Valley, a thick series of Nagthat underlies the Shalis. The Nagthat in turn is underlain by Chails, thus the section along the Karnali gives the most complete stratigraphic sequence within the Galwa Window. This is evidence that there are upright stratigraphic successions thrust on each other as already found in the Hiunchuli area (FUCHS & FRANK, 1970). Overlying an even lower complex of Blaini, Shali Slates, and Shali Dolomite (C 1a) the formations of Chail Nappe 1 swing around from southern dip into western and finally northern dip. The Nagthats of the southern limb of the anticline are missing in the northern limb. There the Chails are directly followed by Blainis rather rich in phyllites. In the lower portion of the Chails at Galwa a flyschoid series was found. These beds may indicate an anticline of Simla Slates or merely a flyschoid development within the Chails. Such a facies was observed in the same unit in the Thulo Bheri Valley (Fuchs & Frank, 1970, p. 34).

Where the Chail Nappe 1 crosses the Mugu Karnali and in the eastern parts of the Khatyar Dara, all the lower formations of the unit become squeezed off. The complex of Blaini, Shali Slate, and Shali Dolomite is in contact with the same formations of the underlying unit (C 1a). From the general situation (see Pl. 1) it is evident that also there a separating thrust plane must be existing.

2.2.4. Chail Unit 1a (C 1a)

As described above, there is a unit consisting of Blaini, Shali Slates, and Shali Dolomite exposed in the deepest part of the Galwa Window. In all directions the unit dips beneath the surrounding Chail Nappe 1. Along the thrust line its rocks come in contact with various formations of Chail Nappe 1. The existence of unit C 1a indicates that all the overlying structural units are allochthonous, at least in the western parts of the Galwa Window. The roots of the Chail Nappes overlying unit C 1a, however, are not far away. They are supposed to be in the north-eastern portions of the Galwa Window.

2.2.5. Review

The Galwa Window is the north-western continuation of the Chail Nappes of the Hiunchuli area. The litho-units are the same in both regions, the sequence of the Galwa Window, however, is less complete. Yet it is evident that each of the structural units is composed of upright stratigraphic successions.

To the W the Tejam- and Pithoragarh Zones represent the continuation of the Chail Nappes exposed in the Galwa Window. There is resemblance in the rock material as well as in tectonics. But from the observations made in Nepal that new tectonic elements (C 1a) may come in, when the Chail zone is followed along the strike, and other units (C 2 or 3) become less distinct, I am aware that it is difficult to correlate the individual structural units of Kumaon with those of the Galwa Window.

3. The High Himalaya

From the Galwa Window up the Mugu Karnali to Dolpo one crosses the root zone of the Crystalline Nappes, the Central Crystalline, where these nappes dip beneath the Tibetan Zone. Geographically this is a traverse of the Great Himalayan Range up to the Inner Himalayas. First I shall give the section along the Mugu Karnali from the margin of the Galwa Window to the region of Mugu (chapter 3.1.) Then in chapter 3.2. follows the description of the western portion of the Dolpo Synclinorium (Tibetan Zone).

3.1. Traverse along the Mugu Karnali

The Galwa Window is left just E of the confluence of the Ghatta Khola with the Mugu Karnali. There, the white quartzites and amphibolites of Chail Nappe 3 are overthrust by typical Jutoghs: Garnet-mica schists, garnet phyllites frequently dark grey, graphitic rocks, banded micaceous quartzites (± garnet), quartzite-gneisses, fine- to medium-grained platey paragneisses, and amphibolites. This series dips NE to ENE at medium angles.

In the upper portions of this succession, which represents the Lower Crystalline Nappe, W of the village Kumpha the grade of metamorphism increases. In addition to garnet, kyanite, and staurolite (up to cm-sizes) appear in certain beds.

Under the microscope such a rock shows quartz, brown biotite, muscovite, and plagioclase (20% An) as main constituents; idiomorphic garnets rich in inclusions indicate rotation of si; kyanite and staurolite; accessory constituents are sphene, graphite, tourmaline, and ore.

N of Kumpha the Jutoghs are succeeded by well-bedded, fine- to medium-grained, banded two-mica gneisses, which indicate the Upper Crystalline Nappe. Over the banded gneisses follows a zone of thin- to thick-bedded, light to grey quartzites and quartzite-gneisses (50 m), and then light-coloured garnet-mica schists to paragneisses (plagioclase contains 18—23% An). These rocks contain greenish layers, which under the microscope show blue-green hornblende, brown biotite, quartz, plagioclase (41—46% An) and some diopside; garnet grows in xenomorphic amoeboidic individuals; carbonate and epidote-clinozoisite make it probable that these layers were former marls; accessories are apatite, rutil, sphene; chlorite is of secondary origin.

The described rocks pass into a grey-brown-green-white banded alternation of quartzite, quartzite-gneiss, garnet-kyanite-two-mica gneiss, fine-grained, laminated calc-silicate (epidote, sphene) bearing paragneiss (plagioclase 27—50%, mainly 38% An), and amphibolite. In a fine-grained gneiss sporadic and much elongated pebbles of quartzitic rock were observed (plagioclase 26—29% An).

Migmatites and augen gneisses (phenocrysts of potassium felspar up to 2 cm) appear at the Sote Khola junction (ca. 3 km SW of the bend of the Mugu Karnali near Mangri). From there upstream fine-grained, banded gneisses, garnet-kyanite-two-mica gneisses (plagioclase 25—28% An), and quartzites alternate with the migmatites. This series is succeeded by a 1500 to 2000 m complex of compact, light augen granite-gneiss and fine- to medium-grained nebulitic migmatite. Like in the Tila Khola, portions of the augen gneiss were found „floating" in the more homogenized migmatite and proved to be older (Fig. 14). In one instance the older gneiss, rather rich in plagioclase (27—29% An) besides biotite contains kyanite and sillimanite, both marginally converted to sericite. The normal type, however, consists of microcline, plagioclase (16—22% mainly 20% An) quartz, brown to green-brown biotite, muscovite as main constituents and apatite, zircon as accessories; sericite is secondary.

Towards the top the granite-gneiss complex becomes inhomogeneous by intercalations of paragneiss to migmatite, some garnet-biotite-hornblende rocks, and amphibolites. About 5 km E of Mangri the paragneisses become predominant. Then comes a 30—40 m band of calc-silicate marble and carbonate gneiss followed by augen gneisses and coarse-grained migmatites containing garnet and silimanite (plagioclase 19—23% An). Within the migmatite series a second marble containing diopside crosses the valley. Some of the migmatite gneisses also are full of calc-silicates. These are pale hornblende (up to 2 cm long), diopside, epidote, zoisite, sphene, and there is also some carbonate. The plagioclase shows 32—60%, with maximum at 55% An.

Upstream to the Langu - Mugu Valley junction one crosses a thick complex of coarse-grained garnet-sillimanite-two-mica gneisses rich in pegmatoid lenses (plagioclase 23—29% An), passing into augen gneiss, fine-to medium-grained, banded migmatite-gneisses, nebulitic migmatites, sillimanite quartzite-gneisses (plagioclase 26% An), and sillimanite quartzites. Sillimanite obviously takes the place of kyanite in these rocks, it is stable in presence of muscovite in some cases, or in others is partly converted into muscovite.

Following the valley to Mugu again kyanite occurs in the garnet-sillimanite paragneisses (plagioclase 20—23% An). It follows a 60 m zone of marble and carbonate gneiss and then a migmatitic gneiss complex. More and more the migmatites become homogenized and finally granite-gneiss to granite prevails. These latter rocks already belong to the Mugu Granite, an Alpine intrusion like the Mustang Granite. The light-coloured, generally fine-to medium-grained two-mica granites still contain some garnet and sillimanite (plagioclase 13—24%, mainly 18% An). Phenocrysts of potassium felspar are rather rare. Pegmatites and aplites containing tourmaline, garnet, biotite, or muscovite were observed. Sillimanite and tourmaline locally are coating the joint planes.

Fig. 14: Older augen gneiss floating in younger, fine- to medium-grained, more homogenized granite-gneiss. Note the sharp boundary between these gneisses, and the mall augen gneiss lens (arrow). Mugu Karnali, near Mangri, Nepal.

Fig. 15: Augen granite-gneiss penetrated by folded granite veins. Mugu Valley, S of Mugu, Nepal.

Thus it is impossible to draw a sharp boundary between the Mugu Granite and the migmatite complex. The migmatization was only in part brought about by the Mugu Granite, for the augen gneisses of the migmatite complex are older and in their occurrence are independent of the Mugu Granite. Within that granite on the further way to Mugu, zones of banded or nebulitic migmatites, augen gneiss, and paragneiss are crossed. Fig. 15 shows augen gneiss penetrated by folded granite veins.

An unfoliated variety of the Mugu Granite, from ca. 4 km S of the village Mugu, shall be described in more detail:

The medium-grained rock shows hypidiomorphic structure. Microcline phenocrysts up to 1 cm are twinned and exhibit zonar arrangement of enclosed plagioclase, sillimanite, and biotite. The longer axes of these minerals are parallel with the zones of growth of the potassium felspar. The euhedral plagioclases are zonar with frequent basic recurrences (20—27% An).

Quartz is anhedral. Red-brown biotite as well as muscovite are further main constituents. Zircon causes radioactive haloes in biotite. Very rare chlorite is secondary after biotite.

The microscopic observations prove the field evidence that the Mugu Granite is a true magmatic granite, the magma, however, may be the product of anatexis (sillimanite content). Cocherie (1976) suggests a palingenetic origin also for the Manaslu Granite.

The mountains around Mugu consist of the Mugu Granite and on my march to Dolpo over the pass E of Mugu and then south to the Chhapa Khola all the outcrops are of that granite. Rather homogeneous, medium-grained two-mica granite is predominant. A variety is porphyric with phenocrysts of potassium felspar generally 1 to 2 cm, occasionally 5 cm long. Further pegmatitic lenses (1—3 cm) containing fine needles of tourmaline were observed in some of the granites.

From the Chhapa Khola eastwards the granite borders with unconformable contacts against metamorphic rocks belonging to the basal beds of the Tibetan Zone of Dolpo (see Pl. 3). The Dolpo Synclinorium has its north-western edge in the Syanath Mountain S of the Chhapa Khola. In the N the beds of that syncline are intruded by the Mugu Granite, in the W and S they probably pass down into the underlying metamorphics of the Upper Crystalline Nappe (The contact was not crossed there, but this is assumed according to my observations from many other places). Structurally the Syanath Syncline affects also the underlying Crystalline: The ESE-dip in the Mugu Karnali Valley W of Syanath is caused by the syncline mentioned.

R e v i e w : The traverse of the Crystalline along the Mugu Karnali showed: The Lower Crystalline Nappe is characterized by the typical rock association of the Jutoghs, as in other parts of the Himalaya. The grade of metamorphism, however, is higher there. Kyanite and staurolite appear already in the upper portions of the Lower Crystalline Nappe. The Upper Crystalline Nappe consists of rocks common throughout the length of the crystalline axial zone, but also shows individual features, such as the quartzite—gneiss—amphibolite alternation in its lower part, the relatively low position of the thick augen granite-gneiss — migmatite complex, the importance of sillimanite in the upper half of the Upper Crystalline Nappe, and the scarcity of carbonates. This strengthens my scepticism against the view held by LeFort (in Bordet et al 1971; 1975, etc.) that the Crystalline may be divided into a regular succession of formations, which may be traced over larger distances. The Alpine granites, intruding the upper parts of the Crystalline and lowest portions of the Tibetan Zone, seem to be comparable with those of Mustang, Manaslu, Badrinath etc.

3.2. The Western Parts of the Dolpo Synclinorium

In the course of the 1963 Dhaulagiri Expedition I investigated the eastern portions of the Tibetan Zone of Dolpo (Fuchs, 1967, p. 153—197, Pl. 7—9). As Dolpo was closed to foreigners for several years, work was continued with the survey of western Dolpo not before ten years later. Admittedly this was a rough survey as two months only were at my disposal. Further several tributary valleys of the Langu could not be entered because of high water and other obstacles. Nevertheless, the general stratigraphic development and structural features of western Dolpo were recognized.

3.2.1. Stratigraphy

3.2.1.1. The Dhaulagiri Limestone and its relations to the underlying Crystalline

Between the Crystalline and the succeeding Palaeo-Mesozoic sequence of Dolpo no major tectonic disturbance is observed. The boundary is not sharp, and the Dhaulagiri Limestone passes gradually down into the marble series of the uppermost Crystalline. The same was observed in the region S of the village Ringmi, where the river flowing from the Phoksumdo Lake descends in a big waterfall. There, the Dhaulagiri Limestone becomes more and more crystalline and merges into the Central Crystalline. The carbonates are metamorphosed to calc-mica schists and marbles. The argillaceous layers are altered to phyllites, the silty and arenaceous beds have become gneissic or quartzitic. But even in these rocks the characteristic sedimentary structures of the Dhaulagiri Limestone are occasionally preserved.

Not only in the S, but also in the N, in the high range separating Dolpo from Tibet, the Dhaulagiri Limestone is underlain by the crystalline complex. The Mugu Granite, however, forms extensive intrusions there and reaches up almost into the passage zone between the Crystalline and the Dhaulagiri Limestone. Therefore the lower gneissic portions of the Crystalline are generally missing. Boulders observed in the Takle- and Khung Kholas show relictic augen gneisses, the characteristic two-mica gneisses with the pegmatoid lenticles, and medium-grained migmatites enclosed in the young granites (Fig. 17). This indicates, that before the intrusion of the Mugu Granite, there was a Crystalline in the N of the Dolpo Synclinorium similar to the Central Crystalline in the S.

The metamorphic carbonate series consists of banded calc-silicate marbles bearing diopside, hornblende etc., grey medium-to coarse-grained, well-bedded marbles, fine-grained, platey carbonate-biotite gneisses, medium-grained biotite schists containing lime-silicate layers, etc. Plagioclase in these rocks may reach An-contents as high as 40%.

In the passage zone indicated in Pl. 3 the grade of alteration decreases and sedimentary structures, fossil layers etc. are frequently preserved.

It is noteworthy, however, that the whole of the Dhaulagiri Limestone and even younger formations have undergone phyllitic metamorphism.

The Dhaulagiri Limestone of western Dolpo shows the silty and arenaceous facies described by FUCHS & FRANK (1970, p. 49—52) from the southern Kanjiroba Range. The formation consists of a rhythmic alternation of grey, fine-grained, calcareous sandstone to calcareous siltstone weathering in red-brown colour, brown, grey, and green carbonate schists, light grey, silty limestone and rare dolomite, light grey to blue, fine-grained limestone, and silvery to greenish phyllitic schists. In the landscape the thick-bedded character of the formation and the brown to greenish-grey weathering colours are typical. Graded bedding, ripple cross-lamination, current bedding, ripple-load convolutions, ripple marks, and intraformational breccias indicate an agitated depositional enviroment (Fig. 18). The several thousand meters thickness of the impure carbonate formation are evidence for rapid subsidence, which apparently was balanced by rich sediment supply. The red sediment colour, and clastic influence in the Dhaulagiri Limestone, increasing westwards, points to a passage into the Ordovician red clastic series of Spiti (HAYDEN, 1904, p. 21—23). The Ralam Conglomerate of Kumaon seems to correlate with the Ordovician basal conglomerate of Spiti.

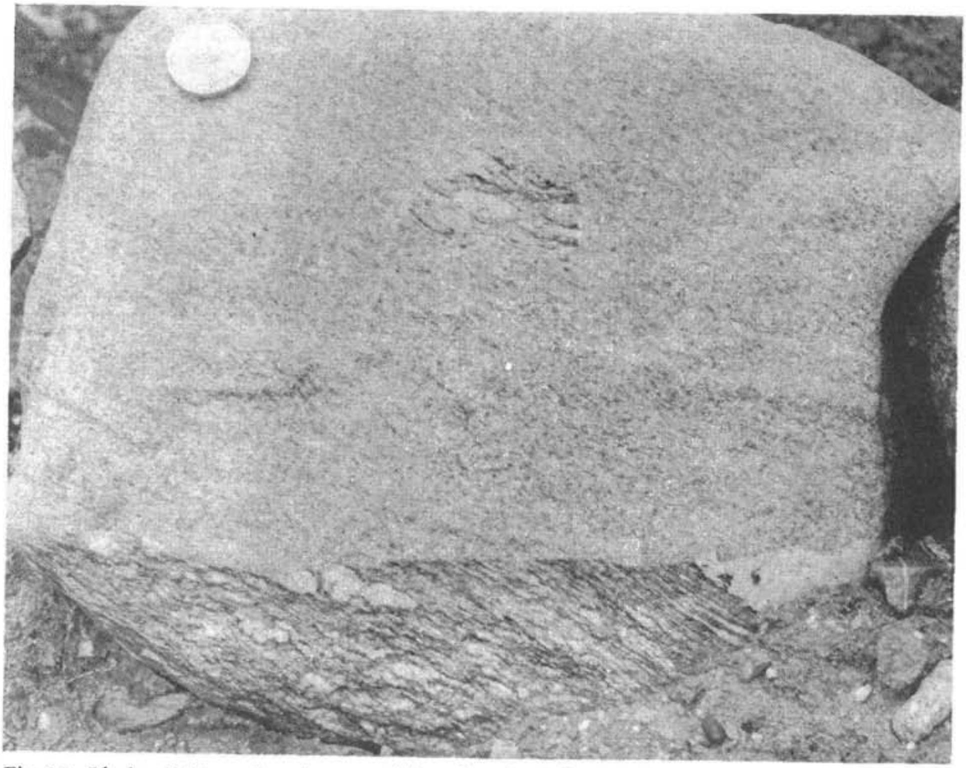


Fig. 17: Block of Mugu Granite containing sharply defined inclusions of augen gneiss. Upper Khung Khola, Dolpo.

Due to the phyllitic metamorphism the minerals sericite-muscovite, commonly green-brown biotite, or less frequent chlorite occur in layers of appropriate composition. The plagioclase seems to be detrital (mainly albite); carbonate (ankerite?) and biotite frequently form porphyroblasts (ca. 1 mm diameter) in the silty and phyllitic layers. Sieve-like biotite porphyroblasts, growing obliquely to the s-planes, exactly resemble those reported from the Budhi Schists of Kumaon (HEIM & GANSSER, 1939, Fig. 66). Veinlets of quartz containing pyrite, chalcopyrite, or tetrahedrite are not rare in the Dhaulagiri Limestone.

Fossils are frequent, but poorly preserved. Characteristic are lumachelles of orthid brachiopoda, low-spired gastropoda, and crinoid stems. They are of the types determined by SIEBER (in FUCHS, 1967, p. 155; and FUCHS & FRANK, 1970, p. 51—52) and V. J. GUPTA (1971, p. 643—644) from other localities in Dolpo. These determinations indicate an Ordovician age of the Dhaulagiri Limestone, which agrees with the finds of BORDET et al (1971) from the Nilgiri Limestone. The calc schists overlying the North Face Quartzite have yielded a still Ordovician fauna (BORDET et al., 1971, p. 91). These beds correlate with the uppermost parts of my Dhaulagiri Limestone. Contrary to the French geologists I regard the underlying Larjung Formation not as a stratigraphic unit, but as strongly altered lower portion of the Dhaulagiri or Nilgiri Limestone. I am aware of the possibility that the lowest parts of the Dhaulagiri Limestone may be of Cambrian age. In the W, in Kumaon, the Garbyang- and Shiala Formations (HEIM & GANSSER, 1939) represent the Dhaulagiri Limestone. VALDIYA & GUPTA (1972) subdivided the Garbyang Formation in a Garbyang- and Changru Series, which is contested by SHAH & SINHA (1974). From the lithology described by these various authors, I think that the thick, monotonous succession at the base of the Tibetan Zone should be considered as one formation with the possibility of subdivision into members.

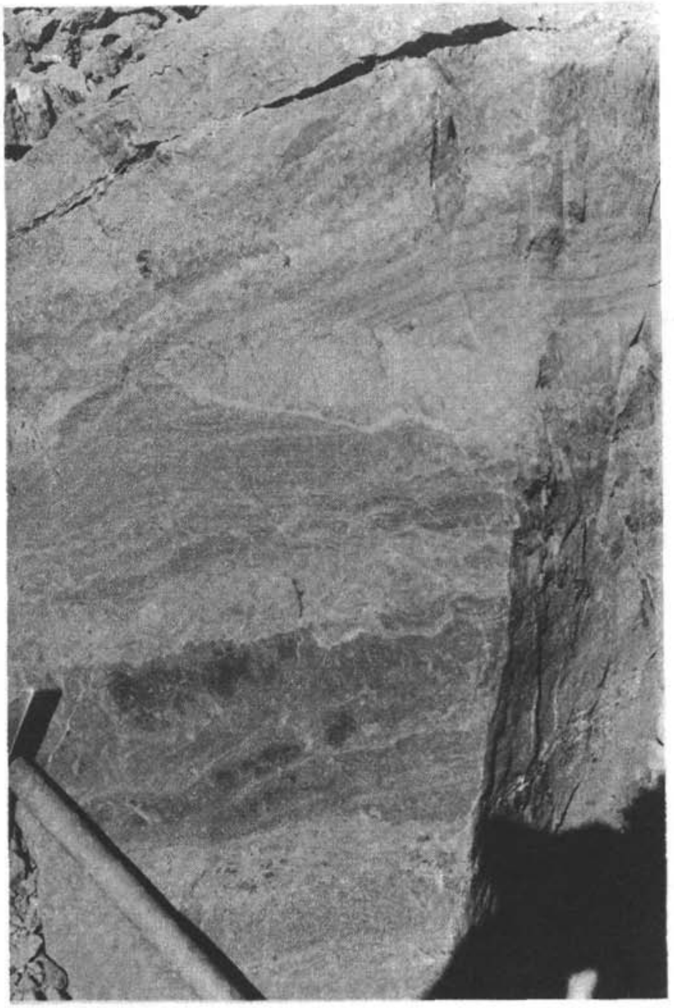


Fig. 18: Dhaulagiri Limestone, western branch of Daldung Khola, Dolpo. Lamination, graded bedding, ripple cross-lamination and current bedding; the sedimentation was frequently disturbed as shown by load casts, lenticular structures etc.

3.2.1.2. The Silurian

Due to facies variation and scarcity of determinable fossils the rock series between the Dhaulagiri Limestone and the Muth Dolomite are somewhat ill-defined. Unfortunately there is also much tectonic disturbance in the zones where the Silurian crops out. This experience was also made by HEIM & GANSSER (1939, p. 204) in Kumaon. The graptolite bearing dark, series reported from the Nilgiri area by EGELER et al. (1964) and BORDET et al. (1971) are missing in western Dolpo. There the Silurian is represented by blue limestones and dolomites, or multicoloured calc schists and flasery limestones.

In several sections (e. g. western Daldung Khola, Sije Khola) the Dhaulagiri Limestone passes upwards into well-bedded, dark blue, marly limestones and silty limestones with a few beds of dark or light dolomite and carbonate quartzite. The impurities in the limestones consist of quartz, quartzite, felspar, muscovite and carbonate, mainly in silt size. Ochre or grey-green weathering is common. The limestones are frequently pelletal, fine-brecciaceous, or nodular, and exhibit traces of bryozoa, burrows, and hieroglyphs. Like all the Silurian rocks they are rich in crinoids and yield nautiloids of "orthoceras" type. One sample (F 133) from this basal horizon in the western branch of the Daldung Khola has yielded small, smooth, and round tubercles of *Nostolepis*. According to Dr. V. J. GUPTA (Geology Dept. Panjab University, Chandigarh), who kindly examined the sample, this fossil indicates Silurian age. In this basal series there are still some beds resembling the Dhaulagiri Limestone, and therefore I have mistaken these orthoceras bearing beds as uppermost Dhaulagiri Limestone in my 1967 paper (e. g. NE of Phoksumdo Lake). From my present experience I place them into the Silurian.

There is also a very conspicuous series of calc schists, schistose marls, and fine-grained, flasery limestones of purple, pink, cream, green, medium grey, occasionally almost white, or blue colour. The thick-bedded sequence shows generally transversal s. Stems and cups of crinoids and "orthoceras" are common fossils (Fig. 19). Desiccation cracks indicate deposition in shallow water. This series may lose its multicoloured nature within rather short distances. So the thick development of multicoloured limestones observed in the Sije Khola is missing in the Khup Khola. In the Phoksumdo region the red and purple sediment colours disappear from NW towards SE. There, a band of green-grey and dark silty slates comes in towards SE. These finely laminated rocks show graded bedding and indicate deepening towards the E.

In the upper part of the Silurian blue-grey limestones and dolomites, very similar to those at the base, form passage beds to the Devonian. A poor brachiopod and gastropod fauna is found beside bryozoan and crinoid remains *).

There is much variation from section to section, but commonly the blue limestones and dolomites are found at the base and at the top, the multicoloured schistose limestones in the central parts of the Silurian. But any of these members may be missing. In the upper Sije Khola, for instance, the whole

*) Prof. J. B. WATERHOUSE still keeps this fauna for determination.

Silurian is represented by 150—200 m of dark limestones and dolomites, whereas, in other sections the Silurian is ca. 1000 m thick (Pl. 3—5).

Regarding metamorphism phyllitic alteration is common in the described sequence.

The multicoloured series, which is missing in the E, no doubt, corresponds with the Variegated Silurian (HEIM & GANSSER, 1939) and the Silurian of Spiti (HAYDEN, 1904). The interesting discovery of the reefal Yong Limestone in Kumaon was made by SHAH & SINHA (1974). This lenticular limestone formation underlying their "Variegated" Formation (Variegated Silurian, HEIM & GANSSER, 1939) is either not represented in Nepal or was missed. Based on the occurrence of polygnathids VALDIYA & GUPTA (1972, p. 13) regard the uppermost part of their Variegated Series as Lower Devonian. In absence of determinable fossils and as there is a passage from the dark limestones into the Muth Dolomite in Nepal, I can not exclude that uppermost parts of these dark limestones are already Devonian. In the Annapurna region, in the E, the French geologists found that the upper part of the Dark Band Formation (EGELER et al.,

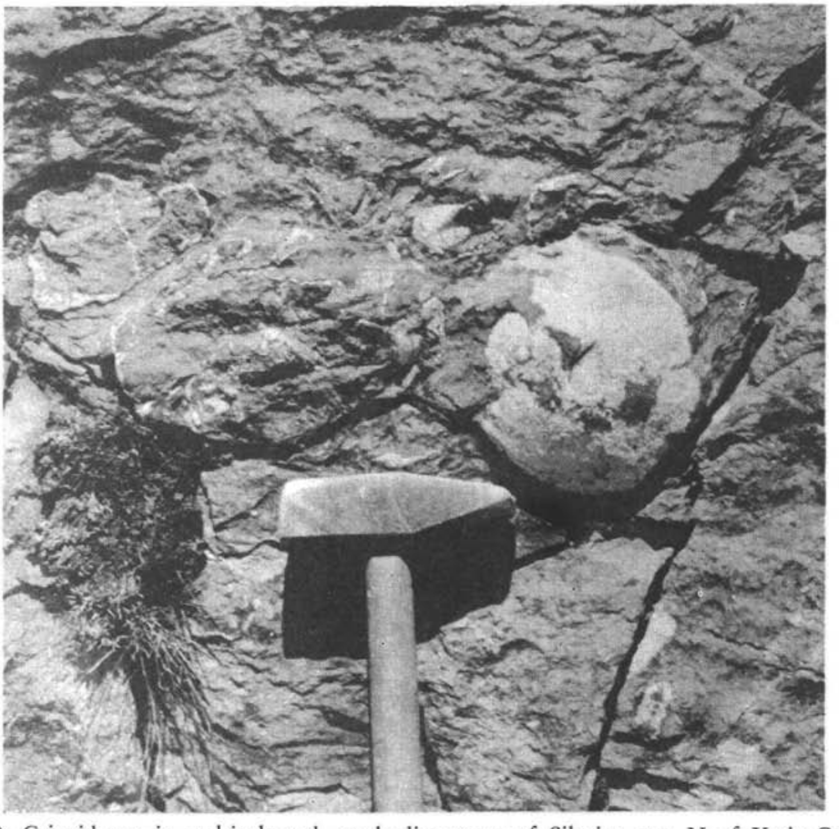


Fig. 19: Crinoid cup in multicoloured, marly limestones of Silurian age. N of Yatir Gompa, Dolpo.

1964) is of Lower Devonian age and thus the Siluro-Devonian boundary is lithologically ill-defined (BORDET et al., 1971, p. 95).

Finally, I should like to stress the palaeogeographic significance of the facies variation within the Silurian. If we consider the country between the Annapurna (Central Nepal) and Spiti there is a distinct shallowing towards the W. Less pronounced the same tendency is already indicated in the Ordovician and is very strong in the succeeding Devonian.

3.2.1.3. The Muth Formation

In Dolpo the facies of the Devonian changes considerably (FUCHS, 1967). The flyschoid Tilicho Pass Formation of the E grades laterally into a calcareous and dolomitic formation towards the W. The recently mapped area of western Dolpo is entirely in the dolomitic facies and there is already strong arenaceous influence like in the W, in Kumaon. I use the term Muth Formation to comprise the predominating dolomites as well as the interbedded quartzites.

Generally the dolomites are thick-bedded, occasionally also rather massive. The colour varies from very light grey to almost black. The latter dolomites give fetid smell on hammering. The light to medium grey types, however, are prevailing. Banding and fine lamination are common, occasionally graded bedding is observed. Wavy algal mats and stromatolitic structures are not rare. Light-coloured micritic tubes, ca. 3 mm thick and over 1 cm long, are probably also derived from algae. Oolites — the diameters of the ooids are generally around 1 mm — and intraformational breccias are frequent (Fig. 20). Ripple cross-lamination, current bedding etc. are particularly observed where dolomite, carbonate quartzite, and quartzites alternate. Desiccation cracks fit well with the shallow-water character of the formation. There are all gradations from sandy dolomite and carbonate quartzite weathering in brown colours, to white, pure orthoquartzite. Current bedding, ripple marks, desiccation cracks, and intraformational breccias are common.

In the N the Muth Formation is barren of determinable fossils, one coral stock excepted (F 137). Prof. Dr. H. FLÜGEL (University of Graz, Austria) kindly determined the fossil as *Cyathopoedium* sp.

In the southern limb of the Dolpo Synclinorium, however, approximately 300 m below the top of the 800—1200 m thick Muth Formation there is a zone, 150—200 m thick, rich in fossils. From this particular horizon farther SE I have collected corals, which are described by FLÜGEL (1966). The fossil zone is composed of dark limestones, marls, and dolomites. They are interbedded with brown and grey quartzite, black, silty, micaceous shales, and siltstones. The latter show hieroglyphs and apparently represent an intertonguing with the flyschoid Tilicho Pass Formation from the E. This fossil zone has yielded algae, corals, bryozoa, brachiopods, high-spired gastropods, and crinoids. I am much obliged to Prof. Dr. H. FLÜGEL for the determination of the corals indicating Middle Devonian age:

Stringophyllum (Sociophyllum) longiseptatum (BULV.) (F 150, 154)
Alveolites cf. *parvus* (LEC.) (F 150)

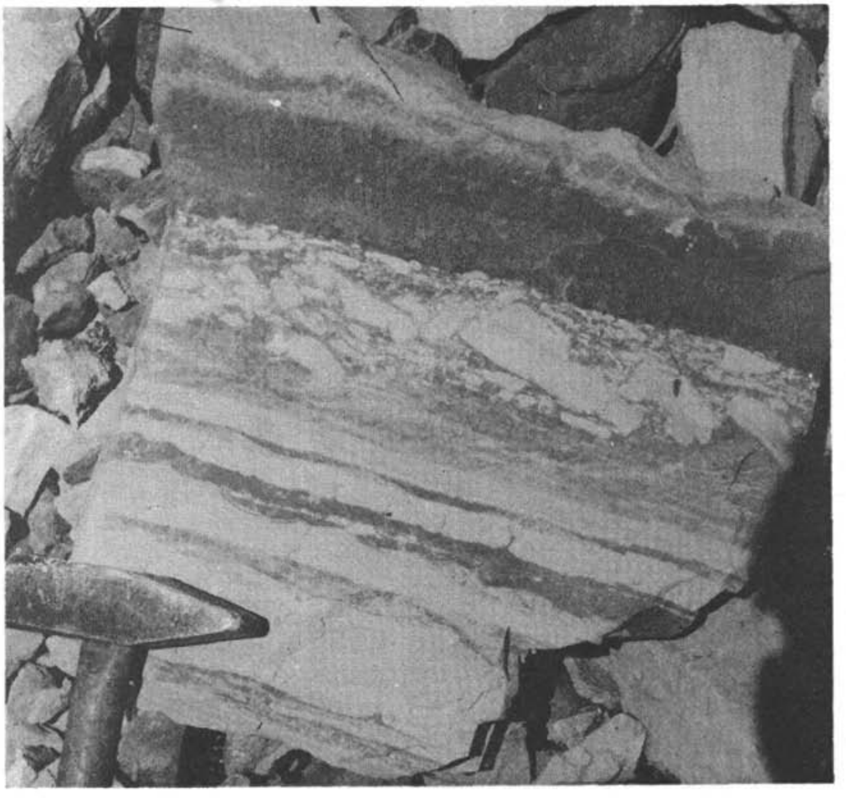


Fig. 20: Block from the Muth Formation showing alternation of dolomite (light) and carbonate quartzite (dark); current bedding, ripple cross-laminations, intraformational breccias, and graded bedding (at the top an arenaceous layer passes upwards into dolomite). Ascent from Daldung Khola to Daldung Dara, Dolpo.

Thamnopora sp. (F 151)
Favosites robustum Lec.(?) (F 153)
Stachyodes (?) (F 155)
Hexagonaria sp. (F 154)
Stromatopore (F 152)

Dr. G. Plodowski (Geology & Pal. Dept., Univ. Marburg, B. R. D.) kindly examined the brachiopods, which gave a Givetian (Upper Middle Devonian) age:

Indospirifer padaukpinensis (Reed) (F 154)
Indospirifer sp. (F 154)
(possibly a juvenile individual of *I. padaukpinensis*)
Crurithyris inflata (Schnur) (F 154)
Emanuella cf. *takwanensis* (Kayser) (F 154)
Stringocephalus burtini (DeFrance) (F 154)
Stringocephalus sp. (F 156)

Schiziphoria sp. (F 154)
[possibly a juvenile individual of striatula (SCHLOTHEIM)]
Camerophorina n. sp. (F 154)
Schnurella cf. *schnuri* (VERNEUIL) (F 154)
Athyris sp. 1 (F 154)
Athyris sp. 2 (F 154)
Spinatrypa sp. (F 154)
Productella sp. (F 154)
Bornhardtina n. sp. (F 156, 157)

This upper Middle Devon fossil zone is approximately in the central portion of the formation, unfortunately fossils are missing near the lower and upper boundary. No doubt, the Muth Formation corresponds with the Muth Series (HEIM & GANSSER, 1939) of Kumaon. There, SHAH & SINHA (1974) found an angular unconformity at the base of the Muth Quartzite. This important discovery is not surprising, if we consider the marked and wide-spread change in depositional conditions at the base of the Muth Formation.

Concerning the upper boundary of the formation some ambiguity has arisen from VALDIYA & GUPTA (1972), who separated the upper portion of the Muth Series (HEIM & GANSSER, 1939) as "Kali Series" from the "Muth Quartzite". Lithologically the "Kali Series" seems not to be very much distinguished from the underlying beds, but the cited authors report Lower Carboniferous fossils from it. I disagree that the rocks of the "Kali Series" lithologically resemble the Tilicho Lake (Ice Lake) Formation of western Nepal. The latter, however, shows great similarity with the succeeding Fenestella Shale of VALDIYA & GUPTA (1972). To decide, whether the upper Muth Series of Kumaon is Lower Carboniferous or not, more details concerning the find of the fossils and the exact position in the stratigraphic column are needed. SHAH & SINHA (1974), working W of the area described by VALDIYA & GUPTA (1972), did not find any Carboniferous beds. The Carboniferous beds are also missing in Dolpo W of the Tarap Khola. Probably this is related with the shallowing of the basin in western direction. This facies tendency, noticed already in the Ordovician, becomes more and more pronounced, particularly in the Devonian, when the flysch facies of the Kali Gandaki region grades westwards into calcareous, dolomitic (western Dolpo), mixed dolomitic-quartzitic (western Dolpo, Kumaon), and quartzitic (Spiti) facies. The Carboniferous is missing in parts of Kumaon and in western Dolpo, which probably is caused by erosion. In case of non-deposition some change in facies should be expected, which, however, was not observed in the Lower Carboniferous of Dolpo. Anyway, the missing of the Carboniferous coincides with a region of shallow-water facies in Siluro-Devonian times.

3.2.1.4. The Thini Chu Formation

The Thini Chu Formation consists of white, grey, green, and rather dark quartzites, conglomerates with components (2—5 cm, max. 10 cm diameter) of quartz, quartzite, and chert, glauconitic sandstones, carbonate sandstones, and -quartzites, blue-grey to black, sandy limestones, and grey-green to black, silty, or sandy shales and siltstones. The grain size of these rocks varies from fine to coarse. The quartzites, sandstones, and carbonate rocks frequently weather in ochre to deep brown colours. The obvious colouring and the banding — by the contrast of the hard, light-coloured and thick-bedded quartzites with the soft, dark argillaceous rocks — characterize the formation in the field. The ferruginous weathering, probably, has led WATERHOUSE (1976) to point out that the sandstones were "red, not yellow". This is misleading as red sediment colours are absolutely insignificant in the formation.

Current bedding is common in the clastic rocks, which often exhibit rather poor sorting. On the s-planes, which are frequently uneven, hieroglyphs and burrows are found. Doz. Dr. F. STEININGER (Palaeontological Inst., University Vienna) kindly informed me, that the hieroglyphs on one of my photos resemble *Spirophycos* and *Zoophycos*, which are indicative of a deeper shelf. A foot print of a tetrapod and plant remains, on the other hand point to near shore conditions (FUCHS, 1967). BORDET et al. (1971) even found the occurrence of coal. The marine nature of the formation, however, is demonstrated by the abundance of fossils, such as corals, bryozoa, brachiopods, pelecypods, gastropods, trilobites, and crinoids.

Regarding the ecology of the formation COLCHEN's find of tillites in the Thini Chu Formation of the upper Marsyandi (N of Annapurna group) is very important (BORDET et al., 1975). It is proof that Gondwana influences have reached the Tibetan Zone not only in the North-Western and Eastern Himalayas, but also in Nepal. In Dolpo the beds referred by WATERHOUSE (1976) from his "Kuwa Siltstone Member" might correspond with this tillite level.

Le FORT (1975) records the occurrence of spilitic volcanics from the Tibetan Zone of Central Nepal. These rocks have the same stratigraphic position as the above mentioned conglomerates and reinforce the existence of a gap already indicated by the biostratigraphical studies of the French geologists.

In western Dolpo the Thini Chu Formation generally is 30 to 70 m thick, E of Phopha towards Lurigaon its thickness increases to 100—120 m. This is rather thin compared to 80—300 m in eastern Dolpo (FUCHS, 1967), 470 m in the Kali Gandaki section (EGELER et al., 1964) and the thickness still increases further eastwards (BORDET et al., 1971, 1975).

Also in northern direction, the thickness of the Thini Chu Formation of eastern Dolpo increases, and sandy shales become predominant (FUCHS, 1967). This indicates deepening of the basin towards the N. In the area recently mapped this facies change is noticed around Nisalgaon. There, the thickness of the Thini Chu Formation increases to several hundred meters. The lowest 200 m of the formation are free of arenaceous rocks. The underlying Devonian dolomites show relief and are reworked. There are lenticular bodies of dolomite breccia (several tens of meters thick) composed of round and angular dolomite fragments up to dm-sizes (Fig. 21) and detrital dolomite. Sometimes it is difficult to discern the latter from the underlying Muth Dolomite. The occurrence of Permian brachiopoda in these reworked dolomites, however, helps in the distinction. The above rocks are associated with an alternation of medium grey to dark shales with sulphidic concretions and blue-grey marly, ochre weathering limestones. Also these argillites and limestones contain unsorted boulders of dolomite, which may range up to 0.5 m sizes. Remains of bryozoa, brachiopoda, and crinoids are not rare.

The described transgressive series is confined to the basal 20—50 m, upwards the argillites are dominant. In these shaley and silty series W of Nisalgaon it may be observed, how the sandstones and quartzites become intertonguing towards the W and SW where we find the normal lithology of the Thini Chu Formation.

Everywhere in western Dolpo the Permian Thini Chu Formation transgresses over the Devonian Muth Formation after a phase of erosion. In the region of Phopha and Bijor the topmost beds of the Muth Dolomite show yellow — khaki tints, and are somewhat silicified, which might be caused by Pre-Permian weathering. NE of Phopha a limonitic layer ca. 30 cm thick is found at the base of the Thini Chu Formation. The basal beds of the Thini Chu Formation — frequently quartzites and sandstones — fill pockets in the dolomite and contain angular pieces of the latter. Burrows, several cm long and a few mm thick, go from the contact into the dolomite and are filled with quartzitic material (Fig. 22, 23). Quartzite-filled crevices are observed in the Phopha area. At the small lamasery (eremitage) NW of Phopha, such "quartzite dikes" are up to 0.5 m thick and penetrate the dolomite down to 8 m.

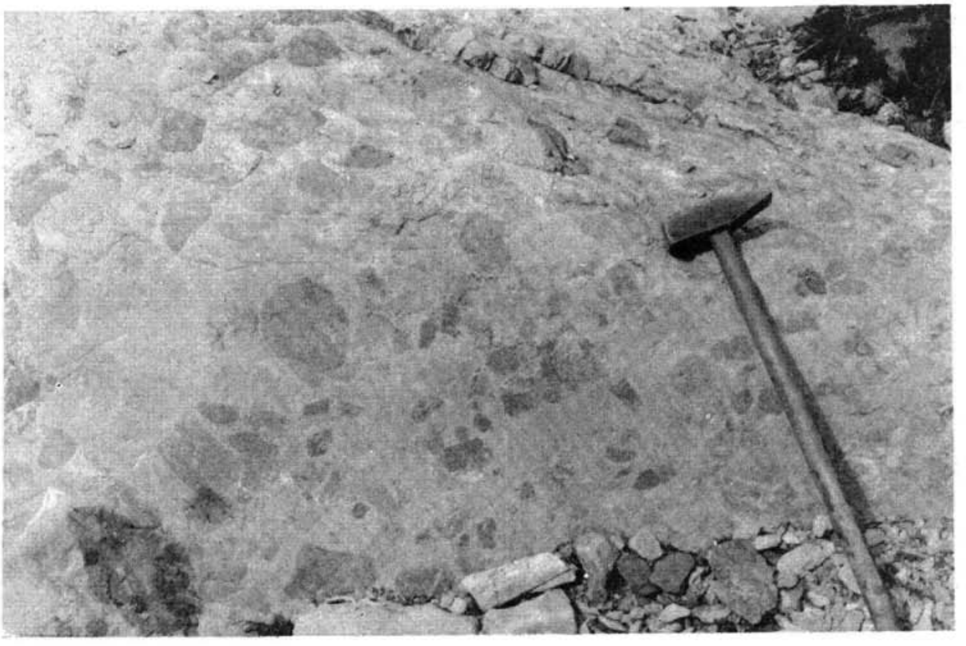


Fig. 21: Dolomite breccia forming the base of the Permian. The bed consists of reworked Devonian dolomite. N of Yatir Gompa, Dolpo.

Fig. 22: Horizontal dolomite of Muth Formation (Devonian) unconformably overlain by quartzite of Thini Chu Formation (Permian). The quartzite fills pockets in the dolomite and contains pieces of the latter. Burrowings are visible above the hammer. Trail from Phophagaon to the bridge E of the village, Dolpo.

Fig. 23: Transgressive contact as in Fig. 22 from the same locality. Detail, showing burrowings filled with quartzite (dark; pencil and hammer point to these fillings).

As to the age of the Thini Chu Formation the examination of the fossils collected in eastern Dolpo clearly showed a Permian (Flügel, 1966), particularly Upper Permian age (Waterhouse, 1966, see also Fuchs, 1967). This was substantiated by the palaeontological work of Waterhouse (1976) in course of our 1973 expedition. He found two separate faunas, an older one of Punjabian (i. e. late Middle Permian age) correlative to the faunas of the Kuling Shales, Lachi Group, and bulk of Zewan Series, and a younger fauna of the Djulfian and Dorashamian Stages (Upper Permian).

From the fact that Bordet et al. (1971) report Carboniferous fossils from the lower portion of the Thini Chu Formation Waterhouse (1976) concludes that the formation name has been misapplied by Fuchs (1967) for the Permian formation of Dolpo, and he suggests the introduction of a series of new stratigraphical terms. I do not follow that proposal for following reasons:

1) Thini Chu Formation has become a widely used term for a very distinctive rock assemblage. From personal contact with Prof. Dr. C. G. Egeler (Amsterdam), who has introduced the name, and Prof. Dr. M. Colchen (Paris) I know that we all are talking about the same rock suite, when using the name Thini Chu Formation. The fact that the Carboniferous and Lower Permian are missing in Dolpo, the Thini Chu Formation being Middle to Upper Permian, and that this gap eastwards becomes gradually reduced, so that the Thini Chu Formation in the E also comprises Middle and Upper Carboniferous is no reason to give up the term of this litho-unit. On the contrary this fact gives information about the basin configuration: Like in previous geological times there was an epeirogenetic high in western Dolpo, whereas, towards the E (Thakkhola) basin conditions prevailed.

2) The terms of Waterhouse (1976) do not conform with code of nomenclature. The type sections are often very far from the localities giving the names. These are in part rather obscure (e. g. Senja Khola, which is not even indicated in Waterhouse's own map (Fig. 1), probably the Segia (Daldung) Khola is meant, along which valley, however, there is not a single outcrop of Permian), or show strange spelling (e. g. Pangjang and Panjang, Pija instead of Bijor, She Gompa instead of Sya Gompa of the official Map 1″ = 1 mile). Furthermore, some of the localities were not even visited by Waterhouse and are in areas of non-Permian rocks (e. g. Kuwa lies in Lower Palaeozoic, Nambdo in the Middle Triassic Mukut Limestone).

3) The Permian as a whole may be traced over great distances even by means of binoculars. The subdivision into two formations and six members, however, requests detailed mapping between the sections studied. But this was not possible due to shortage in time and the vast and rugged character of the country. Correlation between the studied sections is not always based on fossils, but on lithology. Taking into account the facies variability in these near-shore deposits, the stratigraphic scheme of Waterhouse (1976) seems rather doubtful. The variability in thickness and lithology is also evident from Waterhouse's descriptions. So he mentions that several of his members may be equivalent with each other.

Whereas in eastern Dolpo the Permian is succeeded by the Scythian apparently without a break (FUCHS, 1976) a slight gap is indicated by a lateritic layer (ca. 10 cm) on top of the Permian in western Dolpo (FUCHS, 1974). From faunal studies WATERHOUSE (1976) concludes that the gap is very slight.

3.2.1.5. The Lower Triassic

The Scythian of Dolpo is a very good marker horizon. The ochre weathering, very resistant band, 15 to 30 m thick only, may be identified from afar and is easily traced in the field (Fig. 24 on Pl. 6). The formation consists of thin-bedded, dense, partly flasery limestones, interbedded with rather subordinate shales mainly in the central part. The limestones are frequently nodular with wavy s-planes. The colour of the limestone is generally light grey or brownish, but also dark grey to blue, the shales are grey. In certain areas (e. g. SW of Phopha, E of Lurigaon, and in the Kanjiroba Khola) multicoloured beds were found in the middle portions of the Scythian. These consist of pink, red, white, and green, dense limestones and purple and green shales. Some beds are rich in fossils, mainly cephalopoda, and make the apearance of a condensed sediment. The preservation of the fossils, however, generally is poor.

The basal bed of the Lower Triassic shows generally ferruginous weathering and succeeds the Thini Chu Formation, frequently with a limonitic layer a few cm thin in between. The lowest limestone commonly is arenaceous, but the sand content ceases upwards within 20 cm. Besides angular sand grains there are rolled concretions of phosphorite up to 3 cm in diameter in this basal bed *). Under the microscope these show fine filaments and an abundance of micro organisms, e. g. calcareous foraminiferas etc. There are bivalves and ammonites in this basal bed. Prof. Dr. B. KUMMEL (Harvard University Cambridge, Mass., USA) kindly examined my Scythian ammonite collection and identified:

Otoceras woodwardi GRIESBACH (F 106)
Ophiceras sp. indet. (F 106)
from the lower 10 cm of the basal bed, and 50 cm above the Scythian base:
Otoceras sp. (F 90),
? *Ophiceras* sp. indet. (F 90).

From the lower central portion of the Scythian (4—5 m above the base) are derived:

Pseudosageceras multilobatum NOETLING (F 107)
Prionolobus sp. indet. (F 107, F 108)
Orthoceras sp. indet. (F 97)
Gyronites sp. indet. (F 109)
Proptychites sp. indet. (F 128)

and a new genus and sp. with nothing to be compared. In addition to these fossils WATERHOUSE (1976) reports from the lower part of the Scythian *Otoceras concavum* and a number of productid species. This author stresses the significance of

*) For the chemical proof of the phosphatic nature of these concretions I am very much obliged to Dr. P. KLEIN, chemical laboratory, Geol. B.-A., Vienna).

the occurrence of *Claraia bioni* (NAKAZAWA) and of *Glyptophiceras* (= *Xenaspis* of DIENER, 1915) indicating a basal Gangetian age.

In comparison to the prevailing calcareous Scythian of Dolpo the corresponding beds E of the Kali Gandaki are dominantly argillaceous (BORDET et al, 1971). In the W, in Kumaon, the Lower Triassic increases to a 30—50 m thickness and is argillaceous-calcareous (Chocolate Series, HEIM & GANSSER, 1939). Further W, towards Spiti, the thickness decreases again to 13 m.

It has already been mentioned (chapter 3.2.1.4.) that in western Dolpo the Scythian transgresses over the Permian beds after a very slight break in deposition. The lithology of the Scythian indicates deepening, and particularly widening of the basin. The dense limestones and interbedded argillites were deposited far from the shore line, where no arenaceous material reached them; only the lowest bed shows some reworking of the underlying Permian.

3.2.1.6. The Mukut Limestone

In eastern Dolpo the Scythian passes upwards into the calcareous-argillaceous alternation of the Mukut Limestone of Anisian to Carnic age. In the N, near the Tibetan border, exceptionally, the lower 30—80 m of the Middle Triassic are composed of soft, dark grey shales and then the Mukut Limestone commences in normal lithology (FUCHS 1967, p. 181).

In western Dolpo there is a conspicuous horizon of blue-grey, ferruginous weathering, nodular limestone interbedded with dark grey or green argillite at the top of the Scythian. Morphologically this 2—5 m thick horizon forms the top portion of the resistant light brown weathering Lower Triassic band, but the fauna (bryozoa, brachiopoda, and ammonites) clearly shows that this bed belongs to the Anisian. Dr. M. SIBLIK (Geological Survey, Prague, Č. S. S. R.) kindly examined the brachiopods and published his results in 1975. From this nodular limestone are derived:

Spiriferina cf. *stracheyi* (SALTER) (F 76)
Dielasma himalayanum (BITTNER) (F 79)
Spiriferina stracheyi (SALTER) (F 79)
Koeveskallina koeveskalyensis spitiensis (STOLICZKA) (F 79)
Spirigerellina stoliczkai (BITTNER) (F 79).

The numerous ammonoidea and bivalvia were determined by Drs. L. KRYSTYN and B. GRUBER respectively (both Palaeontological Institute of the University Vienna). The material was kept unattended for years by other palaeontologists and finally was returned unexamined, and I am particularly obliged to the named gentlemen for the determination within very short time enabling me to bring their results in this paper. Due to the delayed determination, however, the corrected Mukut Limestone—Tarap Shale boundary is not accounted for in the plates.

The samples from the basal nodular limestone gave:

F 76:	a)	*Ptychites rugifer* (OPPEL) *Buddhaites rama* DIENER	Middle Anisian (Pelsonian)
	b)	*Nicomedites osmani* TOULA	highest part of Lower Anisian

F 79:	*Ptychites* cf. *oppeli* (MOJS.)	Middle (—Upper) Anisian
	Trematoceras sp. ind.	
F 110:	*Ptychites* sp. ind.	Middle—Upper Anisian

Except of the region of Phopha, where the lower 30—100 m of the Mukut Limestone are replaced by dark grey to almost black, bleaching, laminated shales with silty layers, the Mukut Limestone follows above the nodular Anisian Limestone. The Mukut Limestone is composed of well-bedded, dark blue limestones weathering ochre, dark marls and almost black shales. Some of the limestones show fine lamination and nodular s-planes. Burrowings and hieroglyphs occasionally observed, indicate an euxinic environment, which is also shown by the frequent occurrence of pyrite. This pyrite content causes bleaching and the light weathering colour of the formation in the field, which contrasts with the dark colour of its rocks. S of Bijor layers of carbonate quartzite were observed in the Mukut Limestone, which is an exception. The 50—300 m thick calcareous-argillaceous alternation, generally, is intensely folded, making it difficult to trace fossil horizons. Ammonites, brachiopods, bivalves (daonellids), and crinoids are found throughout the formation. The fossils listed in FUCHS (1967) indicate Anisian-Carnic age of the Mukut Limestone.

The examination of my recent collection by Drs. L. KRYSTYN (ammonoidea) and B. GRUBER (bivalvia) gave:

F 81:	*Daonella lommeli* (WISSMANN)	Upper Ladinian
	Daonella indica BITTNER	
F 96:	a) *Joannites* cf. *cymbiformis* (WULFEN)	Lower Carnic
	b) *Projuvavites* sp.	
	Arcestes sp.	upper Upper Carnic
	nautiloid ind.	
F 98:	*Halobia* cf. *austriaca* MOJS.	lower Lower Noric (Lac 1)
F 99:	*Daonella lommeli* (WISSMANN)	Upper Ladinian
F 100:	This sample contains two ammonite associations of different age.	
	a) dense micritic limestone contains	
	Joannites cymbiformis (WULFEN)	Lower Carnic
	Joannites sp.	
	b) spatitic limestone rich in fossil debris yielded	
	Tropites cf. acutangulus MOJS., 1893	
	Tropites torquillus MOJS., 1893	Upper Carnic (Tuval 2)
F 101:	*Anatropites nihalensis* DIENER, 1906	
	Euisculites bittneri (GEMMELLARO, 1904)	
	Gonionotites vincentii GEMM., 1904	
	Projuvavites sp.	just below the
	Griesbachites ? sp.	Carnic-Noric boundary
	Anasirenites ? sp.	
	Arcestes geyeri DIENER, 1918	
	Arcestes schafferi DIENER, 1918	

F 102:	*Sturia sansovinii* (MOJS., 1869)	
	Monophyllites sp.	Upper Anisian-Ladinian
	Daonella sp. ind.	
F 125	(2 m above the nodular limestone):	
	Gymnites sp. ind.	Middle (—Upper) Anisian
F 126	(2 m above the nodular limestone):	
	Ptychites cf. *rugifer* (OPPEL)	Middle Anisian (Pelsonian)
F 141:	*Paratrachyceras* cf. *regoledanum*	upper Upper Ladinian
	(MOJS., 1882)	(= Langobardian)
F 143:	*Daonella esinensis* SALOMON	Anisian-Ladinian boundary

The brachiopods, which were kindly identified by Dr. M. SIBLIK, gave the following determinations (SIBLIK, 1975):

Koeveskallina koeveskalyensis spitiensis (STOLICZKA)
Spirigerellina stoliczkai (BITTNER)
both from the lowest 2 m of the fomation (F 126).
Pexidella aff. *hunica* (BITTNER) (F 101)
Austriellula fuchsi sp. n. (F 101)
Spiriferina cf. *stracheyi* (SALTER) (F 77 in FUCHS, 1967, Pl. 7)
? *Austriellula fuchsi* sp. n. (F 102 in FUCHS, 1967, Pl. 7)
„*Rhynchonella*" cf. *mutabilis* STOLICZKA (F 166 in FUCHS, 1967, Pl. 7)

The sample F 142 was obtained from near the lower boundary of the Mukut Limestone, but its stratigraphic position is somewhat doubtful due to structural complications (see Pl. 3,4 (9) S of Bijor). F 142 yielded:

Dielasma (?) cf. *julicum* (BITTNER)
„*Spiriferina*" aff. *orophila* (DIENER)
and bivalves.

The listed fossils show that the lithologically different basal bed, the nodular limestone, contains forms indicating upper Lower to Middle Anisian age, whereas the overlying lowest portion of the typical Mukut Limestone yields Middle to Upper Anisian forms. Thus the lithological break appears to be in the Middle Anisian.

The fact that samples F 96 and 100 contain fossil associations of different age may be caused by sampling from two horizons, which have come in close contact by disturbances within the formation. More probable is that the Lower Carnic is of rather reduced development, and thus the two different faunas come close together.

Further the recent fossil determinations show that the Mukut Limestone comprises the whole of the Carnic and that its upper boundary lies in the Lower Noric (F 98) or even higher *).

Towards the E the corresponding Middle to Upper Triassic beds are predominantly argillaceous (BORDET et al, 1971, p. 126) whereas towards the W the facies becomes less argillaceous: The Kalapani Limestone of Kumaon, however,

*) A re-examination of my 1963 material of eastern Dolpo yielded *Malayites* sp. ind. from sample 77 (FUCHS, 1967, Pl. 7) which indicates a middle Lower Noric age (Lac 2).

is much thinner, usually 30—50 m (HEIM & GANSSER, 1939). Thus, as in several Palaeozoic formations a deepening of the basin is indicated towards the E and also towards the N (dark shales replacing lower part of Mukut Limestone).

3.2.1.7. The Tarap Shales

In eastern Dolpo the boundary between the Mukut Limestone and the overlying Tarap Shales is not very sharp. There, the carbonates become sandy and silty and pass into the flyschoid Tarap Shales. In western Dolpo the lower boundary of the Tarap Shales is marked by a 3—5 m, occasionally 10 m thick bed of green, grey, impure, micaceous, quartzitic sandstone exhibiting ferruginous weathering.

This quartzite horizon is succeeded by dark grey or green silty shales and shaley siltstones (150—200 m). Some of these rocks bear light mica and chlorite, probably being detrital. The upper portion of the Tarap Shales consists of shaley siltstones, siltstones, and impure sandstones (150—200 m). This upper sequence is of thick-bedded appearance contrasting with the underlying shaley portion.

Hieroglyphs, cabbage leaf structures, flow structures, tool marks, flute casts, and graded bedding are common in the Tarap Shales and underline their flysch character (Fig. 25). Black concretions are not rare in the shales.

The thickness varies between 300 and 400 m, but may be tectonically reduced to 30 m.

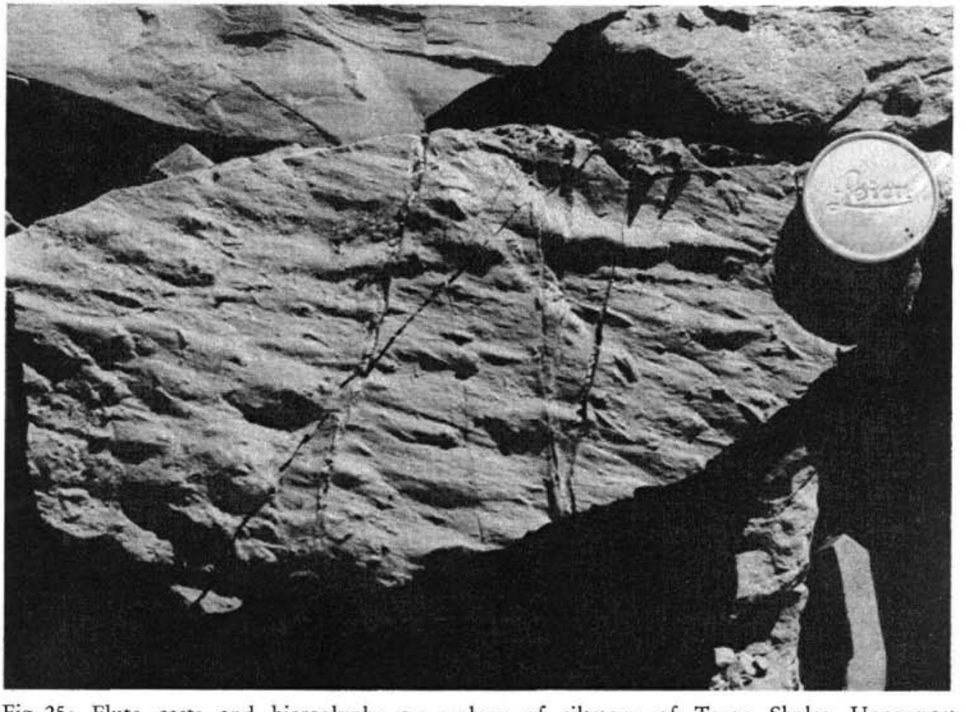


Fig. 25: Flute casts and hieroglyphs on s-plane of siltstone of Tarap Shales. Uppermost Nadadu Khola, Dolpo.

Fossils are rare and rather sporadic (see FUCHS, 1967, p. 182). In course of the 1973 expedition I have found a few occurrences of blue-grey, calcareous, silty shales yielding brachiopods, bivalves, and gastropods. Some of these fossils seem to belong to pectinids, aviculids, mytilids, and oysters. The samples derived from SW of Phopha and SW of Sungjar Gompa are still with Prof. J. B. WATERHOUSE for determination. An ammonite (F 140) was determined as *Tibetites* cf. *ryalli* MOJS., 1896 by Dr. L. KRYSTYN (Palaeont. Inst. University, Vienna), who kindly has undertaken the examination. The fossil indicates upper Lower (?) to Middle Noric age. Small, globular, ribbed ammonites (F 130) did not allow determination.

As to the position in the stratigraphic column and lithology the Noric Kuti Shales of Kumaon match very well with the Tarap Shales. From this fact and the poor fauna collected in Dolpo FUCHS (1967) designated Carnic-Noric age to the formation. Most recent fossil determinations show that the formation is only Noric (see chapter 3.2.1.6.). The French geologists report rich ammonite faunas from the corresponding shales E of the Kali Gandaki, which, however, contain more calcareous horizons (BORDET et al, 1971).

3.2.1.8. The Quartzite Beds and Kioto Limestone

The upper parts of the Tarap Shales show an increase in sand content and they are capped by a conspicuous quartzite series, which contrasts with the underlying sombre-coloured siltstones. The Quartzite Beds consist of a thick-bedded alternation, approximately 50 m thick, of green, white, grey, and brown, thick-bedded quartzites, carbonate quartzites, sandy dolomites, and blue, grey limestones, marls, and grey, green shales. Oolites and current bedding stress the shallow-water character of these deposits. The Quartzite Beds indicate a marked regression, which is noticed throughout the Himalayan Tethys.

Upwards the Quartzite Beds pass into the Kioto Limestone, both together being 200—400 m thick. The Kioto Limestone, also generally thick-bedded comprises light to dark grey, blue limestones and dolomites, and a few arenaceous beds are occasionally interstratified. Many of the dolomites are secondary dolomites. Oolitic and pelletal structures as well as intraformational breccias show that the environment was still rather shallow. Layers full of biodebris are frequent, comprising remains of algae, corals, bryozoans, brachiopods, pelecypods, gastropods, and crinoids. Megalodon-Lithiotis shell beds are conspicuous. Prof. Dr. O. F. GEYER (Geology Dept., University of Stuttgart, B. R. D.) kindly identified *Lithiotis* from my photos (Fig. 26). This is evidence for Liassic age. Also from a photo, Doz. Dr. F. STEININGER (University, Vienna) kindly determined a section of a gastropod as *Endia trachelis* sp. indicating Dogger-Malm age. Further an imprint of a pteridophytic branch was found in a quartzite of the Quartzite Beds. This determination was kindly done by Prof. Dr. W. KLAUS (Palaeont. Institute, University of Vienna) from the photo. Judging from these fossils, and those reported by FUCHS (1967) and BORDET et al (1971) I assume a Rhaetic to Dogger age for the Quartzite Bed — Kioto Limestone sequence. It can not be excluded that there is also uppermost Noric in that succession, a view particularly favoured by V. J. GUPTA (1976).

Fig. 26: Megalodon-Lithiotis shell bed. Kioto Limestone block from the mountain 18376' N of Bijorgaon.

The series described in that chapter forms a very continuous formation in the Tethys Zone from Kashmir to Nepal.

3.2.1.9. The Lumachelle Formation

At the top the Kioto Limestone passes into a thin-bedded sequence of grey to dark blue lumachelle limestones, partly weathering ochre, marls, dark shales, and a few layers of light grey calcareous sandstone.

By fossils this formation is established to be Upper Dogger in age (FUCHS, 1967). In its character the Lumachelle Formation appears to be rather constant; it corresponds with the Dogger described by BORDET et al. (1971), the rich bivalve beds between the Kioto Limestone and the Sulcacutus Beds (DIENER, 1912, p. 102) and the Laptal Series (HEIM & GANSSER, 1939). The latter authors, however, assumed a Liassic age of the Laptal Series, which from comparison with the adjoining regions seems unlikely.

In western Dolpo the Lumachelle Formation was found only in the region S of Sya Gompa. There, it fills the core of a rather disturbed syncline [Pl. 4 (11—13)].

3.2.1.10. The Spiti Shales

In the syncline just mentioned the Lumachelle Formation was found associated with a ca. 50 m thick sequence of highly squeezed, thin-bedded, black shales with concretions. One fragment of a belemnite was observed. There is not much doubt, that these argillites represent the Spiti Shales. But the ferruginous impure limestone bed separating them from the underlying Lumachelle Formation in other sections, is missing there, probably, due to tectonics.

The Spiti Shales are the youngest formation in the succession of Dolpo. They are generally regarded as Upper Jurassic — Neocomian. BORDET et al. (1971), however, showed that in Thakkhola the Spiti Shales are only Malmian, because they are overlain by terrigeneous beds of Wealdian — Barremian age.

3.2.1.11. Review of the Stratigraphy of Dolpo

The succession of the Tibetan Zone commences with thick trough deposits indicating geosynclinal conditions in Cambro — Ordovician times. That does not mean that these sediments were deposited in very deep water, but there was rapid subsidence of the trough, which was balanced by sedimentation. This is proved by the great thickness of approximately 4000—5000 m, the monotony, and rhythmic character of these series. In the Silurian basin conditions persisted in the E with the deposition of graptolite bearing beds in an euxinic environment. Towards the W (western Dolpo, Kumaon) the facies becomes shallow. Even more marked are the facies differences in the Devonian. North of Annapurna and in eastern Dolpo geosynclinal conditions persisted, as shown by the flyschoid Tilicho Pass Formation. Towards the W these beds pass into shallow-water carbonates and further W the arenaceous influence increases (Muth Quartzite). There, sedimentation was of a platform type. The Lower Carboniferous dark, argillaceous carbonate series are preserved only in the E and in part of Kumaon (VALDIYA & GUPTA, 1972), in western Dolpo the whole of the Carboniferous and the Lower Permian are missing. There, the transgressing Thini Chu Formation is of Middle to Upper Permian age, whereas in the E (N of Nilgiri) it comprises also Middle and Upper Carboniferous (BORDET et al, 1971). But also there, a slight gap within the Thini Chu Formation is observable (BORDET et al., 1971; 1975, p. 126; COLCHEN, 1975). Anyhow, in the Upper Palaeozoic the succession is more complete in the E than in the W, which like in older formations indicates basin conditions in the E and an epeirogenetic high in western Dolpo. Such an epeirogenetic high influencing the facies of various formations was recognized also in the E, and called Nar Dome by BORDET et al. (1975). The facies of the Thini Chu Formation shows varying conditions in a near shore environment.

At the base of the Lower Triassic a slight gap is indicated in western Dolpo and the Thakkhola, but is not known from eastern Dolpo, the Nyi-Shang and Jolmo Lungma regions (BORDET et al., 1971, 1975; FUCHS, 1967, 1974; COLCHEN, 1975; WATERHOUSE, 1976). The facies of the Scythian is evidence that the basin has widened and probably also deepened. The Anisian — Carnic deposits are dark carbonates and argillites, which pass into argillaceous — silty series in the Noric. Thus the Triassic formations exhibit basin facies with increasing clastic influx towards the top. The Rhaetic is marked by a regression all along the Himalayan Tethys, and is followed by Lower to Mid-Jurassic shallow-water carbonates. There is a discontinuity comprising the Upper Callovian and Lower Oxfordian. (BORDET et al., 1971, p. 148; COLCHEN, 1975). The Upper Jurassic Spiti Shales, the youngest beds of Dolpo, indicate deepening of the basin. Concerning the younger history I refer to BORDET et al. (1971) and COLCHEN (1975).

This review shows that instable periods with rapid subsidence, real basin facies, alternated with periods of stable shelf environment during Palaeozoic-Mesozoic times. In my view, the Tibetan Zone was not a platform, as envisaged by COLCHEN (1975, p. 92) and LE FORT (1975, p. 14), but represented a miogeosyncline.

3.2.2. Tectonics (Pl. 3, 4)

The succession of Dolpo described in the preceding chapters is connected with the underlying Crystalline. They form one structural unit and are not separated by any tectonic line. Even so, the pile of Tethys sediments exhibits tectonic style, which is different from that of the Crystallines. The crystalline series were deeply burried and subjected to tectonics under metamorphic conditions of amphibolite facies grade, the direction of movements is throughout towards SW. Contrary the non- or slightly metamorphosed Tibetan sedimentaries show open and free folding, the direction of movement varies, generally, it is towards the central axis of the Dolpo Synclinorium. The tectonics would be simple if, minor folding and faulting were not complicating the structure. Due to differences in mechanical properties, for instance, between the rigid Devonian dolomite plate and the succeeding soft formations, reverse faults, wedge structures, and small scale thrusts are numerous. These minor complications make geological mapping, stratigraphical studies, and deciphering of the structure in some places very difficult.

In the area adjoining in the E I have described the structural elements from S to N (FUCHS, 1967). The same way will be followed in this paper.

3.2.2.1. The South-Western Margin of the Dolpo Synclinorium

This zone was investigated along the Phoksumdo Khola. The Dhaulagiri Limestone, which builds up the Kanjiroba Range, forms large folds in the northern face of that range, and dips beneath the Silurian series in the N [Pl. 3, 4 (7—13)]. On the crest of the Kanjiroba Range, there are probably remnants of the Silurian preserved from erosion (binocular observation). In the upper Phoksumdo Valley the Silurian series show synclines and anticlines, whereas, in their south-eastern continuation, N of the Phoksumdo Tal (= Lake), they dip towards the NNE beneath the Muth Formation at medium angles [Pl. 4 (13)]. Following towards NW the Siluro-Devonian boundary becomes steeper, overturned, and finally the Silurian anticline overrides the Devonian along a thrust [Pl. 3, 4 (7—13), Fig. 27 on Pl. 7, 28 on Pl. 8]. It is interesting that this thrust plane cuts the Devonian beds at right angles. A Devonian scale along the thrust contact and parallel to it represents a remnant of the inverted north-eastern limb of the anticline. The horizontal Devonian building up the lofty peak 19630' overlies the Silurian rocks in normal manner.

Like in the Annapurna, Nilgiri, and Dhaulagiri Ranges the movements are towards NE.

3.2.2.2. The Tarap-Charka Syncline

The syncline commences N of Sangdah, near the Thakkhola and may be traced towards the WNW via Charka, Tarap to the area recently mapped (FUCHS, 1967, Pl. 7; Pl. 3 of present paper). The syncline is exposed S of Sya Gompa and ends in the upper Nadadu Khola.

The south-western limb of the Tarap-Charka Syncline shows the normal stratigraphic order and dips gently NE in the area NE of Phoksumdo Tal [FUCHS, 1967, Pl. 7, 8 (1)]. Near the Gand La (= Pass) the Devonian dolomites dip NE, but overthrust the Upper Triassic Tarap Shales along a SW-dipping thrust plane (Fig. 29 on Pl. 8). This thrust is parallel to that one, which separates the Silurian and Devonian described in chapter 3.2.2.1. Tracing the thrust further NW one by one the Mukut Limestone, the Lower Triassic, and the Permian of the inverted south-western limb of the Tarap-Charka Syncline come in at the base of the thrust (Fig. 30 on Pl. 9). The thrust between the Mesozoic and Palaeozoic series ends in that region where the thrust between the Silurian and Devonian begins. It appears that the displacement performed along the Gand La thrust in the E, further westwards jumped over to the Siluro-Devonian thrust.

A minor syncline of the Tarap-Charka Synclinal zone strikes towards the knee of the upper Kanjiroba Khola, where it ends. The main syncline is still well-developed in the upper Nadadu Khola (Fig. 30 on Pl. 9), but farther W there are just two faulted narrow bands of Permian — Triassic rocks in between the Devonian dolomites. The southern one follows a steeply SSW-dipping reverse fault, the northern one dips NE at medium angles and is overthrust by Devonian dolomites from the NE [Pl. 4 (6, 7)]. Thus, the harmonic folding within the Mesozoic beds is replaced by disharmonic block movements in levels near the Palaeozoic — Mesozoic boundary. The downward movement in the syncline is still recognizable in the movement of the block between the two reverse faults mentioned.

The northern reverse fault may be traced SE to the Mandakdin Khola. There, it terminates an anticlinal wedge, which in the N is delimitated by a SSW-dipping reversed fault [Pl. 4 (10, 11)]. In the N follows a second wedge overriding a syncline of Permian — Triassic rocks towards NNE. These structures may be followed to the region N of Sya Gompa.

In the area S of Sya Compa Jurassic rocks mark the central axis of the Tarap-Charka Syncline. There, the steep SSW-limb reveals the vergency directed NNE. Section 13 (Pl. 4) shows that the Kioto Limestone of the SSW-limb locally has overridden the squeezed Jurassic formations. Steep strike faults complicate the boundaries between the Lumachelle Formation, the Kioto Limestone, and the Tarap Shales.

3.2.2.3. The Anticline of the Nagung Khola

In the Nagung Khola there is an anticline of Permian rocks surrounded by Triassic formations. The southern limb of this anticline shows an interesting complication [Fuchs, 1967, Pl. 7, 8 (1); Pl. 3 of this paper]. A wedge of Permian rocks pushes into the Triassic rocks towards the SW.

In the region between the Nagung- and Tar Kholas the anticline is indicated by Mukut Limestone exposed in the smaller valleys, whereas, the ridges of the Sela Mungchung Lekh (= Range) all consist of Tarap Shales. The anticline is a very significant structure in the Tar Khola. The core of the anticline is formed by Muth Formation laid in NE-vergent folds, which are beautifully exposed W of Tatagaon [Pl. 4 (8, 9)]. SSE of that village a wedge of the Devonian dolomites overthrusts Mukut Limestone (Fig. 31 on Pl. 10). The wedge structures in the south-western limb of the anticline have been described with the syncline adjoining in the S (chapter 3.2.2.2.). In the region of the Langu, scale structures complicate the north-eastern limb of the anticline [Pl. 4 (4—9)]. W of the Langu a few narrow bands of Permiam — Triassic rocks have come in midst of the Devonian Muth Formation by the block movements of the latter.

3.2.2.4. The Koma Syncline

The Kioto Limestone forming the core of the Koma Syncline in the name giving region abuts against Permian rocks along a steep fault (Fuchs, 1967). The westward continuation of the Koma Syncline is marked by the Kioto Limestone capping the Kalkya Lekh, W of the Nagung Khola. These rocks show much folding and also some faulting (Fig. 32 on Pl. 11, 33 on Pl. 10). The Kioto Limestone, W of Phophagaon, represents the western most Kioto Limestone occurrence of the Koma Syncline (Fig. 24 on Pl. 6, 34 on Pl. 12).

The south-western limb of the syncline is very complicated in the region Bijorgaon — Langu. S of Bijor, there is a minor syncline, which may be traced to the area SW of Phopha. A Palaeozoic wedge pushes south-westwards into the Mesozoic cover W of Bijor. The Devonian dolomite occurrences E of that village mark the beginning of an anticline, which separates the secondary syncline S of Bijor from the main syncline building up the Kalkya Lekh, N of the village. The mentioned anticline is best exposed S of Phopha (Fig. 34 on Pl. 12). Further westwards it is represented by a wedge overthrusting a narrow zone of Permian and Triassic beds in the SW. At the closure of the Koma Syncline the Palaeozoic — Mesozoic boundary is complicated by secondary folds and scale structures. The vergency varies, either being SW or NE [Pl. 4 (5—7), Fig. 35 on Pl. 12)].

If the Palaeozoic — Mesozoic boundary is followed eastwards, in the northern limb of the Koma Syncline we find scale structures directed NNE (e. g. near the bridge across the Panjang River, Pl. 4 (7), Fig. 24 on Pl. 6) or SSW (e. g. N of Kalkya Lekh W of Chhu Khola). N-S- respectively NW-SE-striking vertical faults make the structure even more complicated (Fig. 33 on Pl. 10). In the Chhu Khola and in the region of Lurigaon there is much folding in the Permian and Triassic formations. SE of Nisalgaon a vertical fault seems to form the boundary between the Permian and different Triassic formations.

Finally, it is necessary to note, that of all the structures of the Dolpo Synclinorium it is the Koma Syncline, which reaches farthest to the WNW. The Dhaulagiri Limestone, forming a large syncline in the Syanath Range, represents the Koma Syncline and the western most extension of the Dolpo Synclinorium. There are several secondary folds in the syncline of the Syanath Range.

3.2.2.5. The Northern Margin of the Dolpo Synclinorium

This is the most complicated and least explored region of western Dolpo. Several valleys leading to the N towards the Tibetan — Nepalese border could not be mapped because of scarcity of time and inaccessability due to high water of the rivers.

Whereas, in the northern face of the Syanath Range the Dhaulagiri Limestone succeeds the Crystalline without larger complications, the section along the Daldung (Segia) Khola offers many difficulties [Pl. 4 (5, 6)]: The Crystallines form a large dome in the Palchung Hamga Himal — the border range to Tibet (Fig. 32 on Pl. 11). They are succeeded by S-dipping Dhaulagiri Limestone, which becomes intensely folded in its southern parts. The direction of these movements is SSW. Whereas, all the higher slopes consist of folded Dhaulagiri Limestone, the lower portions of the slopes consist of Devonian dolomites. Contrary to the obviously overlying Dhaulagiri Limestone the Devonian rocks show gentle dips. These klippen-like Devonian rocks border all the adjoining series with tectonic contacts. W of the Daldung Khola the sequence Dhaulagiri Limestone — Silurian — Devonian appears to be in normal, not too much disturbed order. In the Daldung Khola and E thereof the boundary Dhaulagiri Limestone — Silurian represents a zone of disturbance. I suppose that along this tectonic line, the Devonian rocks have come in their present block-like position below the overthrusting Dhaulagiri Limestone. I regard them as remnants of a syncline, which has been completely squeezed in the Daldung Khola, but which is preserved in the upper course of the Sije Khola in the E.

The Silurian, S of the Devonian blocks in the Daldung Khola, represents a highly squeezed anticline, which has moved over the Dhaulagiri Limestone and the Devonian klippes in the N. This anticline was pressed upwards with regard to the adjacent Muth Formation in the SW. On the crest of the ridge E of the valley, capping the Silurian, there are Devonian dolomites preserved from erosion (Fig. 32 on Pl. 11). The gently dipping Devonian dolomites S of the described Silurian anticline form a depressed wedge. They border the Silurian along a steep tectonic contact and are overridden along a steep reverse fault by another wedge in the SW. It is significant that the mentioned structural lines cut the rock formations discordantly. In the Daldung Dara N of the peak 18210' Permian and Triassic formations have been involved in scale structures showing vergency towards the NE [Pl. 4 (6)].

In the E the Sije- and Khung Kholas were investigated. There, the mountains along the Tibetan border are built up by the Mugu Granite. This instrudes the Crystallines, which upwards pass into the Dhaulagiri Limestone. Then follows a synclinal zone marked by Devonian Muth dolomites. As the Silurian rocks may be missing (Khung Khola) I suppose that the original stratigraphic boundaries are disturbed. In the Sije Khola the Devonian is succeeded by the Permian Thini Chu Formation, which from the S is overthrust by the Silurian. These

Silurian series represent an anticline, which most probably corresponds with that of the Daldung Khola. As mentioned above the Devonian klippes "enveloped" in the Dhaulagiri Limestone of the named valley appear as remnants of the Devonian syncline of the Sije- and Khung Kholas. The Silurian anticline shows a core of Dhaulagiri Limestone in the Khung Khola. The Silurian series of the anticline mentioned are stratigraphically succeeded by the Devonian Muth Formation. These dolomites are disturbed by a series of steep faults and reverse faults [Pl. 4 (13—15)]. Along these tectonic planes wedges of Silurian rocks are pressed upwards into the Devonian dolomites. Locally also the boundary between the Muth Formation and the Permian series is sheared.

In this chapter I was able to give a series of informations on the northern marginal zone of the Dolpo Synclinorium, which, however, is far from being explored.

3.2.2.6. Review of the Tectonics of Dolpo

The Dolpo Synclinorium is separated from the northern parts of the Tibetan Zone in the Tibetan Plateau by an anticlinorium, which makes the border range to Tibet. This anticlinorium is intruded by huge masses of Alpine granites (Mugu, Mustang). The Dolpo Synclinorium extends in a NW-SE direction, its folds, however, strike distinctly WNW — ESE. In consequence the folds strike obliquely to the margins of the synclinorium. Thus, the fold elements of eastern Dolpo successively end, when followed westwards (Fuchs, 1967), the southern elements ending first. Significantly, the north-western most part of the Dolpo Synclinorium is formed by the Koma Syncline, which commences near Dingju in western Dolpo.

It appears that the Dolpo Synclinorium was formed by epeirogenetic movements later than the folding. The vertical movements determined which portions of the Tibetan Zone would be preserved from erosion. The axis of depression shows a clear NW — SE extension and the margins of the synclinorium follow that direction, cutting the internal fold structures obliquely. The huge culmination in the Karnali region, which has led to the formation of the Galwa Window, has probably terminated the western end of the Dolpo Synclinorium. Before that large updoming, the Tibetan Zone of Dolpo was continuous with that of northern Kumaon.

Regarding the style of deformation, it is important that harmonic folding as well as disharmonic faulting and scale structures, are products of one and the same tectonic act or are at least very closely linked. It depends on the material, on the mechanical properties of the formations, how they respond to tectonic stress. Pl. 3 and 4 clearly show, that harmonic folding is replaced by disruptive movements in certain levels of the sedimentary succession. Such levels are at the base and particularly at the top of the Muth Formation, which acted as a rigid plate. This plate also was susceptible to folding, but in the neighbourhood of soft, easily deformable rocks, such as the Triassic formations, deformation became disruptive. A similar relation exists between the Kioto Limestone and the underlying Tarap Shales, respectively the succeeding Middle to Upper Jurassic beds. Strike faults are very characteristic for the Kioto Limestone synclines and are often combined with folding (FUCHS, 1967).

Faults younger than folding definitely are those E of Phopha, which cut the folds. The N-S-striking fault displaced the rocks E of it downwards. Along the NW-SE trending fault the northern block was lifted. The amount of displacement of these faults, however, is a few tens of meters only. Much larger is the displacement along the fault dissecting the north-eastern limb of the Koma Syncline beetween Dingju and Nisalgaon (Pl. 3; FUCHS, 1967, Pl. 7). This type of faults, however, seems rare compared to those closely related with folding and wedge structures.

The structures of the Tibetan Zone of Dolpo are very similar to those reported by EGELER et al. (1964), BORDET et al. (1971, 1975) from the region E of the Kali Gandaki. This is not surprising as the Tibetan Zone N of the Annapurna group is the direct continuation of Dolpo. To the W Spiti shows resembling structures (HAYDEN, 1904). In Kumaon the tectonics, as recorded by HEIM & GANSSER (1939), VALDIYA & GUPTA (1972), and SHAH & SINHA (1974), do not show varying vergency like in Nepal. The structures are strictly directed SW, which is exceptional to all the rest of the Tibetan Zone. In my view this indicates that the Amlang La Nappe (HEIM & GANSSER, 1939; GANSSER, 1964) prior to erosion has reached further S and naturally has influenced the tectonics of the underlying Tibetan Zone. In Nepal, certainly, there is no indication of any nappes in the Tibetan Zone.

References

BORDET, P., COLCHEN, M., KRUMMENACHER, D., LE FORT, P., MOUTERDE, R. & REMY, M.: Recherches géologiques dans l'Himalaya du Népal, région de la Thakkhola. — Edit. Centr. Nat. Rech. Sci., 1—279, Paris 1971.

BORDET, P., COLCHEN, M. & LE FORT, P.: Some features of the geology of the Annapurna Range, Nepal Himalaya. — Himalayan Geology, 2, 537—563, Delhi 1972.

BORDET, P., COLCHEN, M. & LE FORT, P.: Recherches géologiques dans l'Himalaya du Népal, region du Nyi-Shang. — 1—138, Edit. Centr. Nat. Rech. Sci., Paris 1975.

CHANG CHENG-FA & CHENG HSI-LAN: Some tectonic features of the Mt. Jolmo Lungma area, southern Tibet, China. — Scientia Sinica, Vol. 16, 2, 257—265, Peking 1973.

COCHERIE, A.: Données preliminaires sur la géochimie des terres rares dans le massif Leucogranitique du Manaslu (Népal central). — Colloqu. intern. du C. N. R. S. No 268. — Écologie et Géologie de l'Himalaya, Paris 1976.

COLCHEN, M.: Palaeogeographic and Structural Evolution of the Tibetan Area of the Nepal Himalaya (Annapurna Region). — Himalayan Geology, 5, 83—103, Delhi 1975.

DIENER, C.: The Trias of the Himalayas. — Mem. G. S. I. 36 (3), 1—159, Calcutta 1912.

EGELER, C. G., BODENHAUSEN, J. W. A., DE BOOY, T. & NIJHUIS, H. J.: On the geology of Central West Nepal — a preliminary note. — 22th Int. Geol. Congr. India 1964, Pt. 11, 101—122, New Delhi 1964.

FLÜGEL, H.: Paläozoische Korallen aus der Tibetischen Zone von Dolpo (Nepal). — Jb. Geol. B.-A., Sdbd. 12, 101—120, Wien 1966.

FUCHS, G.: Zum Bau des Himalaya. — Österr. Akad. Wiss., math. nat. Kl., Denkschr. 113, 1—211, Wien 1967.

FUCHS, G.: On the Geology of the Karnali and Dolpo Regions, West Nepal. — Mitt. Geol. Ges. Wien, Vol. 66—67, 21—32, Wien 1974.

FUCHS, G.: Contributions to the Geology of the North-Western Himalayas. — Abh. Geol. B.-A., 32, 1—59, Wien 1975.

FUCHS, G. & FRANK, W.: The Geology of West Nepal between the Rivers Kali Gandaki and Thulo Bheri. — Jb. Geol. B.-A., Sdbd. 18, 1—103, Wien 1970.

FUCHS, G. & SINHA, A. K.: On the Geology of Naini-Tal (Kumaun Himalaya). — Himalayan Geology, 4, 563—580, Delhi 1974.

GANSSER, A.: Geology of the Himalayas. — 1—289 Interscience Publishers John Wiley and Sons Ltd. London, New York, Sydney 1964.

GUPTA, V. J.: Contribution to the Lower Palaeozoic Stratigraphy of Western Nepal. — Verh. Geol. B.-A. 1971 (3), 643—646, Wien 1971.

GUPTA, V. J.: The Stratigraphic Position of the Kioto Limestone of Himalaya. — Colloqu. intern. du C. N. R. S. No 268 — Écologie et Géologie de l'Himalaya, Paris 1976.

HAGEN, T.: Über den geologischen Bau des Nepal-Himalaya. Jb. St. Gall. Nat.wiss. Ges., Bd. 76, 1—48, St. Gallen 1959.

HAGEN, T.: Report on the Geological Survey of Nepal. Vol. 2: Geology of the Thakkhola. — Denkschr. Schweiz. Naturf. Ges., *86* (2), 1—160, Zürich 1968.

HAGEN, T.: Report on the Geological Survey of Nepal. Vol. 1: Preliminary Reconnaissance. — Denkschr. Schweiz. Naturf. Ges., *86* (1) 1—185, Zürich 1969.

HASHIMOTO, S.: Geology of the Nepal Himalayas. — 1—286, Himalayan Committee of Hokkaido University, Sapporo 1973.

HAYDEN, H. H.: The Geology of Spiti, with Parts of Bashahr and Rupshu. — Mem. G. S. I. 36 (1), 1—129, Calcutta 1904.

HEIM, A. & GANSSER, A.: Central Himalaya, geological observations of the Swiss expedition 1936. — Mem. Soc. Helv. Sci. nat. 73 (1) 1—245, Zürich 1939.

LE FORT, P.: Himalayas: The Collided Range. Present Knowledge of the Continental Arc. — Amer. Jour. of Science, 275-A, 1—44, New Haven 1975.

LE FORT, P.: A spilitic episode in the Tibetan upper Paleozoic Series of Central Nepal. — Bull. Ind. Geol. Assoc., Vol 8 (2), 100—105, Chandigarh 1975.

PASCOE, E. H.: A Manual of the Geology of India and Burma. — Vol 2, 1—1343, 3. Edition, Govt. Press, Calcutta 1959.

RAINA, B. N. & DUNGRAKOTI, B. D.: Geology of the Area between Naini Tal and Champawat, Kumaun Himalaya, Uttar Pradesh. — Himayan Geology 5, 1—27, Delhi 1975.

SHAH, S. K. & SINHA, A. K.: Stratigraphy and Tectonics of the "Tethyan" Zone in a Part of Western Kumaun Himalaya. — Himalayan Geology 4, 1—27, Delhi 1974.

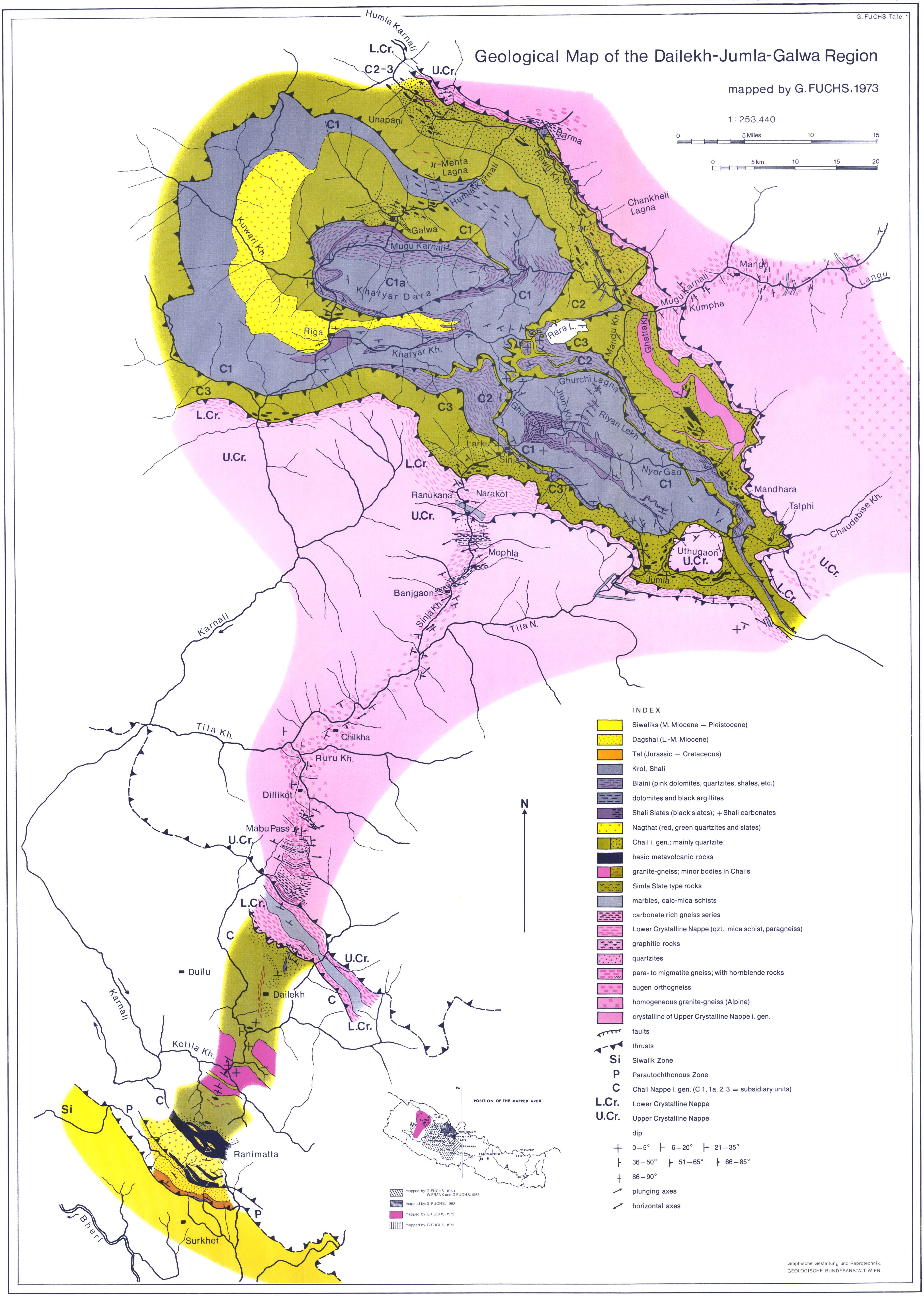
SIBLIK, M.: Triassic Brachiopods from Nepal. — Riv. Ital. Paleont. 81 (2), 133—160, Milano 1975.

VALDIYA, K. S. & GUPTA, V. J.: A contribution to the geology of northeastern Kumaun, with special reference to the Hercynian gap in Tethys Himalaya. — Himalayan Geology 2, 1—33, Delhi 1972.

WATERHOUSE, J. B.: Lower Carboniferous and Upper Permian Brachiopods from Nepal. — Jb. Geol. B.-A., Sdbd. 12, 5—99, Wien 1966.

WATERHOUSE, J. B.: The Permian Rocks and Faunas of Dolpo, North-West Nepal. — Colloqu. intern. du C. N. R. S. No 268 — Écologie et Géologie de l'Himalaya, Paris 1976.

Manuskript bei der Schriftleitung eingelangt am 30. März 1977


G. FUCHS Tafel 1
Geological Map of the Dailekh-Jumla-Galwa Region
mapped by G. FUCHS, 1973
1 : 253.440
0 5 Miles 10 15
0 5 km 10 15 20
Humla Karnali
L.Cr.
C2-3
U.Cr.
Unapani
C1
Darma
Mehta Lagna
Humla Karnali
Rawal Kh.
Chankheli Lagna
Galwa
C1
Mugu Karnali
Kuwari Kh.
C1a
Khatyar Dara
C1
C2
Mangri
Langu
Mugu Karnali
Kumpha
Riga
Rara L.
C3
Khatyar Kh.
Mandu Kh.
Ghatta Kh.
C2
C1
C3
Ghurchi Lagna
L.Cr.
C3
C2
Jiun Kh.
Riyan Lekh
U.Cr.
L.Cr.
Larku
Sinja
C1
Nyor Gad
C1
Ranukana
Narakot
C3
Mandhara
U.Cr.
Talphi
Chaudabise Kh.
Uthugaon
U.Cr.
Mophla
Jumla
U.Cr.
L.Cr.
Banjgaon
Karnali
Sinja Kh.
Tila N.
Tila Kh.
Chilkha
Ruru Kh.
Dillikot
N
Mabu Pass
U.Cr.
L.Cr.
C
U.Cr.
Dullu
Dailekh
C
L.Cr.
Karnali
Kotila Kh.
Si
P
C
Ranimatta
P
Bheri
Surkhet
POSITION OF THE MAPPED AREA
KATHMANDU
mapped by G. FUCHS, 1963; W. FRANK und G. FUCHS, 1967
mapped by G. FUCHS, 1963
mapped by G. FUCHS, 1973
mapped by G. FUCHS, 1973
INDEX
Siwaliks (M. Miocene – Pleistocene)
Dagshai (L.-M. Miocene)
Tal (Jurassic – Cretaceous)
Krol, Shali
Blaini (pink dolomites, quartzites, shales, etc.)
dolomites and black argillites
Shali Slates (black slates); + Shali carbonates
Nagthat (red, green quartzites and slates)
Chail i. gen.; mainly quartzite
basic metavolcanic rocks
granite-gneiss; minor bodies in Chails
Simla Slate type rocks
marbles, calc-mica schists
carbonate rich gneiss series
Lower Crystalline Nappe (qzt., mica schist, paragneiss)
graphitic rocks
quartzites
para- to migmatite gneiss; with hornblende rocks
augen orthogneiss
homogeneous granite-gneiss (Alpine)
crystalline of Upper Crystalline Nappe i. gen.
faults
thrusts
Si Siwalik Zone
P Parautochthonous Zone
C Chail Nappe i. gen. (C 1, 1a, 2, 3 = subsidiary units)
L.Cr. Lower Crystalline Nappe
U.Cr. Upper Crystalline Nappe
dip
0–5° 6–20° 21–35°
36–50° 51–65° 66–85°
86–90°
plunging axes
horizontal axes
Graphische Gestaltung und Reprotechnik: GEOLOGISCHE BUNDESANSTALT, WIEN

Jahrbuch der Geologischen Bundesanstalt, 120. Band, 1977 – Beilage 14
G. FUCHS, Plate 2

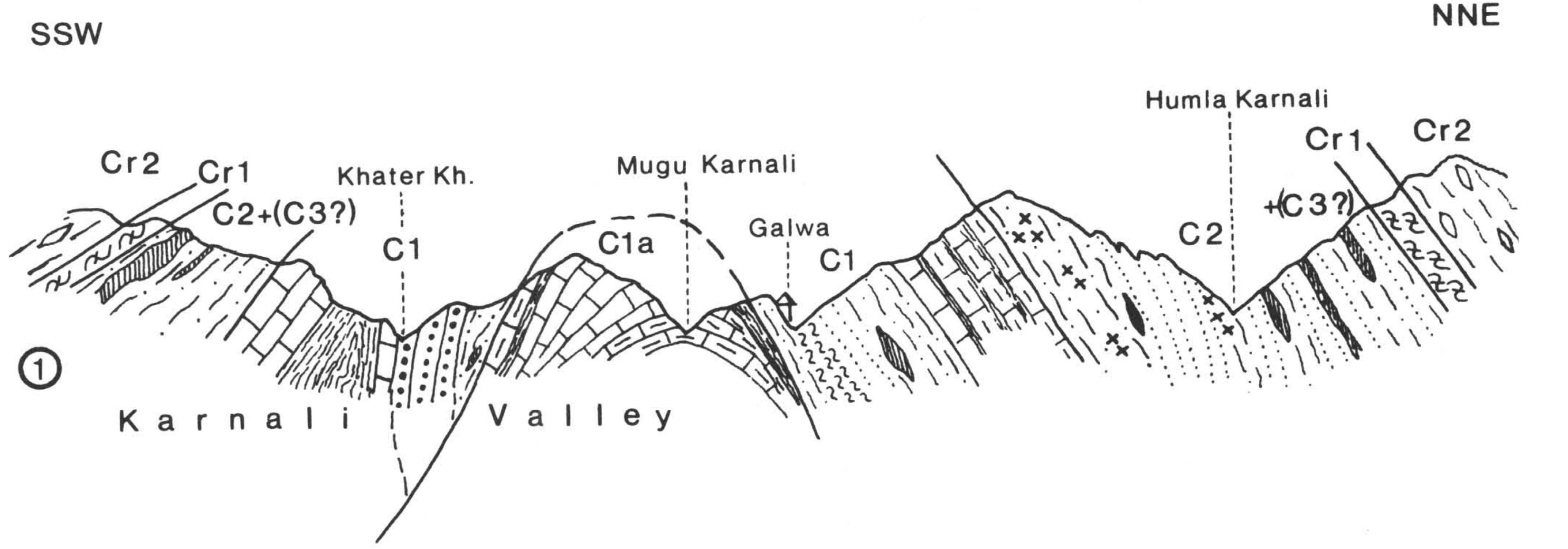
Sections through the Karnali Region, W-Nepal, G. FUCHS, 1974

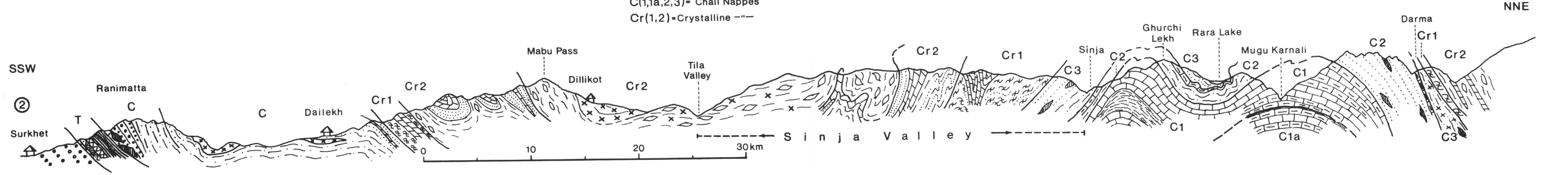
INDEX:

- Siwaliks (Miocene-Pleistocene)
- Dagshai (L. Mioc.)
- Tal, shaley; quartzitic
- Krol, Shali Dolomite
- Blaini
- Infra Krol, Shali Sl.
- Nagthat
- Basic metavolcanic rocks
- Chail, quartzites and shales; quartzites
- Simla Slates
- Metagranite
- Jutoghs (Lower Crystalline Nappe)
- Metamorphic carbonate rocks
- Quartzites in Crystalline
- Gneiss in gen., augengneiss

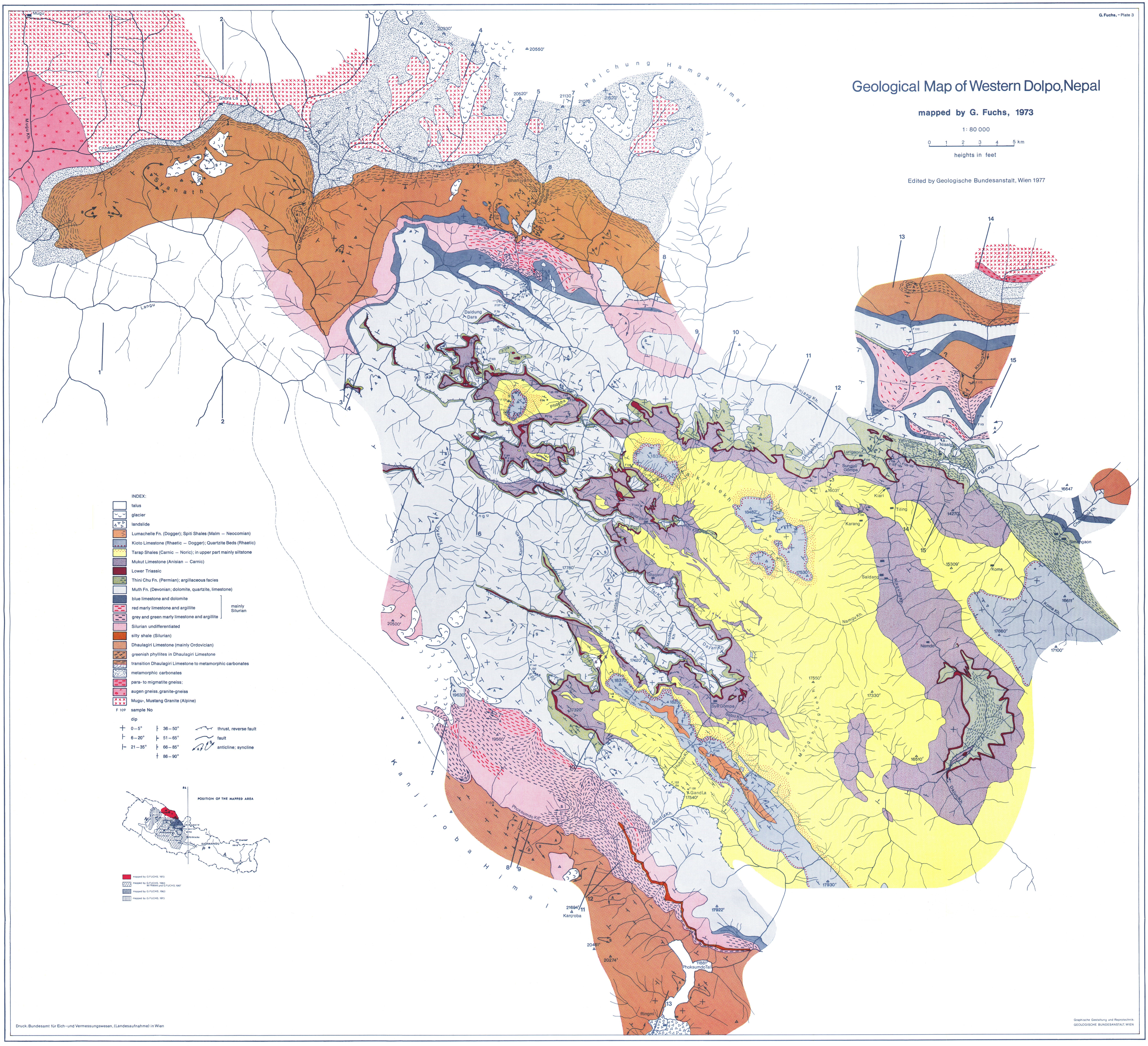
T = Tansing Unit
C(1,1a,2,3) = Chail Nappes
Cr(1,2) = Crystalline –"–

Heights exaggerated



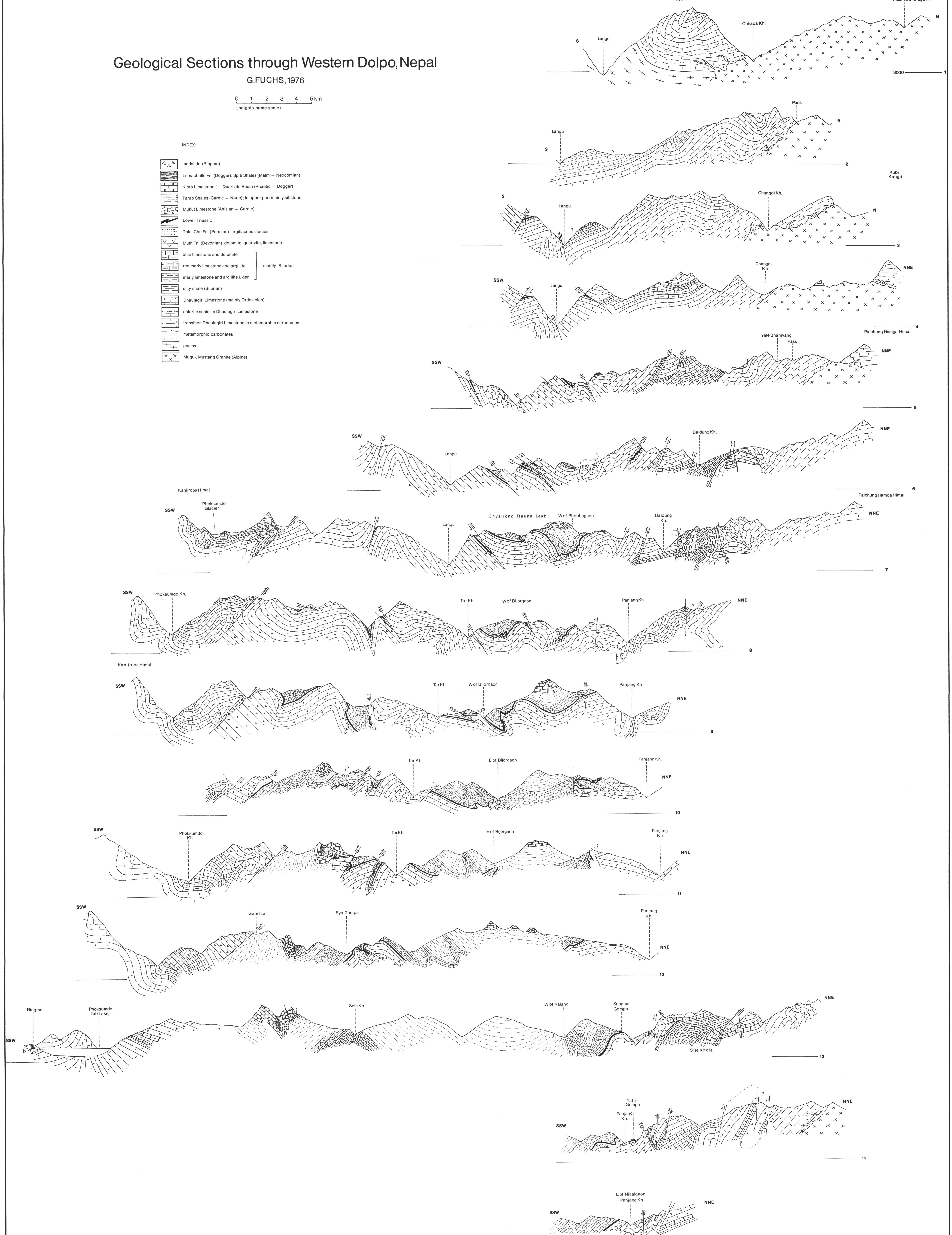


Druck: Bundesamt für Eich- und Vermessungswesen (Landesaufnahme) in Wien

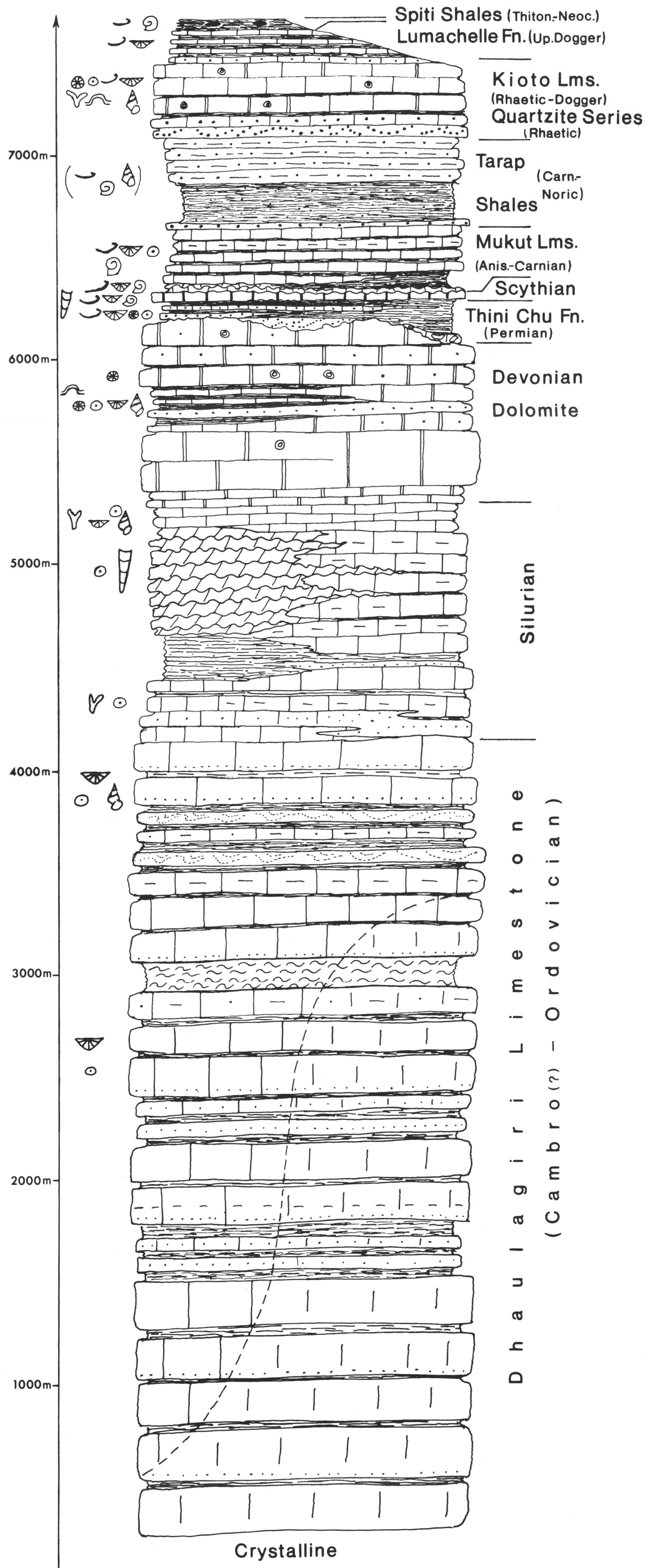

G. Fuchs, – Plate 3
Geological Map of Western Dolpo, Nepal
mapped by G. Fuchs, 1973
1: 80 000
0 1 2 3 4 5 km
heights in feet
Edited by Geologische Bundesanstalt, Wien 1977
INDEX:
talus
glacier
landslide
Lumachelle Fn. (Dogger); Spiti Shales (Malm – Neocomian)
Kioto Limestone (Rhaetic – Dogger); Quartzite Beds (Rhaetic)
Tarap Shales (Carnic – Noric); in upper part mainly siltstone
Mukut Limestone (Anisian – Carnic)
Lower Triassic
Thini Chu Fn. (Permian); argillaceous facies
Muth Fn. (Devonian; dolomite, quartzite, limestone)
blue limestone and dolomite
red marly limestone and argillite
grey and green marly limestone and argillite
mainly Silurian
Silurian undifferentiated
silty shale (Silurian)
Dhaulagiri Limestone (mainly Ordovician)
greenish phyllites in Dhaulagiri Limestone
transition Dhaulagiri Limestone to metamorphic carbonates
metamorphic carbonates
para- to migmatite gneiss;
augen gneiss, granite-gneiss
Mugu-, Mustang Granite (Alpine)
F 109 sample No
dip
0–5°
6–20°
21–35°
36–50°
51–65°
66–85°
86–90°
thrust, reverse fault
fault
anticline; syncline
POSITION OF THE MAPPED AREA
Paichung Hamga Himal
Kanjiroba Himal
Druck: Bundesamt für Eich- und Vermessungswesen, (Landesaufnahme) in Wien
Graphische Gestaltung und Reproduktechnik
GEOLOGISCHE BUNDESANSTALT, WIEN

Geological Sections through Western Dolpo, Nepal

G. FUCHS, 1976



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



Stratigraphic Column of Western Dolpo

G. FUCHS, 1974

I N D E X :

- quartzites, sandstones
- siltstones
- argillites, silty shales
- tuffites
- limestones
- dolomites
- marly, sandy carbonates
- oolitic
- metamorphic limestones
- flasery limestone and marls
- conglomeratic limestones

- algae
- bryozoa
- crinoids
- corals
- bivalves
- gastropoda
- orthoconic nautiloids
- ammonites
- brachiopoda

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

Fig. 16

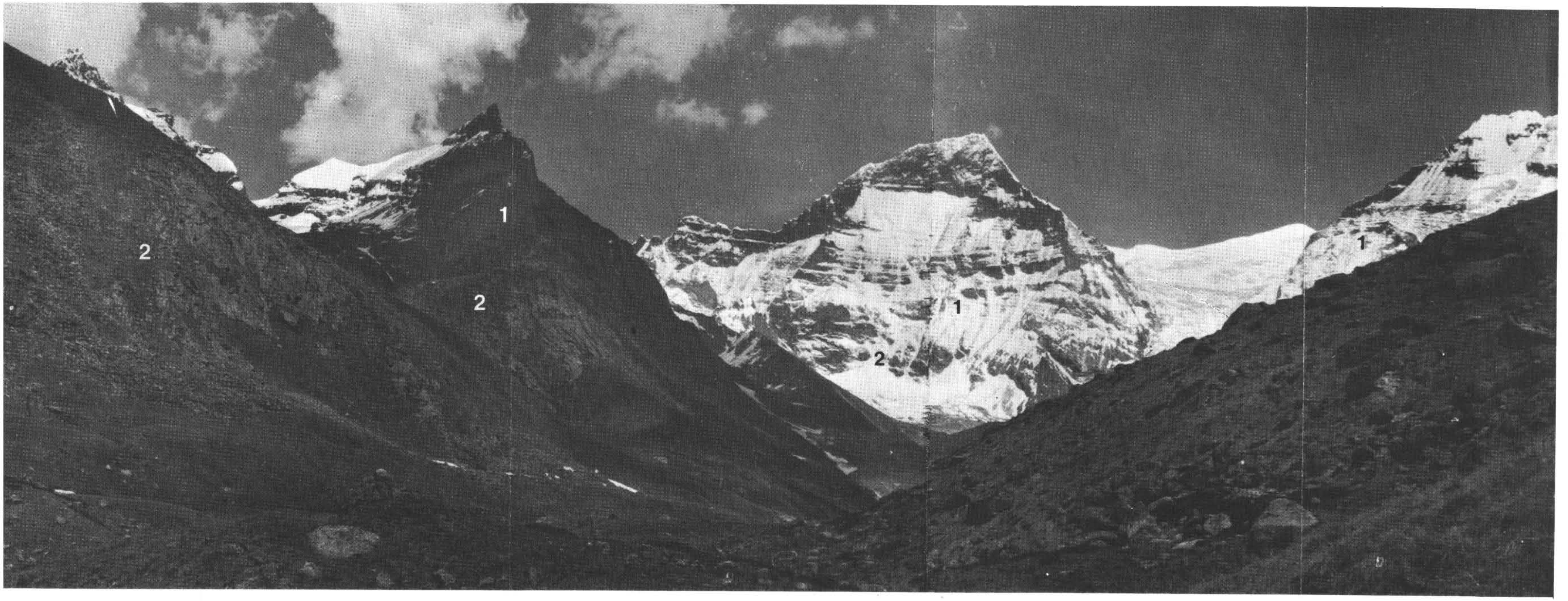


Fig. 16. The Palchung Hamga Himal, the border range to Tibet, seen from point F 62 in the Changdi Khola (see Pl. 3). Metamorphosed carbonate series (1) build up the high summits and higher portions of the slope to the left. The Mugu Granite (2) is exposed in the valley.

Fig. 24

Fig. 24. The syncline of Phophagaon seen from the E.

1 Muth Formation (Devonian)
2 Thini Chu Formation (Permian)
3 Scythian
4 Mukut Limestone (Anisian-Carnic)
5 Tarap Shales (Noric)
5 a Siltstones of upper part of Tarap Shales
6 Kioto Limestone and Quartzite Beds (Upper Triassic-Dogger)

Note the wedge structure in the lower part of the picture.

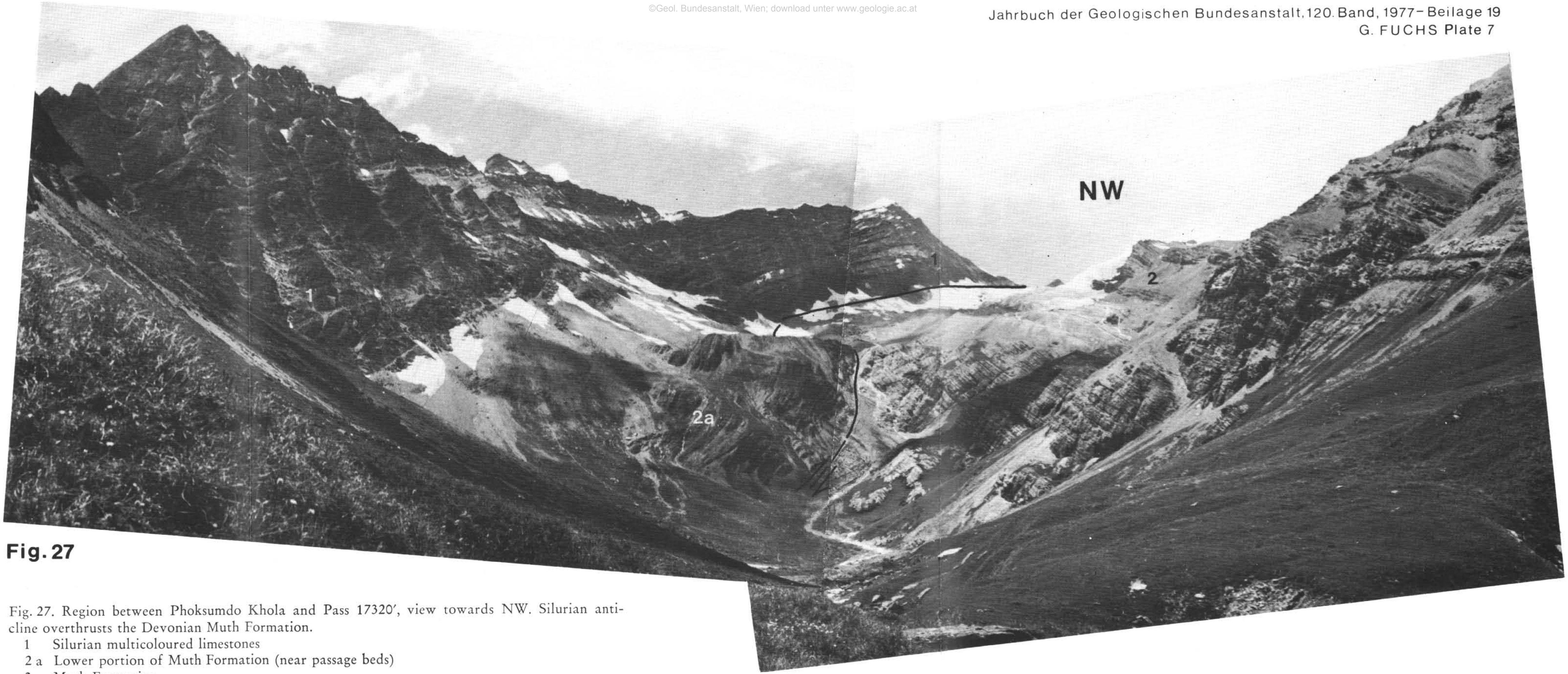


Fig. 27

Fig. 27. Region between Phoksumdo Khola and Pass 17320′, view towards NW. Silurian anticline overthrusts the Devonian Muth Formation.

1 Silurian multicoloured limestones
2 a Lower portion of Muth Formation (near passage beds)
2 Muth Formation

Fig. 28

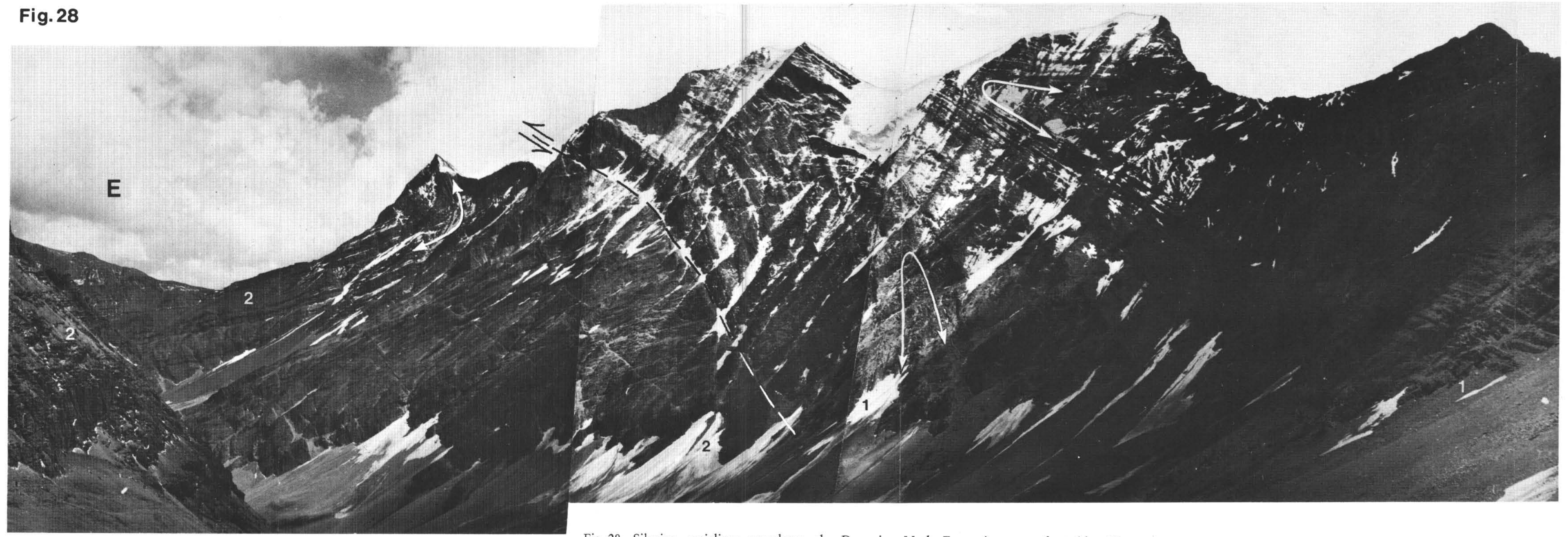


Fig. 28. Silurian anticlines overthrust the Devonian Muth Formation unconformably. View towards ESE from the end of the glacier in the upper Kanjiroba Khola.
1 Silurian
2 Muth Formation (Devonian)

Fig. 29

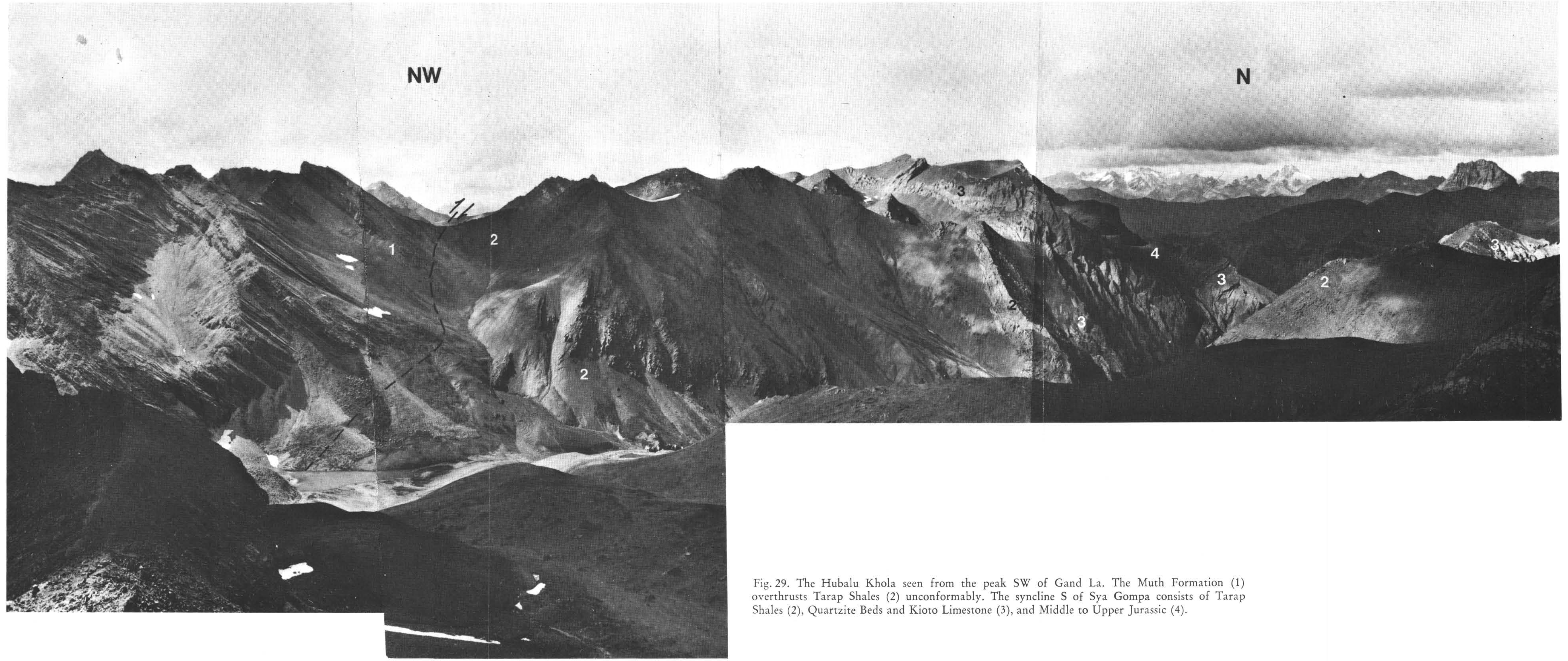


Fig. 29. The Hubalu Khola seen from the peak SW of Gand La. The Muth Formation (1) overthrusts Tarap Shales (2) unconformably. The syncline S of Sya Gompa consists of Tarap Shales (2), Quartzite Beds and Kioto Limestone (3), and Middle to Upper Jurassic (4).

Fig. 30

Fig. 30. From the watershed at the head of the Mandakdin Khola Panorama towards the SE, S, W, and NW.

1 Dhaulagiri Limestone (mainly Ordovician)
2 Silurian
3 Muth Formation (Devonian)
4 Thini Chu Formation (Permian)
5 Scythian
6 Mukut Limestone (Anisian-Carnic)
7 Tarap Shales (Noric)

Fig. 31

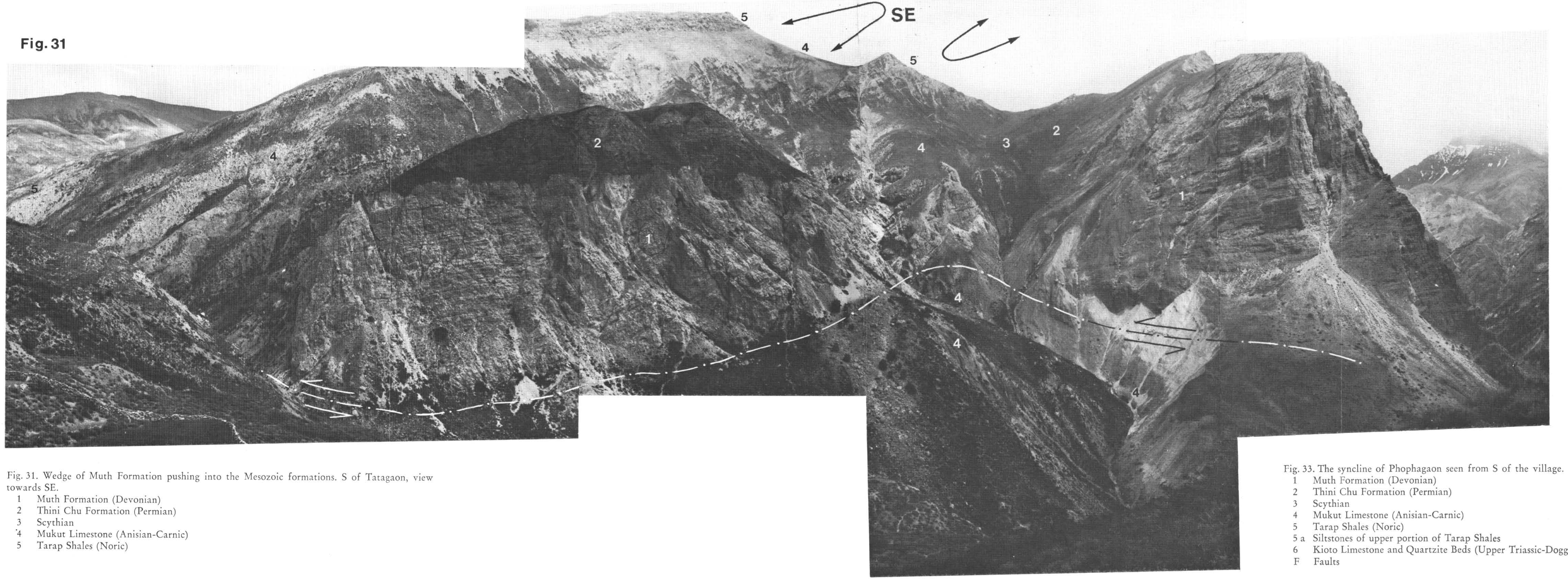


Fig. 31. Wedge of Muth Formation pushing into the Mesozoic formations. S of Tatagaon, view towards SE.
1 Muth Formation (Devonian)
2 Thini Chu Formation (Permian)
3 Scythian
4 Mukut Limestone (Anisian-Carnic)
5 Tarap Shales (Noric)

Fig. 33

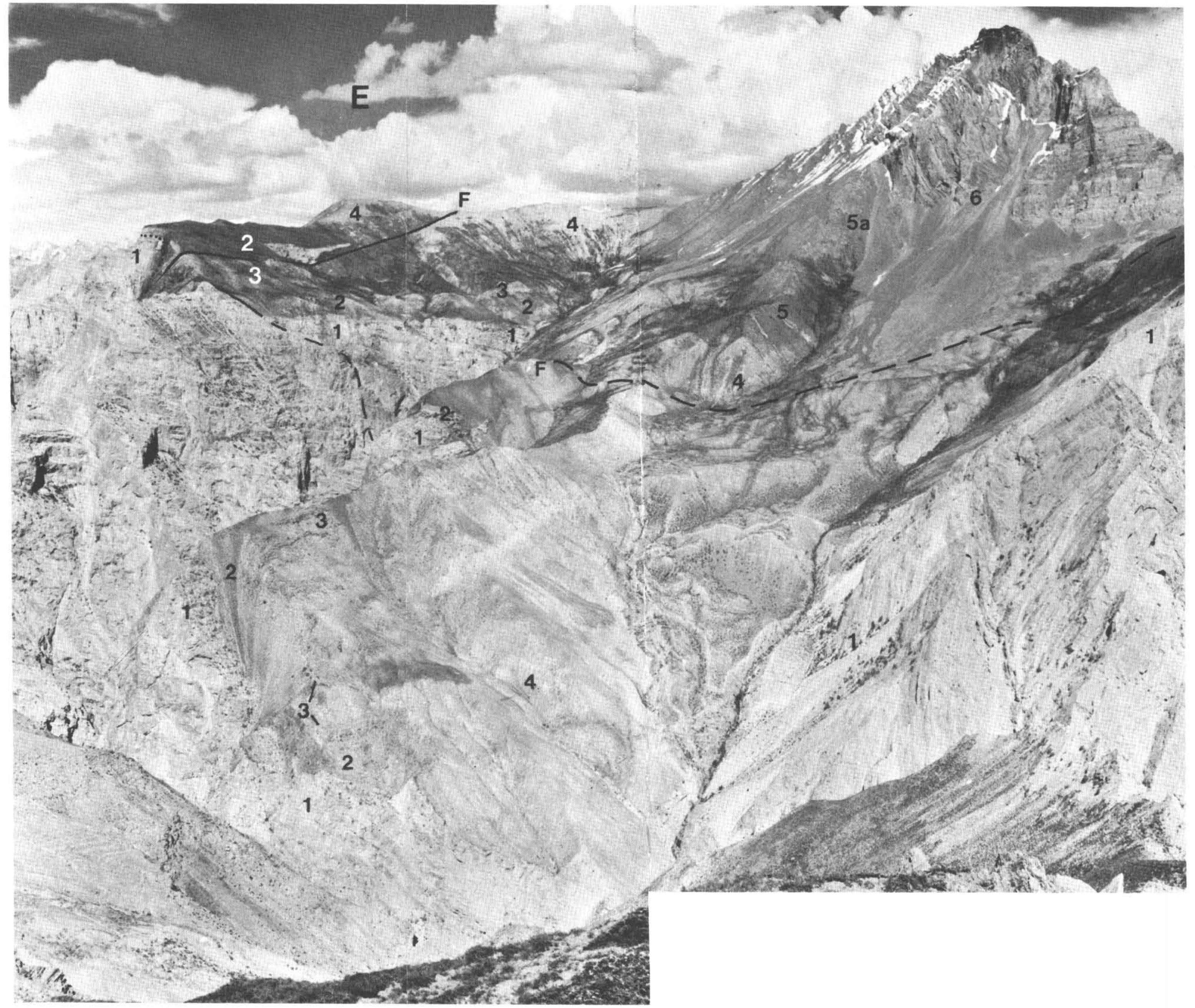


Fig. 33. The syncline of Phophagaon seen from S of the village.
1 Muth Formation (Devonian)
2 Thini Chu Formation (Permian)
3 Scythian
4 Mukut Limestone (Anisian-Carnic)
5 Tarap Shales (Noric)
5 a Siltstones of upper portion of Tarap Shales
6 Kioto Limestone and Quartzite Beds (Upper Triassic-Dogger)
F Faults

Fig. 32

Fig. 32. Panorama view of Dolpo seen from Daldung Dara, Peak 18210'.

1 Metamorphic carbonates
2 Dhaulagiri Limestone (mainly Ordovician)
3 Silurian
4 Muth Formation (Devonian)
5 Thini Chu Formation (Permian)
6 Scythian
7 Mukut Limestone (Anisian-Carnic)
8 Tarap Shales (Noric)
9 Kioto Limestone and Quartzite Beds (Upper Triassic-Dogger)

Fig. 34

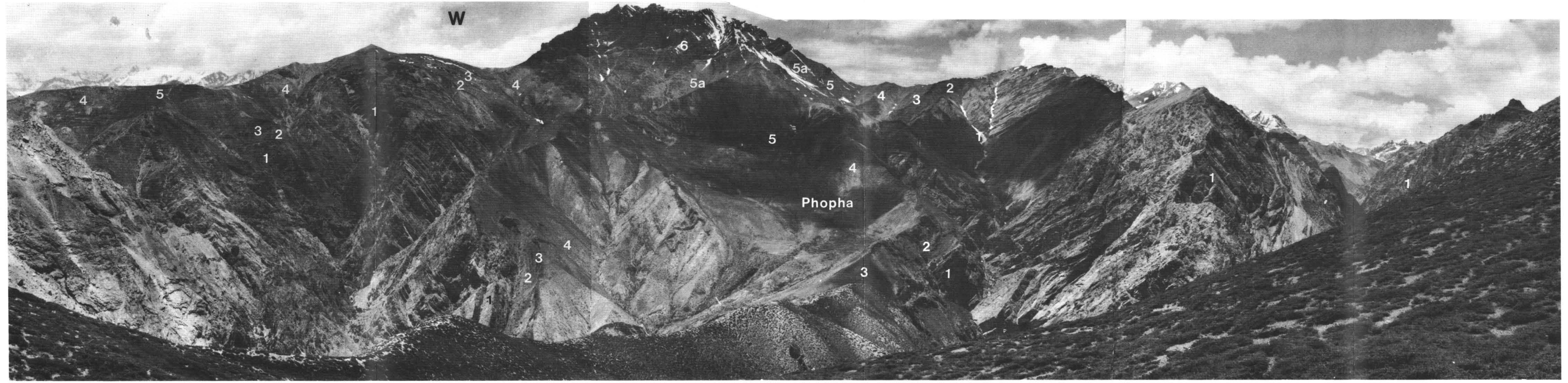


Fig. 34. The syncline of Phopha seen from the E.
1 Muth Formation (Devonian)
2 Thini Chu Formation (Permian)
3 Scythian
4 Mukut Limestone (Anisian-Carnic)
5 Tarap Shales (Noric)
5 a Siltstones of upper portion of Tarap Shales
6 Kioto Limestone and Quartzite Beds (Upper Triassic-Dogger)

Fig. 35

Fig. 35. Folds in the valley W of Phophagaon.
1 Muth Formation (Devonian)
2 Thini Chu Formation (Permian)
3 Scythian
4 Mukut Limestone (Anisian-Carnic)
5 Tarap Shales (Noric)
5 a Siltstones of upper portion of Tarap Shales
6 Kioto Limestone and Quartzite Beds (Upper Trassic-Dogger)
View from S of F 105 towards SE.

Fig.36

Fig. 36. The Daldung Khola seen from the ascent to the Daldung Dara, view towards NE.
1 Metamorphic carbonates
2 Dhaulagiri Limestone (mainly Ordovician)
3 Silurian
4 Muth Formation (Devonian)
F Faults