EXPLANATIONS

of the

GEOLOGIC-TECTONIC MAP OF THE HIMALAYA

by GERHARD FUCHS

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Contents

Preface

The submitted map is identic with that coloured map attached to the authors paper „Outline of the Geology of the Himalaya" (G. FUCHS, 1981a). These explanations are a somewhat changed version of the mentioned paper.

Eighteen years have passed since GANSSER summarised the knowledge of that time in his famous „Geology of the Himalayas" with an attached map at a 1 : 2,000.000 scale. Since then a series of almost unknown regions have been mapped and the intensified research of the last two decades produced a real flood of literature not easy to overlook. Due to different aims of the investigations and the school of workers the results are somewhat heterogeneous and it is often difficult to combine contradicting views. In such doubtful cases it was of help that I have worked in the various stratigraphic-structural zones and in distant areas of the Himalaya. It was the aim to get a uniform map, which reflects the continuity of the units so impressive in nature. Therefore stress was laid on the main structural units. The stratigraphy had to be simplified, because it was not possible to correlate stratigraphic subdivisions, as the grade of exploration is different from area to area. Thus the map was named „geologic-tectonic" and it gives a uniform but naturally somewhat tentative picture.

The present explanations shall provide additional information to the map in rather concise form. The first part gives a description of the main tectonic units, their material and style of deformation, the second part sketches the tectogenesis of the Himalaya. As far as possible the voluminous recent literature is listed at the end of the paper, it was used in the elaboration of the map but can not be fully discussed in the text for want of space.

1. Structural units

The description starts in the south with the Sub-Himalaya and goes to the north dealing with the Lesser, High, and Inner Himalayas. The Indus Zone, a very complex belt of the northern Himalaya, is already linked with the Transhimalaya.

1.1. The Tertiary Belt

The foothills or Sub-Himalayas are built of thick Tertiary fresh-water molasse series deposited in the Himalayan foredeep.

The Siwalik Zone, continuous all along the Himalaya, consists of shales, siltstones, sandstones and conglomerates several thousands of meters thick. In the Lower Siwaliks red and brown argillites are important, in the Middle Siwaliks grey sandstones predominate, whereas the Upper Siwaliks are mainly conglomeratic. Thus the grain-sizes increasing upwards reflect the growth of the Himalaya and beginning denudation (HAGEN, 1959; TANDON & RANGARAJ, 1980 a.o.). From the terrestrial plant and animal fossils the age of the Siwaliks is generally accepted Mid-Miocene to Pleistocene. The Siwaliks are deformed to gentle folds, but towards the north near the Main Boundary Thrust folding is intensified and imbrications are found.

The Murree Zone, forming a belt of Lower Miocene trough deposits between the Siwaliks and the older series of the Lesser Himalaya, is confined to the Hazara- and Punjab Himalaya. The Murree Formation is composed of grey, green sandstones and purple shales alternating. Along thrust planes and in the core of anticlines the base of the Murrees is exposed: Shalis consisting of grey–blue stromatolitic dolomites and dark slates, quartzites and chert breccias of doubtful age and nummulitic limestones and shales of Paleo-Eocene age (Subathu). These beds represent the facies of the Lesser Himalaya.

The base of the Tertiary series of the Potwar Basin is exposed in the Salt Range: Precambrian to Lower Cambrian evaporites and Lower Cambrian continental to shallow marine beds, followed after a gap by the Upper Carboniferous Talchir Tillites and the classical Permian–Mesozoic series; several gaps are found in the Mesozoics. This succession was deposited on the northern margin of the Precambrian Indian Shield. It is sheared off from its base and brought to the surface by a south-facing thrust (Detachment Thrust, SEEBER et al., 1980). Similar decollements, hidden under the young deposits of the present foreland of the Himalaya, probably exist also under the Ganges Plains, a hazard of devastating earthquakes. GANSSER's Main Frontal Thrust (M.F.T.) reported from the eastern Himalayas (PANTIĆ et al., 1981, Fig. 1) may be related with such decollements.

1.2. The Parautochthonous Unit

Stratigraphy

This southernmost unit of the Lesser Himalaya overrides the Tertiary Belt along the Murree- respectively Main Boundary Thrust (M.B.T.) but does not form a nappe (see below).

In the Lesser Himalaya we have to face the problem that most formations are devoid in fossils and the sequence is tectonically much disturbed. Therefore views are so divergent regarding the age of many formations (Precambrian or Palaeozoic), what is stratigraphic and what is tectonic succession, autochthony or allochthony of the units etc. From the comparison of many sections I came to the conclusion that there may be dispute on the age but not about the original sequence of the beds and the tectonic boundaries.

The Parautochthonous Unit shows no uniform stratigraphy, a consequence of local transgressions and the tectonic unit cutting across various facies belts.

The facies of the Krol Belt characterised by thick carbonate formations has the widest extent (Hazara, Simla to Kumaun, Nepal, Baxa). The litho-units are in ascending order:

Fig. 1: Twisted and granulated flute casts in Hazara Slates; Sherwan road west of Abbottabad, Hazara, Pakistan.

Simla Slates (Attock-, Hazara-, Dogra Slates, Damta Group etc.): monotonous flyschoid trough deposits (> 1000 m) comprising grey, green, dark slates, silt- and sandstones, greywackes (Fig. 1); local carbonate intercalations known as Langrial, Naldera, Kakarhatti.

Chandpur: green, grey phyllites, quartzites, basic tuffs (< 1500 m).

Nagthat (Khaira, Jainti Qzt.): red, green, grey orthoquartzites, sandstones, conglomerates, slates exhibiting cross-bedding, ripple marks, clay gall breccias (500–1000 m); haematitic beds and basic volcanics occur northeast Naini Tal.

Jaunsar: grey, green argillites with sporadic sandstone beds locally replace Chandpurs and Nagthats.

Blaini (several hundred meters): red, green, grey slates, sandstones, quartzites, pink, grey dolomites, haematite beds showing cross-bedding and intraformational breccias; in Hazara (Tanakki) and the Krol Belt green grey boulder beds and pebbly mudstones are interbedded in the lower part of the formation, which frequently is transgressive (e.g. JAIN, 1981). Facetted and striated boulders prove a glacial origin of these beds.

Infra Krol (several hundred meters): black, grey argillites with sporadic arenite beds; this euxinic facies may replace the Blaini, interfinger with the latter or overlie it (AUDEN, 1934).

Riri Slates: grey, green laminated and graded slates representing a facies between Infra Krol and Blaini.

Krol-Shali (< 2000 m): blue, grey cherty dolomites (limestones); frequent stromatolites, reworked layers and arenaceous beds show that Shali (Sirban, Deoban, Baxa etc.) represents a shallower facies than Krol; passages and their position in the stratigraphic sequence prove that Krol and Shali are penecontemporaneous formations (FUCHS & FRANK, 1970; FUCHS & SINHA, 1974). The carbonate formations contain intercalated varicoloured beds of Blaini type (Krol B, Lower Shali Limestone) and black slates of Infra Krol type (Shali Slates).

Tal (< 1500 m):
Lower Tal: Flyschoid green, grey, dark argillites, greywackes, sandstones, pebbly mudstones; phosphorites at the base (Mussoorie) and unconformable contacts to underlying formations in Nepal indicate a gap.
Upper Tal: white, green, grey and dark, thick-bedded quartzites interbedded with shale and breccia, blue impure limestones. Based on the sporadic and partly endemic fossils a Jurassic–Cretaceous age is generally accepted; Recently VALDIYA (1975) advocates a Permian age, whereas AZMI et al. (1981) describe Cambro–Ordovician conodonts from the Lower Tal phosphorites.

Subathu (about 50 m): blue nummulitic limestones, grey shales and quartzites of Paleocene–Eocene age.

Dagshai (several hundred meters): grey, green sandstones regularly interbedded with purple and green shales (Lower Miocene, fresh-water).

In Hazara (LATIF, 1970; FUCHS, 1975; CALKINS et al., 1975) the basal flyschoid series (Fig. 1), after a gap is succeeded by the Tanakki tillite – Sirban Dolomite sequence corresponding to typical Blaini – Shali; transgressive phosphatic beds yielded Cambrian fossils (FUCHS & MOSTLER, 1972). A Jurassic–Cretaceous succession follows in Tibetan facies (Spiti Shales to Chikkim Limestone!) transgressing on Lesser Himalayan sequence; above a gap Paleocene to Middle Eocene limestones and shales succeed overlain by the Murrees.

In the southern slope of the Pir Panjal Range of Kashmir the Parautochthonous Unit consists of a thick slate sequence passing upwards into the Agglomeratic Slate (Upper Carboniferous); then Panjal Trap, a few lenses of Mesozoic carbonates and Eocene follows (WADIA, 1928). The Nagthat–Krol (Shali) sequence is missing.

In the eastern Himalayas the Baxas resemble the Blaini–Shali or we find tillite and coal bearing terrigeneous Lower Gondwanas (Damuda); in some places Baxas and Damudas occur together, the latter are always younger, but still closely connected with the Baxa carbonates suggesting no large age difference (ACHARYYA, 1974; ACHARYYA et al., 1975; V. K. RAINA, 1976). There are also marine fossiliferous Permian beds interbedded with the Gondwana rocks in certain places (ACHARYYA et al., 1975; V. K. RAINA, 1976).

Thus the Parautochthonous Unit shows facial influences from the Indian Shield and the Tethys intermingling with a local Lesser Himalayan development. This fact gives a possibility to approach the age problem, which however shall be discussed in chapter 2.1.

The rocks of the Parautochthonous Unit are non- or slightly metamorphosed only.

Tectonics

The Parautochthonous Unit is characterised by folds and wedge structures directed towards the south. Compression post-dating the nappe movements produced steepening of the beds, steep reverse faults and locally even thrusts (e.g. Tansing, FUCHS & FRANK, 1970). The tectonic style obviously is different from the succeeding nappes which appear „less disturbed" because of low dip and only wavy folding. Further it is a characteristic of the nappes that their areal extent shows much variation along the strike. Because of their sheet-like form nappes are eroded in axial culminations and preserved in depressions. To the contrary the Parautochthonous Unit overrides the Tertiary Belt along a rather straight thrust line (M.B.T., Murree T.); the Solon Window (west of Krol Mt.) and a semiwindow southeast of Bilaspur are exceptions proving a displacement of approximately 3 km. In the windows between Mussoorie and the river Ganges (AUDEN, 1937; JAIN, 1972) it is not the Tertiary Belt which is exposed, but scales consisting of Simla Slates and transgressing Subathus (Paleo-Eocene). If we consider the distance from the M.B.T. these windows document a displacement of less than 15 km; but it is a matter of dispute whether it is the M.B.T. exposed or an internal wedge of the Parautochthonous Unit. Though the frontal portions are allochthonous the unit always formed the southern parts of the Lesser Himalaya and does not represent a „Krol Nappe" (AUDEN, 1937; BHARGAVA, 1972; VALDIYA, 1976, 1978 a.o.) derived from the southern foot of the Great Himalaya. The Deoban–Pithoragarh Belt was always north of the Krol Belt and does not form an "autochthonous window" below a "Krol Nappe".

In the west the Parautochthonous Unit builds up the Attock Range (south of Nowshera). In Hazara it comprises the Islamabad Zone – a Jurassic to Tertiary fold belt – and the Abbottabad Zone composed also of older series (FUCHS, 1975). South of the Pir Panjal- and Dhauladhar Ranges the „Autochthonous Fold Belt" (WADIA, 1928) is rather narrow. It is exposed in the Shali Window (WEST, 1939) and possibly also in the Larji Window.

The Krol Belt (WADIA, 1934) continues from the Krol Mt. to Naini Tal, where the Parautochthonous Unit is squeezed out. It appears again in the Karnali area and shows large extent in the Kali Gandaki region of Nepal (Tansing Unit, FUCHS & FRANK, 1970). Further east the unit is covered by the nappes and is confined to a narrow belt characterised by Lower Gondwana- and Baxa rocks. The Rangit Window north of Darjeeling exposes series of the Parautochthonous Unit.

1.3. The Simla- and Rukum Nappes

These thrust sheets are known from rather distant occurrences (Simla, western Nepal), they are non-continuous but have comparable position between the Parautochthonous Unit and the Chail Nappes (FUCHS & FRANK, 1970).

Stratigraphy

The sequence resembles that of the Krol Belt but exhibits individual features: The Simla Slates are well-developed, whereas Chandpurs and Nagthats are reduced to tens of meters and frequently show the facies of Jaunsar. The Blainis of the Simla area contain tillite horizons; the Shalis are missing there but reach 200 to 500 m thickness in Nepal. There the succeeding Tal Formation is well developed; locally the Tals directly overlie on Simla Slates. They are followed by shales and nummulitic limestones, the Subathu, and Lower Miocene Dagshai – the youngest formation.

Compared with the Parautochthonous Unit the alteration is markedly stronger, sometimes reaching the metamorphic grade of the Chail Nappes.

Tectonics

In the Simla area the Simla Nappe, composed of Simla Slate (partly mistaken as Chail by PILGRIM & WEST, 1928), Jaunsar and Blaini, overthrusts the Krol Belt along the Giri Thrust. This plane seems to be younger than the main nappe movements, because it cuts through several structural elements (FUCHS & SINHA, 1978). North of Simla the Simla Nappe rests on the south-dipping Tertiary series of the Shali Window. North of this window roots of the Simla Nappe appear to be missing.

Similarly the Rukum Nappe of Nepal is partly squeezed off from its roots. It forms a thin thrust sheet overriding various structural elements of the Parautochthonous Unit and is overlain by the Chail Nappes (Map, section 5). The Simla Slate belt of Sisne Khola – Uttar Ganga (northeast of Rukumkot) may represent a remnant of the root of the Rukum Nappe (FUCHS & FRANK, 1970, Fig. 1).

Thus the Simla–Rukum Nappes have their source between the Parautochthonous Unit and the Chail Nappes. They are squeezed off from their roots and were passively dragged to the S by the higher nappes. They are not continuous like most other units and appear to be formed locally.

1.4. The Chail Nappes

The Chail Nappe found by PILGRIM & WEST (1928) turned out to be a very characteristic element of the Himalaya continuous from Nowshera in Pakistan to the Brahmaputra Gorge in the east. The monotonous, thick assemblage of quartzites, phyllites, basic metavolcanics and metagranites showing metamorphic grade of the greenschist facies is found everywhere between the non- or slightly-altered series of the Lesser Himnalaya and the meso- to high-grade crystallines. They are known as Tanols, Chails, Dalings etc. Occasionally they contain intercalations of Shali type carbonates (Deoban etc.). Exceptionally a complete stratigraphic succession is found, which correlates to that of the Krol Belt (Indus area, Hiunchuli region of Nepal).

Stratigraphy

Simla Slates are found in a few places only and most sections commence with the Chails corresponding with the Chandpurs of the Krol Belt. Many synonyms are in use for the Chails: Tanol, Bawar, Berinag (VALDIYA, 1976), lower part of Nawakot (STÖCKLIN, 1980), Series of Kunchha (BORDET, 1961), Daling, Schumar Formation (JANGPANGI, 1974), Bomdila (VERMA & TANDON, 1976) etc. The Chails consist of green, grey, silvery sericite schists and phyllites, psammite schists, orthoquartzites metaarkoses, schistose conglomerates, basic and acid metavolcanics. It is characteristic that the arenaceous : argillaceous ratio changes rapidly in this several thousand meters thick clastic series, laterally as well as vertically. Therefore certain quartzite of phyllite bodies can not be used as marker horizons for stratigraphic subdivision. The deposition mostly is of molasse type, regionally also flyschoid. The clastic series were intruded by granites, which like the country rocks have undergone the greenschist metamorphism (e.g. Mansehra, Pir Panjal, Dhauladhar, Kishtwar, Mandi, Lansdowne, Ramgarh, Dailekh, Shumar granites [JANGPANI, 1974] etc.). The intrusive age of the Dhauladhar Granite dated 500 ±100 m.y. by JAEGER et al (1971) has been corroborated by later measurements done by various workers (e.g. FRANK et al., 1976; MEHTA, 1977; see also data referred to in JAIN et al., 1980, p. 78; SAXENA, 1981, Table I). Some acid magmatites gave surprisingly high ages of 1840 ±70 m.y. (FRANK et al., 1976); they may represent sheared off slivers of an ancient basement.

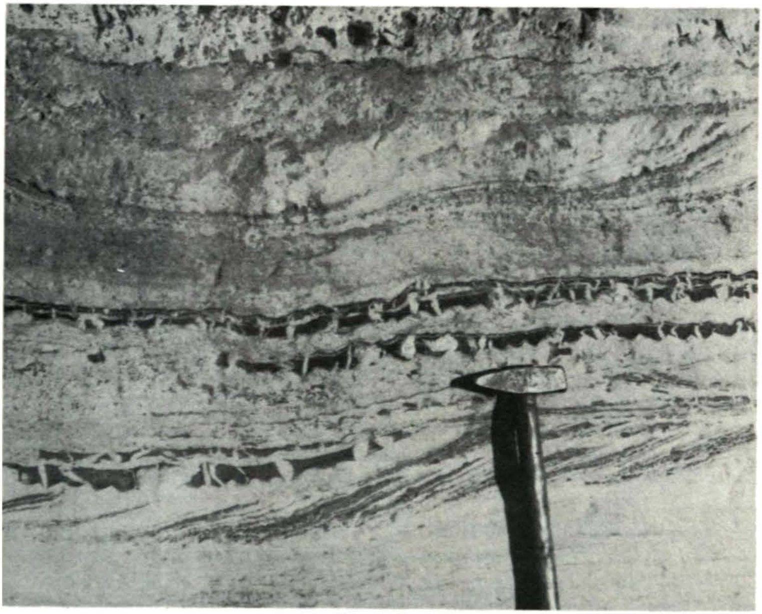

Fig. 2: Nagthat of Chail Nappe 1: current-bedded orthoquartzites, argillaceous layers broken up by desiccation cracks; clay gall breccia in upper part of the picture; south of Palang, northern Hiunchuli Group, western Nepal.

Naghtat (<2000 m): multicoloured argillites, orthoquartzites, conglomerates, basic metavolcanics; clay gall breccias (Fig. 2), current bedding, ripple marks, desiccation cracks etc.

Blaini (<1000 m): multicoloured phyllites, quartzites, dolomites, calc schists; a tilloid boulder bed found in Nepal (FUCHS, 1977, 179–181) corroborates the correlation with the Blaini of the Krol Belt.

Shali (<2000 m; synonyms: Deoban, Tejam, Gangolihat, Dhading, Baxa, etc.): grey, blue stromatolitic dolomites, limestones, partly cherty (Fig. 3). The Shali Slates are dark argillaceous intercalations in the carbonates. Generally the Shalis are the youngest formation of the Chail Nappes

but in the Tons-Deoban region Eocene rocks are involved with the Chail Nappes (Prashra, 1976; see also Fuchs & Sinha, 1978, p. 225).

In many regions (e.g. Garhwal, Kumaun) the succession is reduced to Chail and Shali (Deoban) Dolomite. In these cases the superposition of Berinag Quartzite on these dolomites has been taken as stratigraphic sequence (e.g. Ramji, 1976, a. o.); knowing the complete sedimentary succession, however, it is evident that the boundary Shali / Berinag (Chail) is tectonic.

The fossiliferous Upper Palaeozoic series described by Ganesan (1972) from Garhwal seems to belong to a lower unit of the Chail Nappes. Spores of this age were reported from Chail type rocks by Fuchs & Frank (1970, p. 43) and recently by Ashgirei et al. (1981).

Pantić et al. (1981) describe a series of „well-bedded siliceous and calcareous slates squeezed in between the Sumar-Daling group" and the Crystalline Nappe in Bhutan. This Barsong Formation yielded a Jurassic microflora.

As noted above the rocks of the Chail Nappes generally show metamorphic grade of the greenschist facies, which may increase to amphibolite facies near the root zone.

Tectonics

A review of the development of the Chail Nappes from west to east shows a uniform mass of Chails in certain regions, in others well-defined subunits may be discerned.

The *Tanol Zone* is significant, inasmuch as the Tanols are interbedded with fossiliferous Siluro-Devonian beds (Stauffer, 1968) in the Indus region. East of the Indus the Tanols are transgressed by the Tanakki–Sirban Limestone succession (Muhammad Ali, 1962; Fuchs, 1975). Though this seems to document Palaeozoic age of the whole complex, the situation is controversial, because the Sirban Limestone of the nearby Parautochthonous Unit is overlain by beds yielding Lower Cambrian fossils! (see Fuchs & Mostler, 1972; Fuchs, 1975). Structurally the Tanol Zone overrides the Parautochthonous Unit in the south and is succeeded by the Crystallines in the north. The Mansehra Granite belongs to the Tanol Zone.

East of the north-west-Himalayan Syntaxis the unit is represented by the phyllitic series and intercalated granite-gneisses of the south-western slope of the Pir Panjal (Fuchs, 1975, p. 10). Further south-east the Chail Nappe builds up the Dhauladhar Range and is exposed in the Kishtwar- and Larji-Rampur Windows (Fuchs, 1975; Frank et al., 1973, 1976). In the Simla area there is only one Chail Nappe (Pilgrim & West, 1928) but east of the Chor Mt. additionally two lower subsidiary units appear in the Deoban Dome. The lowest unit, which forms the core of this dome, the Chamoli-, Tejam- and Pithoragarh Windows, probably is parautochthonous. The higher units are nappes (Fuchs & Sinha, 1978). The uppermost thrust sheet (Berinag) does not represent the roots of a hypothetical Krol Nappe (Valdiya, 1976, 1978) nor does it follow stratigraphically on the dolomite formations but correlates to the Chail Nappe of the type area. In the Lansdowne Syncline and south-east of Mussoorie the Chail Nappes

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Fig. 3: Stromatolites in Shali Dolomite.
There are various types: SH-V, SH-V-LLH-C, SH-C; Chail Nappe 1 of Karnali window, north-west Uthugaon north of Jumla, western Nepal.

are preserved in a series of outliers, discovered by AUDEN (1937) and recently studied by JAIN (1972). There are fossiliferous beds too involved (GANESAN, 1972; SHANKER & GANESAN, 1973).

In western Nepal 3 to 4 subsidiary units can be discerned because of the tectonic repetition of upright stratigraphic successions resembling the sequence of the Krol Belt (FUCHS, 1967; FUCHS & FRANK, 1970; FUCHS 1977a); the uppermost unit as elsewhere (Berinag) is exclusively composed of Chails. I suppose that like in Garhwal the lowest units are parautochthonous, the higher ones are definitely nappes with a minimum displacement of 90 km. Both the nappes and the parautochthonous Chail units, however, were deposited north of the Parautochthonous Unit and the Rukum Nappe.

From the work of BORDET (1961), HASHIMOTO (1973), STÖCKLIN (1980) and MARUO & KIZAKI (1981) I conclude that in central and eastern Nepal there exist more than one Chail Nappe; the carbonate formations intercalated in the Chail series separate the individual structural units. The same is suggested for the eastern Himalaya by reports of JANGPANGI (1974), JAIN et al (1974), THAKUR & JAIN (1975), VERMA & TANDON (1976) a. o., which were also used in constructing the map. The Jurassic Barsong Formation (PANTIĆ et al., 1981) is squeezed between the Dalings (Chail Nappes) and the main Crystalline thrust sheet).

1.5. The Crystalline Nappes

The axial zone of the Himalaya, the Great Himalayan Range, is formed by the Central Crystalline. This crystalline mass, 5000–10.000 m thick, is the root zone of the crystalline thrust sheets which are preserved in a series of outliers in the Lesser Himalaya. Generally the Main Central Thrust (M.C.T.) is regarded as the lower boundary of the Crystalline. But commonly there are two tectonic planes, that is why VALDIYA (1976, 1978) speaks of the Munsiari- and Vaikrita Thrusts and BORDET (1961; et al., 1972) assumes a „scale zone". Thus there may be ambiguity which of these structural planes should be regarded as the M.C.T. My experience is that there always is a thin basal wedge of mesograde crystallines between the uppermost Chail Nappe and the overlying high-grade series which make up the bulk of the Crystalline. I termed the basal scale the Lower Crystalline Nappe, the succeeding main mass of the Crystalline the Upper Crystalline Nappe (FUCHS, 1967).

The Lower Crystalline Nappe (Jutogh, Munsiari, upper part of Scale Zone [BORDET et al., 1972]): a sequence (<1000 m) of garnetiferous micaschists and dark phyllites, graphitic rocks, light quartzites, paragneisses, calc-micaschists, marbles and amphibolites; locally there are minor bodies of augen gneiss. The alteration reflects conditions of the highest greenschist facies to the lower to middle subfacies of the amphibolite facies. Retrogressive metamorphism is not rare. The distinctness of the terminating thrust planes depends largely on the difference in metamorphic grade of the adjoining rock series. Thus the lower or upper boundary may locally appear like a „passage" but the individuality of the unit is evident on a regional scale.

The Upper Crystalline Nappe (Vaikrita, Darjeeling, Crystalline of Tibetan Slab etc.) (5.000–10.000 m): coarse-grained garnet-kyanite gneisses (± staurolite or sillimanite) with pegmatoid layers and lenticles

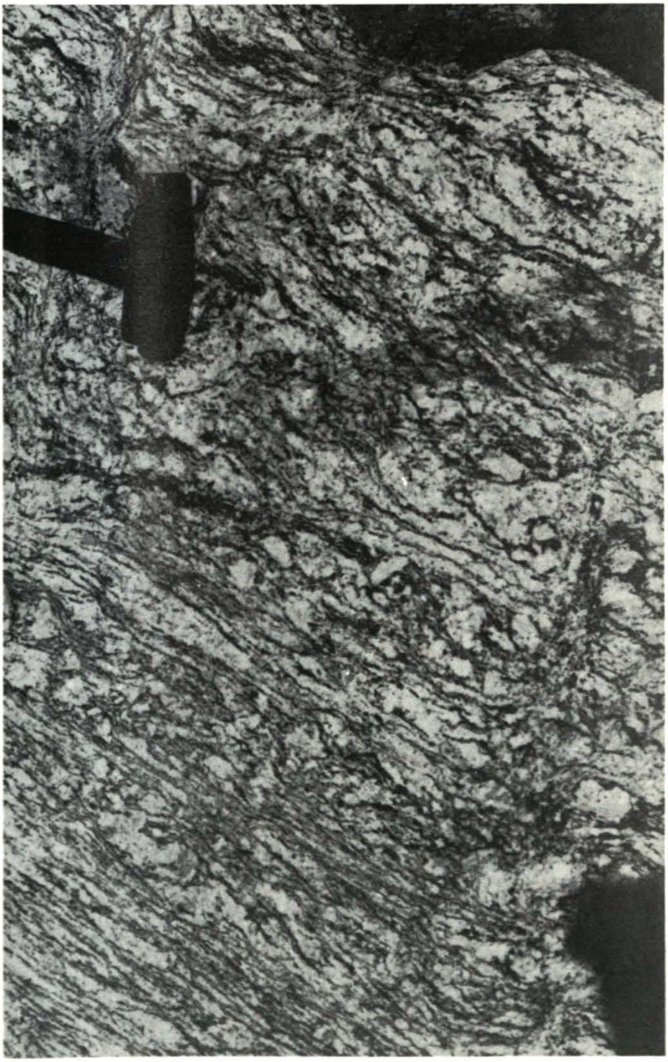


Fig. 4: Nebulitic augengneiss containing pegmatoid lenticles; crystalline of Chamba Synclinorium; west of village Sohal, Chandra Valley, India.

pass into augen granite-gneisses (Fig. 4); these rocks represent an at least somewhat older migmatite complex than the homogeneous, fine- to medium-grained orthogneisses and migmatites which penetrate the above assemblage in a prevailingly concordant way (Fig. 5, 6). Upwards the migmatisation decreases and the higher portions of the Crystalline consist of paragneisses to metagreywackes, quartzites, metasiltstones, phyllites to slates where the succeeding Tibetan Zone commences with argill-aceous-arenaceous series; where the basal sedimentaries are car-

Fig. 5: Fine to medium-grained migmatite encloses relictic layers of coarse-grained, flasery garnet-kyanite paragneiss which obviously is older; at village Sohal, Chandra Valley, India.

bonates, the upper part of the Crystalline is composed of carbonate-gneisses, marbles and calc-micaschists (e.g. Nepal). This and the fact that the metamorphism gradually dies away, are evidence that the basal sedimentary series of the Tibetan Zone have been altered and became part of the Crystalline. From Nepal to Spiti the Early Palaeozoic formations are affected (FUCHS, 1967, 1975, 1977a, 1981b; LE FORT, 1975a, a. o.), whereas in the north-western Himalaya Panjal Traps became amphibolites and the succeeding Triassic carbonates are converted to marble

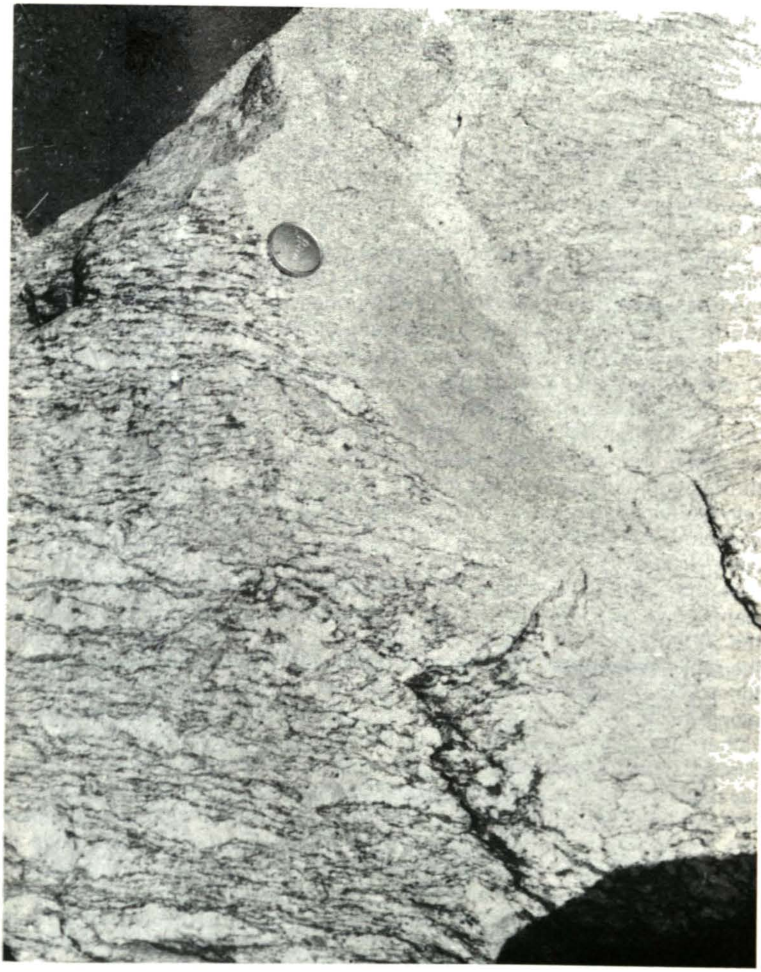


Fig. 6: Coarse-grained augen granite-gneiss is unconformably cut by younger, medium-grained, nebulitic granite-gneiss; Sinja Khola, south of Banjgaon, western Nepal.

(FUCHS, 1977, 1979; HONEGGER et al., 1981). VIRDI et al. (1978) and VIRDI (1981, p. 143) report of Upper Palaeozoic–Triassic sediments altered around the Tso Morari Crystalline, which fits well with GANSSER's observations from similar crystalline uplifts in Tibet (1981, p. 5). Therefore the Crystalline should not be referred to as the „Precambrian basement of the Tibetan Zone". This relation between Crystalline and sedimentaries may be locally disturbed (e.g. Malari Fault, SHAH & SINHA, 1972; GANSSER, 1981, p. 6; BAUD et al., 1982). NANDA & SINGH (1976) refer to a conglomerate at the base of the Zanskar sedimentary sequence which they regard as indicator of a regional gap.

The polymetamorphic nature of the Crystalline postulated by FUCHS (1967) is substantiated now by series of absolute age datings: Precambrian (BHANOT et al., 1977a, b), Assynthian–Caledonian (MEHTA, 1977), Caledonian (FRANK et al., 1976) and Alpine, Oligo–Miocene ages (KRUMMENACHER, 1966 and in BORDET et al., 1971; KRUMMENACHER, et al., 1978; FRANK et al., 1976; MEHTA, 1977, a. o.). Granites intruded predominantly before 500 m.y. and in the Miocene. Unlike the 500 m.y. granites of the Chail Nappes which intruded into a cold environment, the granitoids of this age in the Crystalline are closely connected with migmatisation and show gradational contacts. From this it may be inferred that they took their place during active regional metamorphism.

The Alpine granites are characterised by leucogranitic trends. The granites in the frontal portions of the Upper Crystalline Nappe were generated just beneath the rear M.C.T. and intruded along the foliation planes of the Crystalline Nappe in a late tectonic stage according to ANDRIEUX et al., 1976. Further a series of leucogranites penetrated the rootzone of the Crystalline and the Tibetan Zone (Makalu, Manaslu, Mustang, Mugu, Kamet, etc.) According to LE FORT (1981) the leucogranitic melts are generated in the migmatite complex of the Tibetan Slab; the necessary fluids are produced from the cool sedimentary pile of the Lesser Himalaya overthrust by the hot crystallines; the generated magma extends very far laterally along permeable horizons, later it dissolves the mainly calcareous sedimentaries by means of its rich fluids and thus forms the plutons of the High Himalayas.

In the Central Crystalline the K/Ar ages are growing younger downwards towards the M.C.T. which KRUMMENACHER et al. (1978) explain by the young age of this thrust and by the fact that denudation started from the top, keeping the lower parts of the Crystalline at higher temperatures for a longer time. The Crystalline Nappes are transported to the south along the M.C.T. for a distance of 100 km as shown by the frequent and rather extensive outliers (Crystalline of Kashmir-Chamba Synclinoria, Simla, Chor, Almora, Kathmandu, Darjeeling, of Bhutan- and NEFA Himalayas). Some of these outliers are still connected with the Central Crystalline. On the back of the Upper Crystalline Nappe Tethyan sedimentaries are transported from the Tibetan Zone to the south. The Synclinoria of Kashmir and Chamba, the largest occurrences, represent a facies deposited somewhat south of the present Tibetan Zone. The basal crystallines of the named synclinoria thin out in the frontal parts of the nappe; thus the Kashmir sedimentaries come into tectonic contact with metasediments of the Lesser Himalayan Chail Nappes (Map, section 1). Other occurrences of Tibetan sediments overthrust to the Lesser Himalaya are Jaljala Dhuri (FUCHS & FRANK, 1970), Kathmandu (BORDET et al., 1960), Thang Chu (GANSSER, 1964).

1.6. The Tibetan Zone (s. l.)

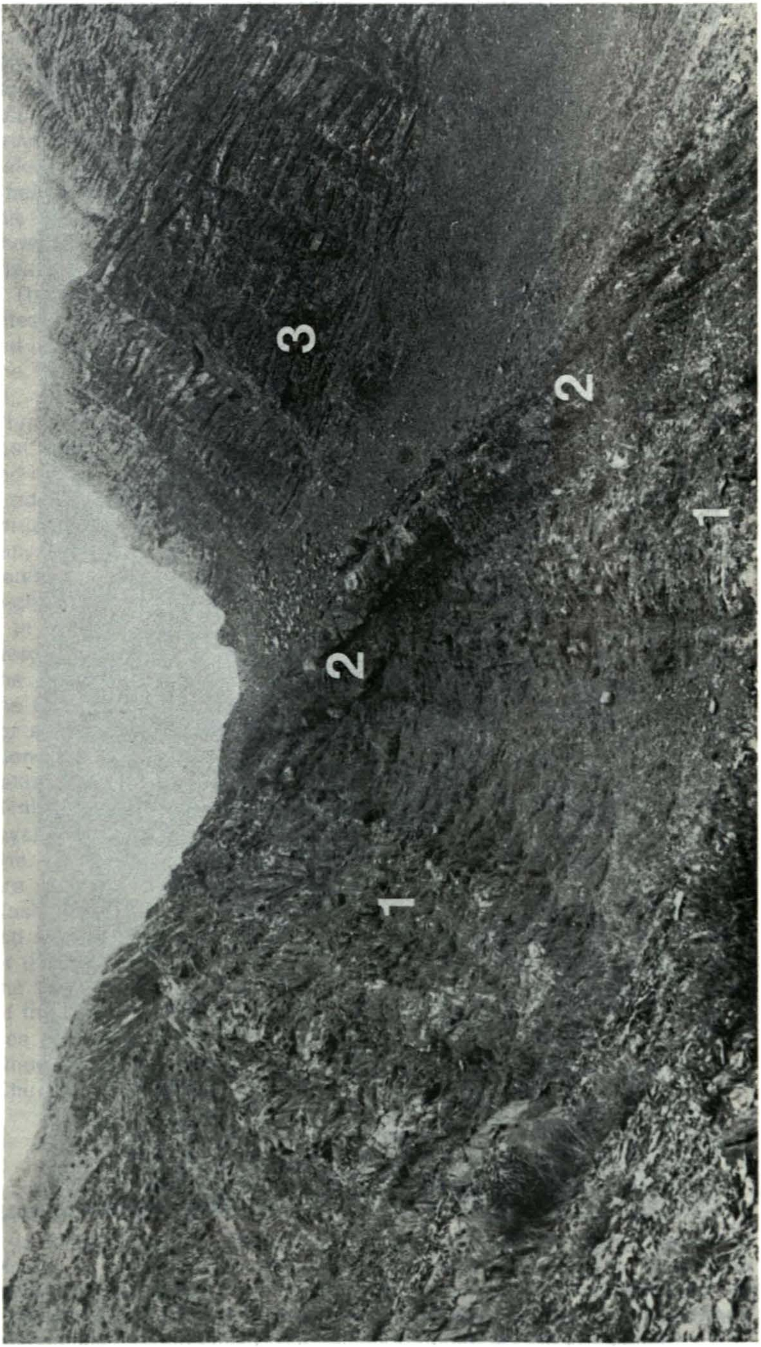
Stratigraphy

In this chapter the Tibetan Zone (s. s.) north of the Great Himalayan Range is dealt with as well as the Kashmir- and Chamba Synclinoria south of this range.

Precambrian – Ordovician: monotonous, frequently rhythmic and flyschoid trough deposits, several thousand meters thick. The Dogra Sla-

Fig. 7: Flute casts in Haimantas of upper Pin Valley, Spiti, India.

tes, Early Palaeozoics of Kashmir, Haimantas (Fig. 7), Martolis, Sangsing La Series represent an argillaceous-arenaceous facies; the Garbyang, Shiala, Dhaulagiri Lms., Larjung Formation and Nilgiri Lms. are composed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of impure carbonates. In Spiti the Haimantas are succeeded by the fossiliferous Middle to Upper(?) Cambrian Parahio Series which is transgressed by the Ordovician basal conglomerate and red quartzites with an angular unconformity (Fig. 8, 9, 10; HAYDEN, 1904; FUCHS, 1981b); the overlying Ordovician – Silurian is composed of arenaceous, silty and carbonate beds.

Silurian (several hundred meters): There is a basin facies consisting of dark shales, siltstones and carbonates yielding graptolites (Kashmir–Spiti, Nilgiri–Annapurna [Nepal]) and a shallow-water facies of red, green, grey shales, marls and limestones (Kumaun, western Dolpo [Nepal]).

Devonian: Three facies may be discerned:

Flyschoid (1000 m) are the Tanols of Kashmir-Chamba, Tilicho Pass Formation (Nepal); according to BORDET et al. (1971) the dark argillites, sandstones and carbonates at the base of the Tilicho Pass Formation (Thakkhola) are already Devonian, a facies observed also further eastwards except in the Nar dome (Bangba Formation, BORDET et al., 1972, 1975).

Carbonate-quartzite: shallow-water facies consisting of grey dolomites, blue limestones and quartzites (Muth Formation, 1000 m, Kumaun, western Dolpo [Nepal]).

The light-coloured Muth Quartzite represents a mainly terrigeneous (plants) facies with rare beds of ferruginous dolomite in the upper part (Kashmir, Spiti–Kumaun).

Lower Carboniferous (250–350 m): dark limestones, argillites and occasional arenites (Syringothyris Lms., Lipak S., Tilicho Lake Formation).

Upper Carboniferous (500–2000 m): argillites, quartzites, conglomerates (Fenestella Shales, lower part of Thini Chu Formation [BORDET et al., 1971, 1975]), partly flyschoid with tillites (Agglomeratic Slates, Po Series, lower parts of Chulu Formation [BORDET et al., 1975]). The basaltic to andesitic Panjal volcanism commences in the Upper Carboniferous and remains active locally up into the Triassic (WADIA, 1934). The volcanics occur in Kashmir, Chamba, Zanskar or even Central Nepal (spilite, LE FORT, 1975b; BORDET et al., 1975).

Permian: Hercynian movements are indicated by a gap below the Agglomeratic Slates of western Kashmir (WADIA, 1934) or beneath the Permian of Spiti, Kumaun and Dolpo (Nepal) where Permian beds transgress even on Lower Palaeozoic formations (Fig. 11). Intercalated or succeeding the Panjal Trap the terrigeneous Gangamopteris Beds indicate Gondwana influence in Kashmir; plant fossils and footprints of tetrapods are also observed in the Thini Chu Formation of Dolpo and BORDET et al. (1971) even report the occurrence of coal. The plant beds interfinger with marine shales, arenites and limestones (Zewan S., Kuling Formation, Thini Chu Formation, 50 – 400 m).

The tilloids of the Lachi Series (WAGER, 1939) seem to be related with the Permian glaciation of the Peninsula and the Lesser Himalaya. They were followed north towards the Tsangpo Suture Zone by CHANG et al. (1977).

Fig. 8: The Ordovician basal conglomerate overlies the Haimantas with angular unconformity. The Haimantas (1) dip north-east with steep to near-vertical angles; the Ordovician conglomerate (2) dips north-east at about 50° and passes upwards into thick quartzite series (3). Ridge 2.3 km south-west of Mud (Muth), Pin Valley.

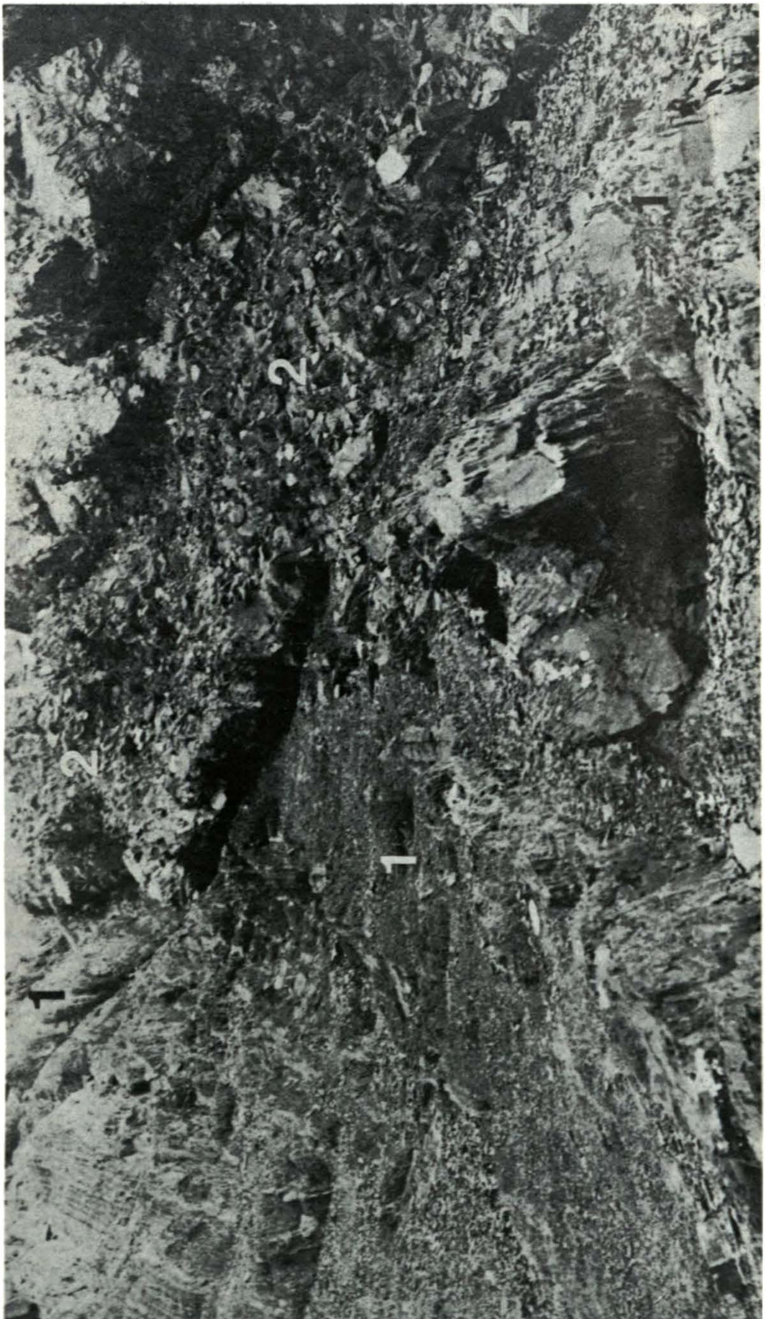
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Fig. 10: The Ordovician conglomerate contains huge boulders derived from the underlying beds (compare to size of rucksack). Faint stratification is developed in finer layers only (near rucksack). Thango, Parahio Valley, Spiti.

Scythian (15–40 m): Well-bedded, dense, grey, blue limestones often rich in ammonites and subordinate grey shales forming a resistant brownish weathering band, a very good marker horizon. The top of this formation, however, comprises Middle Anisian in Dolpo (FUCHS, 1977a, p. 204) and even Lower Ladinian in Spiti (KRYSTYN, pers. comm.).

Anisian–Lower Noric: Dark limestones, marls and shales (in Spiti [< 700 m]: Daonella Sh. [Ladinian], Daonella Lms. [Ladinian–Carnic], Grey Beds and Tropites Lms. [Carnic]; Kalapani Lms. [< 50 m]; Mukut Lms. [< 300 m]). Silty-arenaceous intercalations are rare (e. g. Kashmir, in the Tropites Lms. of Spiti).

Noric: a thick (< 800 m) alternation of dolomites, limestones and shales in Kashmir-Zanskar which also comprises lower stages of the Triassic; silty and sandy shales with layers and intercalations of limestone (< 500 m, Juvavites-, Monotis Beds of Spiti; Kuti Shales of Kumaun); flyschoid shales and siltstones (< 500 m, Tarap Sh. of Dolpo, Fig. 12).

Rhaetic–Dogger (a 300–700 m shallow-water sequence): The Quartzite Beds consist of white, green, brown quartzites, carbonate quartzites, grey, blue carbonates and subordinate shales; they pass upwards into the Kioto Lms. composed of thick-bedded limestones and dolomites (Rhaetic–Lower Dogger); passage into Lumachelle Formation (Bajocian–Bathonian consisting of thin-bedded blue limestones, marls, shales and subordinate sandstones; the Laptal Series (Kumaun) rather corresponds to the Dogger Lumachelle Fn. than to the Lias. Callovian blue, impure limestone succeeds after a gap (Sulcacutus Beds a few meters).

Malm–Neocomian: The Spiti Shales (< 100 m) consist of dark shales and siltstones overlain by the Giumal Sandstone – a series of green, grey, brown quartzites, sandstones and green and black argillites

Fig. 9: Detail of Fig. 8 showing the angular unconformity between the Cambrian beds (1) and the transgressing Ordovician conglomerate (2).

Fig. 11: Horizontal dolomite beds of Muth Formation (Devonian) unconformably overlain by quartzite of Thini Chu Formation (Permian). The quartzite fills pockets in the dolomite and contains fragments of the latter; burrows are visible above the hammer; west of the bridge, east Phophagaon, Dolpo, western Nepal.

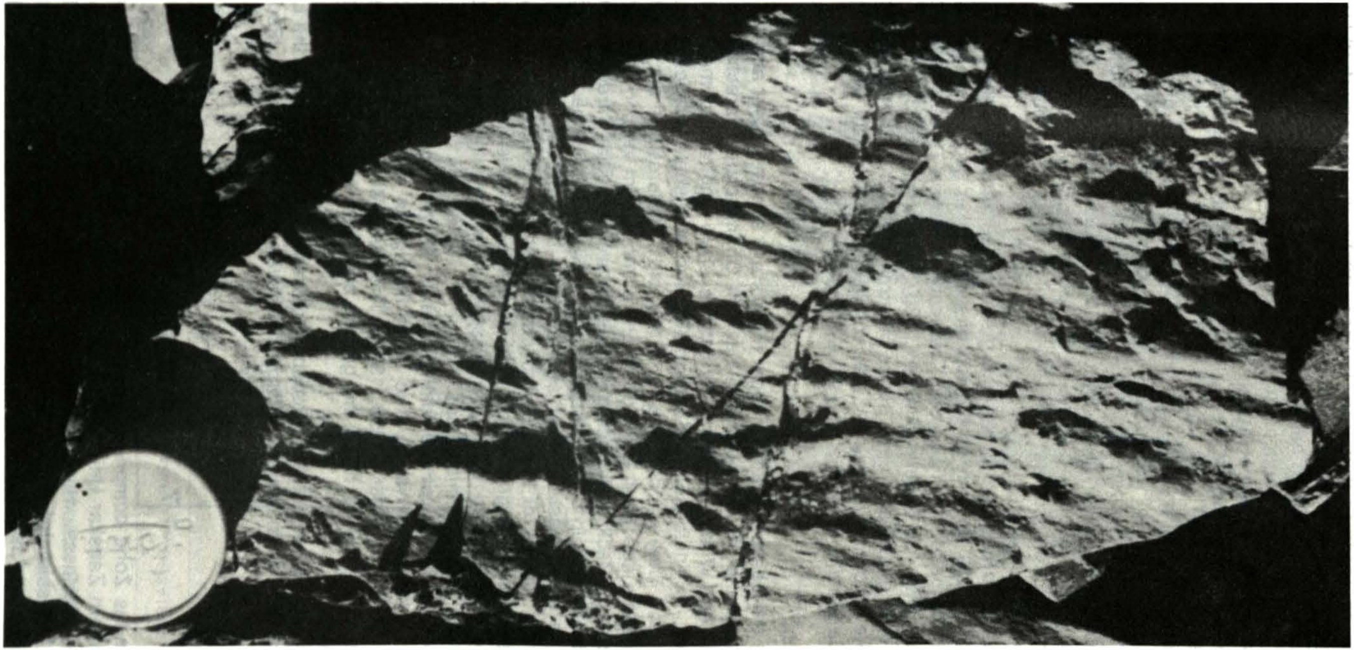

Fig. 12: Flute casts and hieroglyphs on the s-plane of siltstone of Tarap Shales; uppermost Nadadu Khola, Dolpo, western Nepal.

(150–500 m). BORDET et al. (1971, 1972) record of 100–150 m of continental plant bearing sandstones at the base of their green sandstones (Lower Aptian); both together probably represent the Giumal Sandstone. The top of the Nepal sequence consists of light-coloured limestones and marly sandstones of Upper Aptian age (300 m).

Cenomanian–Campanian: light grey pelagic limestones (Chikkim Lms., 30–50 m).

Campanian–Lower Maestrichtian: Kangi La Flysch of south-west Zanskar consisting of grey-green, ochre weathering slates, silty slates, marls and impure sandstones (400–600 m); Chikkim Shales (50 m exposed); subdivision a) of Upper Flysch (HEIM & GANSSER, 1939, p. 147).

Upper Maestrichtian–Upper Paleocene: grey, blue, thick-bedded benthonic limestones of south-west Zanskar (Spanboth Lms., ≈ 300 m, GAETANI et al., 1980).

Eocene: unfossiliferous red and green slates and siltstones (Chulung La Sl., 200–400 m) forming the top of the Zanskar succession probably represent Eocene. In Tibet the Cretaceous–Lower Tertiary sequence ends also with the Eocene (HAYDEN, 1907; MU et al., 1973).

Miocene granites form a series of intrusions in the Tibetan Zone affecting the adjoining formations with contact metamorphism (e. g. Mugu, Kamet-Badrinath, Mustang, Manaslu, Makalu).

Tectonics

Unlike the Lesser Himalaya larger thrusts are almost absent and the Tibetan Zone and the Synclinoria of Kashmir Chamba are characterised by open folding. Where adjoining formations show contrasting mechanical properties, for instance rigid carbonates and soft shales, reverse faults are frequent. They are combined with the fold structures and are obviously of the same age. Both show directions of movement varying south-west or north-east. Back folds facing north-east are particularly frequent near the southern margin of the Tibetan Zone in Nepal (Kanjiroba, Dhaulagiri, Nilgiri). In south-west Zanskar and Kumaun the vergency is altogether south-west; further for Kumaun imbrications directed south-west are typical. The uniform vergency observed in these areas is exceptional and probably was caused by higher nappes overriding the Tibetan Zone (Spongtang, Kiogar-Amlang La).

Transverse faults cut the fold structures of the Tibetan Zone in the Thakkhola (northern Nepal). The down through in the Thakkola graben may be 3000 m (HAGEN, 1959, 1968). The thick Mio–Pliocene deposits (BORDET et al., 1971) filling the graben are tilted by still younger fault movements.

A major traverse structure probably crosses all the zones from the Lesser Himalaya north towards Kargil (Kishtwar–Kargil lineament, FUCHS, 1982).

1.7. The Indus Zone (s. l.)

The Indus Zone comprises several tectonic units from south to north: the Northern Zanskar Unit, Lamayuru Unit, Dras Unit (plus Indus Flysch) and Indus Molasse, which transgresses on the Ladakh Batholith building up the Transhimalaya. The named units, very distinct from each other, are generally separated by ophiolitic melanges. Ultramafic rocks are typi-

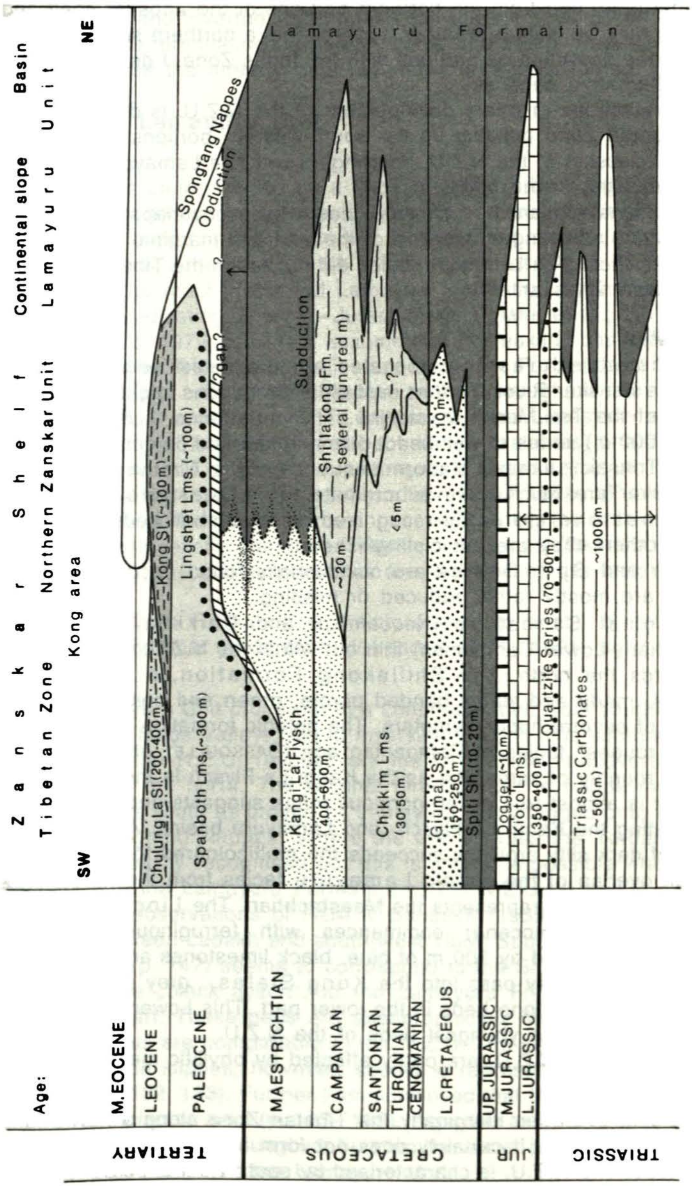

Fig. 13: Facies scheme of the Mesozoic succession of Zanskar.

cal for the Indus Zone and may form large thrust sheets. Repeatedly the great importance of the Indus Suture Zone was stressed by GANSSER (1964, 1974, 1980a, b, c, 1981).

1.7.1. The Northern Zanskar Unit (N.Z.U.)

The unit is formed from the northern portions of the Zanskar shelf and thus there may be dispute whether it represents a northern subunit of the Tibetan Zone or should be grouped with the Indus Zone. I decided on the second alternative because:

1) The Cretaceous–Tertiary development of the N.Z.U. is different from the Tibetan Zone building up the south-western portions of Zanskar.
2) The succession of the N.Z.U. interfingers with the Lamayuru basin facies adjoining in the north.
3) In the Maestrichtian the Lamayuru basin facies overlaps the area of the N.Z.U. indicating subduction of the northern marginal parts of the Zanskar shelf. The Lamayuru facies did not reach the Tibetan Zone of south-west Zanskar.

Stratigraphy

The Triassic–Jurassic carbonates are the oldest series exposed west of the Zanskar River. Further east older formations might crop out in the uplift of the Tso Morari Crystalline. The carbonates, a monotonous, thick (≈ 1000 m) series of well-bedded limestones and dolomites, is similar to the Triassic–Jurassic platform sequence of the Tibetan Zone, argillites however are much more subordinate. The Quartzite Beds and Kioto Limestone are easily recognised by their shell beds in certain areas, in others they are not distinguished.

Dogger and Spiti Shales are occasionally found (e. g. Honupatta area) but are mostly rather reduced or missing.

The Giumal Sandstone (Neocomian) and Chikkim Limestone (Cenomanian–Lower Campanian) thin out within the N.Z.U. to a few meters towards the north. The Shillakong Formation, a sequence of limestones, marls and slates banded purple, green and beige, attains a thickness of several hundred meters. The pelagic formation represents a „couches rouges“ facies of Campanian age (Bassoullet et al., 1978b). Thus it is roughly of same age as the Kangi La Flysch in the south. The fact that it is almost free of terrigeneous influx suggests deposition on a sill separating the Kangi La Flysch- and Lamayuru basins. A thick development of dark silty argillites succeeds the multicoloured formation indicating an overlap of the euxinic Lamayuru facies from the north. This Lamayuru Formation represents the Maestrichtian. The Lingshet Limestone (Upper Paleocene) commences with ferruginous quartzites (20–40 m) succeeded by 100 m of blue, black limestones and light dolomitic limestones. They pass into the Kong Slates, grey slates with a few nummulitic limestone beds in the lower part. This Lower Eocene formation represents the youngest beds of the N.Z.U.

The rocks of the N.Z.U. are partly affected by phyllitic metamorphism.

Tectonics

The N.Z.U. overrides marginally the Tibetan Zone along a north-east-dipping reverse fault. It certainly does not form a nappe but it is parautochthonous. The N.Z.U. is characterised by south-west-directed isoclinal folding, showing that the intensity of deformation was stronger than in the Tibetan Zone. This is due to the overthrust Spongtang Nappes. Under their influence the Cretaceous–Early Tertiary sequence of the N.Z.U. was sheared off from the Triassic–Jurassic carbonates and was enriched in the south-west (Map, section 1). Compression after the nappe movements produced the fan–shaped steeply folded Honupatta Anticlinorium (KELEMEN & SONNENFELD, 1981) between the Spongtang Outlier and the tightly compressed and inverted root zone. Then the south-west and north-east facing thrusts terminating the N.Z.U. came into being (FUCHS, 1982b). In a latest phase the already dead counterthrusts were folded.

1.7.2. The Lamayuru Unit

Stratigraphy

The unit is characterised by a thick complex of dark argillites alternating with silt- and sandstones or blue marls and limestones. Parts of this Lamayuru Formation are distinctly flyschoid but others remind of the Triassic Mukut Limestone of the Tibetan Zone of Dolpo (FUCHS, 1967; 1977a). In the much deformed Lamayuru Formation occasionally fossils were found indicating Triassic–Jurassic age (FRANK et al., 1977, p. 101; FUCHS, 1977b; 1979, p. 517). I assume that this euxinic basin facies comprises also Maestrichtian parts like the Lamayuru Formation of the N.Z.U. and thus has a stratigraphic range almost throughout the Mesozoic. Within the dark argillites we find klippes of Kioto Limestone and Shillakong Formation. They slumped into the basin (olistolites) or are interstratified as grainstone or grain flow sediments (BASSOULLET et al., 1981) proving an interfingering of the platform and basin facies (FUCHS, 1977b; 1979). Close to the ophiolitic melanges, terminating the unit in the south and the north, exotic Permian–Triassic limestones (BASSOULLET et al., 1978c), quartzites and serpentinites are found which are tectonically emplaced.

The Lamayuru Formation is mainly altered to anchi- or even greenschist metamorphic grade (see HONEGGER et al., 1981, fig. 14).

Tectonics

The Lamayuru Unit crops out in a continuous belt from south-east Dras to the upper Indus Valley. Due to inversion the unit dips south and southwest under the N.Z.U. respectively the Crystalline and overthrusts the Dras Unit in the north. The original direction of the nappe movements, however, was south as proved by Lamayuru Unit dragged onto the N.Z.U. by the Spongtang Nappes. Where the unit overlies the Tertiaries of the N.Z.U. it is easily recognised but this is almost impossible where it is in contact with the Lamayuru Formation of the N.Z.U.

From the observations of HEIM & GANSSER (1939) much resemblence appears between Ladakh and south-west Tibet: Subdivision b) of the „Upper Flysch" (p. 147) seems to correspond to the Shillakong Fn. (Campanian), c), the „black flysch", to the Lamayuru Fn. – probably its Maestrichtian part. These beds are stratigraphically linked with the Tibetan Zone and thus are comparable to the N.Z.U. The black flysch associated with limestone klippes, however, seems to represent the Lamayuru Unit (p. 163, fig. 132, 133). Further I am convinced that the black argillite complex of Shinglaptsa area (p. 167–168), regarded as Spiti Shales by GANSSER, and the shales of Jungbwa building the upper part of the Raksas Series (p. 169) represent the Lamayuru Unit.

In a 1981 paper on Tibet in the meridian of Lhasa GANSSER mentions Triassic–Jurassic flysch resembling the Lamayuru flysch and in similar position. There are also some imbrications of pink *Globotruncana* limestones which in my view correspond to the Shillakong Fn. of Zanskar. Thus the great regional importance of the Lamayuru Unit seems to be proved.

1.7.3. The Dras Unit and Indus Flysch

Stratigraphy

North of the Lamayuru belt there is a prominent zone composed of basaltic and subordinate andesitic-dacitic lavas and pyroclastics – the Dras Volcanics (WADIA, 1937) which become partly replaced by Cretaceous flysch towards the south-east (GANSSER, 1976). There are also some minor intrusions of various composition in the volcanic series. The flysch consists of grey-green breccias, sandstones, siltstones, green, grey and purple slates, tuffitic rocks and radiolarian cherts. The ophiolitic melanges, which separate the Dras Unit from adjoining tectonic units contain radiolarites, serpentinites and klippes of various exotic limestones in a flysch-volcanic matrix. But in certain sections (e. g. southern portion of the Spongtang Outlier) the flysch itself is full of exotic limestones in cm- to km-dimensions. Such olistolitic parts of the flysch form a huge breccia of „wildflysch" type (KELEMEN & SONNENFELD, 1981; FUCHS, 1982). There are also grey, cream and red marls and limestones interbedded with the flysch. The Khalsi Limestone, a grey to blue fossiliferous limestone of Mid-Cretaceous age (see GUPTA & KUMAR, 1975) is interstratified with the Indus Flysch and contemporaneous volcanic beds (FUCHS, 1979).

Upper Jurassic radiolarians (HONEGGER et al., 1981), Mid-Cretaceous to Maestrichtian foraminiferas from interstratified carbonates (VIRDI, 1981; FUCHS, 1982), the Khalsi Limestone and age datings of the Dras Volcanics (SHARMA et al., 1978: 77,5±1 m.y.) indicate an Upper Jurassic–Upper Cretaceous (Early Tertiary?) age of the Flysch-Dras Volcanics complex.

SRIKANTIA & RAZDAN (1980) subdivide the Dras Unit (their „Sangeluma Group") into four formations in upright sequence. Their age, partly determined by indirect evidence, ranges from Cenomanian to post-Eocene. If we consider the intense internal deformation – these authors also admit that the contacts of their formations are frequently tectonic (p. 530) – and the total inversion of the Indus Zone, some doubt regarding this subdivision and the age of formations seems advisable.

The rocks of the Dras Unit show alteration up to the grade of greenschist facies; in the ophiolitic melanges blueschist metamorphism is observed (FRANK et al., 1977, p. 194; KUMAR, 1978; VIRDI, 1981; DESIO & SHAMS, 1980; BARD et al., 1980).

The Dras Volcanics are regarded as formed in an island arc (FRANK et al., 1977; KLOOTWIJK et al., 1979; ANDREWS-SPEED & BROOKFIELD, 1982; KELEMEN & SONNENFELD, 1981; a. o.). This is substantiated by petrochemical investigations by HONEGGER et al. (1981). According to these authors the basic lavas of the Rusi La area (south of Kargil) are quite distinct from Dras Volcanics by their alkaline character typical of oceanic islands. From their association with green and purple flysch and cherty limestone I took the series as Dras Volcanics, definitely not as Lamayuru Unit as HONEGGER et al. Accepting the petrochemical discrimination I regard it an individual unit, the Rusi La Zone, having a position between the Lamayuru Unit and Dras Unit. After this experience it is quite possible that uppermost parts of the Dras Unit further east might turn out to correspond with the Rusi La Zone on petrochemical evidence.

Tectonics

GANSSER (1976) and FUCHS (1977b; 1979) distinguished a southern Dras Volcanics-Flysch unit from the Indus Flysch s. s. in the north, two units separated by an ophiolitic melange zone in the Khalsi area. It is questionable, however, how far distinction can be made outside of the named area and thus both are regarded now as one major unit, the Dras Unit. This unit is intensely folded and sheared in the root zone. Terminated by ophiolitic melanges the Dras Unit dips beneath the Lamayuru Unit in the south and overthrusts the Indus Molasse in the north. This sequence is inverse as shown by the Spongtang Klippe, where the original succession is preserved: N.Z.U. – Lamayuru Unit – Dras Unit – Peridotite mass (in ascending order).

In south-west Tibet (HEIM & GANSSER, 1939) the basic igneous rocks, associated flysch and exotic Permian to Liassic Klippes, which GANSSER (1974) termed the Kiogar Nappe have a position like the Dras Unit of Ladakh: above the „black flysch" (= Lamayuru Unit) and below the ultramafic mass of the Jungbwa Nappe. As in Ladakh ophiolitic melanges separate these units.

The continuation of the Dras Unit towards the west is the basic rock complex of Kohistan, north of the Kohistan Line (DESIO, 1979; DESIO & SHAMS, 1980) or Main Mantle Thrust (M.M.T.) as called by TAHIRKHELI et al. (1979). Particularly the Utror Volcanics (BARD et al., 1980) are correlative to the Dras Volcanics. BARD et al. (1980) describe the Kohistan sequence as a unique example of an island arc exposed in a complete section up from the mantle. Therefore we find large intrusive complexes affected by two pyroxene granulite metamorphism which are not exposed in the eastern continuation of the belt in Ladakh. COWARD et al. (1982) show that the section is the product of polyphase tectonics. After the obduction of the island arc onto the Indian Plate along the M.M.T. the Kohistan sequence was tightly folded and partly overturned. Obviously this folding phase was the same which led to the complete inversion of the Indus Suture Zone and to the formation of the counterthrusts.

1.7.4. The Peridotites and Ophiolitic Melanges

The highest parts of the Spongtang Outlier consist of ultramafic rocks (FUCHS, 1977b; 1979; 1982; BASSOULLET et al., 1978a; 1980a). Harzburgites predominate but there are also dunites, pyroxenites, gabbros, dioritic and diabase dikes etc. which were studied by BASSOULLET et al. (1980), KELEMEN & SONNENFELD (1981) and HONEGGER et al (1981). The ultramafics of Spongtang are derived either from the ophiolitic melange zone within the Dras Unit (S of Khalsi) or from the melange zone which terminates that unit against the Indus Molasse. The thrust distance is about 30 km. GANSSER found similar but more extensive masses of peridotites in south-west Tibet (HEIM & GANSSER, 1939; GANSSER, 1964; 1976). This Jungbwa Nappe is derived from the Indus Suture Zone in the north, which proves a displacement of at least 80 km.

The ophiolitic melanges (GANSSER, 1974) mark very much tectonised zones separating the stratigraphic-structural units of the Indus Suture Zone. They consist of lenticular bodies of ultrabasic, mostly serpentinised rocks, basaltic lavas and pyroclastics, gabbros, ophicalcite, radiolarites, quartzites and exotic Permian–Mesozoic carbonates in a flysch-volcanic matrix. GANSSER (1974) explains these zones as produced by the obduction of the oceanic crust of basins which were obliterated during the collision and subduction of continents.

GANSSER (1981) crossed the Suture Zone further east in the Tsangpō Valley (Shigatse area) and found ophiolitic melanges of similar composition and slabs of ultramafic rocks.

From the structures of the rock series surrounding the Spongtang Outlier I deduce that previously its extent was not much larger (1982). Thus the analogous ultrabasic masses of Spongtang and south-west Tibet rather form slivers squeezed out from the Suture Zone than representing a continuous thrust sheet. In the case that a thrust sheet continuous from south-west Tibet to Spongtang was eroded away, the peridotites should dominate in the pebble spectra of the Indus Molasse and Quaternary deposits, which is not substantiated.

1.7.5. The Indus Molasse

A. P. TEWARI (1964) discerned between the flysch-volcanic complex and the continental molasse sediments north thereof, which he termed the Ladakh Molasse and compared with the Kailas Molasse (HEIM & GANSSER, 1939). Today the name Indus Molasse is in common use. The latter is overthrust by the Dras Volcanics and Flysch from the south. In the north it transgresses on the Ladakh Intrusives.

The Indus Molasse is mainly composed of thick-bedded conglomerates, pebbly sandstones and silty shales exhibiting bright colours purple, green and beige. Occasional coaly seams in the middle portion of the molasse stress the continental character (FRANK et al., 1977). However there are flyschoid portions too (SRIKANTIA & RAZDAN, 1979; 1980; BROOKFIELD, 1981). BROOKFIELD's Eocene flysch is interbedded with thin nummulitic limestones proving a marine environment; this stage is succeeded unconformably by the typical continental series. I explain this by the fact that in its earlier stages central parts of the molasse basin still were reached by marine ingressions; after a younger tectonic phase the sedimentation became of molasse type all over the basin.

Regarding the age of the Indus Molasse following facts must be considered: LYDEKKER (1883), DAINELLI (1934), SRIKANTIA & RAZDAN (1980), BROOKFIELD (1981) report on Eocene beds within the Indus Molasse. Limestone pebbles in the conglomerates are of Lower Eocene, Paleocene or Upper Cretaceous age (FRANK et al., 1977). The Indus Molasse transgresses on the Dras Volcanics and reworks this series south of Kargil (FUCHS, 1981a; 1982); in the north it overlies unconformably the Ladakh Intrusives from which most of its pebble content is derived (TEWARI, 1964; GANSSER, 1976 a. o.). The age of these intrusives ranges from Cretaceous to Oligocene (see below). TEWARI (1964) based on his studies and considering the scanty fossil references, comes to the result that the molasse is post-Eocene, possibly post-Middle-Miocene. GUPTA & KUMAR (1975, p. 556) also review the fossil references and support Oligo-Miocene age.

The above facts and arguments suggest an Eocene to Miocene age of the Indus Molasse. In my view the molasse deposition was initiated by the post-LowerEocene nappe tectonics of the Indus–Zanskar region and lasted into the Miocene. The renewed compression leading to the formation of the Lesser Himalayan nappes in the post-Lower Miocene probably put an end to the molasse sedimentation of Ladakh. The Indus Molasse was overthrust by the Dras Unit and is locally imbricated with it; the molasse was folded and wedge structures formed. The vergency of these movements is north-east, north or west-north-west (south of Kargil). According to my view Flysch-Dras Volcanics Unit and the Indus Molasse represent two successive stages of the Indus Suture Zone and did not form contemporaneously in two parallel troughs as proposed by SRIKANTIA & RAZDAN (1979, 1980).

In south-west Tibet the Kailas Molasse, 4000 m thick, transgresses on the Transhimalayan Pluton in the north and is overridden by the flysch along the counterthrust (HEIM & GANSSER, 1939; GANSSER, 1964; 1976; 1980, etc.). This and the pebble content resemble the Indus Molasse very much.

In a recent paper GANSSER (1981a, p. 4) records about conglomeratic molasse in similar position but interfingering with black shales yielding an Upper Cretaceous ammonite fauna. It appears that in the Shigatse region the molasse sedimentation started earlier, when there was still deposition in Lamayuru facies.

1.7.6. The Transhimalayan Plutons

The Indus Suture Zone or Peri-Indian Suture Zone as termed by GANSSER (1980b) is accompanied in the north by a batholithic belt 30–50 km wide. This belt comprises magmatites of Kohistan, the Ladakh- and Transhimalayan Intrusives and the Kangdese belt of the Chinese geologists (ref. GANSSER, 1981). The batholith belt is composed of olivine norites, gabbros, diorites, tonalites, granodiorites and granites. According to HONEGGER et al. (1981) the mafic intrusives are estimated 10–20%, the intermediate rocks 20–30% and the granodioritic types 50%. Oceanic crust subducted along the Indus Suture is regarded as the source of these magmatites (FRANK et al., 1977).

Regarding the age of the intrusives it is of interest that HONEGGER et al. (1981) interprete their U/Pb results of 103±3 m.y. as the formation of the magma; the Somau granodiorite gave an intrusion age of 80±3 m.y., the granite of Shey Gompa of 60±10 m.y. Age determinations referred by KLOOTWIJK et al. (1979, p. 51) group around 49–45 m.y. BROOKFIELD & REYNOLDS (1981b) measured mineral ages of 42 and 39 m.y. from a dacite dike respectively a hornblende biotite granodiorite. SHARMA et al. (1978) obtained an age of 27.8±0.6 m.y. (Upper Oligocene) by K/Ar whole rock method for a porphyritic granite in the core of the Ladakh batholith. The Kailas intrusives and volcanics gave a well-defined isochrone of 38.8±2 m.y. according to HONEGGER et al. (1981). Thus it appears that the magma formation started in the Upper Cretaceous, the composite intrusion ranges from Upper Cretaceous to Upper Oligocene.

In the north the Ladakh Intrusives are succeeded by volcanics (and volcanosedimentary rocks) of basaltic to rhyolitic composition named the Shyok Volcanics by SHARMA & GUPTA (1978). The volcanics and Ladakh Intrusive rocks are overthrust along the NE-dipping Nubra-Shyok Thrust by granite and their metamorphic host rocks belonging to the Karakorum system. Small bodies of sheared serpentinites occur along this tectonic plane, which according to GANSSER (1980c) represents the Northern Suture Zone (N.S.Z.). The Peri-Indian Suture Zone splits off into the Southern Suture Zone of Ladakh (S.S.Z.) and the N.S.Z. – the boundary to the Karakorum. North of the Nanga Parbat – Haramosh spur these suture zones come close together and then separate again bordering the Kohistan sequence in the south and the north.

2. Evolution of the Himalaya

After the brief description of the Himalayan units I try to develop a picture of the evolution of the mountain belt in three steps. The first part dealing with the Precambrian–Palaeozoic history contains several unsettled problems and the views of workers are rather divergent. In the second and third parts presenting the Mesozoic evolution and Alpine orogenesis it is easier to combine prevalent views.

2.1. The Pre-Mesozoic Development

Today a view adopted by many workers (e. g. GANSSER, FRANK, STÖCKLIN, VALDIYA, a. o.) is that the Indian Shield with its basement and Precambrian–Early Palaeozoic sedimentary series (Vindhyans) extends into the Lesser Himalaya. The facies of the Chandpur–Krol (Shali) sequence (red quartzites, tillites, algal dolomites), frequent and determinable stromatolites (VALDIYA, 1969; SINHA, 1977 a. o.) in otherwise almost non-fossiliferous series and the passage from the Simla Slates into the Blaini Boulder Bed of Simla are regarded as proof for Precambrian–Early Palaeozoic age. Strong arguments are Precambrian radiometric ages of certain granitoids of the Chail complex (FRANK et al., 1976; KRUMMENACHER in BORDET et al., 1971; KRUMMENACHER et al., 1978 a. o.) and the Cambrian fossils in the Hazira Formation of Hazara which implies an older age of the underlying Sirban (Shali) Dolomite (FUCHS & MOSTLER, 1972). Recently AZMI et al., (1981) report Cambro–Ordovician conodonts from the Tal phosphorites of Mussoorie which means that the underlying Chandpur-Krol succession is older. Further the north-east–south-west-structures, not rare in the Lesser Himalaya particularly in the Chail Nappes, are taken as remnants of the ancient Aravalli strike. Very few transgressions reached the Lesser Himalaya (marine beds interbedded with Damudas, Upper Palaeozoics of Lansdowne area, Tals [?], Early Tertiary). The northern margins of the Indian continent are covered by Palaeo-Mesozoic platform sediments of the Tibetan Zone (GANSSER; COLCHEN, 1975; LE FORT, 1975a). Geosynclinal conditions appear only north thereof in the Indus Zone. Since the Precambrian no orogeny disturbed the Himalayan region till the Cretaceous–Tertiary revolution.

In the above hypothesis it is not considered that Late Precambrian-Early Palaeozoic typical geosynclinal formations are found throughout the Himalayas but are unknown from the Peninsular area. Simla Slates (VALDIYA, 1970; RUPKE, 1974) Hazara Slates (FUCHS, 1975), Attock Slates, Dogra Slates, Haimantas, Martolis, Garbyang, Dhaulagiri-Nilgiri Limestone (FUCHS & FRANK, 1970) etc. all are of enormous thickness, rather monotonous and show rhythmic bedding; all are indicative of sedimentation in rapidly subsiding troughs, in some of them subsidence was balanced by sediment accumulation and the deposition remained in shallow water (e. g. Dhaulagiri Lms.) but most of them exhibit distinct flysch features (Fig. 1, 7). From the extent of these formations it is evident that a Late Precambrian–Early Palaeozoic geosyncline did exist along the northern margin of the Indian Shield parallel to the present Himalaya (FUCHS, 1967; VALDIYA, 1970).

A marked change in the conditions of sedimentation indicates the end of this geosynclinal period: Ordovician conglomerates transgress with an angular unconformity on Middle Cambrian or older beds of Spiti (HAYDEN, 1904; FUCHS, 1981b; Fig. 8–10). With the Silurian and particularly the Devonian the sedimentation becomes diversified: Silurian multicoloured shallow-water facies – dark graptolite facies; Muth Quartzite – Muth carbonates (FUCHS, 1977a) – Tanols – Tilicho Pass Fn. (flysch). The Upper Carboniferous Agglomeratic Slates transgress on Lower Palaeozoics of Kashmir (WADIA, 1934). Most of the granitoids of the Chail complex and Central Crystalline gave radiometric ages grouping around 500 m.y. (JAEGER et al., 1971; FRANK et al., 1976; MEHTA, 1977 a. o.). Thus a Caledonian event in Cambrian to Lower Devonian times is proved.

After this event the sedimentation was mainly of platform type in the Tibetan Zone but with many exceptions: Flyschoid formations are the Devonian Tilicho Pass Fn. (Nepal), the Tanol-Agglomeratic Slate sequence of Kashmir, the slate complex underlying the Agglomeratic Slate (Manjir Congl.) of Chamba. It is of palaeogeographic significance that the Middle to Upper Palaeozoics of Kashmir – Chamba and the Tibetan Zone situated in the north, clearly show deepening towards the south.

The facies pattern of the Lesser Himalaya indicates sills and basins parallel to the present Himalayan strike (FUCHS & FRANK, 1970). The thickness of the shallow-water formations there is considerable suggesting that strong subsidence of the basin was balanced by sedimentation.

Regarding the age of the Lesser Himalayan succession FUCHS (1967; 1975 etc.), PANDE & SAXENA (1968), SAXENA (1981), JAIN (1981) a. o. hold the view that it is mainly Palaeozoic deposited in a continental basin, which was separated from the Tethys by a barrier formed during Caledonian orogeny. Arguments are:

1) It is suggestive to compare the geosynclinal formations at the base of the Palaeozoics of the Tibetan Zone with similar ones underlying the Lesser Himalayan sequence.
2) The Chandpurs – Chails (Berinag) – Tanols resemble the Muth Quartzite – Tanols of Kashmir – Chamba dated Mid-Palaeozoic.
3) The Tanols interfinger with Siluro–Devonian beds of Swabi-Nowshera and are succeeded by the Tanakki (Blaini) - Sirban (Shali) sequence in Hazara (FUCHS, 1975).
4) The non-fossiliferous Blaini and Tanakki Boulder Beds are correlated to glacial beds of neighbouring areas, all being Upper Palaeozoic (FUCHS, 1975; JAIN, 1981): the Talchir of the Salt Range, Damudas, Agglomeratic Slates, Po Series, Chulu Fn. (BORDET et al., 1975), Lachi Series (WAGER, 1939).
5) The Blaini-Krol sequence resembles lithologically to the Talchir-Productus Lms. succession of the Salt Range.
6) Though the Damudas (Permian) of the eastern Himalaya are always younger than the Baxa (Shali) they are closely connected and no major gap is to be assumed (ACHARYYA et al., 1975; RAINA, 1976).
7) BASHYAL (1980) describes plant bearing Damudas influenced by contemporaneous trachyte-keratophyre volcanism and a glacio-marine pebbly shale from south-east Nepal. These Gondwana series contain as youngest member stromatolitic dolomite (= Shali type) with gradational contact to the underlying plant bearing beds.
8) GUPTA & VIRDI (1978) review all the fossil finds reported from the Lesser Himalayan succession; some of them seem anorganic or doubtful,

the rest is evidence against Precambrian age.

9) Recently ASHGIREI et al. (1981) discovered doubtless Lower Carboniferous spores in the Chail Formation of Himachal Pradesh, which is in accordance with finds in Nepal (FUCHS & FRANK, 1970, p. 43).

In view of these arguments I still favour a Palaeozoic age of the Lesser Himalayan succession. The Cambrian fossils (FUCHS & MOSTLER, 1972; AZMI et al., 1981), inconsistent with this hypothesis might be redeposited; the Precambrian ages of Chail rocks are partly due to detrital micas (see KRUMMENACHER in BORDET et al., 1971; KRUMMENACHER et al., 1978), the old (1840 ±70 m.y.) granitoids (FRANK et al., 1976) may represent slices of the ancient basement on which the Chails were deposited. Anyhow the stratigraphic range of the Chails is considerable, at least Cambrian to Carboniferous.

The above discussion, however, shows that the age problem of the Lesser Himalaya is full of inconsistencies and far from being settled.

Hercynian disturbances too are indicated in the Himalaya: In the Tibetan Zone Middle to Upper Palaeozoic formations are occasionally missing and the Permian transgresses on various older beds (e. g. Spiti, Kumaun, western Dolpo [Nepal], Fig. 11). In Spiti the Permian overlaps both Muth Quartzite and Silurian beds, which are faulted. Some of these faults end at the Permian transgression plane and are obviously pre-Permian, others are rejuvenated (FUCHS, 1981b). Further the extrusions of the Panjal Trap suggest a Hercynian disturbance. The movements probably were of epirogenic type or related with rifting (STÖCKLIN, 1980; ANDREWS-SPEED & BROOKFIELD, 1982). These movements enabled a certain exchange between the Tethys and the Lesser Himalayan Basin (SAXENA, 1981). Glacial and Gondwana beds reached the Tethys, and marine ingressions are found among Damudas of eastern Himalaya, or in the Lansdowne area.

Though there is uncertainty regarding their Upper Palaeozoic age the Blainis should be mentioned which transgress on various older formations (AUDEN, 1934; JAIN, 1981 a. o.).

The Hercynian movements, however, did not reach the intensity to be called an orogeny.

2.2. The Mesozoic Development

The above hypotheses are diverse regarding the Precambrian–Palaeozoic development of the Lesser Himalaya but agree that Mesozoic formations are almost missing in that region. The age of the Tal Formation generally accepted as Jurassic–Cretaceous on the basis of poor fossil finds is doubted now by VALDIYA (1975) and AZMI et al. (1981) who advocate Permian respectively Cambro–Ordovician age. There remains only the Upper Jurassic–Cretaceous sequence of Hazara, which is of distinct Tethyan-Tibetan facies. This marine ingression overlaps typical Lesser Himalayan succession. The Salt Range Mesozoic sequence is of litoral character and shows several gaps.

On the contrary the Mesozoic succession is rather complete in the Tibetan (Tethys) Zone. Actually the Mesozoic sedimentary cycle commences with the Permian transgression. With the beginning of the Triassic and up into the Carnic the carbonate sedimentation is contaminated mainly by argillaceous matter. With the Upper Carnic and Lower Noric silty and sandy influx increases; the Noric may be mixed calcareous-argillaceous-arenaceous (e. g. Spiti) or attain the character of flysch (Dolpo, Fig. 12); in Kashmir and Zanskar the Trias consists almost throughout of carbonates and argillites representing a shallow shelf; it seems that the depth of water, proximity of land and basin configuration changed eastwards: deepening and increase of land derived material in the Noric. A regression in the Rhaetic brought about sedimentation in shallowest water uniform throughout the northern Himalaya and persistent into the Dogger (Quartzite Beds, Kioto Lms., Lumachelle Fn.). The Spiti Shales (Upper Jurassic) mark a new transgression after a gap. The Lower Cretaceous Giumal Sandstone, a flyschoid formation, heralds the Alpine revolution. BORDET et al. (1971) record terrigeneous beds between the Spiti Shales and Giumal Sandstone of Nepal; the Upper Aptien carbonates on top of the Giumal Sandstone indicate quiet conditions again. The same is shown by the pelagic Chikkim Limestone of Spiti-Zanskar (Cenomanian–Lower Campanian). The succeeding Chikkim Shales or Kangi La Flysch (Upper Campanian–Lower Maestrichtian) signal new epirogenic movements; they received the terrigeneous material from the south, because the coeval pelagic Shillakong Formation, deposited on a sill north thereof, is free of such contamination. With the Maestrichtian the northern margins of the Zanskar shelf are overlapped by euxinic basin facies (Lamayuru) from the north showing subsidence. After this episode the shallow-water carbonate facies, which commenced in southern Zanskar in the Upper Maestrichtian spread towards the north and overlies the mentioned basin argillites with Paleocene beds (Lingshet Lms.). After the deposition of Lower Eocene slates and limestones in the north (Kong Sl.) and of multicoloured slates and siltstones in the south (Chulung La Sl.) Zanskar is overridden by the nappes (see 2.3.).

From the described Palaeo–Mesozoic development of the Tibetan Zone follows that it was of shelf and miogeosynclinal type mixed. The northern margin of the Indian continent is documented in Ladakh: The euxinic Lamayuru Formation was deposited on the continental slope and in the adjoining basin. Carbonates from the shelf slid into the basin in form of olistolites, grapeflows etc. (BASSOULLET et al., 1981) and interfinger with the flyschoid, partly calcareous basin complex. The latter has a very wide stratigraphic range – almost throughout the Mesozoic. In Nepal I observed similarly that the dark Mid-Triassic carbonate-argillite formation (Mukut Lms.) is partly replaced by dark argillites towards the north (1967).

North of the Lamayuru belt our knowledge is rather meagre: the exotic Permian–Triassic or Jurassic limestones of the melange zones may be remnants of microcontinents (HONEGGER et al., 1981) and basic alkaline volcanics may be associated (BASSOULLET et al., 1978c). The alkaline volcanics of the Rusi La Zone (FUCHS, 1982a) connected with multicoloured flysch and limestones probably formed on oceanic islands and seamounts (HONEGGER et al., 1981). According to these authors the ultramafics, gabbros and tholeiitic series exposed in the ophiolitic melange zones may represent the oceanic crust of the Tethys; Upper Jurassic radiolarian cherts and Upper Cretaceous pelagic foraminiferal limestones are further tests of this ocean, mixed up along the Indus subduction zone.

North of this subduction zone the Dras Volcanics or Utror Volcanics of Kohistan (BARD et al., 1980) formed in an island arc active in Upper Jurassic–Cretaceous (Early Tertiary) times (FRANK et al., 1977; KLOOTWIJK et al., 1979; ANDREWS-SPEED & BROOKFIELD, 1982; BROOKFIELD & REYNOLDS, 1981a, b; KELEMEN & SONNENFELD, 1981 a. o.). The volcanics are associated with flysch, which partly is olistolitic (wildflysch). There are also Mid-Cretaceous shallow-water limestones (e. g. Deosai, Khalsi) and Upper Cretaceous pelagic marls and limestones interbedded with the flysch.

The continued subduction of oceanic crust along the Indus Suture led to anatexis and to the intrusion of the Ladakh-Transhimalayan Plutons and the extrusion of intermediate to acid volcanics in Tibet (POWELL & CONAGHAN, 1973; 1975; FRANK et al., 1977; ANDREWS-SPEED & BROOKFIELD, 1982; HONEGGER et al., 1981 a. o.). This magmatism started in the Upper Cretaceous and continued until the Upper Oligocene. In its later development besides oceanic crust sialic material too may have been involved in the anatexis (HONEGGER et al., 1981).

2.3. The Himalayan Orogenesis

(Fig. 13; Pl. 1)

As there is no sharp boundary between the Mesozoic sedimentary stage and the beginning Himalayan revolution I touched this event already in the previous chapter.

The overlap of the Lamayuru basin facies onto the shelf sediments of northern Zanskar documents a downward movement of the northern marginal portions of the shelf. This shows that in the Maestrichtian the Indian continent approached the subduction zone; that means that the Tethys was closing. The Upper Paleocene shallow-water limestones overlying the Lamayuru Formation of the N.Z.U. indicate an upward movement of northern Zanskar which is caused by the initial collision of India with the Dras island arc. KLOOTWIJK et al. (1979) and KLOOTWIJK (1980) dated this event with 55 m.y. by palaeomagnetic measurements. BROOKFIELD & REYNOLDS (1981a, b) dated an undeformed syenite among deformed Dras Volcanics with 82±6 m.y. ($^{40}Ar/^{39}Ar$) and therefore argue for a Late Cretaceous age of the nappe tectonics of Zanskar. BROOKFIELD & REYNOLDS (1981b, p. 161) and SEARL (1981, pers. comm.) put arguments for a Late Cretaceous emplacement of the ophiolitic melanges of the Indus Zone. It is however documented by the Lower Eocene beds underlying the Spongtang Nappes that the thrust sheets reached Zanskar only after that time (FUCHS, 1981; 1982a; KELEMEN & SONNENFELD, 1981). The deformation of the remaining Tethys floor, however, may have started already in the Late Cretaceous: Under submarine conditions the principal tectonic units were pre-formed separated by ophiolitic melanges. This happened while the Dras volcanic arc still was going on beeing active.

High pressure metamorphism of blue schist grade was active in parts of the Suture Zone of Ladakh (FRANK et al., 1977; VIRDI et al., 1977; KUMAR, 1978; VIRDI, 1981, a. o.) and Kohistan (DESIO & SHAMS, 1980). In the latter region the highest grade – two pyroxene granulite facies – was observed affecting a cumulate basic complex above the suture zone (M.M.T.) (BARD et al, 1980; COWARD et al., 1982). It appears that this high grade metamorphic belt is exposed only due to late mega-folding of the whole Kohistan sequence (COWARD et al., 1982).

Post-Lower Eocene: the thrust sheets of the Indus Zone took their place on the Zanskar sequence, which was folded and the Cretaceous–Early Tertiary series of the N.Z.U. were partly sheared off from their base (Map, section 1). The folds are generally directed south-west, in the N.Z.U. they are of a tight isoclinal type, in the Tibetan Zone, not reached by higher thrust sheets, there is free open folding.

The nappe tectonics and the first folding phase of Zanskar followed immediately the collision of the Indian continent with the Dras island arc in the Late Paleocene–Lower Eocene (KLOOTWIJK et al., 1979). After this event subduction may be taken up by the Northern Suture Zone (GANSSER, 1980c), not in the Late Cretaceous as suggested by BROOKFIELD & REYNOLDS, 1981a, b).

Between the root zone of the nappes and the Ladakh-Transhimalayan Batholith, which formed in successive steps between the Upper Cretaceous and the Upper Oligocene, the Indus Molasse basin developed. The molasse transgresses on both the Dras Volcanics in the south and the Ladakh Intrusives in the north. In the Eocene marine flyschoid series are still found in parts of the basin (BROOKFIELD, 1981), later the continental molasse seems to dominate all over it.

In a second tectonic phase the nappe structures were deformed: The syncline developed where the Spongtang Outlier is preserved; north of it the Honupatta Anticlinorium (KELEMEN & SONNENFELD, 1981), a fan-shaped, tightly and steeply folded belt was formed; the limb connecting the above structures was overturned to the south-west; the whole root zone was steepened and inverted towards the north and north-east; finally the old thrust planes were rejuvenated and the counterthrusts directed north and north-east became active. Probably at the same time the N.Z.U. separated from the Tibetan Zone and overthrust this zone marginally from the north (Map, section 1; FUCHS, 1982). The fact that the tight vertical folding is confined to the belt adjacent to the Spongtang Outlier is an indication that the latter acted as an abutment; this infers that the nappes did not form a thrust sheet continuous from Spongtang to Tibet but isolated slivers in analogous position (FUCHS, 1982).

It appears that this second structural phase was responsible also for the tight folding of the Kohistan Sequence described by COWARD et al. (1982). The second deformation phase of Zanskar is probably related with the final intimate collision between India and Asia 38 m.y. ago proposed by MOLNAR & TAPPONNIER (1975) and KLOOTWIJK et al. (1979) based on palaeomagnetic data. The Northern Suture Zone seems to have closed then. Further it is significant that the Indus Molasse containing Miocene beds is overthrust by the Dras Unit along a counterthrust. The above suggests that this compressive phase culminated in the Miocene putting an end to the molasse stage.

Until then the Indus Zone (s. l.) was centre of the tectonic activity and I tried to analyse the structural evolution in Ladakh, where the Suture Zone is best explored. With the Miocene the thrust sheets of the Lesser Himalaya were transported to the south. This dating is evident from the presence of marine Paleo-Eocene Subathus and the Lower Miocene freshwater beds of the Dagshais in tectonic windows. The Lesser Himalayan nappe tectonics seem to have triggered the molasse sedimentation of the Siwaliks in the southern foredeep. In the western Himalaya molasse sedimentation commenced somewhat earlier with the Lower Miocene Kasaulis, Murrees etc.

The nappe tectonics mentioned above are related with the formation of an intracontinental new subduction zone in the northern part of the Indian continent (POWELL & CONAGHAN, 1973; LE FORT, 1975a). Along the M.C.T. the relatively cool Lesser Himalayan units were subducted beneath the hot crystalline complex being in the state of active high-grade regional metamorphism. These relative movements explain the reversed metamorphism of the Himalaya (FRANK et al., 1973; 1976; LE FORT in BORDET, 1971; 1975a). The thermal peak of the metamorphism was between 40 and 30 m.y., rapid cooling around 16 m.y. reflects the influence of the less heated underthrusting units (FRANK et al., 1976). According to them the Crystalline Nappe developed from a huge recumbent fold deforming the metamorphic isogrades. This is discernible in the Kulu area. Further east the shear movements along the M.C.T. predominated. These deformations occurred very rapidly. The highest metamorphic grade (sillimanite grade of amphibolite facies) is observed in the central lower portions of the Central Crystalline. Downwards and upwards the grade of alteration decreases. The melts of the Alpine leucogranite formed by anatexis close above the M.C.T. where the hot slab received abundant fluids from the underthrust Lesser Himalayan series (LE FORT, 1981). From there the granites migrated into the frontal portions of the Crystalline Nappe (Mahabharat Granites, ANDRIEUX et al., 1976) or penetrated the upper parts of the Crystalline and the Tibetan Zone (Manaslu, Mustang, etc.).

The Crystalline overthrusting the Lesser Himalayan Basin led to severe deformation. From its northern portions the Chail Nappes or the Simla-Rukum Nappe formed. Other units remained parautochthonous (lowest Chail unit, e. g. Tons-Deoban dome, Galwa, Hiunchuli, particularly the southern parts of the basin [Krol Belt]). The alteration increases from non- or anchimetamorphism to amphibolite facies, if we go from the south towards the north (root zone) and ascending to higher units (inverse metamorphism!). In the Chail Nappes cross-folding and north-east–southwest lineations are frequently observed. The Chail Nappes show the highest metamorphic grade of the Lesser Himalayan units and are deformed under deep burial, beneath the Crystalline Nappes. It appears that under these conditions the elongation along B led to contemporaneous folding along the a-axis (B⊥B') (FUCHS & FRANK, 1970). Thus the cross structures are regarded as indicators of a certain deformational environment of the Tertiary orogenesis and not as Precambrian relict structures.

In the High Himalaya the alteration decreases gradually to anchi-grade or the rocks appear to be non-metamorphosed. Most of the Tibetan Zone, however, is affected by slight metamorphism. In the North-West Himalaya all units are altered; the Ladakh Intrusives and Indus Molasse too show anchi- to zeolite grade (HONEGGER et al., 1981).

Mica cooling ages from distant areas varying between 10 and 17 m.y. suggest nearly contemporaneous Miocene cooling all along the Himalayas (HONEGGER et al., 1981). When the crystalline complex was still in a mobile state a third deformation phase occurred in Ladakh (FUCHS, 1982): The counterthrusts were already inactive and were folded in the Rusi La-Phulungma region. This folding seems to be related with late movements along the tectonic plane separating the N.Z.U. from the Tibetan Zone. The Crystallines, obviously still rather mobile, formed a diapiric fold protruding into the sedimentaries along this structural plane (Itchu south of Kargil).

The migmatic Nanga Parbat Crystallines (MISCH, 1949) may represent a similar diapiric mass but of huge dimension. Like in the Suru area much of the so-called Salkhalas might turn out to be altered Upper Palaeozoic--Mesozoics. The Nanga Parbat-Haramosh Spur (GANSSER, 1980c) borders the surrounding zones with tectonic contacts. The way these zones bend around the spur suggests that it protruded northwards in a late orogenic stage when the Crystalline behaved as a rigid mass. These movements must be seen as part of the North-West Himalayan Syntaxis. All tectonic zones from the Salt Range in the south to the Pamirs in the north make a marked bend from the Himalayan north-west–south-east to the north-east–south-west strike of the Hindukush and Baluchistan. The bend is particularly sharp in the Ihelum Valley between Hazara and Kashmir and around the Nanga Parbat Spur. The syntaxial bend obviously is a late orogenic event affecting also the youngest Tertiary zones (Siwaliks). It is related with post-collisional indentation of a protruding part of the Indian continent (Ihelum Spur, WADIA) in the Asian Plate. Palaeomagnetic observations from the region suggest counter-clockwise rotations in the western limb, clockwise rotations in the eastern limb of the North-West Syntaxis (KLOOTWIJK & CONAGHAN, 1979, p. 179). These data are consistent with the above explanations of the Syntaxis.

Like in the north-west the Himalaya makes a sharp bend in the east where the east-north-east-strike changes into the north–south-direction of the Burmese ranges. The North-East Syntaxis is much less explored. From the work of THAKUR & JAIN (1975) it appears that the Chail Nappes (Mishmi Fn..) directly overthrust the Siwaliks. The upper portions of the Mishmi Fn. correspond with the Central Crystalline; this is overthrust in turn by the Tiding Fn. which represents the Suture Zone. The Lohit meta-granites and meta-diorites seem to correlate to the Ladakh-Transhimalayan Intrusives (see also GANSSER, 1980b, p. 142). It may be expected that the North-East Syntaxis has a similar origin as the North-West Syntaxis.

A young transverse lineament crossing various zones of the Himalaya is the Kishtwar–Kargil lineament; along this the Zanskar-Chamba block moved north-westwards upon the Kashmir block; the imbrications of Indus Molasse and Dras Volcanics were intensified then. Transverse faults cutting and displacing the regional structures were observed in many parts of the Himalaya; the Thakkhola graben is one of the largest.

We have seen that the subduction zones and related nappe and fold tectonics started in the north and migrated southwards in the course of the Himalayan orogenesis; the folded terrains were only affected by some later deformation, mainly of disruptive type (see above). This trend continued and in the Plio–Pleistocene the Main Boundary Thrust (M.B.T.), a new intracontinental shear zone, came into being (LE FORT, 1975a). The already rather consolidated parts of the orogene, folded and consisting of a pile of nappes, moved "en block" southwards onto the Siwalik Molasse. The horizontal displacement is small, 10–15 km, as compared with the 100 km distances of Lesser Himalayan nappes. The ductile formations of the Siwaliks were folded and partly imbricated. In the Lesser Himalaya this compressional phase led to some folding of the pile of nappes along regional axes and deformation across the strike producing axial culminations and depressions. These deformations are responsible for the erosion of windows and the preservation of outliers.

Seismic studies show that also in the Recent thrust movements are active (SEEBER et al., 1980). Still further south under the foreland of the Indo-Gangetic Plains the basin sediments are sheared off from their basement along a shallow thrust of gentle dip termed the Detachment. In the Punjab the Infracambrian salt may cause aseismic slip, further east the decoupling thrust is a high seismic hazard.

According to KALVODA (1976) the Great Himalaya is lifted by 4000–5000 m in the Pleistocene. The rivers which since the Miocene had developed a drainage system with the watershed in the northern Himalaya were forced now to cut through the growing range. The present Quaternary relief is cut and displaced by a series of relief thrusts in eastern Nepal (JAROS & KALVODA, 1978); the zone of the M.C.T. and the M.B.T. for instance are rejuvenated. The youth of these thrust movements is amazing at the first glance but this theory explains a series of characteristics of the Himalayan scenery: north of the foothills, just after crossing the M.B.T. respectively the Murree Thrust, a continuous range rises with steep southern slopes for 1500–2000 m (Pir Panjal-, Dhauladhar-, Krol-, Mussoorie-, Lansdowne-, Naini Tal-, Mahabharat Ranges). It is very young tectonism which formed these ranges, because the rock material is not different from the Midlands north thereof, a region 1000 m lower. This geomorphologically soft terrain is overtowered by the Great Himalaya, a lofty barrier with steep icy flancs of 5000 m. Likewise in Ladakh rather mature scenery changes to rugged wild country along rejuvenated tectonic zones (Kangi-Photaksar furrow, FUCHS, 1982).

I am certain that JAROS & KALVODA found a general principle explaining the geomorphology of the whole Himalaya.

2.4. The Himalaya and some special Plate-Tectonic Problems

I have tried to give a coherent picture of the tectogenesis of the Himalaya, also seen in the light of plate-tectonics. The early history excepted, there appears to be principal agreement among most geologists concerned. Regarding certain questions, however, views are rather diverse.

In the model of POWELL & CONAGHAN (1973; 1975) the mantle beneath the Asian Continent was replaced by sialic crust of the Indian Continent in a process of peeling off. This underthrusting started after the Oligocene and was active up to the Early Pleistocene; it led to a double thickness of the sialic crust under the Tibetan Plateau. The result was isostatic uplift of the Tibetan Plateau by almost 5000 m, proceeding from south to north. The width of underthrusting is 700 km north-north-east of Spiti increasing to 1500 km north-north-east of Nepal.

This seems to be consistent with seismic and gravimetric studies indicating an average thickness of the continental crust of 30–40 km in the Indian Plate, increasing to 80 km beneath the Himalaya and being 60 km under the Tibetan Plateau (QURESHY cit. in LE FORT, 1975a, p. 31).

GANSSER (1980a, p. 48) on the contrary explains the enormous concentration of sub-recent volcanism in Central Tibet as a "hot spot". This, however, indicates an exceptionally thin lithosphere (MOLNAR & TAPONNIER, 1977, cit. in GANSSER, 1980a). The change from thick to thin lithosphere seems to coincide with the Indus-Tsangpo Suture Zone. In his 1981 paper GANSSER refers to earthquake analysis showing a thickness of the Tibetan crust of 70–75 km and stresses that „the very low travel time of surface waves cutting the total crust rather suggest a hot and 'soft' compressed crust with no underthrust rigid plate" (p. 7).

Another problem is the width of drift. Palaeomagnetic data from India and the Indian Ocean indicate that the Indian Continent drifted from the southern hemisphere for almost 60° of latitude. In the Jurassic it was still separated from Asia by a wide ocean. It is well established now that all the zones of the Himalaya north of the Indus Suture Zone always were adjacent to each other and to the Indian Continent. Marine ingressions from the Tethys reached the southern Himalayas and Gondwana influences are found in the Tibetan Zone. Therefore CRAWFORD (1974) regarded the Tibetan Plateau still as a fragment of Gondwanaland. The facies, floral and faunal affinities also cross the Indus-Tsangpo Suture Zone. According to MU et al. (1973, p. 110) there was a close interrelation between the Everest region south of the Suture Zone and North- and Central China, particularly in the Palaeozoic. Thus ANDREWS-SPEED & BROOKFIELD (1982) advanced the view that there was a continuous continent comprising India and Asia in the Upper Palaeozoic, and the Neo-Tethys came into being by Late Palaeozoic rifting (Panjal Trap) and oceanisation. The generation of an ocean within one land mass and its later closure explains the facies- and bioaffinities found in different continental fragments, but appears to contradict the palaeomagnetic data. A revised assembly of continents in a Mid-Palaeozoic Pangaea according to RICKARD & BELBIN (1980, p. 1) "features no large Tethyan Ocean and consequently a more coherent pattern of Early Palaeozoic orogens". The model explains the faunal and floral affinities across the Indus Suture Zone and, according to these authors, accounts for the existing palaeomagnetic evidence.

STÖCKLIN (1977; 1980) and GANSSER (1976; 1980a; 1981) collect the scanty informations existing about the vast regions of Central Asia north of the Indus-Tsangpo Suture Zone. There appears a mosaic of continental fragments, geosynclinal and ophiolitic belts of various ages; the orogenic zones are repeatedly reactivated. To account for this picture CHANG & CHENG, 1973) suggest that a series of small plates broke off from an old larger Indian continent drifted northwards and successively accreted to Eurasia. Thus there are suture zones of Caledonian, Hercynian, Early Mesozoic, Late Mesozoic and Tertiary age, growing younger southwards and each marked by flysch and ophiolite belts. Similarly STÖCKLIN (1977; 1980) describes his Central Domain, comprising Tibet north of the Peri-Indian Suture Zone, as a mosaic of Gondwana continental fragments which broke off from the mother continent and welded with Eurasia in the Mesozoic (Kimmerian and Early Alpine tectonism). Their drift closed the Palaeo-Tethys in the north and opened the Neo-Tethys in the south. The latter ocean closed in the Late Cretaceous. The Axial Ophiolite Belt (= Peri-Indian Suture Zone) is the test of this ocean and separates the Central Domain from the Southern Domain, which comprises the Himalaya, the marginal parts of the Indian Continent.

STÖCKLIN's concept is not supported by palaeobiogeographic work by TALENT & MAWSON (1979) and is contested by KLOOTWIJK & CONAGHAN (1979) who investigated the Upper Devonian of Chitral. This occurrence is situated in STÖCKLIN's Central Domain. Palaeomagnetic data suggest that the position of the Upper Devonian beds has not much changed in respect to the adjacent Siberian Plate. "The combined palaeomagnetic and palaeontological evidence therefore indicates that the Chitral area is an original part of Asia and does not have Gondwanic affinities" (p. 179).

BOULIN (1981) follows the ideas of STÖCKLIN and accounts for the above arguments inasmuch as he assumes that the Chitral-North Tibet fragment detached from Gondwana in the Early Devonian and crossed Tethys 1; in the Upper Devonian it had the northern position requested from palaeomagnetic data and finally collided with Eurasia leading to the Hercynian Hindu Kush and Kun Lun Belt. In the Permian–Triassic Central Afghanistan and South-Tibet separated from Gondwanaland, crossed Tethys 2 and collided with Asia (Neo-Kimmerian orogeny). Behind them Tethys 3 opened, the ocean which closed in the Cretaceous–Cenozoic, when India accreted to Asia. It should be mentioned that BOULIN apparently means the area north of the Peri-Indian Suture Zone when he speaks of South-Tibet; the southern portions of Tibet south of the Suture Zone consist of the marginal parts of the Indian Continent and basin sediments deposited on the continental slope and north thereof; thus this region was connected with the Indian Continent.

The discussions of this chapter show that, though a wealth of observations and data has been collected, still further work is needed to resolve certain problems. We also must be aware that the research had and has to be done under expedition conditions in vast, inhospitable highlands, deserts and the highest mountains. These regions are difficult to access not only for logistic-touristic obstacles but also for restrictions and political reasons. If the present tendency to release restrictions still continues, rapid progress in geological knowledge may be expected in near future.

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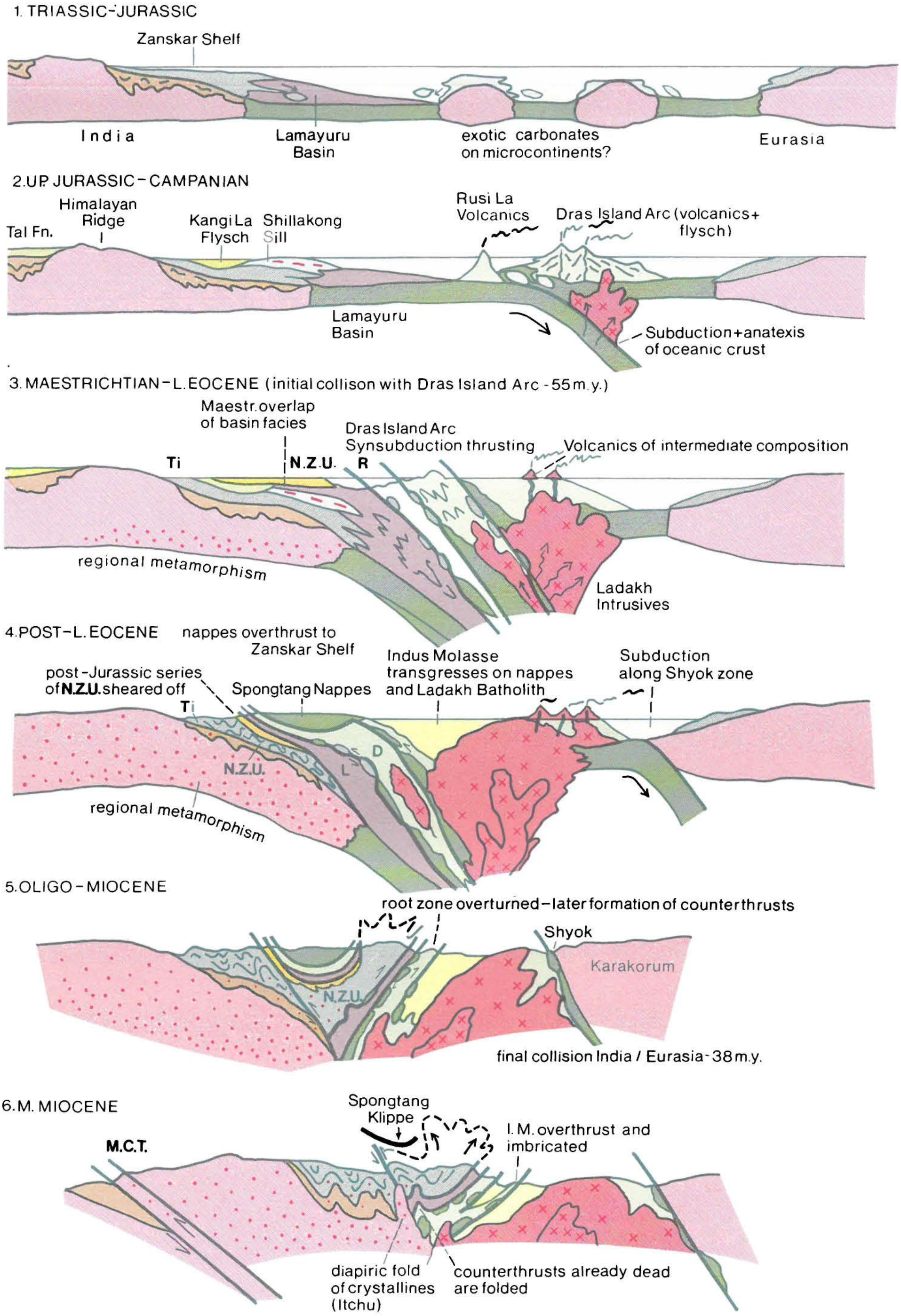
The Evolution of Zanskar and the Indus Zone

(Schematic sketch based on literature and own interpretation)



Indus Molasse (Eocene – Miocene)	Mesozoic / Palaeozoic shelf sediments i. g.
Ladakh Intrusives (Up. Cretaceous – Oligocene)	Oceanic crust
Intermediate to acid volcanics	Continental crust
Up. Maestrichtian – L. Eocene shallow-water sediments	Continental crust and sediments remobilised
Cretaceous – Early Tertiary (?) volcanics and flysch	**Ti** Tibetan Zone
Kangi La Flysch (Up. Campanian – L. Maestrichtian); Tal Fn.	**N.Z.U.** Northern Zanskar Unit
Up. Cretaceous sill facies (Shillakong)	**L** Lamayuru Unit
Lamayuru basin facies (Triassic – Up. Cretaceous)	**R** Rusi La Zone
Exotic carbonates	**D** Dras Unit
	I.M. Indus Molasse
	M.C.T. Main Central Thrust

Explanations geologic-tectonic map Himalaya

PLATE 1


Published 1981
Geologic-Tectonical Map of the Himalaya
compiled from literature and own observations by G. FUCHS, 1980
Gestaltung u. Reprotechnik: Fachabteilung für Kartographie
und Reproduktion der Geologischen Bundesanstalt, Wien
Scale 1: 2.000 000
0 20 60 100 km
Selected Sections across the Himalaya
NW of Jammu
MBT
MuT
MCT
Pir Panjal R.
KS
Kishtwar Window
Great Himalayan Range
Z a n s k a r
Spongtang
Indus
Ladakh Range
Shyok
Si
Mu
P
C
Cr
Cr1
Cr2
Ti
NZU
L
D
I
IM
SE Dehra Dun
Satengal
Dunda
Uttarkashi
C1
C2
C3
Mangshang La
Amlang La
Jungbwa
Transhimalaya
Kailas
L or NZU
After HEIM & GANSSER, 1939
Surkhet
Dailekh
Tila Valley
Rara Lake
Mugu Karnali
Jaljala Dhuri
Rukumkot
Hiunchuli Range
Kanjiroba Range
D o l p o
Palchung Hamga Himal
Ru
Scale 1: 500 000
0 10 20 30 40 50 km
Heights slightly exaggerated
Lesser Himalaya
Siwalik (M. Miocene–Pleist.)
Murree (L. Miocene)
Tal–Dagshai (Jur.–L Mioc.)
Blaini–Krol, Shali
Nagthat
Chandpur; Jaunsar i. gen.
Chail
Granitoids
Simla Slates
Crystalline
High Himalaya
Indus Molasse (Oligo.(?)–Miocene)
Paleo.–Eocene limestones
Multi-coloured slates (Eocene?)
Late Maestr.–Paleocene limestones
Maestr.–Paleocene(?) portion of Lamayuru Fn. (N.Z.U.)
Kangi La Flysch (Camp.–Early Maestr.)
Multi-coloured limestones and slates (Camp.)
Giumal Sandstone (L. Cret.) and Chikkim Limestone (Mid.-Cret.)
Mid.-Cretaceous – Early Tertiary flysch and volcanics (e.g. Dras)
Ophiolitic melange; peridotite
Lamayuru Formation (Triassic–Up. Cretaceous?) (±parts of Northern Zanskar Unit)
Triassic–Jurassic formations (mainly carbonates)
Agglomeratic Slate; Panjal Trap (Permo–Carbonif.)
Palaeozoic i.gen.
Muth Quartzite, Muth Fn., Tanol (Mid.–Pal.)
Dogra Slates, Haimanta; Dhaulagiri Limestone (Precambr.–Early Pal.)
Crystalline
Alpine granites, granodiorites
Tectonic Units
Si Siwalik Zone
Mu Murree Zone
P Parautochthonous Unit
Ru Rukum Nappe
C1,2,3 Chail Nappes
Cr1,2 Crystalline Nappes
KS Kashmir Synclinorium
Ti Tibetan Zone
NZU Northern Zanskar Unit
L Lamayuru Unit
D Dras Unit
I Indus Flysch
IM Indus Molasse
Thrusts
MBT Main Boundary Thrust
MCT Main Central Thrust
MuT Murree Thrust
Alluvium (+Karewa, Thakkhola deposits etc.)
Siwalik Zone
Murree Zone (+Subathu, Dagshai)
Tertiary Belt
Jurassic to Miocene (Tal–Dagshai) of Lesser Himalaya and Salt Range
Palaeo–Mesozoic of Salt Range
Simla Slate–Krol (Shali) sequence of Parautochthonous Unit
Simla Slate–Krol (Shali) sequence of Simla–Rukum Nappe
Simla Slate–Chail Formation (+granitoids) of Chail Nappes
Siluro–Devonian intercalations in Tanols of Indus region
Nagthat–Shali sequence of Chail Nappes
Upper Palaeozoic fossiliferous series of Garhwal
Crystalline Nappes
Alpine granitoides
Tibetan Zone (s.s)
Synclinoria of Kashmir, Chamba, Kathmandu etc.
Triassic–Jurassic of Northern Zanskar Unit (N.Z.U.), Chilamkurkur Series
Lamayuru Unit and Cretaceous–Eocene of N.Z.U.
Dras Unit, Indus Flysch, Shyok Volcanics
Ophiolite zones; peridotites
Indus Molasse
Main thrusts
Younger thrusts (counterthrusts)
Major faults
Dip
AFGHANISTAN
Gilgit
Indus
Nanga Parbat 8126
Kohistan
Nowshera
Peshawar
Swat
Tarbela
Rawalpindi
Potwar Basin
Salt Range
Jhelum
Chenab
Jammu
Srinagar
Kashmir
Pir Panjal Range
Dras
Kargil
Nun Kun
Kishtwar
Shyok
Leh
Ladakh Range
Ravi
Beas
Sutlej
Rohtang P.
Larji
Rampur
Bilaspur
Simla
Kamet
Nanda Devi
Mussoorie
Yamuna
Ganges
Almora
Pithoragarh
Naini Tal
Saipal 7040
Kali
Tsangpo
Raga Tsangpo
Mustang
Dhaulagiri 8172
Annapurna 8078
Pokhara
Kunchha
Butwal
Gandak
Kathmandu
Sisha Pangma 8013
Mt. Everest 8848
Okhaldhunga
Kangchendzonga 8586
Darjeeling
Tista
Phung Chu
BANGLA DESH
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