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On the Geology of Western Ladakh

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Schlüsselwörter
NW-Himalaya
Ladakh
Indus Zone
Tibetan Zone (Zanskar)
Central Crystalline

CONTENTS

Abstract 513
Zusammenfassung 514
1. Introduction 514
2. The Indus Zone 514
2.1. The Indus Molasse 515
2.2. The Indus- and Dras Flysch 515
2.3. The Lamayuru Unit 517
3. The Tibetan (Tethys) Zone 519
4. The Spongtang Klippe 527
5. The relation of the Tibetan Zone to the Central Crystalline 531
6. Conclusions 532
Acknowledgement 537
Literature 538

Abstract

Geological work along the route Khalsi – Lamayuru – Honupattan – Spongtang – Shillakong – Himiskut – Kangi – Rangdum – Suru – Liddar Valley gave the following results: The Indus Zone consists of several units, which are from N to S: the Indus Molasse, Indus Flysch (s. s.), Dras Flysch-Volcanic Zone, and Lamayuru Unit. These structural units are separated from each other by ophiolitic melange zones. In the midst of the Tibetan Zone of Zanskar the Spongtang outlier is evidence that the Lamayuru Unit, the Dras Flysch-Volcanic Zone, ophiolitic melange, and peridotite masses have been overthrust towards the SW onto the Tibetan Zone for at least 30 km. Later compression led to intensive steep folding of the pile of nappes and caused the inversion of the whole Indus Zone. So the NE-directed "counterthrusts" are actually re-activated older thrust planes.

The Tibetan (Tethys) Zone is represented in the Zanskar Synclinorium. Due to tectonic complications and metamorphism the stratigraphy and facies distribution are not entirely clear in the central and northern parts of the Zanskar Synclinorium.

The Alpine metamorphism reaches exceptionally high into the Palaeo-Mesozoic succession of the Tibetan Zone. Thus all the Palaeozoic formations older than the Panjal Trap are converted to gneisses. In the Nun-Kun area even the Triassics are altered to high grade marbles, which can be traced towards the NW into the slightly metamorphosed Triassics of Kashmir.

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Zusammenfassung

Geologische Arbeiten entlang der Route Khalsi – Lamayuru – Honupattan – Spongtang – Shillakong – Himiskut – Kangi – Rangdum – Suru – Liddartal erbrachten folgende Ergebnisse: Die Indus-Zone besteht aus mehreren Einheiten, von N nach S in folgender Reihung: Indus-Molasse, Indus-Flysch (s. s.), Dras-Flysch-Vulkanit-Zone und Lamayuru-Einheit. Diese tektonischen Einheiten sind durch „ophiolitische Melangezonen" voneinander getrennt. Die Spongtang-Deckscholle, inmitten der Tibetischen Zone von Zanskar gelegen, beweist, daß die Lamayuru-Einheit, die Dras-Flysch-Vulkanit-Zone, ophiolitische Melange und Periodit-Massen wenigstens 30 km gegen SW auf die Tibet-Zone überschoben wurden. Spätere Zusammenpressung führte zu einer intensiven und steilen Verfaltung des fertigen Deckenstapels und zur Überkippung der gesamten Indus-Zone. Die NE-gerichteten „Gegenüberschiebungen" sind somit reaktivierte ältere Überschiebungsbahnen.

Die Tibet-Zone (Tethys-Zone) baut das Zanskar-Synclinorium auf. Dessen zentrale und nördliche Teile sind infolge tektonischer Komplikationen und der Metamorphose in ihrer Stratigraphie und faziellen Stellung nicht gänzlich geklärt.

Die Alpine Metamorphose reicht ungewöhnlich hoch in die paläozoisch-mesozoische Schichtfolge der Tibet-Zone empor. So sind sämtliche Formationen älter als der Panjal-Trap vergneist. Im Nun-Kun-Gebiet ist selbst die Trias in hochmetamorphe Marmore umgewandelt, die gegen NW in die schwach-metamorphe Kashmir-Trias zu verfolgen sind.

1. Introduction

For a long time Tibet was forbidden country for foreigners and only a few western geologists like STOLICZKA, LYDEKKER, HAYDEN, NORIN, and GANSSER had opportunity to work there, sometimes under rather hazardous circumstances. At present Tibet forms part of China and is absolutely closed. Due to this situation and the remoteness of the country the geological knowledge of the northernmost zones of the Himalaya is scarce. A few years back the Indian government opened Ladakh – also known as Western or Little Tibet – for tourism. Since then a large number of visitors and also many geologists come to this part of the Himalaya, the only place where the flysch and basic volcanic series of the Indus Zone can be studied. This zone is particulary important for plate tectonic considerations. Naturally, the country along the old caravan route from Kashmir to Leh, which is a modern motor road now, is studied best. The interior of Zanskar, however, remained almost unknown. To fill that gap and particulary to study the relationship between the Indus Zone and the Tethys Himalaya I mapped the region of Lamayuru and S thereof. Further I made the traverse from Himiskut via Kangi – Kangi La – Rangdum – Suru (Panikar) – Chilung Pass to Pahlgam in the Liddar Valley. The research of summer 1976 led to the discovery of the flysch-ophiolite klippe of Spongtang, which rests as an outlier on the central portions of the Zanskar Synclinorium of the Tibetan (Tethys) Zone (FUCHS, 1977 b). This klippe found great interest and was subsequently visited by French, Austrian, and Indian groups of geologists.

After my preliminary report (1977 b) I got the determinations of the fossils of my collection, and then compiled my data in the geological map presented in this paper (Pl. 1).

In describing the geology of the area investigated I start with the northern zones and go on to the S.

2. The Indus Zone

Along the Indus Valley there is a highly tectonized zone consisting of flysch, basic volcanic series, and molasse type formations. Several subunits are to be distinguished, which are separated from each other by ophiolitic melange zones (GANSSER, 1974, 1976). These are composed of exotic limstone blocks, radiolarian cherts, ultrabasic and basic volcanic rocks, and flysch all mixed by sedimentary as well as tectonical processes. They definitely represent deep sutures.

2.1. The Indus Molasse

A. P. TEWARI (1964) working in the Kargil area recognized a thick succession of continental molasse deposites, which hitherto have been taken as part of the Cretaceous Flysch. These beds, however, are much younger, probably Mio-Pliocene, and are separated from the Dras Volcanics and Cretaceous Flysch by a thrust. TEWARI compares the molasse formation of Ladakh with the Kailas Conglomerate of Tibet (HEIM & GANSSER, 1939). I just touched this molasse belt in the Indus Valley W of Khalsi. There the bright coloured purple, red, green, and beige banded rocks are a conspicuous feature of the landscape: Dipping SW at medium angles the molasse builds up the lower slopes of the Ladakh Range, and overlies the light-coloured granites and granodiorites forming the upper parts and the crest of that range, which belongs already to the Transhimalaya. The Indus Molasse transgresses directly on the Ladakh Instrusives (TEWARI, 1964; GANSER, 1976; FRANK et al, 1977). In the last two papers a lower autochthonous unit is distinguished from a higher parautochthonous one, called the Hemis Conglomerate. The first is composed of a transgression series of reddish arkose, coarse conglomerates containing mainly granitic boulders followed by an alternation of conglomerates, arkosic sandstones, silty shales, and a coal seam in the middle part of the sequence. The Hemis Conglomerate is separated by a steep thrust from the autochthonous molasse in the N. It consists of a distinctly banded alternation of conglomerates, silt- and sandstones, and shales. FRANK et al. particulary point to the content of volcanic pebbles in the conglomerates ranging from rhyolite to andesite.

For dating the age of the sequence it is important that the fossils derived from limestone pebbles are not younger than Lower Eocene; as LYDEKKER (1883) and DAINELLI (1934) report intercalated nummulitic limestones, FRANK et al. (1977) suggest an Eocene age. Considering the arguments of TEWARI (1964, p. 47–48) and the references of GUPTA & KUMAR (1975, p. 556) to the fossil finds, a Miocene age of the younger portions is probable.

COLCHEN (1977) opines that there is a change of facies along the Indus Zone and so the Hemis Conglomerates pass laterally into flysch towards the NW. He therefore contests the separation of molasse and flysch. However, it was just in the NW, in the Kargil area, where TEWARI (1964) distinguished the molasse from the flysch. SHANKAR et al. (1976) assume two facies belts parallel to the strike. Their "Indus Formation" corresponds to the Indus Molasse, their "Samdo Formation" to the flysch zones next to be described.

2.2. The Indus- and Dras Flysch

The flysch series and associated basic volcanics are most characteristic formations of the Indus Zone. They follow SW of the Molasse belt described above and are separated from it by a tectonic line marked by ophiolitic melange (GANSSER, 1976). Such tectonic planes are met within the flysch belt, too, and thus in the region of Khalsi we may divide an Indus Flysch s. s. from the Dras Flysch-Volcanic belt in the S. The ophiolite zones should not be confused with the Dras Volcanics and associated flysch.

The Indus Flysch s. s. is highly squeezed and consists of flyschoid shales and sandstones, volcanic breccias, tuffs and basic effusiva. E of Khalsi fossiliferous Middle Cretaceous limestones are associated with the flysch. These blue-grey, fine-grained or dense limestones are massive or thick-bedded and rich in foraminifera, bivalves (rudistids a. o.), and crinoids. GUPTA & KUMAR (1975) designate an Aptian age to the Khalsi Limestone, based on literature and their own observations. M. E. SCHMID (Geol. B.-A. Vienna) Kindly examined a series of samples taken by me from different horizons of the Khalsi Limestone. He determined *Orbitolina* sp. and from the appearance of the fossils suggests an Albian to Cenomanian age. Thus a Mid Cretaceous age is proved. In the upper part of the SW-dipping limestone grey, green shales and schistose sandstones are intercalated, which yielded rotaliid foraminifera.

E of the outcrops along the Khalsi-Leh Road, in a small ravine, the close connection of the Khalsi Limestone with the overlying flysch is exemplarily exposed: The orbitolina limestones are interlayered with volcanic breccias and conglomerates, tuffaceous sandstones and shales, and black to green, partly siliceous shales. This alternation proves a Mid Cretaceous age of the basic volcanism and of the adjoining flysch.

The Khalsi Limestone is succeeded by several hundred meters of dark argillites alternating with thin layers of sandstone (fig. 1 on pl. 5). Approximately 300–400 m above the top of the Khalsi Limestone there is a 20 m zone with lenses and beds of brecciaceous, impure limestone full of undeterminable belemnites. Again shales and sandstones, and then another body of Khalsi Limestone follow. The limestone is duplicated SE of Khalsi due to folding or imbrication.

Contrary to BASSOULLET et al. (1978, fig. 1) and in accordance with GANSSER (1976) and FRANK et al. (1977) the Khalsi Limestone and associated flysch and volcanics are to be separated from the Indus Molasse in the N. They form two different structural units.

In the SW the flysch of the Indus Valley is terminated by an ophiolitic melange zone, which crosses the Yapola Valley a little upstream from its confluence with the Indus (fig. 2 on pl. 5). This highly disturbed zone is several hundred meters thick and consists of ultrabasic rocks, mostly in form of serpentinites, gabbros, porphyritic lavas, agglomerates, tuffs, ophicalcite, flysch shales, and klippes of blue limestone, which shows crinoid ossicles and cross-sections of megalodon.

S of this ophiolitic melange a flysch series follows again (fig. 1), being about 2000 m thick. It is the Dras Zone (Nindam Unit of BASSOULLET et al, 1978), which consists mainly of volcanics to the W (WADIA, 1937) and passes laterally into a flysch complex towards the E (GANSSER, 1967; FRANK et al, 1977). According to these authors the facies change is observed along the road section from Lamayuru to Khalsi. The volcanic rocks are mainly augite andesites and basalts, and hornblende andesites and their pyroclastic products; like the associated sedimentary series they show metamorphic grade almost up to greenschist facies (FRANK et al, 1977, p. 102). The sedimentaries are essentially green, grey slates in the northern portions of the Dras Zone, the main mass, however, consists of a thin-to thick-bedded cyclic alternation of green sandstone, tuffaceous sandstone, siltstone, and green laminated slates. Green-grey colours predominate in that series, a few purple zones are also to be found. Graded bedding is frequently observed. De TERRA (1935) in his map shows all the Yapola gorge built of Dras Volcanics, whereas I found sedimentary rocks predominating.

The age of the Indus- and Dras Flysch is roughly Mid to Upper Cretaceous, if we consider the fossils recorded in literature (see GUPTA & KUMAR, 1975, p. 554) and agree with TEWARI (1964) and GANSSER (1976) who separate the Indus Molasse from the flysch.

The Dras Zone shows large scale folding in the flanks of the Yapola gorge the dip being predominantly SW.

An ophiolitic melange belt terminates the Dras Zone in the SW. It is significant that this tectonic belt strikes WNW-ESE (dipping SSW) and cuts the NW-SE striking beds of the Dras Zone unconformably. N and NE of Lamayuru I found lenticular bodies of green quartzite in a groundmass of red and green argillites, siltstones, and sandstones. NE of Lamayuru a klippe of limestone is exposed near the road. It consists of white, cream to pink, dense limestone rich in crinoids and corals. TEWARI & PANDE (1970) report Upper Permian limestones with brachiopods and foraminifera from this zone, BASSOULLET et al. (1978) refer to manganese and iron coated ammonite limestones.

2.3. The Lamayuru Unit

Between the Dras Volcanics and -Flysch, which form the range SW of the Indus, and the rough Zanskar mountains, there is a marked morphological depression, which is also used by the Leh road from Mulbekh to Lamayuru. This zone is composed of soft dark argillites alternating with sand- and siltstones and dark limestones (Lamayuru Formation). The landscape gets its unique character by klippes of limestone, which stand out from the morphologically soft terrain in form of teeth, and steep cliffs.

The Lamayuru Formation consists of black to dark grey, frequently laminated shales, slates, and phyllites, silty and calcareous shales, which alternate with dark to light grey, impure sandstone or siltstone beds (up to 30 cm thick) and blue, platey limestones. Also these limestones are sandy or silty. In the rather thick and much disturbed formation there are zones rich in sandstone, and carbonate series resembling the Mukut Limestone of Dolpo (NW Nepal). Load casts, flute casts, and current bedding are frequently observed with the sandstones.

The argillites often show graded bedding. In addition to these sedimentary structures and the cyclic alternation of beds, fucoids and other hieroglyphs give a distinct flyschoid character to part of the formation. Since the formation is not entirely of flysch nature, I do not follow GANSSER (1976) terming the belt "Lamayuru Flysch".

Volcanic rocks are generally missing in the Lamayuru Formation, but in the limestones of the type locality a carbonate bed rich in chlorite might represent a tuff.

Though fossils are generally scarce, flat bivalves are relatively frequent in the vicinity of Lamayuru and were first reported from there by GANSSER (1976). Their determination by H. RIEBER gave *Daonella indica (D. longobardica* or *moussoni* are not excluded) (FRANK et al., 1977, p. 101). The bivalves collected by me from the same locality were kindly examined by Dr. B. GRUBER (Palaeontological Institute, University of Vienna), who determinated them as *Monotis salinaria rotunda* CHEN. This indicates an Up. Noric age instead of a Ladinic age suggested by the former determination. These fossils are also found close to the ophiolitic melange zone terminating the Lamayuru Unit in the N. From the Prikiti La, a pass leading from Lamayuru to Shilla and Wanlah, a small fauna of brachiopods, gastropods, and crinoids was found in a blue limestone sequence.

Small indeterminable brachiopods were derived from the middle course of the ravine S of the named pass.

Lower down the same ravine I found a fragment of an ammonite, which was determined by Dr. L. KRYSTYN as very similar to *Tibetites,* which indicates Norian age. Due to the preservation of the fossil this determination is not definite.

A blue limestone layer in the black shales of the lowest part of the above nala (valley) yielded indeterminable crinoids, bivalves, and a belemnite.

The monotonous character of the formation and the strong tectonization do not allow a stratigraphic subdivision, but the fossils mentioned above document that the Lamayuru Formation represents deposits of a large span of time, the Triassic-Jurassic and possibly also the Cretaceous.

The limestone klippes in the Lamayuru Unit are of special interest. Part of them are proved to be Upper Triassic by their fossils and resemble the Kioto Limestone (DE TERRA, 1935; FRANK et al., 1977). Other limestone klippes correspond with the multicoloured limestones characteristic for the northern portions of the adjoining Zanskar Synclinorium. Many of these lenticular bodies have tectonic contacts to the surrounding rocks of the Lamayuru Formation. But there are instances (e. g. village Dang Dang in the Yapola Valley, Shilla) where a passage from the klippe into the neighbouring rock series is observed: Along the margins the blue limestone of the klippe is interbedded with the surrounding dark argillites and no definite boundary can be drawn. It seems that the multicoloured limestones and the Kioto Limestone of the Tibetan Zone of Zanskar were interfingering with the trough sediments N of them. During the Himalayan orogenesis the connection between the epicontinental facies of the Zanskar Tibetan Zone and the eugeosynclinal Lamayuru Unit was lost. The intertonguing limestones were deformed to tectonic blocks, and the stratigraphic contacts with the adjoining argillites are only locally preserved.

The Lamayuru Unit was subdued under P/T conditions of the greenschist facies, and the rocks have reached this metamorphic grade depending on their composition.

Regarding tectonics the Lamayuru Unit is much squeezed. The dip of the beds changes due to local folding, but generally it is SSW. As described above an ophiolitic melange zone separates the Lamayuru Unit from the Dras zone in the N, and a similar zone of tectonic mixture forms the boundary between it and the Tibetan Zone of Zanskar. A chain of serpentinite bodies and limestone klippes marks this vertical or steeply SW-dipping thrust. Along this line the Zanskar limestones overlie the Lamayuru Unit. However, this thrust must be regarded as overturned as will be discussed in chapters 4 and 6. In the region S of Lamayuru it can be seen that thick bands (tens of meters) of the dark argillites of the Lamayuru Formation are intercalated with the limestones of the Zanskar Synclinorium. This shows that the movements occurred on several planes and not only along one simple thrust plane.

The Lamayuru Unit does not only abut against the Dras Zone unconformably (see chapter 2.2.), but apparently also along its southern boundary, though not being so distinct there: The Zanskar limestones, steeply dipping SW, are cut by the WNW-ESE-striking thrust plane against the Lamayuru Unit in the area S of Fotu La.

Finally I should like to mention that I regard the Lamayuru Unit as one stratigraphic-tectonic zone in a position between the Dras Zone and the Zanskar Synclinorium. It continues from Lamayuru to Mulbekh, and to me there appears no necessity to separate a "Namika La Flysch" from a "Lamayuru Flysch" as proposed by FRANK et al. (1977). In the paper quoted the term Indus Flysch is used as a general name for the whole Mulbekh-Lamayuru belt including Lamayuru- and Namika La Flysch, whereas GANSSER (1976, section across Lamayuru area) seems to have restricted the term Indus Flysch to the northern flysch belt in the Indus Valley. I followed that suggestion in my 1976 b, and do so in the present paper.

3. The Tibetan (Tethys) Zone

Between the Mulbekh-Lamayuru depression in the N and the Central Crystalline building the Great Himalayan Range in the S spans the rugged mountaineous country of Zanskar. The mountains form lofty cliffs and pinnacles, and most of the rivers flow through narrow gorges with vertical walls. The access to the interior of Zanskar from the N, therefore, is rather difficult and since the traverses in the course of LYDDEKKER's pioneer explorations (1883) not much geological work has been done there.

The Zanskar mountains mainly consist of carbonate rocks, and this sedimentary belt represents the north-western continuation of the Tibetan or Tethys Zone of Spiti. We may speak of the Zanskar Synclinorium in Ladakh as we do of the Dolpo Synclinorium in NW Nepal or the Spiti Synclinorium. Within that sedimentary belt there are marked changes in the facies, when crossing it in SW-NE direction. Most of the rocks are altered up to the grade of greenschist facies, and many of the formations are devoid of fossils. Moreover under the influence of the extreme compression along the Indus Zone, the northern parts of the Zanskar Synclinorium consist of isoclinal, mostly vertical folds, which makes it difficult to reconstruct the stratigraphic order. Therefore the stratigraphy of the Tibetan Zone of Zanskar has yet to be studied in more detail. Though most of the fossils are destroyed by metamorphism, the stratigraphy of the southern parts of the Synclinorium are well established, for the lithology of the formations corresponds very closely either to Spiti or Kashmir. Therefore I suggest to describe that part first.

From the Rangdum Gompa (monastery) in the Suru Valley towards NE to the Kangi La (pass) we find a complete section from the Upper Palaeozoic to the Upper Cretaceous and possibly Early Tertiary.

Whereas most of the Palaeozoics have become part of the gneiss complex (see chapter 5), the Panjal Trap still exhibits its typical lithology. This Upper Carboniferous to Permian formation is exposed in the monastery hill of Rangdum and NW and SE thereof (fig. 3). It consists of light to dark green, blocky weathering trap, which has become rather schistose and alternates with layers of phyllite. Inspite of the strong alteration the amygdales are still recognizable. M. P. SINGH et al. (1976) describe that series as Ralakung Volcanics from the Zanskar Valley and proved an Up. Carboniferous to Mi. Permian age.

The Panjal Trap is succeeded by a 100–150 m series of dark blue schistose limestones, calc schists, and black phyllites forming a thin-bedded alternation. These much recrystallized brownish weathering rocks seem to represent the Middle to Upper Permian, the Zewans of Kashmir. Further ESE JOSHI & ARORA (1976) found the Upper Palaeozoic-Lower Triassic formations rich in fossils and similar to those of adjacent Spiti.

A banded succession, approximately 500 m thick, comprises almost the whole of the Triassic (fig. 3 on pl. 5). The lower 100–120 m of this sequence consist of a thick-bedded alternation of light grey to dark grey (fetid) limestone and light dolomite, all being marble.

From this series a 50–70 m band of cream, yellow to light brown, cellular dolomite (Rauhwacke) develops. Again an alternation of limestone and dolomite follows, being 300–350 m thick. The limestones are light or blue, schistose, and may be interbedded with dark calc schists and phyllites. The dolomites show white, cream, grey, or pink colours. There are some layers of cellular dolomite and of intraformational breccia. Lenticular and current bedding, fossil detritus layers as well as ghostly sections of bivalve or brachiopod valves are recognizable.

The Quartzite Series (70–80 m) follow, consisting of white, grey, brown, or dark grey quartzite, carbonate quartzite, and in the lower 40 m dark grey, sandy or silty argillites also occur. The rest of the formation is again an alternation of light dolomite, cellular dolomite, and dark limestones and calc schists. These beds also contain breccia and arenaceous layers. Undeterminable corals, crinoids, and shells were found in impure limestone. The top of the sequence is formed by a conspicuous 8 m thick bed of light dolomite.

The Kioto Limestone is composed of thick-bedded, blue and grey limestone with thin argillaceous layers. Oolite and breccia beds are not rare. In contrast to the light – dark banded Triassic sequence and the light Quartzite Series (Noric? – Rhaetic) the 300–400 m thick Kioto Limestone (Rhaetic – Dogger) makes a dark impression in the scenery. The Kioto Limestone shows less metamorphism than the underlying formations.

The Upper Dogger, being only 7–10 m thick, consists of ochre weathering, medium grey, current-bedded carbonate quartzite and sandstone, and blue arenaceous limestone. Particularly the basal 1 m bed weathers in deep brown colour. Sporadic fragments of limestone in certain layers of these beds give the character of a breccia. The sand grains are subangular to angular and are embedded in a carbonate matrix. Crinoids and recrystallized shells were found.

The Spiti Shales (Upper Jurassic – Lower Cretaceous) are also rather thin measuring 15 m only. They comprise black fissile shales and silty slates.

The Giumal Sandstone (Lower Cretaceous) consists of light to dark grey, green (glauconitic), fine- to coarse-grained quartzites and quartzitic sandstones. The thick-bedded sequence disintegrates to coarse, round blocks and weathers in brown colours. In the upper 150 m of the approximately 250 m thick formation dark grey to black, sandy, or silty slates are interstratified. In the topmost part of the Giumal Sandstone there are layers full of belemnites. These fossils occur in a dark medium- to coarse-grained, ill-sorted carbonate sandstone containing black rock fragments up to 0.8 cm. These components show fine angular quartz grains in a dark brown to opaque, phosphoritic matrix*. The groundmass of the sandstone, however, is carbonate.

Above the Giumal Sandstone 30 to 40 m of thick-bedded blue, grey, dense, and nodular limestones follow, representing the Chikkim Series. In their basal portion the limestones still contain sandy layers and yield indeterminable belemnites. Part of these limestones are rather schistose and recrystallized. Dr. OBERHAUSER (Geol. B.-A., Vienna) kindly identified *Globotruncana* exgr. *lapparenti* suggesting a Turonian-Santonian age. The fossils are only just determinable due to the alteration of the rock.

The limestones are succeeded by a flysch series up to 1000 m thick, the Kangi La Flysch (FUCHS, 1977 b). The rocks are grey, green, and also rather dark slates, sandy and

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* Dr. P. KLEIN (Geol. B.-A., Vienna) kindly examined such a black rock fragment and measured a P_2O_5-content of 11.80%. Considering the high content of quartz grains, the analysis proves the phosphoritic nature of the matrix.

silty slates and shales, and argillaceous sandstones. Transversal schistosity is common. Dark concretions and hieroglyphs are not rare in that flysch. The formation is recognized from afar by its ochre weathering colour and the soft geomorphological forms.

A sample derived from the northern portions of the Kangi La Flysch, close to its tectonic contact with the Quartzite Series and the Kioto Limestone, yielded *Omphalocyclus* sp., indicating a Campanian (?) – Maestrichtian age.

Without sharp boundary a 200 to 300 m thick, well-bedded limestone series follows above the Kangi La Flysch. The dark blue, partly nodular limestones show their high content of large foraminifera on the ochre coloured weathered surface even to the unaided eye. Interbedded with these limestones there are shales and a few beds of green-grey and dark grey quartzite to carbonate quartzite. The latter occur particularly in the lower 50 m of the formation. Some of the limestones are rich in fossils, containing foraminifera, bryozoa, corals, gastropods, bivalves, and crinoids. Dr. M. E. SCHMID (Geol. B.-A., Vienna) gave the following determinations of the foraminifera:

Omphalocyclus macroporus LAMARCK
Heterohelix sp.
? *Siderolites* sp.
? *Globotruncana* sp.

The first cited fossil, which is rather frequent in two of the samples, indicates Maestrichtian age. The age determination is important as it gives the upper age limit of the Kangi La Flysch. In the field I have mistaken the foraminiferal limestones for nummulitic limestones. From LA TOUCHE's (1888) description it seems very probable that the "nummulitic limestones" he rediscovered in central Zanskar are identical with the Maestrichtian limestones of the Kangi La. They appear to be the continuation of the Cretaceous series described above on the eastern side of the Spongtang Klippe.

The youngest formation in the Rangdum – Kangi La section forms the core of the large syncline SSW of Kangi La. It consists of purple and green shales, at least 200 m thick, with subordinate cross-bedded sandstones. The purple colour is reminiscent of the Indus Molasse, but it is rather doubtful whether the formations can be correlated in age. Thus post-Maestrichtian Cretaceous or even Paleocene-Eocene age is possible.

The Panjal Trap and the argillaceous-calcareous facies of the Permian indicate close relation to Kashmir. The banded Triassic sequence resembles the Kashmir Triassic very much, particularly of the Zoji La section. The Quartzite Series and Kioto Limestone show a uniform development throughout the Tethys Himalaya from Nepal to Kashmir. Also the succeeding Jurassic to Mid Cretaceous is very similar to the corresponding formations in other parts of the Tibetan Zone. The existence of an autochthonous flysch in the Tibetan (Tethys) Zone is very significant. The only comparable instance was described by HEIM & GANSSER (1939) from northern Kumaun; lithologically however, there is not much resemblance between the two flysch occurrences.

Not only stratigraphically but also regarding tectonics the described section is well-comparable to the Tibetan Zone in other regions. The Upper Palaeozoic-Upper Cretaceous (Early Tertiary?) succession is deformed in open folds with south-western vergency. The first syncline NE of Rangdum has a core of Kioto Limestone (fig. 3 on pl. 5).

The northern limb is disturbed, and the banded Triassic series forms the steep core of an anticline. More to the N a wide syncline with the post-Maestrichtian purple series in the core is adjacent. There is much detail folding in the limbs of this syncline, the minor folds of which, overturned to the SW, are very conspicuous in the mountains around Kangi La. A steep thrust terminates the southern subunit of the Zanskar Synclinorium described above. Along that structural plane Quartzite Series and Kioto Limestones come in contact with steeply dipping and much disturbed Kangi La Flysch.

N of the named thrust there are changes in facies, and the stratigraphy is more doubtful. Also the style of deformation is different; the beds are steeply inclined or vertical, and the folds are often rather narrow.

Within the Kioto Limestone of the Kong Valley, NE of the thrust mentioned above, there is a steep and squeezed syncline consisting merely of Paleocene-Eocene:

These beds are 60–100 m thick and consist of beige, cream to greenish, light-coloured calc schists and schistose limestones with layers of blue -grey limestone. The large foraminifera are macroscopically visible. Their determination by Dr. M. E. SCHMID (Geol. B.-A., Vienna) gave:

Assilina exgr. *laxispira*
Assilina sp.
Nummulites sp.

The first named fossil points to an Ypresian (Lower Eocene) age.

In the otherwise normally developed Kioto Limestone a 1 m band of green slate is accompanied by light grey, yellowish weathering dolomite. In the area between Kong and Kangi the thickness of the Kioto Limestone varies between 300 and 600 m.

Down the Kong valley at the junction of three side valleys we cross an anticline. Underneath the Kioto Limestone the Quartzite Series, 30–70 m thick, consists of green, grey, white, brown weathering, thick-bedded quartzites, showing cross-bedding, interbedded with dark grey to green, silty slates and dark schistose limestones.

The core of the mentioned anticline is formed by dark grey, silty slates, which are obviously in stratigraphic contact with the overlying formations. Therefore the silty argillites, recalling the Noric Tarap Shales of Nepal or Kuti Shales of Kumaun, suggest an Upper Triassic age, possibly also comprising Mid Triassic. In the SE-side valley also red and green schistose beds were observed by binocular beneath the Quartzite Series.

N of the described anticline the folded Kioto Limestone and Quartzite Series build up both slopes of the valley. To the SE the Kioto Limestone is overlain by a complex of dark argillites. At the bend of the valley (called Mendi encamping ground) these dark slates reach the valley in a syncline. In my view these beds do not represent the Spiti Shales, but the overthrust Lamayuru Unit (see chapter 4), which builds up almost all the upper Chomo Valley.

At Kilchu the Kioto Limestone, forming the northern limb of the above synform, is followed by an anticline composed of Quartzite Series, and then comes a syncline showing the following stratigraphic sequence (from below): Black argillites at their top pass into the Quartzite Series consisting of 15–30 m of green and white, thick-bedded quartzites. These are succeeded by about 70 m of black slates and schistose dark limestones and then the typical Kioto Limestone follows. The dark beds between the Quartzite Series and the Kioto Limestone are unusual, but obviously represent a stratigraphic intercalation.

Towards the N, down the valley to Kangi, one crosses a thick complex of dark argillites, which contain the 250–300 m band of steeply SW-dipping multicoloured limestones S of the village Kangi. This complex represents the Lamayuru Unit, which unfortunately borders the dark argillites unterlying the Quartzite Series and Kioto Limestone belonging to the Tibetan Zone of Zanskar. In that case it is difficult to demarcate the boundary between the two structural units. The black argillites of Kangi as well as the multicoloured limestones N thereof are allochthonous (Spongtang Klippe). Their tectonic contact with the Kioto Limestone and multicoloured limestone complex of the lower Kangi Valley is documented by lenticular bodies of flysch along the thrust.

N of that thrust we enter the northern subunit of the Zanskar Synclinorium, the most compressed part of the latter. I studied this belt in three sections: the Kangi Valley, the Shillakong and the Yapola Valley-Honupattan section. The dip varying around the vertical and isoclinal folding, are characteristic for this northern portion of the Zanskar Synclinorium, and therefore it is very difficult to establish the stratigraphic order of formations.

The multicoloured limestones: This formation, up to 1000 m thick, is composed of white, grey, blue, cream, red, and green limestones, some being dolomitic alternating with red, purple, and green slates, phyllites, and calc schists. The conspicuous series is banded in a dm- to m-rhythm, but also shows major cycles of a few meters to 40 m. Transversal shearing is common, and the rocks generally show phyllitic metamorphism. Though the calcareous layers are very fine-grained, they have recrystallized during deformation. The series is devoid of fossils. This may be due to the alteration. The barreness of the multicoloured limestones seems to be caused also by environmental conditions of sedimentation, because fossils are not missing in the adjoining Kioto Limestone. Regarding the age it is important that the multicoloured formation is closely associated with the Kioto Limestone. In the steep and isoclinal series along the northern margins of the Zanskar Synclinorium it can hardly be decided which formation is the younger. Near Honupattan, however, the Kioto Limestone certainly forms synclines in the multicoloured series. Therefore I assume a Triassic age for the latter (1977 b, p. 223). BASSOULLET et al, 1978, p. 564) compare the facies with the Scytho-Anisian of the Middle Austro-Alpine Unit.

The multicoloured limestones are characteristic for the northern marginal parts of the Tibetan Zone and form klippes in the Lamayuru Unit – all the occurrences in central Zanskar are tectonically derived from the N.

Between the multicoloured limestones and the Kioto Limestone the Quartzite Series is missing. Near Honupattan light grey, flasery limestones containing crinoids and rare, recrystallized corals were found in that position. Up the valley from Honupattan to Spongtang and in the Shillakong Valley the Quartzite Series is well-developed. It comprises green, grey, white, impure quartzites, carbonate quartzites, impure, micaceous sandstones and quartzites, silty shales and slates of green-grey colour, sandy limestones, and blue thick-bedded limestones of Kioto type. There are also intraformational breccias with components of Kioto Limestone . The rocks disintegrate to irregular blocks of brown weathering colour.

The thickness of the Quartzite Series may reach even 150–200 m, generally it is less. The formation yields poorly preserved fossils: Corals, hydrozoans, brachiopods, bivalves of megalodon type, and crinoids. Hieroglyphs were also observed.

The Kioto Limestone, which follows above the Quartzite Series or directly above the multicoloured limestones, is very important for correlation. The formation is continuous from the southern to the northern margins of the Zanskar Synclinorium, and many of the klippes within the Lamayuru Unit consist of this limestone.

Fig. 4: Kioto Limestone showing cross sections of *Megalodon;* upper part of Shillakong gorge (Zanskar).

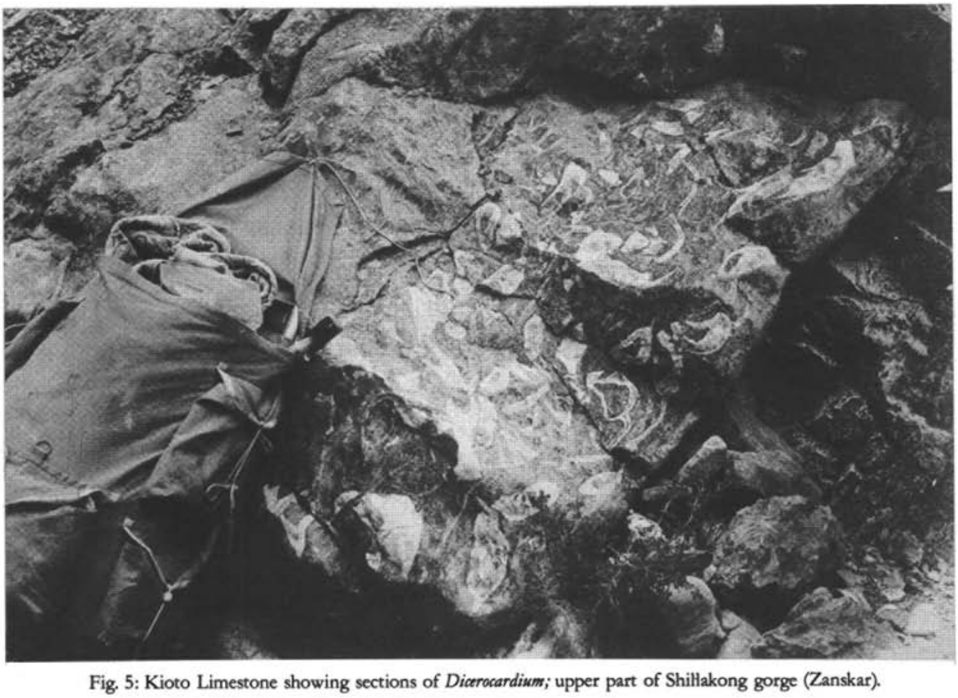

Fig. 5: Kioto Limestone showing sections of *Dicerocardium;* upper part of Shiłlakong gorge (Zanskar).

Fig. 6: Shell bed of *Lithiotis* in Kioto Limestone E of the village Honupattan (Zanskar).

Fig. 7: Kioto Limestone E of Honupattan; *Lithiotis* shell bed in blue limestone; layer exhibiting sections. of other bivalves near rucksack corner; bed of mottled dolomitic limestone, near rucksack.

The Kioto Limestone is composed of dark blue, grey to white limestone and dolomitic limestone. The thick-bedded sequence, in which argillaceous layers are rather subordinate, is light-dark banded. The light, shell beds, consisting of *Megalodon* and *Dicerocardium* (figs. 4, 5) or *Lithiotis* (figs. 6, 7) are several meters thick and very spectacular. They are well-developed, particulary in the northern parts of the Zanskar Synclinorium. In the upper Shillakong gorge the *Lithiotis* horizon was met 50 m below the top, which, however, is a tectonic boundary. The disturbance by folding and wedge structure is rather severe, and so horizons yielding *Lithiotis* respectively *Megalodon* are found close together. Besides the named fossils corals, hydrozoans, bryozoans, brachiopods, gastropods, and crinoids were observed. From a sample W of Honupattan Dr. B. GRUBER (Palaeont. Inst. of the University of Vienna) kindly indentified: *Indopecten seinaamensis multicostatus* CHEN and *I. seraticosta* BITTNER.

The fossils show that the Kioto Limestone was deposited in shallow water, as in other parts of the Himalaya. The same is proved by the sedimentary structures: These are intraformational breccias, arenaceous limestones exhibiting current bedding, fine-oolitic layers, and nodular mottled beds (probably being the product of secondary dolomitization, fig. 7).

In the Shillakong Valley dark slates were found alternating with the Kioto Limestone in a certain zone. Downstream the same valley some pink to cream layers were observed in the higher portions of the formation. These occurrences might indicate facial intertonguing with the adjacent Lamayuru belt or the multicoloured carbonates of the northern marginal parts of the Tibetan Zone as proposed in the facies schema (fig. 1, FUCHS, 1977 b), and pl. 3 of the present paper. The Kioto Limestone is definitely of uppermost Triassic–Liassic age. I assume that the formation reaches up into the Dogger like in other parts of the Tibetan Zone. The lower boundary of the formation, however, is doubtful: The Kioto Limestone of western Zanskar overlies different formations and may be partly substituted by the formations underlying (see above).

WSW of Honupattan in the Kioto Limestone there are rather squeezed synclines of younger series. They consist of a few meters of ochre weathering arenaceous-calcareous beds and black to dark grey argillites, which in my view represent the Dogger correspondingly the Spiti Shales. Black slates also cross the Kangi Valley in its lower course. The approximately 200 m thick slate band occurs between Kioto Limestones (pl. 1, 2). NE of Honupattan a similar band forms a steep syncline in the multicoloured limestones. It consists of 100–150 m of dark grey to green, laminated, silty shales and slates with brownish weathering layers of carbonate sandstone to arenaceous limestone. There are also a few beds of blue limestone. Hieroglyphs and small black concretions were observed. Regarding these occurrences it is probable that the black argillites form synclines, but they may either be Spiti Shales in normal contact with the surrounding rocks or infolded parts of the overthrust Lamayuru Unit. Without determinable fossils this question can not be decided.

The Structure of the northern parts of the Zanskar Synclinorium is characterized by tight and steep folds and wedges. In the lower Kangi Valley (pl. 2, section 2) we find mainly Kioto Limestone with a few intercalations of the multicoloured formation and the black argillite band mentioned above. The rocks dip steeply SW.

The Shillakong section (pl. 2, section 3) in the lower (northern) course of the valley shows the multicoloured limestones and Kioto Limestone folded and faulted, vertical or dipping SW at steep angles. In the upper course of the Shillakong gorge the Quartzite Series forms anticlinal cores in the Kioto Limestone or marks reverse faults. The conspicuous anticline just before the upper end of the gorge is tectonically succeeded by multicoloured limestones dragged to that position by the Lamayuru Unit (fig. 8, 9 A on pl. 6, 7). In the core of this Kioto Limestone anticline cross-folding causes the anomalous eastern dip of the beds.

The Yapola Valley-Spongtang section (pl. 2, section 4) consists mainly of the multicoloured formation in the northern parts, adjoining to the Lamayuru Unit. The spectacular steep mountain E of the Yapola Valley seems to be composed of Kioto Limestone. The syncline of dark argillites in the multicoloured limestone has already been mentioned. Near Honupattan there are two synclines of Kioto Limestone overturned to the NE, whereas all the anticlines consist of the multicoloured series. Up from the knee of the valley W of Honupattan to Spongtang we find anticlinal cores of Quartzite Series and synclines of Spiti Shales in the folded Kioto Limestones. Detached multicoloured limestones follow above the described folded sequence of the Tibetan Zone like in the Shillakong Valley.

4. The Spongtang Klippe

LYDEKKER (1883, p. 116) reports about "a large outflow of coarsely crystalline trap, occurring apparently in the midst of mesozoic rocks, and similar to the trap within the tertiary area of the Indus to the eastward of the Zanskar river". The occurrence has not been visited by LYDEKKER because of difficulties to access*. Since then a patch of basic volcanic rocks in midst of Mesozoic formations is shown on the geological maps of the NW-Himalayas . It was this occurrence of basic rocks which made me choose the traverses S and SW of Lamayuru in the course of my 1976 expedition. As I expected, the basic rocks are associated with flysch and turned out to be an outlier of a thrust sheet derived from the Indus Zone. But there is not only the flysch-basic volcanics outlier building up the highest sombre coloured peaks of the Spongtang area, for this unit is underlain by a thick sequence of black argillites, in which light limestone klippes stand out in many cliffs (figs. 8–11 on pls. 6–8). It is the Lamayuru Unit, which forms this spectacular landscape. Like in the Indus Zone ophiolitic melange belts separate the different tectonic units. The discovery of the Spongtang outlier proves that the structural units of the Indus Zone were thrust towards the SE for a distance of at least 30 km and covered the Tibetan Zone of Zanskar. This is particularly important for the right interpretation of the structure as all the thrust planes of the Indus Zone dip towards SW suggesting "counterthrusts".

I now continue with the description starting with the basal portions of the Spongtang outlier. The Kioto Limestones of the Tibetan Zone described in the previous chapter, are tightly folded and in the Spongtang area their beds are vertical or even dip NE. To the S the multicoloured series, 60 to 120 m thick follows after a 4 m band of black silty slate. There might be doubt whether in Spongtang these multicoloured limestones are in

* A historical remark may be necessary as FRANK et al. (1977, p. 106) note that the Spongtang Klippe was discovered by LA TOUCHE and described by MAC MAHON (1901). This is not correct because LYDEKKER reported about the occurrence in 1883, as referred in my 1977 b paper, whereas LA TOUCHE took two samples of serpentinite, probably on the trip when he rediscovered the nummulitic rocks of Zanskar (publication 1888). Neither LA TOUCHE nor MAC MAHON (1901) dealt with the geological aspects of the Spongtang occurrence. In 1976 I discovered the tectonic nature of the Spongtang rocks and reported about my finds at the 1976 Colloquium in Paris (referred in the discussion part of the Geology publication on p. 525).

tectonic contact with the Kioto Limestone or whether they also belong to the Tibetan Zone. The multicoloured limestones, however, can be traced to the Shillakong (500 m thick there) and further to the Kangi Valley. There flysch rocks in form of squeezed lenticular bodies measuring several tens of meters occur in the multicoloured limestones near their contact with the Kioto Limestone. The flysch rocks are fine-grained, green-grey sandstone and silty slates. The occurrence of the flysch klippes close to the contact between the Kioto Limestone and the multicoloured series indicates that the two formations join along a tectonic plane. In the Kangi Valley the multicoloured series overlies the Kioto Limestone, steeply dipping SW. The reverse can be observed in the Shillakong and Spontang Valleys, and therefore BASSOULLET et al. (1978) opine that the whole limestone belt, their "Shillakong Unit", forms an allochthonous mass on the Lamayuru Unit. However, the steep north-eastern dip observed in the bottom of the valleys becomes vertical, and finally SW if followed up to the high mountains framing the valleys (figs. 8, 9 on pls. 6, 7). This observation, the regional extent, and the arrangement of the tectonic zones suggest that the Lamayuru Unit was thrust over the limestone belt and not the reverse (FUCHS, 1977 b). I regard the multicoloured limestones between the Kioto Limestone and the Lamayuru Unit, or in the basal portions of the latter as dragged from the northern marginal parts of the Tibetan Zone.

From the trail leading from the Spongtang to the Shillakong Valley via Snuzi La a series of small lenticular bodies of serpentinite were observed along the boundary between the above dealt multicoloured limestones and the black argillites of the Lamayuru Unit (fig. 9 on pl. 7; fig. 12). Certainly these ultramafic rocks mark a tectonic plane. W of the pass

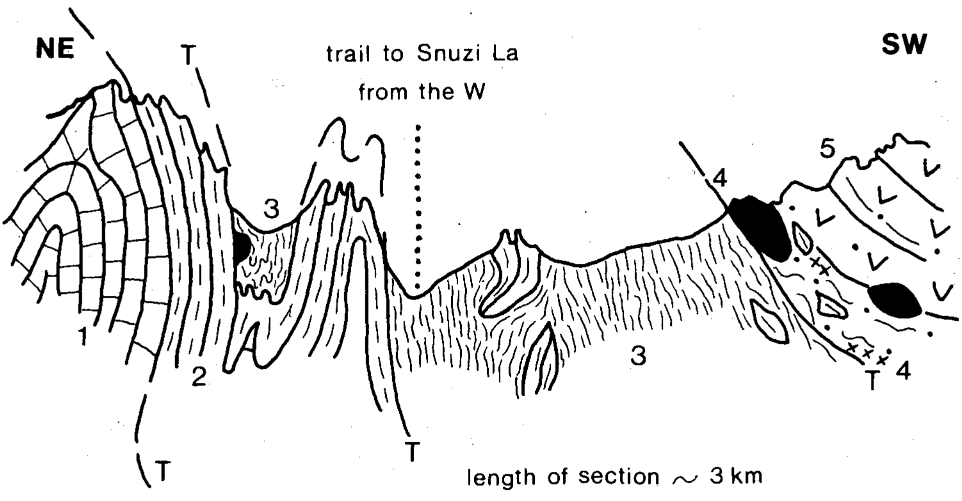

Fig. 12: Section W of Snuzi La seen from Shillakong Valley (Zanskar)
1 Kioto Limestone (Tibetan Zone)
2 multicoloured limestones — Spongtang outlier
3 Lamayuru Unit containing limestone klippes and serpentinite (black) — "
4 ophiolitic melange: flysch, serpentinite, limestone klippes and radiolarian cherts — "
5 basic volcanics, peridotite and flysch — "
T thrusts

the black argillites form a steep isoclinal synform in the multicoloured series. This synform does not reach the bottom of the Shillakong Valley. (fig. 12). It is a common observation that in the Lamayuru Unit the klippes of the multicoloured limestones occur predominantly in its basal portions. This fact and the intensive steep folding after thrusting are explaining why the klippes are frequent in topographically low terrain and are rare in the higher regions.

Besides the multicoloured limestones also quartzites of the type of the Quartzite Series and Kioto Limestone occur as klippes in the Lamayuru Unit, but are less common. The Lamayuru Formation is composed of dark grey to black argillites, marls, and some calcareous, or silty, sandstone layers and resembles closely that of the type area. These soft rocks make up the groundmass for the klippes, which come out as steep cliffs. The result is a scenery of spectacular contrasts (figs. 8–11 on pls. 6–8).

The upper boundary of the roughly 1000 m thick Lamayuru Unit is formed by an ophiolitic melange zone dipping SW at medium angles (figs. 9–11 on pls. 7, 8; fig. 12). It is composed of a variety of rocks: A flysch sequence of grey slates, silty slates, green-grey sand- and siltstones, fine breccias exhibits disturbed bedding (e.g. slump structures) and flute casts. The sandstones are felspatic and ill-sorted, the grains being angular and of low sphaericity. Mixed with the flysch there are large lenticular bodies of serpentinite, bright red, grey, and green radiolarite, probably Triassic limestones, calc schists, quartzite, etc. Volcanic rocks are abundant in that series. Fine-grained diabase, pillow lavas, amygdaloidal lavas, green and red porphyrites showing phenocrysts of hornblende, augite, and felspar, medium-to coarse-grained dioritic to gabbroidic rocks, red-green coloured agglomerates and volcanic breccias, and tuffs containing also carbonate rocks as components. The primary contact between Triassic limestone and a basic volcanic rock was observed in a block. BASSOULLET et al. (1978, p. 565) report about a primary contact between a red ammonite bearing limestone of Hallstatt facies and agglomerates.

In the course of my hurried survey I just touched the basal portions of the flysch-ophiolite unit of Spongtang. It appears that the ophiolitic melange zone, characterized by the serpentinites and exotic blocks, passes into the overlying complex of flysch and basic volcanics, which is several hundred meters thick. The coarse-grained, dark green peridotites, which yield the brown coated boulders so frequent in the rivers, were not observed in situ. I suppose that they have a rather high position within the thrust mass.

Dr. A. DAURER (Geol. B.-A., Vienna) kindly examined two of my peridotite samples and gave the following description: The heteroblastic rock shows no orientation of the minerals. It consists of fresh olivine (46 vol.%), coarse-grained orthopyroxene (probably bronzite, 35 vol.%), clinopyroxene (10 vol.%), chromite (1 vol.%) and ore (1 vol.%). Amphibole (7 vol.%) of the grunerite-cummingtonite series forms aggregates of colourless needles growing after the deformation and replacing clino- and orthopyroxene. The replacement product of clinopyroxene seems to be grammatite, of orthopyroxene cummingtonite correspondingly. There is also incipient serpentinization of bronzite. The secondary effects are observed in one of the samples, which is also rather cataclastic. The preserved and fresh specimen seems to be derived from the central portion of the peridotite body. The peridotites are best termed harzburgite-lherzolites.

A dioritic rock consists of idiomorphic plagioclase (ca. 35% An, 50 vol.%) pale green hornblende (43 vol.%), quartz (2 vol.%), chlorite (2 vol.%), sphene (2 vol.%) and ore (1 vol. 2). The foliated rock also shows transversal shearing with growth of chlorite-epidote aggregates.

We find the following tectonic sequence in the northern Spongtang area (figs. 8–12):

6. peridotite
5. flysch and basic volcanics
4. ophiolitic melange
3. Lamayuru Unit
2. multicoloured limestones dragged from the northern part of the Tibetan Zone
1. Tibetan Zone steeply folded

Pl. 1 shows that the higher units (4–6) do not continue towards the WNW as wrongly drawn by BASSOULLET et al. (1978, fig. 1). In the Shillakong Valley the units 4–6 are confined to the high mountains SSE of the valley. The Lamayuru Unit, however, builds up a wide area in the upper Shillakong and Chomo Valleys. The ridge closing the Chomo Valley in the S consists of Kioto Limestone dipping NE beneath the dark argillites of the Lamayuru Unit. This limestone of the Tibetan Zone is folded together with the overlying Lamayuru Unit in the upper Kangi Valley (S of Kilchu). There is also some possibility that the series between the Kangi La Flysch and Kilchu, to which the above Kioto Limestone belongs, represent a frontal (lower) subunit of the Lamayuru Unit and thus are derived from N of the Tibetan Zone. S of Kangi and at this village itself a belt of black argillites of the Lamayuru Unit crosses the Kangi Valley. These two argillite zones are separated by a ridge formed by multicoloured limestones representing an anticline, which plunges SE-wards in the Chomo Valley (pl. 1–3). The map clearly shows that the units building up the Spongtang Klippe strike into the air towards the NW. So one might expect that not far NW of the Kangi Valley also the Lamayuru Unit might end. But FRANK et al. (1977, p. 106) report about peridotite boulders found at Bod Kharbu, which hints to the possibility that the outlier widens again in the Kharbu Valley, and even the highest units are preserved in an axial depression.

The described areal extention of the subunits of the Spongtang outlier is evidence that the belt between Kangi La Flysch and Kilchu is lower than the Lamayuru Unit, either being Tibetan Zone or representing a lower subunit of the Lamayuru Unit (?). The northern carbonate belt is explained as autochthonous belonging to the Tibetan Zone (FUCHS, 1977 b), or as an allochthonous mass overlying the Lamayuru Unit (BASSOULLET et al, 1978, figs. 1, 2, p. 565). I am convinced that this latter interpretation is wrong for the following reasons:

1. There is no indication that limestones of the „Shillakong Unit" overlie the ophiolites of the Spongtang Klippe.

2. It is highly improbable that the thick flysch-ophiolite complex composing the Spongtang Klippe has its root between the Lamayuru Unit of Spongtang and the carbonate belt ("Shillakong Unit"), where a few small serpentinite bodies are found only.

3. There is also no indication that the Lamayuru Unit of the type area represents a dome or window.

4. According to the explanation of the French geologists (fig. 2) the root of the Shillakong Unit is to be expected between the ophiolite zone N of Lamayuru and the Dras Flysch-Volcanic belt, which does not seem to be probable either.

My explanation (1977 b) is that the carbonate belt in question ("Shillakong Unit") represents the northern part of the Tibetan Zone, and thus is the lowest unit. The symmetric arrangement of the tectonic zones in the SW and NE of this carbonate belt suggests that it was in turn overridden on subhorizontal thrust planes by the Lamayuru Unit, the Dras Flysch-Volcanic Zone, and the peridotites probably derived from the ophiolitic melange belt N of the Dras Zone. Along the boundaries between these units ophiolitic melange is very common. In the Spongtang area the above tectonic sequence was preserved, whereas the extreme compression, later to the low angle thrusting, brought about the inversion of the whole tectonic succession in the Indus Zone. In all the sections (pl. 2) the deformation by folding or wedge structures increases from the inner parts of Zanskar towards the NE, to the Indus Zone. The vergency of these later movements was NE, opposed to the earlier thrusts, and led to the overturning. Thus the "counterthrusts" of the Indus Zone are actually steepened, finally overturned older thrust planes, along which the thrust masses were originally displaced in south-western direction, as documented by the large outliers described by HEIM & GANSSER (1939, Amlang La, Jungbwa) or the comparatively small klippe of Spongtang. Possibly during the late compression the older thrust planes could have been re-activated and NE-directed movements occurred. But these displacements were of less importance than earlier thrusts, and were not the cause for the formation of the major tectonic belts and the order in which they are arranged. ANDRIEUX et al. (1977) come to the same conclusions.

5. The relation of the Tibetan Zone to the Central Crystallines

The Tibetan or Tethys Zone, as elsewhere in the Himalaya, follows above the Central Crystalline, which builds up the Great Himalayan Range or at least its basal portions. In literature the Crystalline is often called "Precambrian basement of the Tethys Zone".

From all my traverses and also from the observations of many other workers I came to the conclusion that nowhere in the Himalayas apparently there is proof of a transgressive contact of the sedimentary series with the Crystalline. A sharp boundary can not be drawn, and by decrease in metamorphic grade the crystallines pass into slightly altered sedimentary series. Generally this transition occurs in the basal, Early Palaeozoic succession of the Tibetan Zone. In south-western Ladakh, however, the passage into the crystallines concerns much younger beds: The Permo-Triassic series are already metamorphosed N of Rangdum, and the Panjal Trap ist the oldest formation still identifiable. All the underlying Palaeozoic formations have become part of the mica schist-gneiss complex and are no more recognizable. W of Rangdum, down the Suru Valley, the alteration increases and the Panjal Trap is represented there by biotite-hornblende gneiss and amphibolite.

Also S of Rangdum along the road to Pense La it can be observed that in the syncline, S of the two-mica granite-gneiss intrusion, the Upper Palaeozoic-Triassic series show the metamorphic grade of the amphibolite facies.

In the region of Suru (Panikar) and the Chilung Pass the mica schists and gneisses contain garnet, kyanite, and staurolite. In the midst of these amphibolite facies rocks there are remnants of folded Triassic series. They are altered to marble and calc-mica schist, and form conspicuous folds in the Chilung Valley at its bifurcation. The partly garnetiferous amphibolites accompanying the carbonates may represent the Panjal Trap.

W of the Chilung Pass, in the Kainthal Nar Valley (also named Bhot Kol Valley) the grade of alteration decreases gradually in NW-direction. It can be traced how the high grade metamorphic rocks pass into the only slightly altered Palaeozoic-Mesozoic succession of Kashmir. The marbles of the Nun Kun area extend into the Triassic of the Shesh Nag-Zoji La region, as correctly shown on LYDEKKER's map (1883).

Thus in the Nun Kun region the Alpine metamorphism reaches up into extraordinary high levels of the Palaeozoic-Mesozoic succession of the Tibetan Zone. I assume some relation with the also locally intensified metamorphism reported from the Nanga Parbat area (MISCH, 1936, 1949). The folded marbles there, associated with schistose basic rocks, recall the altered Upper Palaeozoic-Triassic series of the Nun Kun region. So the "Salkhalas" of the Nanga Parbat area might turn out to be much younger than Precambrian.

6. Conclusions

Geological work in Ladakh is of importance as it gives us information about the northernmost zones of the Himalaya and the relation to the Transhimalaya. Let us first deal with the reconstruction of the depositional basins.

Sediments of the Tethys are found in several synclinoria in the NW-Himalaya. The southernmost are those of Kashmir and Chamba, which show certain facial peculiarities and the strongest influence from the Indian subcontinent (see FUCHS, 1975). The Tibetan Zone of Spiti-Ladakh was deposited N thereof, but was continuous with the above mentioned synclinoria before the great morphogenetic phase, which led to the formation of the Great Himalayan Range. Therefore it is not surprising that there are facies similarities between the Kashmir-Chamba succession and the south-western portions of the Tibetan Zone (e.g. occurrence of the Panjal Trap, facies of the Triassic). The younger formations of south-western Ladakh exhibit much resemblance with Spiti, which forms the lateral continuation.

As shown in chapter 5 there is no crystalline basement existing beneath the sedimentaries of the Tibetan Zone in the SW. From the descriptions of HAYDEN (1904), BERTHELSEN (1953) and others I also doubt the existence of a „Precambrian basement" underlying the Tibetan sediments in the NE.

Towards the NE the facies of the Mesozoic formations of the Tibetan Zone becomes diversified. Below the Quartzite Series and Kioto Limestone, which form a continuous horizon in the Himalayas, we find the development of dark silty slates in central Zanskar instead of the banded limestone-dolomite sequence of SW-Ladakh. Further N the Kioto Limestone is directly underlain by the thick multicoloured banded carbonate-argillite succession. This indicates a complicated facies pattern for the Triassic (older rocks are not exposed in the area of investigation): The epicontinental development of Kashmir and the southern Tibetan Zone is replaced by trough sedimentation in central Zanskar and again by a shelf, in the N, where the multicoloured carbonates were deposited. N of that swell the Lamayuru Unit shows typical trough sedimentation (pl. 3 A). As noted in chapter 2.3. I explain at least part of the klippes in the Lamayuru Unit as former facies interfingerings between the Lamayuru basin facies and the multicoloured shelf facies. During thrusting they were deformed to tectonic blocks. This facies scheme is derived from the tectonic pattern, which I regard as the more probable one (pl. 2, 3 A). However, the basin facies (Kong) was observed in the Kangi-Kangi La section only, and thus my interpretation is based merely on one section, which implies some uncertainty. There appears also the possibility that the Triassic basin facies observed between Kilchu and the thrust onto the Kangi La Flysch represents a lower tectonic subunit (Kong Subunit), L. 1 of the Lamayuru Unit. In this case its source was between the latter and the Tibetan Zone, and a trough between the shelves needs not be assumed. An argument gainst this interpretation is the presence of the multicoloured limestones in both the Lamayuru Unit and the northern Tibetan Zone, whereas they are missing in the Kong Subunit, which should have its source in between (pl .3 B). The difficulty may be avoided by the assumption that the dark silty facies of the Triassic comprises the higher levels only, immediately below the Quartzite Series, and the multicoloured limestone facies is connected with the klippes of the Lamayuru Unit in lower levels not exposed in the Kong Valley. The advantage of this assumption (pl. 3 B) is that the dark silty facies is between the shelf facies and the trough facies of the Lamayuru Unit, and thus indicates a continuous deepening from the plateform to the trough. A decision can only be reached after the adjoining areas are mapped. Anyhow, the facies differences between the southern, central, and northern parts of the Zanskar Synclinorium and the abrupt change along tectonic lines show that the original facies pattern must have been considerably disturbed. According to pl. 3 A the Tibetan Zone exhibits fold and schuppen structure, whereas the interpretation B implies that the Kong Subunit was thrust from the northern margins of the Tibetan sedimentary belt.

The existence of an autochthonous Upper Cretaceous flysch in the Tibetan Zone of Zanskar is of special interest, because the only instance hitherto reported was in northern Kumaun (HEIM & GANSSER, 1939). There is no doubt that the Kangi La Flysch follows stratigraphically above the preceding Tethyan formations. Contrasting to the flysch of the Indus Zone neither volcanic rocks were found associated with the flysch nor any exotic blocks. These series are confined to the Spongtang outlier, which, however, forms a higher thrust sheet and has nothing to do with the Kangi La Flysch. The deposition of flysch approximately 1000 m in the Upper Cretaceous indicates a phase of strong subsidence after a long period of plateform sedimentation. But this phase was of short duration, for the Maestrichtian limestones succeeding the flysch, document a new phase of shallow sedimentation.

The multicoloured argillaceous–arenaceous beds following the Maestrichtian limestones probably mark the end of sedimentation in the Zanskar Synclinorium. Unfortunately their age is not fixed.

All the sedimentary zones from the Lesser Himalaya to the NE to the Lamayuru Unit show certain facial relations with each other. Therefore they were deposited in belts adjoining the Indian Subcontinent in the N the latter influencing even the northern Tethyan zones (Upper Palaeozoic tillites, Gondwana flora and fauna, etc.) So it is not possible to place the "actual" suture – the "Mid-Himalayan Suture" – along the base of the Main Central Crystalline (SRIKANTIA & BHARGAVA, 1978, p. 56). There are too many facies relations crossing this tectonic line to assume the Himalayan zones N and S of the M.C.T. to belong to different continents, as the above mentioned authors, KANWAR (1970), and others do.

The stratigraphic record of the Dolpo Synclinorium of Nepal shows instable periods with rapid subsidence alternating with periods of stable shelf conditions, and so FUCHS (1977 a, p. 211) terms the Tibetan basin a miogeosyncline. Contrary COLCHEN (1975, p. 92) and LE FORT (1975, p. 14) envisaged plateform conditions. In the Zanskar Synclinorium, however, the exposed Mesozoic succession is predominantly of plateform type. A downbuckling in the Upper Cretaceous is indicated by the Kangi La Flysch, and is caused by the Himalayan orogenesis.

Contrasting to the Zanskar Synclinorium the Lamayuru Unit exhibits typical basin facies in the Triassic to Cretaceous (?). The depth of the water was not extreme, but the thick, ill-sorted sequence indicates typical trough conditions. I think that the term eugeosyncline is justified, though the Lamayuru Formation is not associated with volcanism.

The Dras Flysch-Volcanic belt and the Indus Flysch are difficult to compare with the zones adjacent to the S, because they are composed only by Mid to Upper Cretaceous (Early Tertiary?) series and basic to intermediate volcanics formed contemporaneously. This strong volcanic activity distinguishes the Upper Cretaceous flysch of the Indus Zone from the Kangi La Flysch. There are also shallow-water limestones (Khalsi Limestone) associated with the Indus Flysch.

The Cretaceous flysch sedimentation and volcanism indicate the beginning of the Himalayan orogenesis and the trough of deposition probably was initiated by that event. Unfortunately we do not know the basement of the Cretaceous succession. It may be represented by the rocks composing the ophiolitic melange zones.

The Indus Molasse documents a later stage (Eocene-Miocene) in the development of the Himalaya. In the course of the orogenic events the marine synorogenic flysch sedimentation has come to an end, and the products of beginning decomposition were deposited in a continental basin. The Indus Molasse transgresses on the huge Upper Cretaceous–Early Tertiary Ladakh intrusive mass.

The ophiolitic melange zones (GANSSER, 1974) with their exotic blocks certainly document that much space has been consumed between the individual belts of the Indus Zone. But it is impossible to say how far the Lamayuru Unit, Dras Zone, and Indus Flysch were separated from each other.

Now the tectonics shall be considered.

The Zanskar Synclinorium shows open Jura type folds in its south-western portions. The style of deformation corresponds very well with other parts of the Tibetan Zone, the vergency, however, is uniform, distinctly SW, which like in Kumaun is an exception. This seems to be caused by the higher nappes which have overridden the Tibetan Zone in Kumaun and Ladakh. The intensity of deformation increases as we go towards the NE, to the Indus Zone. The northern portions of the Zanskar Synclinorium are subvertical, tightly folded, and show wedge structures.

There are schuppen structures between the southern, central, and northern parts of the Zanskar Synclinorium unfortunately the magnitude of displacement is not exactly known. As discussed earlier it is also possible that the Kong Subunit is a distached mass derived from near the boundary to the Lamayuru Unit. But the Spiti-Zanskar Synclinorium as a whole is definitely autochthonous.

In the central parts of the Zanskar Synclinorium the Spongtang Klippe rests on the series of the Tibetan Zone. This outlier consists of several tectonic units. Immediately above the Kioto Limestone of the Tibetan Zone separated by a few meters of black argillites or blocks of flysch multicoloured limestones follow. They are dragged from the northern marginal parts of the Tibetan Zone by the overthrusting Lamayuru Unit. Lenticular bodies of serpentinite between the Lamayuru Formation and the multicoloured limestones indicate a tectonic contact. Multicoloured limestones however, are also found within the Lamayuru Unit forming many of the klippes. These limestones, however, are not to be confused with the exotic blocks. Like blocks of Kioto Limestone or the Quartzite Series they are either tectonically derived from the adjacent Tibetan Zone or represent the remains of former facial interfingerings. The exotic blocks, however, are of unknown source, and appear to be confined to the melange zones. A conspicuous ophiolitic melange zone separates the Lamayuru Unit from the succeeding flysch-volcanic series. The peridotites seem to take the highest position. Thus the Spongtang outlier consists of a number of thrust sheets, which cannot be explained by the synsedimentary gliding mechanism envisaged by SHAH (1976). The fact that the autochthonous flysch of the Tibetan Zone (Kangi La) is free of klippes does not support the hypothesis of SHAH either.

The tectonic succession in the Spongtang region matches very well with that of northern Kumaun and southern Tibet (HEIM & GANSSER, 1939; GANSSER, 1964, 1974, 1976). There the Jungbwa Nappe composed of very similar peridotites forms the highest and much extended unit. It is underlain by the Kiogar Nappe consisting of ophiolitic melange. In the type region the Kiogar Nappe overthrusts the flysch of the Tethys Zone, but further N it rests on thick dark coloured argillaceous series partly being also arenaceous and calcareous. These flyschoid series were studied by GANSSER along the Mangshang River N to Shinglabtsa and at Jungbwa, where they were termed the Raksas Series (HEIM & GANSSER, 1939, p. 167–169). GANSSER regards these series as an extraordinary thick development of the Spiti Shales (Upper Jurassic – Lower Cretaceous). The sporadic fossils show that these argillaceous series also comprise the Lower and Middle Jurassic. The description of the lithology recalls the Lamayuru Formation, and the tectonic position is exactly the same. The limestone klippes, which are so common in the Lamayuru Unit, appear to be missing in Tibet, but the limestone "which projects out of the badly exposed region over a long distance in the shape of a crest" (1939, p. 167, fig. 137) may represent a klippe. Thus I suppose that the Lamayuru Unit is a regional stratigraphic – tectonic element like the Kiogar or Jungbwa Nappes, which are found in Ladakh as well as in southern Tibet.

BERTHELSEN (1953, p. 364–365) reports about the serpentinite ocurrence in the Karzok Valley, W of Tso Morari (Rupshu), which he explains as a second ophiolite belt parallel to that of the Indus (1951, pl. 1). Close to these ultrabasic rocks there are dark slates, phyllites alternating with blue limestone, and grey, thin-bedded quartzitic schists. These series accompanying the serpentinites might represent the Lamayuru Unit. From my experience of the Spongtang outlier and considering GANSSER's reports about southern Tibet I follow GANSSER (1964, p. 74, 78), who explains the Rupshu serpentinites as an outlier and not as a suture zone. In the Spongtang area strong compression after the thrust movements has led to tight folding of the northern parts of the Tibetan Zone, of the Lamayuru Unit, and the separating thrust planes. I suppose that the ultrabasics of Rupshu were folded together with the adjoining formations in the course of this late tectonic phase and came into their SW-dipping position. In this way they probably were preserved from erosion.

After dealing with the allochthonous masses resting on the Tibetan Zone I want to discuss the source of the thrust sheets. Judging from the material there is not much doubt that they are derived from the Indus Zone. This is very important as all the structural planes in the Indus Zone dip towards the SW, giving the impression of NE-directed thrust movements ("counterthrust"): The limestones of the Tibetan Zone appear to override the Lamayuru Unit which follows above the Dras Zone. The Spongtang outlier, however, shows the reverse sequence and this, in my view, reveals the original tectonic succession. Considering the tectonic sequence in the Spongtang outlier and the order of the zones in the Indus belt (see pl. 1) I connect the units as indicated in pl. 2 and 3, which is conform with ANDRIEUX et al., 1977), but differs considerably from the tectonic interpretation of BASSOULLET et al. (1978). My arguments are given in chapter 4. Indisputable, however, is the fact that the Spongtang thrust mass is displaced from the Indus Zone for at least 30 km in south-westerly direction. This agrees well with southern Tibet, where GANSSER reports thrust distances of even 60–80 km. Thus nappes were squeezed out from the Indus Zone and moved over the Tibetan Zone adjacent in the SW.

From the above it is concluded that the entire sequence of tectonic units of the Indus Zone is inverted. In my view this inversion is related with the late compression, which also caused the intensive folding of the ready pile of nappes. As mentioned earlier in this paper the effect of this late compression increases, if we approach the Indus Zone. The tectonics of that zone are evidence for extreme compression. This is easily understood as the Indus Zone is a root zone, but the deformation was further intensified by the mentioned compressional phase after the thrusting. In view of this facts and considering the structural pattern of the Indus Zone it is hard to understand when SRIKANTIA & BHARGAVA (1976, 1978) explain those structures by the assumtion of tensional forces. Contrary to the statement of these authors on p. 56 (1978) blue schist metamorphism is reported from the Indus Zone by FRANK et al. (1977, p. 104) and low temperature-high pressure metamorphism by S. KUMAR (1978). From the western continuation of the Indus line DESIO records the recent discovery of glaucophane schists (1978, p. 18).

After the regional overturning it is likely that along the pre-existing structural planes movements were directed NE (counterthrusts). But it should be stressed that these movements just modified the earlier structures – the tectonic units and their order of arrangement were formed before in the course of the nappe movements.

The question of the age of all these events is very important.

The Giumal Sandstone of Lower Cretaceous age is the first indication of the approaching Himalayan orogenesis. With the upper Lower Cretaceous the Indus and Dras Flysch sedimentation started. The huge basic volcanic masses then produced, show the magnitude of the disturbance. The plateform sedimentation of the Tibetan Zone was interrupted in the Upper Cretaceous by the sedimentation of the Kangi La Flysch. In the Maestrichtian shallow water conditions were restored. From the Lamayuru Unit, this Triassic-Cretaceous (?) eugeosynclinal trough, we have no indication when the sedimentation ended.

Definitely post-Maestrichtian, probably in the Early Tertiary (Eocene) the nappe movements started. Along thrust planes reaching deep into the mantle the ophiolitic melange was formed: Slices of the mantle, oceanic crust, and pelagic sediments (radiolarites, exotic blocks) were mixed with flysch and associated volcanic material. The flysch trough was deformed and the Lamayuru Unit, ophiolitic melanges, Dras Flysch-Volcanic belt, Indus Flysch, and peridotites were thrust from the Indus Zone onto the adjoining Tibetan Zone.

In Late Cretaceous-Early Tertiary times the huge granodiorite batholith of the Ladakh Range intruded. According to FRANK et al. (1977, p. 110) the geochemical properties suggest that the intrusives were formed from recycled oceanic crust.

After the nappe movements a continental trough remained, where the Indus Molasse was deposited, transgressing on the south-western flank of the Ladakh batholith.

Probably in the Miocene, when the great nappe movements of the Lesser Himalaya occurred and the beginning of the Siwalik sedimentation indicates a major disturbance, the Indus Zone was subdued to severe compression. The ready pile of nappes was tightly folded and the whole root zone became inverted. Former tectonic planes were re-activated, and structures directed NE, towards the Transhimalaya, were formed along the Indus Zone. At that time or somewhat later the Indus Flysch belt overrode the Indus Molasse adjoining in the NE putting an end to the molasse sedimentation in this interior zone.

The drainage pattern came into being and thick alluvial masses were deposited in the Inner Himalaya. This was certainly caused by the morphogenetic phase, when the rivers flowing from the Tibetan Plateau to the Punjab or Ganga Plaines were dammed up by the growing Himalayan ranges. Lake deposites (e. g. at Lamayuru) and raised river terrasses high on the flanks of the valleys are tests of the intensive uplift which is still going on.

Finally a few words concerning plate tectonics: Long before the birth of the "New Global Tectonics" HEIM & GANSSER (1939), based on ARGAND's work (1922), stressed the importance of the Indus Zone. Since the advance of plate tectonics the Indus region plays an essential role as suture zone in the diverse plate tectonic models (CAREY, 1955; GANSSER, 1964, 1966, 1974, 1976; DEWEY & BURKE, 1973; CRAWFORD 1974; LE FORT, 1975; POWELL & CONAGHAN, 1973, 1975; MOLNAR & TAPPONIER 1975, and others).

The reader therefore might be surprised that in the present paper the plate tectonics vocabulary is missing. The paper aims to contribute to the geological knowledge of western Ladakh, and from work in this rather restricted area definite conclusions on such hypotheses are not to be expected. Investigations on a much larger scale are necessary for such decisions. It is indisputable that an oceanic belt, the Tethys, showing a variety of facies has been deformed and that the planes of disturbance reached down into the mantle. The nappes are proof for large scale horizontal displacements. But these facts are equally explained by "conservative" orogenic theories as by plate tectonics. I feel that at the present state of knowledge gathering of further data is more essential than to subscribe the one or the other hypothesis.

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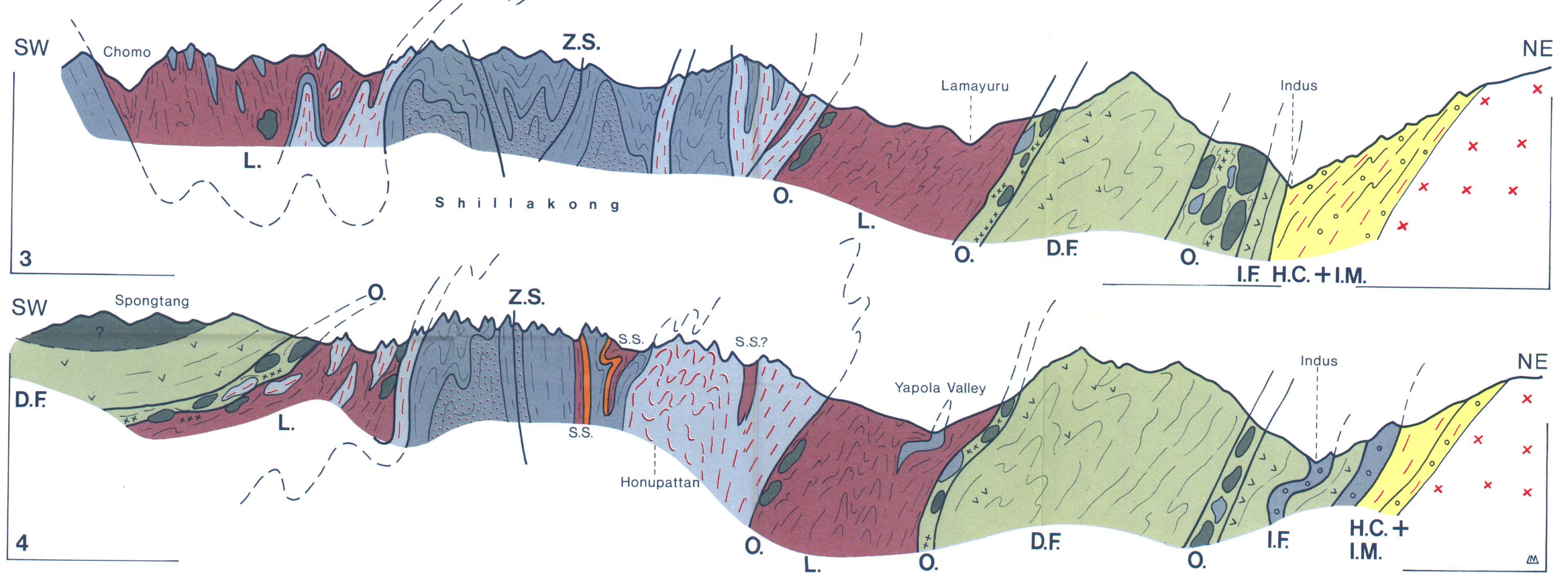
G. FUCHS Plate 2

Sections through the Zanskar Mountains

G. FUCHS, 1976



Z.S. = Zanskar Synclinorium (Tibetan Zone)

- Marls and limestones (Paleocene – Eocene)
- Red and green shales and sandstones (Uppermost Cretac. – L. Tertiary?)
- Foraminiferal limestones (Maestrichtian)
- Kangi La Flysch (pre – Maestrichtian)
- Chikkim Limestone (Up. Cretaceous)
- Giumal Sandstone (Lower Cretaceous)
- Spiti Shales (S.S.)
- Dogger
- Kioto Limestone (Rhaetic – Dogger)
- Quartzite Series (Noric? – Rhaetic)
- Dark silty slates (Mi. – Up. Triassic)
- Multicoloured limestones and slates (Triassic?)
- Permian to Up. Triassic
- Panjal Trap (Permo – Carboniferous)

Cr. = Crystalline:
- Gneisses i. gen.
- Metagranites – granite – gneisses

O. = Ophiolitic melange zones:
- Ultrabasics (serpentinites)
- Radiolarites

L. = Lamayuru Unit:
- Lamayuru Fn. (Triassic – Jurassic); limestone klippe

D.F. = Dras Flysch; I.F. = Indus –··–
- Flysch; volcanics
- Khalsi Limestone (Mid. – Up. Cretaceous)

H.C. = Hemis Conglomerate; I.M. = Indus Molasse
- Multicoloured conglomerates, sandstones, shales, etc

- Ladakh Granite

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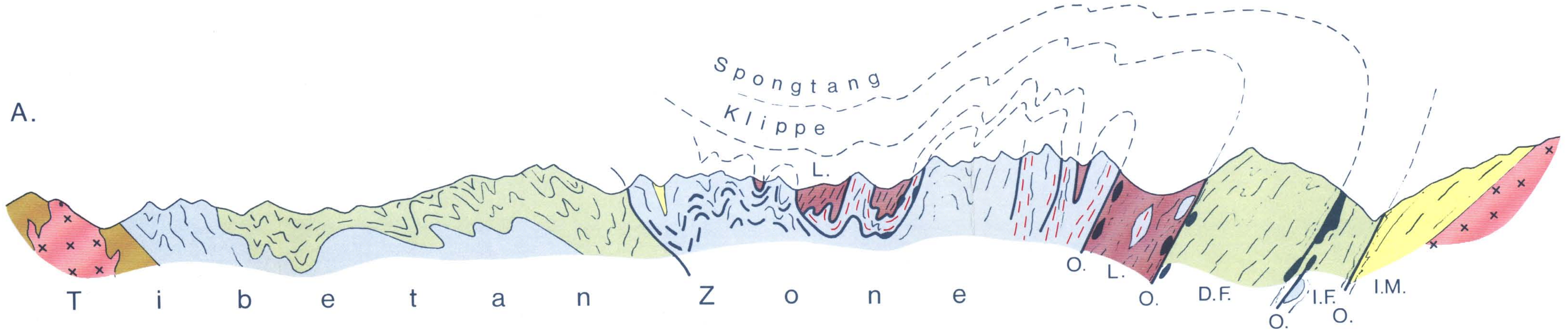
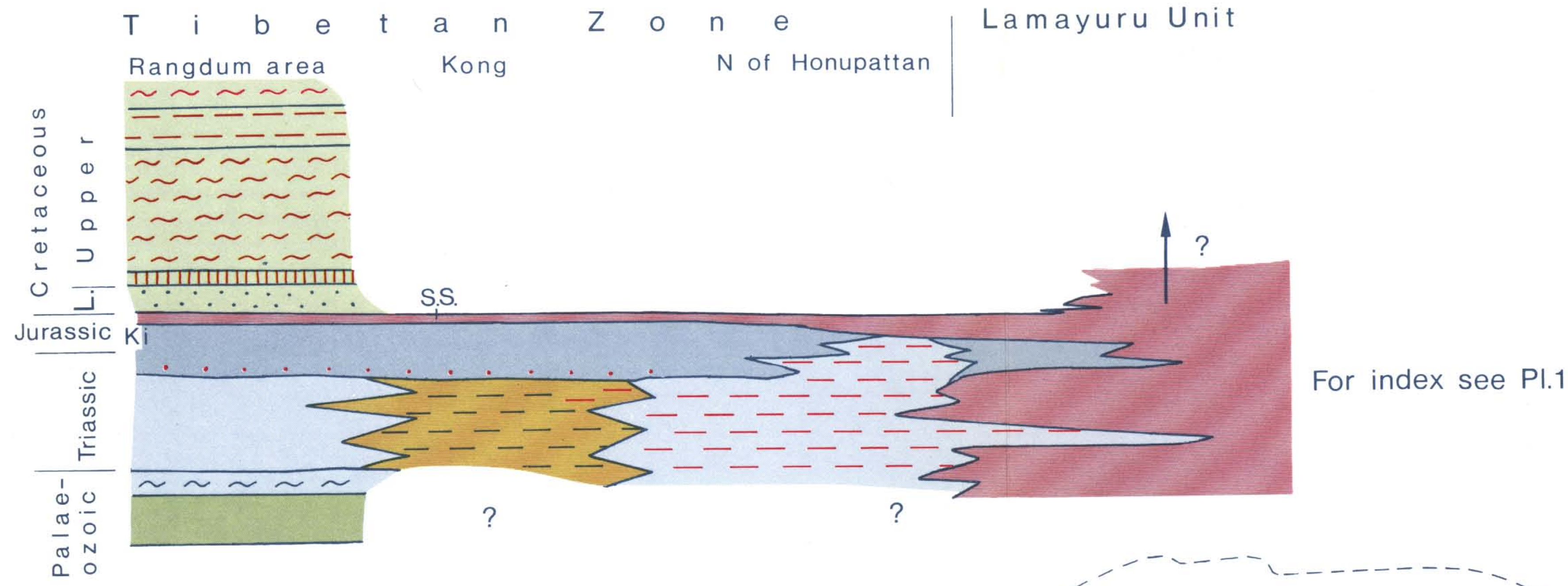
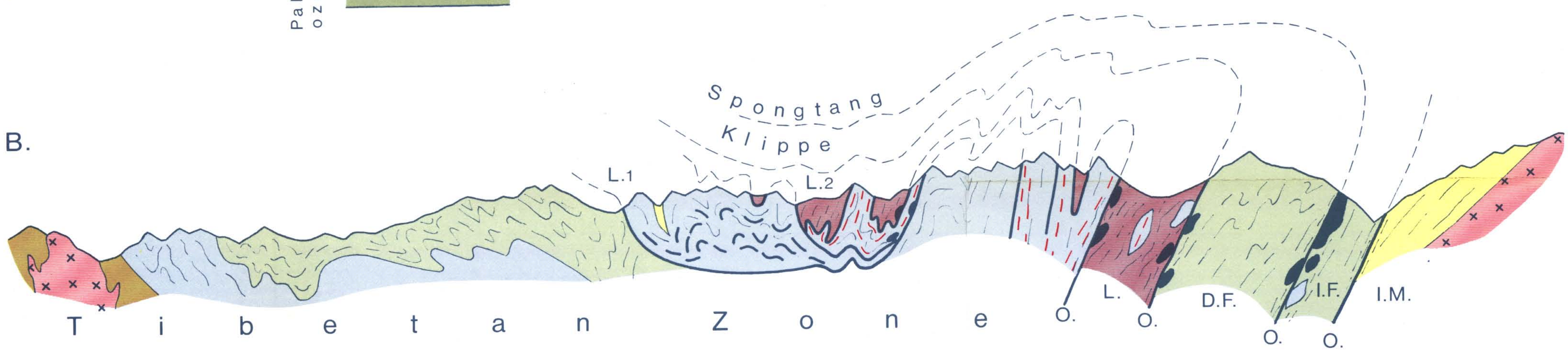
Two tectonic interpretations and their consequences on the facies distribution

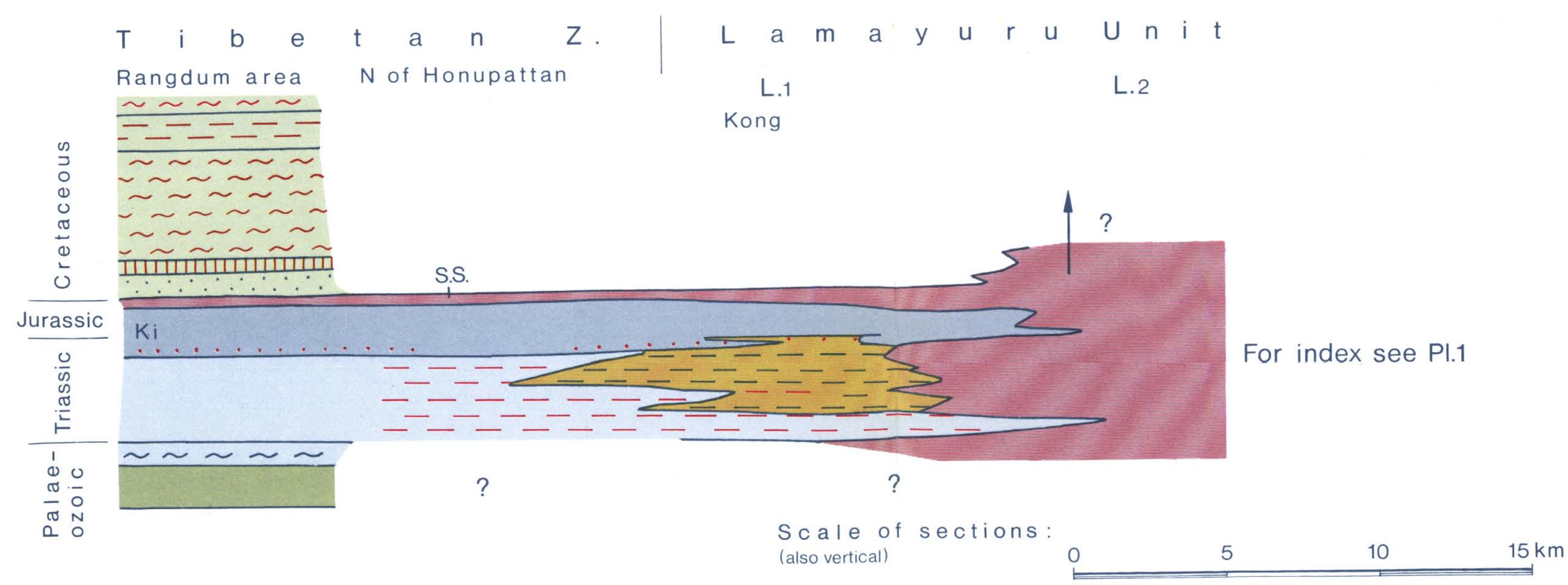
A.





B.





Index for the sections:

- Tertiary (I.M. = Indus Molasse)
- Cretaceous-Early Tertiary (D.F. = Dras Flysch, I.F. = Indus Flysch)
- Triassic-Jurassic
- Multicoloured facies of the Triassic
- Dark argillite facies of the Triassic
- Lamayuru Unit (L.)
- Palaeozoic
- Granites
- Ophiolitic melange with ultrabasites (O.)

For the index of the facies diagrams see Pl. 1

Jahrbuch der Geologischen Bundesanstalt, 122. Band, 1979 – Beilage 15
G. FUCHS Plate 4

Fig: 1A
For index see Fig. 1 on Plate 5

Fig. 1

Fig. 1: View upstream the Indus seen from the road E of Khalsi.
1 Khalsi Limestone (Mid Cretaceous)
2 alternation of limestone, argillite, and volcanics at the top of the Khalsi Limestone
3 Indus Flysch: Argillites with sandstone layers
4 zone of belemnite limestone
5 ophiolitic melange
6 Dras Flysch
7 alluvial terraces of the Indus

Fig. 2

Fig. 2: The Indus-Yapola River junction seen from the S, from the Lamayuru-Khalsi Road.
1 Ladakh Intrusives (mainly granodiorite)
2 Indus Molasse
3 ophiolitic melange zone (Indus Flysch not visible in the photo)
4 terrace of Indus Valley

Fig. 3

Fig. 3: Panorama view of the Rangdum area in the upper Suru Valley.
1 Central Crystalline (mainly gneisses)
2 Panjal Trap (Permo-Carboniferous)
3 Zewan Series (?)
4 banded Triassic limestones and dolomites
5 Kioto Limestone (Jurassic – Lower Cretaceous not visible in the photo)
6 Kangi La Flysch
7 Maestrichtian limestones

Fig. 8

Fig. 8: The Shillakong Valley seen from the E, from the trail descending from Snuzi La (Zanskar).
1 multicoloured limestones
1a multicoloured limestone klippe within the Lamayuru Unit
2 Kioto Limestone
3 Lamayuru Unit
4 earth pillars
T thrusts

S p o n g t a n g

continued → Fig. 9B

Fig. 9: Panorama view from the Snuzi La towards the W to the Shillakong Valley (A) and towards the E into the Spong Valley (B).
1 multicoloured limestones
1a multicoloured limestone klippes within the Lamayuru Unit (L)
2 Kioto Limestone (Tibetan Zone = Ti)
3 Lamayuru Formation (+ smaller klippes)
4 serpentinite (O = ophiolitic melange)
5 flysch and volcanics (D. F. = Dras Flysch-Volcanics)
6 peridotite
7 moraine
T thrusts

Fig.10

Fig. 10: Panorama view of the Spongtang area
1 multicoloured limestones
1a multicoloured limestone klippes
2 Kioto Limestone (Ti = Tibetan Zone)
3 Lamayuru Formation (L = Lamayuru Unit)
4 serpentinite (O = ophiolitic melange)
5 flysch and volcanics (D. F. = Dras Flysch-Volcanics)
6 peridotite
T thrusts

Fig. 11

Fig. 11: Panorama view of the north-western Spongtang area seen from the Spong Valley towards the SW and W (Snuzi La).
1 multicoloured limestones
1a multicoloured limestone klippes within the Lamayuru Unit
2 Lamayuru Formation
3 serpentinite
4 flysch, volcanics, peridotites
T thrusts