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Outline of the Geology of the Himalaya

By Gerhard FUCHS*

With 1 Plate

Abstract

The paper characterises the stratigraphic-structural units of the Himalaya, which are continuous throughout the length of this mountain chain. The latter does not exclude certain facies changes giving individual features to some regions. In a special chapter various problems of Himalayan geology are dealt with: Geosynclinal development, existence of Caledonian orogeny, age of the Lesser Himalayan succession almost devoid of fossils, and the age of the Crystalline complex. The history of the Himalayan orogenesis is deduced from the stratigraphic-tectonic development. Finally the Himalaya is shown in the light of plate tectonics and related problems are discussed.

Zusammenfassung

Dem vorgesehenen Umfang der Arbeit entsprechend werden die Baueinheiten des Himalaya in knapper Form nach Material und Tektonik charakterisiert. In Text und Karte wird nach einer möglichst einheitlichen Darstellung gestrebt.

Die *Tertiär-Zone* wird von gefalteten klastischen Serien der mio-pleistozänen Vorsenke aufgebaut.

An der Main Boundary Thrust bzw. Murree Thrust überfahren die älteren Serien (Präkambr.-Unt. Mioz.) des *Niederen Himalaya* die Tertiär-Zone. Sie zeigen einheitliche, meist fossilleere Schichtfolge, aber mit faziesmäßiger Differenzierung. Die *Parautochthone Einheit*, die südlichste und tiefste Einheit, zeigt vorwiegend Falten- und Schuppenbau, der sich deutlich von den meist flach gelagerten Decken abhebt. Die *Simla-* und *Rukum-Decken* sind unzusammenhängende Abscherungsdecken, die sich von der Parautochthonen Einheit durch stärkere Deformation und leichte Metamorphose unterscheiden. Die *Chail-Decken* bestehen aus aufrechten, epimetamorphen Serien in tektonischer Wiederholung. Die tiefste Untereinheit ist parautochthon, die höheren sind echte Decken.

Die Einheiten des *Hohen Himalaya* folgen zunächst mit den *Kristallin-Decken*, welche die Zentralzone bilden und als z. T. sehr ausgedehnte Deckschollen im Niederen Himalaya auftreten. Die *Untere Kristallin-Decke* stellt eine etwas schwächer metamorphe Basisschuppe dar. Die *Obere Kristallin-Decke* besteht aus der hochmetamorphen (oberste Amphibolit-Faz.) und migmatisierten Hauptmasse

* Address of the author: Dr. Gerhard FUCHS, Geologische Bundesanstalt, Rasumofskygasse 23, A-1030 Wien

des Kristallin, dessen Metamorphose in den tieferen Schichtfolgen der *Tibet-Zone* ausklingt. Diese ist somit tektonisch mit dem unterlagernden Kristallin verbunden. Die ziemlich vollständige Schichtfolge reicht vom tiefsten Paläozoikum bis ins Alt-Tertiär und hat teils miogeosynklinalen teils Schelf-Charakter. Bewegter Faltenbau ist typisch, nur in Kumaun herrscht SW-gerichteter Schuppenbau.

Die *Indus-Zone* (s. l.) ist sehr komplex: Die *Nördliche Zanskar-Einheit* zeigt bis in die Unter-Kreide die Schichtfolge der Tibet-Zone, Ober-Kreide bis Eozän besitzt sehr individuelle Züge. Diese parautochthone Einheit ist der Tibet-Zone aufgeschoben. Die *Lamayuru-Einheit,* aufgebaut aus einer dunklen eugeosynklinalen Schieferfolge (Trias-Kreide) und verschiedenen Klippen, wird an der Basis der Dras-Einheit über Nördliche Zanskar-Einheit und Tibet-Zone verschleppt. Die *Dras-Einheit* besteht aus kretazisch-alttertiären, meist basischen Vulkaniten und Flysch. Ihre Abtrennbarkeit von dem sehr ähnlich aufgebauten *Indus-Flysch* (s. s.) ist problematisch. *Ophiolithzonen,* ein sedimentäres und tektonisches Gemisch von Mantelgesteinen, Vulkaniten, Flysch, Radiolariten und pelagischen Kalken, sind besonders an die tektonischen Grenzen der drei letztgenannten Einheiten gebunden. Nach deren SW-gerichteter Deckenüberschiebung erfolgte in einer jüngeren Phase eine Inversion der gesamten Wurzelzone. Daher taucht auch die oligo-miozäne *Indus-Molasse* gegen SW unter den Indus-Flysch ab. Im N transgrediert sie auf dem alttertiären *Ladakh-* bzw. *Transhimalaya-Batholith.*

In einem eigenen Kapitel werden eine Reihe von Problemen angeschnitten. Gab es außer in der Indus-Zone eine *Geosynklinale* im Himalaya, oder nur Ablagerungen auf einem kontinentalen *Schelf?* Gab es eine *kaledonische Orogenese* im Himalaya? Welches *Alter* hat die fast fossilleere Schichtfolge des *Niederen Himalaya?* Wann entstand das *Kristallin?* Ist es präkambrisches Grundgebirge, rein alpidisch oder polymetamorph? Es wird versucht, das *Werden* des Himalaya aus der stratigraphisch-tektonischen Entwicklung abzuleiten. Schließlich wird der Himalaya aus der Sicht der *Plattentektonik* betrachtet und offene Fragen diskutiert.

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I. Introduction

The Himalaya forms one of the strongest features in the face of the world. Its ranges frame the Indian subcontinent in a huge 2400 km arc, an icy barrier between tropical India and the highlands of Central Asia. On both ends there is a marked bend of the strike, the NW- and NE-Himalayan Syntaxes. There the mountain chains spread into the ranges of Pakistan respectively Burma, which show moderate elevations compared to the Himalaya.

120 years have passed since the first geologists have started to explore the highest mountains of the world (STOLICZKA, MEDLICOTT, LYDEKKER, MIDDLEMISS, GRIESBACH, v. KRAFFT, DIENER a. o.). A lot of information was collected by these pioneers as well as in later periods. The interest in Himalayan geology has been particularly great since areas, hitherto restricted, have been opened to foreigners (Nepal 1950, Ladakh 1974). Certainly the appearance of plate tectonics was a strong stimulus to investigate the Himalaya and several models for its origin were advanced (CAREY, 1955; GANSSER, 1964, 1966, etc.; DEWEY & BURKE, 1973; CRAWFORD, 1974; LE FORT, 1975; POWELL & CONAGHAN, 1973, 1975; MOLNAR & TAPPONIER, 1975; STÖCKLIN, 1977; KLOOTWIJK 1980; ANDREWS-SPEED & BROOKFIELD, 1981; and others).

Apart from great hypotheses much detail work is being done but unfortunately many investigators, keen to introduce a terminology of their own, made much confusion. It might seem that the geology changes rapidly from area to area, but instead of this the principal lithounits and tectonic units are surprisingly constant. As in former papers it is my intention to characterise these units, to correlate, and show their continuity.

II. Structural Elements

The folowing description goes from S to N starting with the foothills and proceeding to the Lesser-, High- and Inner Himalayas and finally the Indus Zone, which is already connected with the Transhimalaya.

A) The Tertiary Belt

The Sub-Himalayan foothills are composed of the folded and partly imbricated fresh-water molasse deposits of the Himalayan foredeep. The *Siwalik Zone* is continuous from the Potwar Basin in the W to Assam in the E. It consists of thick series of shales, sandstones, and conglomerates of Mid-Miocene to Pleistocene age. The rise of the Himalaya and its denudation are reflected by changes in the assemblage of accessory detrital minerals (RAJU, 1967) and an upward increase of grain-sizes (HAGEN, 1959; TANDON & RANGARAJ, 1980; a. o.).

The folded Siwaliks submerge beneath the recent gravels of the Plains in the S. The Salt Range is an exception, where the Palaeozoic-Mesozoic-Lower Tertiary sequence forming the basement of the Siwaliks is brought to the surface by a S – vergent thrust (Detachment Thrust, SEEBER et al, 1980). In the N the Siwalik Zone is terminated by the *Main Boundary Thrust* (M. B. T.).

The Siwaliks exclusively make up the Tertiary Belt in the Eastern and Central Himalaya, only in the Punjab and Hazara Himalaya trough deposits (Murree, Dagshai) of a *Lower Miocene foredeep* are exposed between the Siwaliks and the older rock series of the Lesser Himalaya. They consist of an alternation of thousands of meters of grey sandstones and purple shales. The deformation is stronger than in the Siwaliks. In anticlines and wedges older beds are exposed: Grey-blue stromatolitic dolomites and dark shales (~2000 m, Shali), quartzites and chert breccias of doubtful age and Paleocene-Eocene shales, marls, and nummulitic limestones (Subathu). The Murree Thrust demarcates the zone in the N (WADIA, 1928).

B) The Units of the Lesser Himalaya

The units of the Lesser Himalaya override the Tertiary Belt along the Murree Thrust respectively the Main Boundary Thrust. Fossils are very rare and the tectonics are rather complicated. Therefore there is much dispute regarding the age of the beds, their stratigraphic order, and the demarcation of structural units (see FUCHS, 1975, p. 52 and chapter III B).

I found that the stratigraphic sequence established by AUDEN, PILGRIM, and WEST and accepted in PASCOE (1959) for the Krol Belt, is also represented in northern units of the Lesser Himalaya (Simla-, Rukum-, Chail Nappes). The deposition was in *one* basin S of the present Great Himalayan Range.

1. The Parautochthonous Unit

a) Stratigraphy

It is a characteristic of the Himalaya that no crystalline basement is exposed beneath the sedimentaries, a fact which seems to be related with the decollement indicated by SEEBER et al (1980).

The sequence of lithounits is listed in ascending order:

Simla Slates (Attock-, Hazara-, Dogra Slates, Dampta Group, etc.): Grey, green, dark argillites, siltstones, sandstones, greywackes; (>1000 m) monotonous trough deposits with flyschoid features (VALDIYA, 1970; RUPKE, 1974; FUCHS, 1975 etc.). Local carbonate intercalations known as Langrial, Naldera, Kakarhatti.

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

Nagthat (Khaira-, Jainti Qzt. etc.): Orthoquartzites, sandstones, conglomerates, slates of red, white, green, and grey colour (500–1000 m); current-bedding, ripple marks, clay gall breccias etc; haematite beds and basic volcanics are associated NE Naini Tal and in W-Nepal (FUCHS & SINHA, 1974).

Jaunsar: Grey, green slates with sporadic sandstone layers may replace the Chandpurs and Nagthats.

Blaini (Jainti Qzt., etc.): Red, green, grey slates, sandstones, quartzites, pink, grey dolomites, haematite beds (several hundred meters), cross-bedding, intraformational breccias; grey, green pebbly mudstones, boulder beds are associated with the above beds in Hazara (Tanakki) and Simla – Naini Tal. (Krol Belt). Though contested (MARKS & MUHAMMAD ALI, 1961; VALDIYA, 1970 a. o.), their glacial origin is proved by striated and facetted boulders.

Infra Krol (several hundred meters): Black, grey slates, phyllites, sporadic arenites; an euxinic, deeper facies which may replace the Blaini or may be intertonguing.

Riri Slates: Banded slates representing a facies between Infra Krol and Blaini.

Krol-Shali (<2000 m): Grey, blue dolomites (limestones); black slates (Shali Sl.) and varicoloured beds (Krol B, Lower Shali Lms.) may be intercalated indicating close connection with the underlying formations (Infra Krol, Blaini). Shali (Sirban, Baxa) characterised by stromatolites, arenaceous and reworked layers, represents a shallower facies than Krol; however, there are passages (FUCHS & FRANK, 1970; FUCHS & SINHA, 1974).

Tal (<1500m): Lower Tal (flyschoid): Green, grey, dark shales, greywackes, sandstones, pebbly mudstones, phosphorites at the base (SHARMA, 1974). The contact with the underlying carbonates is unconformable and indicates a gap (at least in Nepal). Upper Tal: Thick-bedded quartzites, white to dark, interbedded with shale and breccia. Ill-preserved fossils (partly endemic) point to Jurassic-Cretaceous age, whereas VALDIYA (1975) suggests Permian age.

Subathu (50 m): Grey shales, blue nummulitic limestones and quartzites (Paleocene – Eocene).

Dagshai (Several hundred meters): Green-grey sandstones alternating with purple and green shales (Lower Miocene).

In Kashmir (Pir Panjal) the Parautochthonous Unit contains Agglomeratic Slate, Panjal Trap (Permo-Carboniferous), a few lenses of Mesozoic carbonates, and Eocene (WADIA, 1928); the Nagthat-Krol sequence is missing. In Hazara the lower part of the stratigraphic column is of Lesser Himalayan development, the Jurassic-Cretaceous beds show Tibetan facies. In the eastern Himalayas there are either Baxas or Damudas (L. Gondwana); where they occur together the Damudas are younger, but still in close connection with the Baxa carbonates (ACHARYYA, 1974; ACHARYYA et al, 1975). The terrigeneous Damudas are associated with marine fossiliferous Permian beds in certain areas. (ACHARYYA et al, 1975; V. K. RAINA, 1976).

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

b) Structure

Fold- and wedge structures vergent towards the S are typical. Late compression produced steepening of the beds, steep reverse faults and local thrusts (e. g. Tansing). The tectonic style is quite distinct from the overlying nappes which generally show shallow dip or wavy folding. Therefore I regard the unit as parautochthonous, sheared off from its base, but not as a nappe (Krol Nappe, AUDEN, 1937; BHARGAVA, 1972; VALDIYA, 1976, 1978 and many others). Certainly the frontal portions of the unit override the Tertiary Belt and windows (Solon S of Simla, SE Mussoorie) document a displacement up to 15 km, which however is small compared to the one of the nappes (up to 100 km).

The Parautochthonous Unit comprises the Attock Range, the Islamabad- and Abbottabad Zones (Hazara, FUCHS, 1975), Autochthonous Fold Belt (WADIA, 1928), Larji (?)- and Shali Windows (WEST, 1939), Krol Belt (AUDEN, 1934), Tansing Unit (FUCHS & FRANK, 1970), Damuda-Baxa Belt, and Rangit Window (near Darjeeling).

2. The Simla- und Rukum Nappes

From two occurrences (Simla, W-Nepal) thrust sheets are known in a position between the Parautochthonous Unit and the Chail Nappes (FUCHS & FRANK, 1970).

a) Stratigraphy

In principle it corresponds to that of 1a) but shows individual features: *Simla Slates* are prominent, whereas *Chandpur* and *Nagthat* are reduced to tens of meters or are developed in *Jaunsar* facies. The Blainis contain boulder beds at Simla. *Shali* is 200 to 500 m only (Nepal) or is missing (Simla). The *Tal* is well-developed in Nepal and may overlie directly on Simla Slates. It is succeeded by fossiliferous *Subathu* and *Dagshai*.

Generally the *alteration* is much stronger than in the Parautochthonous Unit and may reach the grade observed in the Chail Nappes.

b) Structure

Structurally the nappe is a squeezed, rootless thrust sheet dragged to the S at the base of higher nappes.

3. The Chail Nappes

Continuous throughout the Himalayas the Chail Nappes may be represented by monotonous phyllitic-quartzitic series (Chail, Tanol, Daling) or exhibit a complete stratigraphic section resembling that of the Krol Belt (Hiunchuli area) (Pl 1, section 5).

a) Stratigraphy

Simla Slates are exposed in a few cases, but most sections start with *Chail*, which corresponds to Chandpur. Synonyms are Tanol, Bawar, Berinag (VALDIYA, 1976), lower part of Nawakot Gr. (STÖCKLIN, 1980), Series of Kunchha (BORDET, 1961), Daling, Shumar Fn. (JANGPANGI, 1974) Bomdila (VERMA & TANDON, 1976), etc; green, grey, silvery phyllites, sericite schists, psammite schists, orthoquartzites, metaarkoses, schistose conglomerates, basic and acid (LE FORT, 1975) metavolcanics. This clastic, predominantly shallow-water formation, up to several thousands of meters thick, shows rapid lateral facies changes (coarse to fine clastics). The character is mainly of a molasse, regionally also of flysch. Intrusive *granites* became gneisses by the greenschist metamorphism of the whole complex (Mansehra, Pir Panjal, Kishtwar, Dhauladhar, Lansdowne, Ramgarh, Dailekh, Shumar granites [JANGPANGI, 1974] etc.). The intrusive age of the Dhauladhar granites has been dated 500 ± 100 m. y. (JÄGER et al, 1971); other acid magmatites gave 1840 ± 70 m. y. (FRANK et al, 1976). *Nagthat* (<2000 m), *Blaini* (<1000 m), *Shali Slates,* and *Shali* (<2000 m) are well-developed. In many regions the succession is reduced to Chail and Shali (Deoban, Tejam, Pithoragarh, Dhading [STÖCKLIN, 1980], Baxa etc.). In Garhwal, Nepal, and Sikkim fossiliferous Upper Palaeozoic series form part of the Chail Nappes (GANESAN, 1972; FUCHS & FRANK, 1970, p. 43; V. K. RAINA, 1976).

The rocks of the Chail Nappes generally show *alteration* of greenschist facies which increases towards the root zone.

b) Structure

In the Indus region fossiliferous Siluro-Devonian beds (STAUFFER, 1968) interfinger with the Tanols of the *Tanol Zone* and are overlain by transgressive Tanakki to Sirban Limestone (MUHAMMAD ALI, 1962; FUCHS, 1975). The Tanol Zone continues through the SW slope of the Pir Panjal to the Dhauladhar Range (Tanols, granite-gneiss). They reappear in the Kishtwar- and Larji-Rampur Windows. The carbonates of the latter may be connected with the Berinags (FRANK et al, 1973, 1976) and thus belong to the Chail Nappes or correlate with the Shali Window (Parautochthonous Unit, FUCHS, 1967). The Chail Nappe of the type area (PILGRIM & WEST, 1928) represents the highest sheet. East of the Chor Mt. two lower subsidiary units appear (FUCHS & SINHA, 1978). The lowest of them building up the Deoban Dome (Tons Valley), and the core of the Chamoli-, Tejam-, and Pithoragarh Windows may be parautochthonous, the higher units are definitely nappes. SE of Mussoorie and in the syncline of Lansdowne we find outliers of the Chail Nappes. In the latter occurrence Upper Palaeozoic fossiliferous series are involved (GANESAN, 1972; SHANKER & GANESAN, 1973). VALDIYA (1976, 1978) presented his tectonic conception of Garhwal-Kumaun, which in my view is inconsistent (compare Pl. 1, FUCHS & SINHA, 1978 and Pl. 1 of present paper).

In W-Nepal there are 3 to 4 units, the lowest of which appears parautochthonous, the upper ones show displacements of 90 km. Stratigraphic successions are always upright and tectonically repeated (Pl. 1 section 5). As elsewhere the uppermost nappe consits exclusively of Chail.

From the work of JANGPANGI (1974), JAIN et al (1974), THAKUR & JAIN (1975), VERMA & TANDON (1976), RAINA (1976) it is probable that in the eastern Himalaya too several subunits may be discerned, separated from each other by Baxa (Shali) carbonates.

C) The Units of the High Himalaya

There are three great units: The *Crystalline Nappes,* which form the Central Crystalline of the Great Himalaya and the partly rather extensive outliers in the Lesser Himalaya; the *Tibetan Zone* builds up the sedimentaries, which overlie the Central Crystalline in the N; S of the same there are the Synclinoria of Kashmir, Chamba and smaller ones; the *Indus Zone,* a complicated belt of flysch, volcanics, etc, the test of a squeezed ocean.

1. The Crystalline Nappes

The Central Crystalline, the axial zone, continues throughout the length of the Himalaya except in Kashmir. It is the root zone of the crystalline sheets which are preserved in a series of outliers S of it. In certain areas there may be ambiguity regarding the basal thrust (Main Central Thrust, MCT, see STÖCKLIN 1980, p. 4) and so VALDIYA (1976, 1978) speaks of the Munsiari- and Vaikrita Thrusts. FUCHS (1967) advocated the existence of a Lower and an Upper Crystalline Nappe. The latter makes up the bulk of the Crystalline, the first forms a basal thrust sheet or scale (shown on Pl. 1 only in the sections).

The *Lower Crystalline Nappe* (Jutogh, Munsiari, part of the Scale Zone [BORDET et al, 1972]) is composed of garnetiferous micaschists and dark phyllites, graphitic rocks, light quartzites, paragneisses, amphibolites, calc-micaschists and marbles; locally minor bodies of augen gneiss. This succession (<1000 m) shows albite-epidote-almandine subfacies of greenschist facies to lower subfacies of amphibolite facies; retrogressive metamorphism is not rare.

The *Upper Crystalline Nappe* (Vaikrita, Darjeeling, Tibetan Slab, etc.) comprises the high-grade crystallines and migmatites: Coarse-grained garnet-kyanite gneisses (± staurolite or sillimanite) with pegmatoid lenticles pass into augen granite-gneiss and represent an older complex. Homogeneous, fine — to medium-grained orthogneisses and migmatites penetrate the above assemblage in a predominantly concordant way. The higher portions of the Crystallines consist either of a series of carbonate gneisses, marbles, and calc-micaschists or of an assemblage of paragneisses to metagreywackes, quartzites, metasiltstones, phyllites to slates, depending on the nature of the succeeding series of the Tibetan Zone. There is clear indication that the basal parts of the Tibetan sedimentaries have become metamorphosed. From Nepal to Spiti the Early Palaeozoics have been converted into the Crystalline, whereas in the NW-Himalaya even the Triassic series are altered. Therefore no sharp boundary can be found between the Crystalline and the succeeding sedimentaries: The metamorphism decreases upwards and finally dies away. Therefore it should be stressed that the 5000–10.000 m thick crystalline complex does not represent a "Precambrian basement" of the Tibetan Zone as frequently referred to. Its polymetamorphic nature (FUCHS, 1967) is documented now by absolute age datings: Precambrian (BHANOT et al, 1977 a. b.), Assynthian-Caledonian (MEHTA, 1977), Caledonian (FRANK et al, 1976) and Alpine ages (KRUMMENACHER, 1966 and in BORDET et al, 1971, KRUMMENACHER et al, 1978; FRANK et al, 1976; MEHTA, 1977 and others). Granites formed predominantly before 500 m. y. and 20–15 m. y. The Alpine Granites are found in the nappes

(ANDRIEUX et al, 1976) as well as in the root zone and to the N of it (Mustang, Manaslu, Makalu, etc.). The fact that K/Ar ages are younging towards the M. C. T. is explained by the young age of this thrust and by the fact that denudation started from the top, keeping the deeper parts of the Crystalline a longer time at higher temperatures (KRUMMENACHER et al, 1978).

The Crystalline Nappes are transported to the S up to 100 km as documented by a series of outliers (Simla, Chor, Almora, Kathmandu, Darjeeling, Bhutan). Many of them are still connected with the root zone. Structurally the Upper Crystalline Nappe and the Tibetan Zone form one unit. Thus southern portions of the sedimentaries were transported on the back of the Upper Crystalline Nappe far to the S. Largest occurrences are the synclinoria of Kashmir and Chamba. There the high-grade crystallines are thinning out in the frontal parts of the nappe and the Tibetan sedimentaries come in tectonic contact to Lesser Himalayan units (Chail Nappes) (Pl. 1, section 1).

Minor occurrences of beds of the Tibetan Zone S of the Great Himalaya are Jaljala Dhuri (FUCHS & FRANK, 1970), Kathmandu (BORDET et al, 1960), Thang Chu (GANSSER, 1964).

2. The Tibetan Zone (s. l.)

a) Stratigraphy

The following review of the sedimentary development deals with the Tibetan Zone (s. s.) N of the Great Himalaya as well as with the Synclinoria of Kashmir-Chamba S of this range:

Precambrian-Ordovician: trough deposits several thousands of meters thick, monotonous, partly of flyschoid character; sedimentation was frequently rhythmic. The Dogra Slates, Early Palaeozoics of Kashmir, Haimantas, Martolis, Sangsing La Series are argillaceous-arenaceous; impure carbonate series are Garbyang, Shiala, Dhaulagiri Lms., Larjung – and Nilgiri Lms.

Spiti is an exception, where the Middle Cambrian Parahio Series is overlain by the Ordovician basal conglomerate and red quartzites with angular unconformity (HAYDEN, 1904, own observation); the succeeding Ordovician-Silurian consists of arenaceous, silty, and carbonate beds.

Silurian (several hundred meters): There are two facies: Dark graptolite shales, siltstones, and carbonates (e. g. Kashmir – Spiti, Nilgiri – Annapurna in Nepal). Red, green, grey shales, marls, and limestones (e. g. Kumaun, western Dolpo).

Devonian: Three facies: *Flysch type* (1000 m) are Tanols of Kashmir-Chamba, Tilicho Pass Fn. (Nepal); dark carbonates and shales form the base of the Nepal sequence (BORDET et al, 1971). Shallow-water *carbonate-quartzite* facies composed of grey dolomites, blue limestones, and quartzites (Muth Fn., 1000 m, Kumaun, western Dolpo). *Muth Quartzite* mainly terrigeneous (plants) with rare dolomite beds (Kashmir, Spiti-Kumaun).

Carboniferous: Lower Carboniferous (250–350 m): Dark limestones and shales (occasional arenites) (Syringothyris Lms., Lipak S., Tilicho Lake Fn.).

Upper Carboniferous (500–2000 m): Argillites, quartzites, conglomerates (Fenestella Sh.) partly with flyschoid portions and tillites (Agglomeratic Sl., Po

Series, Chulu Fn. [COLCHEN in BORDET et al, 1975]). In the NW-Himalaya the Panjal volcanism starts with the Upper Carboniferous and may be active locally up to the Triassic (WADIA, 1934).

Permian: In certain regions there is a gap beneath the Permian (Spiti, Kumaun, Dolpo) or below the Agglomeratic Slate (western Kashmir, WADIA, 1934) indicating Hercynian movements as does the Panjal volcanism. Terrestric beds (Gondwana [Gangamopteris] beds, parts of Thini Chu Fn.) are interstratified with marine shales, sandstones, quartzites, and limestones (Zewan S., Kuling S., Thini Chu Fn., 50–400 m). Tilloids in the Lachi Series (WAGER, 1939) point to Gondwana influence. A small lacuna comprising the uppermost Permian is indicated in Spiti and Dolpo.

Scythian (20–40 m): Well-bedded, light grey to blue, dense ammonite limestones and grey shales.

Anisian – Lower Noric: Dark limestones, marls, and shales (Daonella Sh., Daonella Lms., Grey Beds, Tropites Lms. of Spiti, [<700 m]; Kalapani Lms. [<50 m], Mukut Lms. [<300 m] etc); arenaceous-silty beds are subordinate (Kashmir, Tropites Lms. of Spiti).

Noric: In Kashmir-Zanskar a thick alternation of dolomites, limestones and shales (<800 m); in Spiti- Kumaun (<500 m): Silty shales with limestone intercalations (Juvavites-, Monotis Beds of Spiti; Kuti Shales); in W-Nepal (<500 m): Shales and siltstones (Tarap Sh.).

Rhaetic – Dogger (300–700 m): Shallow-water succession seems to be constant from the NW- to Nepal Himalaya: Quartzite Beds – Kioto (Jomoson) Limestone – Lumachelle Formation – gap – ferruginous limestone (Sulcacutus Beds).

Malm – Neocomian: Dark shales and siltstones (<100 m, Spiti Sh.) overlain by sandstones, quartzites, and shales (150–500 m, Giumal Sst.).

Mid-Cretaceous: Light grey pelagic limestones (30–50 m, Chikkim Lms.).

Upper Cretaceous: Shales (50 m, Chikkim Sh.), silty shales and siltstones (400–600 m, Kangi La Flysch; subdivision a) of Upper Flysch, HEIM & GANSSER, 1939, p. 147).

Late Maestrichtian shallow-water limestones of Zanskar (FUCHS, 1977; METZELTIN & NICORA, 1977; GAETANI et al, 1980) (Cretaceous and Tertiary parts 200–400 m total thickness).

Early Tertiary: The above benthonic limestones pass into the Paleocene; the sedimentation of the Zanskar Basin ends with several hundred meters of unfossiliferous purple and green shales and siltstones (Eocene?). This sequence was observed in south-western Zanskar; northern Zanskar forms a separate unit linked with the Tibetan Zone and the Lamayuru Unit of the Indus Zone. Zanskar presents an extensive and complete Cretaceous-Early Tertiary succession, which can compete with the famous occurrences of Kampa Dzong and N Jolmo Lungma region in Tibet (HAYDEN, 1907; MU et al, 1973).

The *Miocene granite* intrusions in the Tibetan Zone (e. g. Mustang, Manaslu, Makalu etc.) noticed in chapter IIC1 produced contact metamorphism in the adjoining beds of the Tibetan Zone.

b) Structure:

The tectonics of the Tibetan Zone (s. s.) and the Kashmir and Chamba Synclinoria are not as complicated as those of the Lesser Himalaya. Fold structures are characteristic and the vergency is frequently varying SW or NE. Large back folds are observed in the northern Dhaulagiri and Nilgiri Ranges. Reverse faults are frequent where formations consisting of rigid and soft material join each other. Like the folds the direction of these movement may be either SW or NE. In certain areas, however, the folds are altogether directed SW (Zanskar) and imbrication occurs (Kumaun). Higher nappes overriding the Tibetan Zone have caused these exceptional structures.

Transverse faults younger than folding made the Thakkhola graben in northern Nepal (HAGEN, 1959, 1968).

3. The Indus Zone

It is a complex belt consisting of several tectonic units: The Northern Zanskar Unit, Lamayuru Unit, Dras Unit, Indus Flysch and Indus Molasse. Along the boundaries of these units ophiolitic melanges (GANSSER, 1974) and larger peridotite masses are found.

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

Northern Zanskar, one of the riddles of Ladakh, came closer to understanding by the find of a Campanian fauna in the multicoloured limestones by BASSOULLET et al (1978b), the determination of my samples from the Spongtang Lamayuru Formation as Maestrichtian by R. OBERHAUSER, and my regional survey of western Zanskar.

α) Stratigraphy

The Triassic-Jurassic carbonate platform resembles the Tibetan Zone, but is poorer in argillites. The transgressing Giumal Sandstone (L. Cret.) and overlying Chikkim Limestone (Mid-Cret.) are thinning out towards the N. The multicoloured limestones, marls and slates are several hundred meters thick in the range bordering the Lamayuru belt. They interfinger with the Lamayuru Formation in the N and thin out towards the S. BASSOULLET et al found an Upper Campanian fauna in the rocks of this pelagic sill facies, which thus is comtemporaneous with the Kangi La Flysch S thereof. Hence the latter is not related to the Indus Flysch in the N and received its terrigeneous material from the S. The succeeding complex of thick dark silty shales, regarded by me as Lamayuru Unit (FUCHS, 1979) yielded Maestrichtian foraminiferas (*Globotruncana arca* (CUSHMAN), *Gltr. stuarti* (LAP.), *Pseudotextularia* sp. and Globigerinas det. kindly by R. OBERHAUSER, Geol. B.-A., Vienna). Thus the flyschoid euxinic Lamayuru sedimentation extended towards the S in the higher Upper Cretaceous, and overlapped the northern portions of the Zanskar platform – an indication of subduction. This basin facies is followed by 20–30 m of ferruginous quartzites passing upwards into about 100 m of U. Paleocene foraminiferal limestones*. Grey shales

* Prof. Dr. L. HOTTINGER (Palaeontology Inst., University Basle) kindly determined the foraminiferas of my samples.

with occasional nummulitic beds (<100 m) follow. LA TOUCHE (1888) first reported about these Eocene beds. Thus the ,,Shillakong Unit" (BASSOULLET et al, 1978a, 1980) forms *one stratigraphic* sequence with my "Lamayuru Unit" (FUCHS, 1979) of Spongtang. Now the Lamayuru Formation immediately underlying the Dras Unit of the Spongtang Outlier only is regarded as Lamayuru Unit. The stratigraphy of the Northern Zanskar Unit thus shows distinct individuality: The Lower to Middle Mesozoic platform carbonates are similar to those of the Tibetan Zone, the Cretaceous is distinct by the Campanian multicoloured limestones and slates and the Maestrichtian black flyschoid shales.

β) Structure

The Northern Zanskar Unit overthrusts marginally the Tibetan Zone, but is of parautochthonous nature. This thrust is difficult to locate where Triassic-Jurassic carbonates border on both sides. Under the influence of the higher nappes the Cretaceous-Eocene succession is somewhat sheared off from its carbonate base and is enriched in the frontal portions of the unit (Pl. 1 section 1). Compression younger than the nappe tectonics produced the vertical folds and wedges of northern Zanskar.

b) The Lamayuru Unit.

This unit is composed of thick series of dark argillites, siltstones, locally interbedded with dark limestones or sandstone layers. The much disturbed Lamayuru Formation yielded rare fossils indicating Triassic-Jurassic age (FRANK et al, 1977, p. 101; FUCHS 1977; 1979, p. 517–518). It is probable that the formation ranges up into the Upper Cretaceous like the Lamayuru Formation of the adjoining Northern Zanskar Unit, but this is not yet proved. In the flyschoid euxinic formation there are klippes of Kioto Limestone, multicoloured limestones (Camp.) and close to the terminating ophiolitic melanges Permian-Triassic limestones (BASSOULLET et al, 1978c) quartzites, and serpentinites; some of these klippes are sedimentary intercalations, some have slumped into the basin, or are of tectonic origin.

In the Spongtang Outlier the Lamayuru Formation between the Eocene series of the Northern Zanskar Unit below and the Dras Unit above represents the Lamayuru Unit. Where the Paleo-Eocene is missing, distinction from the Lamayuru Formation of the Northern Zanskar Unit is difficult (eg. Photaksar, Spongtang). In the type area, the root zone, the Lamayuru Unit dips SW beneath the Northern Zanskar Unit and overlies the Dras Unit due to the total inversion of the Indus Zone.

After my survey of western Zanskar I should like to reinterprete the observations of HEIM & GANSSER (1939, p. 147): Subdivision b of the ,,Upper Flysch" very much recalls the Campanian multicoloured limestone-slate succession of Zanskar and c the "black flysch" resembles the Lamayuru Formation – probably representing the Maestrichtian portion of it. Whereas the named beds are stratigraphically connected with the underlying sequence of the Tibetan Zone, the upper parts of the black flysch, particularly those associated with various limestone klippes, appear to represent the Lamayuru Unit (p. 163, figs. 132, 133). The black argillaceous series of the Shinglaptsa area (p. 167–168, taken as Spiti Shales) suggest to be Lamayuru Unit. The same holds for the black shales of Jungbwa (upper part of Raksas Series, p. 169); the underlying flyschlike argillaceous-arenaceous series (f. in section 9c, Pl. V) might correspond with the Kangi La Flysch, e with the Giumal Sandstone; c and the Chilamkurkur series probably correlate to the Triassic carbonates of northern Zanskar. Very much interesting is GANSSER's remark (1939, p. 171), that the Chilamkurkur series on the Sutlej suggests a reversed position and that black flyschoid slates are underlying there. This recalls the situation in the Mulbekh-Lamayuru belt, where the Lamayuru Unit is overlain in the S by the carbonate series of the Northern Zanskar Unit – also in a reversed position. In fig. 143 and GANSSER (1964, Pl. A) SW-dipping flysch rests on the Chilamkurkur series; both may form a stratigraphic Triassic-Upper Cretaceous sequence.

GANSSER (1976) also stresses the analogy between SW-Tibet and Ladakh, but not in respect to the Lamayuru Unit. The above thoughts may seem speculative, my intention, however, is to show that the Lamayuru Unit is represented in SW-Tibet and thus forms a regional structural element.

c) The Dras Unit

It consists of basic to intermediate volcanic series and minor intrusions of varying composition in the type area (WADIA, 1937) and western Ladakh. To the SE Cretaceous flysch becomes predominant (GANSSER, 1976, FRANK et al., 1977). Ophiolitic melanges with klippes of various limestones with radiolarites, serpentinites etc. separate the Dras Unit from the Lamayuru Unit in the S and from the Indus Flysch (s. s.) in the N. In the Spongtang Outlier Dras Volcanics, Flysch, and "wildflysch" overlie the Lamayuru Unit after ophiolitic melange. The wildflysch mentioned contains various limestones of km-dimension down to cm-sizes forming a huge breccia (Photak La).

In the Kiogar region (Kumaun [HEIM & GANSSER, 1939]) the basic igneous rocks, related flysch, and exotic Permian to Liassic klippes (GANSSER, 1974: Kiogar Nappe) between the underlying "black flysch" and the peridotites at the top (Jungbwa Nappe) can be correlated with the Dras Unit and the terminating ophiolitic melanges. On the basis of the scanty literature on Tibet and by the aid of satellite imagery GANSSER (1976, 1980) intends to locate the Indus Suture Zone further E in Tibet.

Towards the W the Dras Unit continues in the Belt of basic rocks (amphibolites) N of the Kohistan Line (DESIO, 1979; DESIO & SHAMS, 1980), also called the Main Mantle Thrust (M. M. T.) by TAHIRKHELI et al (1979).

d) The Indus Flysch

It consists of flyschoid shales and sandstones, tuffs, volcanic breccias, and basic effusiva. Intercalated fossiliferous limestones of Mid-Cretaceous age (Khalsi) are contemporaneous with the volcanism (GUPTA & KUMAR, 1975; FUCHS, 1979). The Indus Flysch, which is much tectonised, is separated from the Dras Unit as well as from the Indus Molasse by ophiolitic melanges (GANSSER, 1976; FRANK et al, 1977). The age of the Indus Flysch (s. s.) and of the Dras Volcanics and -Flysch is Middle to Upper Cretaceous (Early Tertiary) and it is questionable how far the two units are separable outside of the Khalsi area.

In the Spongtang Outlier (FUCHS, 1977, 1979, BASSOULLET et al, 1978a) and in southern Tibet (HEIM & GANSSER, 1939, GANSSER 1964, 1976) extensive masses of *peridotite* (harzburgite-lherzolite) are the highest unit (Jungbwa Nappe). They are derived from the ophiolitic melanges of the Indus Suture Zone either from between Dras Unit and Indus Flysch (s. s.) or from the boundary of the latter to the Indus Molasse. The horizontal displacement, about 30 km in Ladakh, reaches even 80 km in Tibet. The mentioned occurrences are evidence that the units of the Indus Zone (s. l.) were thrust far to the S onto the Tibetan Zone. In the Indus Zone, however, the dip of the beds and of all the thrust planes is S or SW. There the whole pile of tectonic units has become inverse by late compression: The Northern Zanskar Unit (now highest) – Lamayuru Unit – Dras Unit – Indus Flysch – Indus Molasse (now lowest). Counterthrusts directed NE were formed, partly using the boundaries of older SW vergent nappes (FUCHS, 1977, 1979).

The rocks of the Indus Zone may show low-grade metamorphism, in ophiolitic melanges blue schist alteration was observed (FRANK et al 1977, p. 194; S. KUMAR 1978), which fits well with findings in the Kohistan Belt (DESIO & SHAMS, 1980).

e) The Indus Molasse

It was recognised by A. P. TEWARI (1954) as a thick sequence of continental molasse sediments, which transgress on the Ladakh Intrusives in the N and are tectonically separated from the Indus Flysch in the S. The Oligocene (?) to Miocene molasse consists of thick-bedded conglomerates, pebbly sandstones and silty shales, frequently bright coloured red, green, and beige. According to FRANK et al (1977) the pebbles are mainly derived from the underlying Ladakh Intrusives, acid volcanites from further N, and subordinate carbonates of up to Lower Middle Eocene age. These authors discern a transgressive northern belt from a southern wedge (Hemis Conglomerates). S of Kargil (Chaskor, Lomba) I found the Indus Molasse transgressing on Dras volcanics, from which most of the pebbles are derived. Later it was overthrust towards the W by these volcanics (younger tectonics!).

In the E the Kailas Molasse (HEIM & GANSSER, 1939, GANSSER, 1976, 1980) up to 4000 m thick, resembles the Indus Molasse very much. It also transgresses on granitoids, the Transhimalayan pluton, and shows similar pebble content.

Though the Ladakh- and Transhimalayan plutons do not belong to the proper Himalaya a few words are needed: Their composition is tonalitic contrasting with the potassium rich granites of the Himalaya (FRANK et al, 1977). Age datings referred in GANSSER (1980, p. 46) and the data of BROOKFIELD & REYNOLDS (1981) and ANDREWS-SPEED & BROOKFIELD (1981) infer that the main phase of intrusion was Paleocene-Eocene and possibly younger.

N of the Ladakh batholith there is another suture zone along the Shyok, which splits off from the Indus Suture Zone E of the Nanga Parbat Spur, SHARMA & GUPTA (1978) give some information about that little known belt.

III. The Evolution of the Himalaya and Problems related

After the brief characterisation of the main structural units I shall try to develop a picture of the evolution of the Himalaya. Numerous are the views of the various workers and on some problems they are rather divergent. Space of this paper does not allow a full discussion and thus the following account is somewhat tentative.

A) Himalayan Geosyncline versus Platform, Caledonian Orogenesis

To deal with the *geosynclinal stage* is already a problem, because a series of workers deny such a stage except for the units of the Indus Zone (e. g. GANSSER, 1964, 1976, 1980; LE FORT, 1975; COLCHEN, 1975; STÖCKLIN, 1980; a. o.). They regard all the Himalaya including the Tibetan Zone as belonging to the Indian continent, which is marginally covered by platform sediments. The greater part of the Lesser Himalayan sequence is correlated with the Vindhyans, and cross-structures (NE-SW) are explained as continuation of the Aravallis of the Peninsula. Contrary I always stressed that there was a *geosyncline,* at least in the Late Precambrian – Early Palaeozoic, where typical trough sediments were deposited in the Lesser and the Tibetan Himalayas (Simla-, Dogra Slates, Haimantas, Martolis, etc.). This type of sediments is missing in the adjacent peninsular region and they mark a trough parallel to the northern margin of the Indian continent (FUCHS, 1967, VALDIYA, 1970).

When did this geosynclinal stage end? The fossiliferous sediments of the Tibetan Zone give the answer: It was in the Cambrian to Lower Devonian, indicating a *Caledonian event:* A marked *angular unconformity* in Spiti, Ordovician conglomerates and quartzites transgress after an Upper Cambrian gap (HAYDEN, 1904; own observation); the hitherto rather uniform sedimentary development becomes *diversified* with the Silurian and particularly the Devonian: Lesser Himalaya and Tibetan Zone, and also within the latter (e. g. multicoloured Silurian – dark graptolite beds; Muth Quartzite-Tanol-Tilicho Pass Fn. [Flysch]). The Agglomeratic Slates (Up. Carb.) transgress on Lower Palaeozoics of Kashmir (WADIA, 1934).

After this Caledonian event sedimentation in the Tibetan Zone was of *platform* type, but not always and everywhere: The Devonian Tilicho Pass Fn. (Nepal), the Tanol-Agglomeratic Slate sequence of Kashmir, the slate complex underlying the Agglomeratic Slates of Chamba (FUCHS, 1975) show flyschoid features; the Noric of Spiti-Kumaun-Dolpo indicates strong terrestrial silty influx in the Tethys basin, and particularly the Tarap Shales are flyschoid (FUCHS, 1967, 1977a); the Spiti Shales also represent a basin facies. Further it is of interest that a comparison of the Middle to Upper Palaeozoics of SE-Kashmir-Chamba with the Tibetan Zone shows deepening towards the S.

Thus the platform sedimentation was intertonguing with basin facies and for such a transition zone the term *miogeosyncline* appears to be appropriate.

In the above considerations the Lesser Himalayan successions were not touched as their age is another problem. Whatever their age may be, their facies development clearly indicates basin configuration with sills parallel to the strike of the present Himalaya (FUCHS & FRANK, 1970). Also the type of sediments indicates a basin, though this probably was continental and of shallow water depth. The subsidence, however, was considerable to produce the thousands of meters of Chail-Dalings, Chandpurs, Nagthats or Shali Dolomites.

B) Age of Lesser Himalayan Succession

Concerning the *age* there are three standpoints favoured:

a) The Chandpur (Chail) – Krol (Shali) sequence is Palaeozoic (PASCOE, 1959; FUCHS, 1967, 1975; PANDE & SAXENA, 1968 a. o.)
b) The above succession is Precambrian (FRANK in FUCHS & FRANK, 1970, a. o.)
c) Chail-Shali is Precambrian, Chandpur-Krol is Palaeozoic-Mesozoic (GANSSER, 1964; VALDIYA, 1964, 1976, 1978; SINHA, 1975, 1977; STÖCKLIN, 1980 a. o.).

a) Arguments are: Correlation of the basal geosynclinal series to the Precambrian – Lower Palaeozoic deposits of the same type in the Tibetan Zone. Resemblance between the Chandpur – Chail (Berinag) – Tanol and the Mid-Palaeozoic Muth Quartzite – Tanol of Kashmir – Chamba; Tanols, which are overlain by Tanakki (Blaini) – Sirban (Shali) sequence in Hazara interfinger with Siluro-Devonian beds in the Indus area (FUCHS, 1975). Correlation of the non-fossiliferous Lower Himalayan boulder beds (Blaini, Tanakki) to glacial beds of fixed age (Talchir of Salt Range, Damudas, Agglomeratic Slate, Po Series, northern Nepal [BORDET et al, 1975], Lachi Series [WAGER, 1939]). Lithologic resemblance of Talchir – Productus Limestone (Salt R.) to Blaini – Krol. Close connection of Baxa (Shali) and Damuda in eastern Himalaya (ACHARYYA et al 1975; V. K. RAINA, 1976). GUPTA & VIRDI (1978) refer all the fossil finds in the Lesser Himalayan succession indicating a Phanerozoic age; some of them are certainly anorganic or doubtful, the rest, however, is proof against Precambrian age.

b) VALDIYA (1969) correlates the Shali-Deobans with the carbonates of the Vindhyans on the basis of stromatolites. Frequent stromatolites are taken as leading fossils for Precambrian (Early Palaeozoic) age in otherwise non-fossiliferous series (GANSSER, FRANK, SINHA, a. o.). Lithologic similarities of Lesser Himalayan with Precambrian series (red quartzites, tillites, algal dolomites etc.). Passage from Simla Slates into Blaini of Simla is proof against Upper Palaeozoic age. Radiometric ages of rocks from the Chail complex have given Precambrian ages (e. g. FRANK et al, 1976). MOSTLER (in FUCHS & MOSTLER, 1972) stresses a Cambrian age of the fossils found in the Hazira Formation of Hazara, which implies a Precambrian or Early Cambrian age of the underlying Sirban (Shali) Dolomite.

c) On the basis of stromatolites Shali-Deoban is designated to Precambrian-Early Palaeozoic and the Blaini-Krol sequence is regarded Upper Palaeozoic-Mesozoic because of the glacial horizon and fossil references.

From the experience in the many areas I have worked I must discard hypothesis c), because the sequence of lithounits is almost indentical in the Krol- and Shali belts. The two thick carbonate formations, Shali and Krol, have never been observed in one stratigraphic section. The stromatolite facies occurs locally also in Krol (e. g. Naini Tal FUCHS & SINHA, 1974; Tansing FUCHS & FRANK, 1970). Repetition of carbonate formations in the Chail Nappes (inner carbonate belt) are due to tectonics. This may be doubtful in a limited area, but is evident from regional mapping.

Thus hypotheses a) and b) remain and the age problem is still unsettled. I am inclined to favour a) because it is easier in Palaeozoic formations to explain the occurrence of fossils suggestive of Precambrian to Early Palaeozoic age (reworking etc.) than the reverse.

C) Age of the Crystalline Complex

The passage into the succeeding formations of the Tibetan Zone, up to different levels, gives clear evidence that the Crystalline does not represent a Precambrian basement. My view (1967) that Caledonian elements are important in the Crystalline was mainly based on sedimentary development (see IIIA). First support from physical age determinations was given by JÄGER et al (1971) (Mandi granites, 500 ± 100 m. y.) But it is argued that granite intrusions are not proof for an orogenesis.

In the meantime FRANK et al (1976) examined series of granite-gneisses from the Central Crystalline and all cluster around 500 m. y. (Rb/Sr whole rock.). These granitoids, however, particularly the augen gneisses are concordant granites without sharp contacts, passing into the surrounding migmatites. This is the type of granite which formed *during regional metamorphism,* not in "cold" environment.

The strong Alpine metamorphism, which is responsible for the young K/Ar ages (KRUMMENACHER, 1966; BORDET et al, 1971; FRANK et al, 1976; KRUMMENACHER et al 1978 a. o.), apparently was not able to homogenise the old granitoids and their migmatites. Thus the Crystalline is to be regarded *polymetamorphosed,* but, surprisingly disequilibrium is rarely noted in the mineral assemblages.

D) Alpine Orogenesis in the Himalaya

Recent work in Ladakh gives new information regarding the orogenic development: In the Tibetan Zone (Zanskar) the *Triassic* to *Dogger* carbonate sedimentation is of platform type, followed by a short phase of deepening (Spiti Shales) in the *Upper Jurassic.* The *Lower Cretaceous* Giumal Sandstone signals first motions (increase of sand content, flysch character). With the beginning of the *Mid-Cretaceous* the flysch sedimentation starts in the Dras-Indus Zone and lasts into the Early Tertiary. It is accompanied by volcanism, which produces thick lavas and pyroclastics of mainly basic composition. The eugeosyncline (Lamayuru basin) between this volcanic-flysch belt in the N and the Tibetan platform in the S is free of volcanism. There the sedimentation of dark argillites with silty-arenaceous or calcareous beds persists throughout the Mesozoic. With the Maestrichtian the basin facies overlaps also the northern parts of Zanskar indicating subduction in the Indus Zone.

The *Upper Mid-Cretaceous* Chikkim Limestone is deposited under quiet pelagic conditions. The succeeding Kangi La Flysch *(Campanian – Early Maestrichtian),* however, indicates a disturbance. This basin facies is confined to the southern Zanskar Synclinorium and received its detritus from the S, because in the N, adjoining to the Lamayuru eugeosyncline, a sill exists with pelagic calcareous-argillaceous sedimentation (multicoloured series, Campanian according to BASSOULLET et al, 1978b).

The *Late Maestrichtian* is marked by a regression in southern Zanskar: Benthonic limestrones follow the Kangi La Flysch and persist up into the Paleocene (GAETANI et al, 1980). The Campanian sill facies of northern Zanskar is overlapped from the N by Maestrichtian silty shales of the Lamayuru Formation. With the *Paleocene* the marine sedimentation ends in the Tibetan Zone, the purple and green silty shales and sandstones following may represent a non-marine facies of the *Eocene*. In the Northern Zanskar Unit the euxinic basin facies ends: U. Paleocene shallow-water foraminiferal limestones transgress on the black argillites with basal quartzites. The Eocene regression concerns the Tibetan Zone as well as the Northern Zanskar Unit N thereof. After the *Lower Eocene* the nappes of the Indus Zone are thrust towards the S. The Tibetan Zone is folded and marginally overridden by the Northern Zanskar Unit. The Lamayuru- and Dras Units and peridotite masses form nappes and are thrust onto the Zanskar Synclinorium. According to MU et al (1973) the marine history ends with the Middle Eocene also in Tibet. Ophiolitic melanges separate the named units showing that the tectonic planes reached down to the mantle. The mentioned units are the remains of a squeezed ocean basin.

Subduction along the Indus Suture leads to the anatexis of oceanic crust and the Up. Cretaceous-Eocene intrusion of the Ladakh batholith (GANSSER, 1964, 1976, 1980; POWELL & CONAGHAN, 1973; LE FORT, 1975; FRANK et al 1977; ANDREWS-SPEED & BROOKFIELD, 1981 and others). The deposition of the Indus Molasse starts after this orogenic phase.

The *Mid-Miocene* orogenic phase brings additional compression to the Indus Zone. N of the Spongtang Outlier the pile of nappes is steeply folded and faulted, the sequence of units becomes inverted in the Indus Zone and thrusts are directed NE using the old inverted thrust planes. The Indus Molasse too is involved in these and later movements.

The scene of nappe movements, however, is shifted to the S: the Crystalline Nappes form by subduction of the Lesser Himalayan units (LE FORT, 1975) or overthrusting of the Crystallines (FRANK et al, 1973, 1976). In both models to explain the reversed metamorphism, the Crystalline is considered to be in state of active high-grade regional metamorphism. The thermal peak was between 30 and 40 m. y.; cooling ages of about 16 m. y. are interpreted by FRANK as rapid cooling of the heated Crystalline Nappe in contact with the cooler units overthrust. LE FORT (1975), ANDRIEUX et al (1976) hold the view that the Alpine granites of the High Himalaya (Manaslu, etc.) as well as those in the frontal parts of the Crystalline Nappe (Mahabharat Lekh) formed by anatexis close above the Main Central Thrust (M. C. T.). ANDRIEUX et al (1976) consider mineral ages of 26–22 m. y. to indicate the end of the Himalayan metamorphism and of the overthrusting of the granites.

The Crystalline Nappes override the Lesser Himalaya not earlier than *after the Lower Miocene,* because beds of this age are the youngest formations exposed in the windows. Under the pressure of the overthrusting Crystalline Complex nappes formed from the northern portions of the Lesser Himalayan basin (Chail Nappes, Rukum Nappe). Some units remained parautochthonous (lowest Chail units) and particularly the southern parts of the Basin (Krol Belt). The Miocene phase responsible for the nappe movements in the Lesser Himalaya produces the foredeep where the Siwalik molasse is deposited in the *Mio-Pliocene*.

In the *Pleistocene* the Siwalik Zone is folded and overridden by the inner parts of the Himalayan orogene – the Main Boundary Thrust (M. B. T.) forms. Along this plane the ready pile of nappes in the Lesser Himalaya is sheared off and moves "en bloc" some distance onto the molasse belt – not as a nappe. This later compression produces the folding of the nappes in the Lesser Himalaya: along the strike synclines form, where the outliers of higher nappes are preserved, and anticlines, where the windows are eroded. Deformation also crosses the strike giving rise to axial culminations and depressions. Locally the transverse tectonics are of a disruptive type and produce faults, cross-lineaments etc: Nanga Parbat uplift, Kishtwar-Kargil lineament, Almora, Thakkhola graben, Arun (see also GANSSER, 1976, map).

According to KALVODA (1976) the Pleistocene folding lifts the Great Himalaya by 4000–5000 m and forces the rivers, which since the Miocene had developped a system with the watershed close to Tibet, to cut through the growing range. The present relief is Quaternary in age. JAROS & KALVODA (1978) found a series of relief thrusts, which cut and displace the Quaternary relief in E Nepal. The zone of the Main Central Thrust and the Main Boundary Thrust are rejuvenated.

A series of characteristics of the landscape of the Himalaya are explained by this theory: The important and continuous ranges which rise just N of the Sub-Himalayan hills with steep southern slopes (Panjal-, Dhauladhar-, Krol-, Mussoorie-, Lansdowne-, Naini Tal-, Mahabharat Ranges); the most imposing example, however, is the Great Himalayan Range – the breath taking southern face of this icy barrier, overtowering the geomorphologically soft terrain of the Midlands by 5000–6000 m. These young Quaternary nappe tectonics underline the youth of this greatest of mountain chains.

E) The Himalaya and Global Tectonics

Most plate tectonists regard the Himalaya as result of continent to continent collision: The Indian Plate, a fragment of Gondwanaland, drifted northwards, collided with Asia, the Himalaya formed by this convergence, and the two continents welded. From palaeomagnetic data and oceanographic research in the Indian Ocean a fast northward drift of large magnitude of the Indian Plate is deduced for the late Mesozoic – earliest Cenozoic (LE FORT, 1975, KLOOTWIJK et al, 1979, KLOOTWIJK, 1980, a. o.). During the Cretaceous the Tethys Ocean between India and Asia started to close, and the Indus Flysch and basic volcanics belt came into being at the southern margin of the Asian Plate. The subduction of oceanic crust led to anatexis producing the intrusion of the Ladakh- or Transhimalayan plutons and the intermediate to acid volcanism N thereof (POWELL & CONAGHAN, 1973, 1975; FRANK et al, 1977; ANDREWS-SPEED & BROOKFIELD, 1981 a. o.).

Initial collision between India and the Ladakh magmatic arc occurred during Late Paleocene – Early Eocene and palaeomagnetic data suggest that between 55 and 38 m. y. both moved together about 10° of latitude northwards (KLOOTWIJK et al, 1979; KLOOTWIJK, 1980). BROOKFIELD & REYNOLDS (1981) dated an undeformed syenite among deformed Dras Volcanics with 82 ± 6 m. y. (^{40}Ar / ^{39}Ar) and therefore suggest that the nappe movements of the Indus Zone started as early as in the Late Cretaceous. Considering the consequences some doubt seems advisable: First it is an isolated measurement needing additional control by further data. Secondly a boss composed of a homogeneous syenite is more resistant against deformation than the surrounding volcanic series and thus may just appear to be undeformed. Anyhow the Northern Zanskar Unit and Tibetan Zone were overthrust by the Spongtang Klippe not pre-Maestrichtian, but after the deposition of the Eocene sediments of central Zanskar (see IIID).

The final intimate collision between India and Asia occurred about 38 m. y. ago (MOLNAR & TAPPONNIER, 1975). Post-collisional compression sheared off a northern marginal part of the Indian continent and this continental slab was underthrust along the Main Central Thrust (M. C. T.) (POWELL & CONAGHAN, 1973; LE FORT, 1975). The Lesser Himalayan nappe movements are post-Lower Miocene. In the Indus Suture Zone (GANSSER 1964; 1980: Himalayan Suture Zone) this or later compression produced the counterthrusts and the deformation of the Indus Molasse. According to LE FORT (1975) a new intracontinental shear zone, the Main Boundary Thrust (M. B. T.) became active further S in the Plio-Pleistocene. Thus from N to S successively younger subduction zones came into existence, while the older ones became inactive.

This southward migration of tectonic activity fits well with observations on *seismicity,* which is not very important under the northern Himalaya and the Tibetan Plateau and is restricted to shallow earthquakes (LE FORT 1975, p. 31, fig. 12). SEEBER et al (1980) point to the existence of a Detachment Thrust separating the sediments from their basement under the foreland and the Lesser Himalaya. The M. B. T. and M. C. T. are imbricate faults splayed off from the gently northward dipping master fault. Under the High Himalaya the dip of the fault increases and this portion is termed the Basement Thrust. This is the site of frequent earthquakes of generally low intensity, whereas the infrequent but great earthquakes, which cause devastation over wide areas, have their source in the S in the Detachment Thrust.

Seismic and gravimetric studies show that the continental crust has an average thickness of 30 to 40 km in the Indian Plate, thickens beneath the Himalaya to a maximum of 80 km, and a mean value of 60 km under the Tibetan Plateau (QURESHY cit. in LE FORT 1975, p. 31). LE FORT (p. 35) holds the view that not all the movement which may be deduced from sea-floor spreading of the Indian Ocean was consumed in the Himalaya. There was also crustal shortening and thickening in the Chinese Plate. POWELL & CONAGHAN (1973, 1975) explain the double thickness of the sialic crust under the Tibetan Plateau and its elevation by underthrusting of one continental block beneath the other. The width of underthrusting was 700 km NNE of Spiti, increasing to 1500 km NNE from E Nepal. It started after the Oligocene and lasted to Early Pleistocene. In a process of peeling off, the mantle beneath the Asian Continent was replaced by sialic crust of the Indian Continent. An isostatic response is the uplift by almost 5 km of the Tibetan Plateau proceeding from S to N. This model accounts for the palaeomagnetic data suggesting a convergence of India and Asia of approximately 2500 km 53 m. y. ago. Only half of this distance is consumed by the crustal underthrusting in Tibet.

Regarding the crustal thickness beneath Tibet there is no consensus: In contrast to the doubled thickness stressed by POWELL & CONAGHAN (1973, 1975), GANSSER (1980, p. 48) explains the enormous concentration of young volcanism in Central Tibet as a "hot spot", which implies an exceptionally thin lithosphere. The change from thick to thin lithosphere appears to coincide with the Indus Suture Zone.

POWELL & CONAGHAN (1975) give a review of the various plate tectonic models. Most Himalayan geologists believing in Global Tectonics will more or less agree with the plate tectonic development outlined above. Regarding the early development, however, there is disagreement. Palaeomagnetic data suggest that India has drifted from afar, from the southern hemisphere and that still in the Jurassic it was separated from Asia by a wide ocean. The affinities between the sedimentaries of peninsular India, the Himalayas, and southern Tibet made CRAWFORD (1974) envisage that the Tibetan Plateau was still a fragment of Gondwanaland. POWELL & CONAGHAN (1975) contest this argument with the remark that all the zones related to the Peninsula are situated S of the Indus-Tsangpo Suture, which is generally regarded as the continental boundary.

But there are also indications that facies and faunal affinities cross this suture zone. According to MU et al (1973, p. 110) there was a close interrelation between the Jolmo Lungma region (S of the suture line) and North- and Central China, particularly in the Palaeozoic. This affinity is difficult to explain by plate tectonists, and the problem is only partly settled if we assume a series of smaller plates, which have broken off from an older larger India and drifted northward to collide with ancient Eurasia (CHANG & CHENG, 1973). According to these authors each of these plates shows a migmatised southern margin, and is bordered by a flysch trough on the northern side associated with an ophiolitic belt. Successive accretion of these plates to Asia occurred in Caledonian, Hercynian, Indo-Sinian (Early Mesozoicum), Yenshanian (Late Mesozoicum), and Himalayan cycles. STÖCKLIN who correlates the tectonic zones of Iran to Central Asia came to similar conclusions (1977, 1980): The Central Domain comprising Tibet N of the Indus Suture Zone "can be conceived as a mosaic of Gondwana continental fragments" (1980, p. 30). They drifted northwards closing the Palaeo-Tethys and welded with Asia in a Late Triassic orogeny. Their separation from India opened the Neo-Tethys, which later was closed in the course of the Himalayan (Alpine) orogeny. STÖCKLIN assumes that the rifting, which led to the origin of the Neo-Tethys, started in the Late Palaeozoic (1980, p. 30).

STÖCKLIN's concept however, does not explain the close affinities between the Palaeozoics of the Himalayan region and of Northern and Central China (MU et al, 1973). In this respect it is of great interest that in the opinion of ANDREWS-SPEED & BROOKFIELD the Neo-Tethys might have come to existence by Late

Palaeozoic rifting of a *continuous continent* comprising India and Asia (1981). Oceanisation according to TOLLMANN (1978) has considerable influence on the generation of the Mediterranean Tethys. The theory that the Tethys Ocean came into being within *one* continental land mass, that the fragments separated under a process of rifting and later closed again, explains facies and faunal affinities between the involved continents, but seems to be inconsistent with the results of palaeomagnetic research. Concerning the width of the ocean separating India and Asia, GANSSER, a prominent advocate of plate tectonics, evaluates the distance to 5000–6000 km at the most (1976, p. 189). RICKARD & BELBIN (1980) suggest a revised assembly of continents in the Pangaea for the Mid-Palaeozoic, which „features no large Tethyan Ocean and consequently a more coherent pattern of Early Palaeozoic orogens" (p. 1). This model conforms with palaeomagnetic data according to these authors and explains facies and faunal similarities across the Indus Suture.

STÖCKLIN (1977, 1980) and GANSSER (1976, 1980) review the existing information about the vast and little known regions of Central Asia N of the Indus Suture: There are several platform- and geosynclinal zones, ophiolite belts of various ages and orogenic belts repeatedly reactivated.

But S of the Indus Suture Zone too the geology is complex. There ist not simply the Precambrian continent marginally covered by Precambrian to Cenozoic shelf sediments as advocated by the named authors, but an Early Palaeozoic orogenic belt parallel to the present Himalaya was attached to the Indian Shield, obliquely to the interior SW-NE-structure of the latter (Aravalli, Vindhyan) (FUCHS, 1967).

In view of this structural mosaic and the facial interrelations between certain units, the geologist gets an uneasy feeling when he has to locate a suture where continents welded, which still in the Jurassic should have been separated from each other by an ocean thousands of km wide, as suggested by palaeomagnetic data. In the Himalaya improved knowledge showed that a continental boundary can not be drawn within its major units. Similarly I expect that the more we know about the regions N of the Indus Suture, the more relations across this line will be found. This does not imply that the concept of subduction and closure of the Tethys Ocean along this suture was wrong, but the original distance of the continents was moderate compared to the drift distances envisaged by most plate tectonic reconstructions.

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Geologic-Tectonical Map of the Himalaya
compiled from literature and own observations by G. FUCHS, 1980
Scale 1: 2.000 000
Selected Sections across the Himalaya
Scale 1: 500 000
Heights slightly exaggerated
After HEIM & GANSSER, 1939
Published 1981
Graphik M. LEDOLTER
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
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
A F G H A N I S T A N
P A K I S T A N
I N D I A
T I B E T
N E P A L
B H U T A N
BANGLA DESH
BURMA