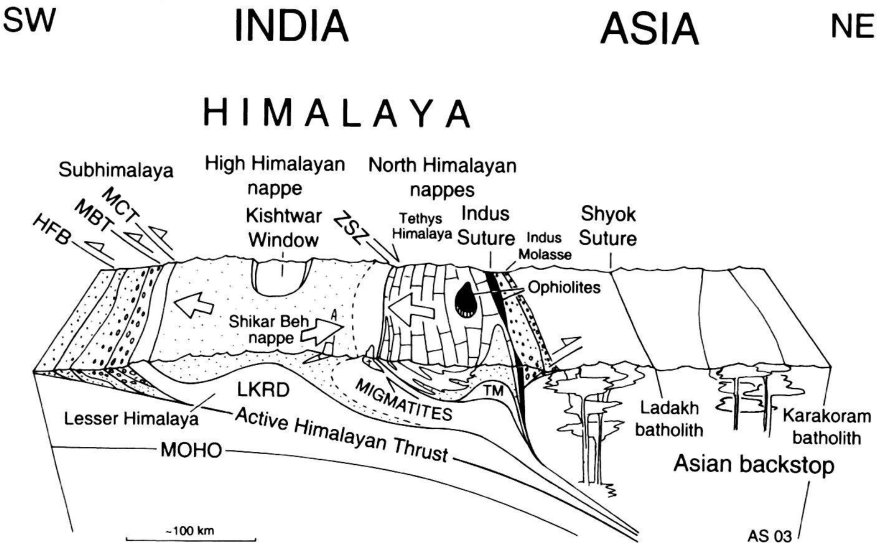

Fig. 1. The main tectonic units of the NW Indian Himalaya
HFB = Himalayan Frontal Boundary
LKRD = Larji-Kullu-Rampur dome
MBT = Main Boundary Thrust
MCT = Main Central Thrust
ZSZ = Zanskar Shear Zone

1. Introduction

In 1964, Gansser based his compilation, in form of a geological map, updated by Fuchs in 1981, at a scale of 1:2'000'000 and his famous monography on the Geology of the Himalaya, on the classical geological work produced by the Geological Survey of India and various international expeditions (Fig. 1). Tourism development during the seventies opened the still poorly known NW Indian Himalayan regions of Himachal Pradesh and Ladakh to new geological studies by American, Austrian, Australian, English, French, Indian, Italian and Swiss researchers.

Since 1979, geologists of the University of Lausanne have carried out a complete and continuous traverse across the Himalayan range between Leh, north of the Indus-Tsangpo suture, and Mandi at the southern border of the frontal thrusts of the High and Lesser Himalayan nappes (Fig. 2), using a multidisciplinary approach combining classical methods, such as geological mapping, stratigraphy, structural geology, petrography, with modern techniques, such as geochemistry, geochronology and thermo-barometry. The new geological data from the NW Indian Himalaya limited by the Ladakh batholith to the N, the Srinagar basin in Kashmir to the W, the Indus-Ganges molasse to the S and Tibet to the E, have been compiled on a geological map at a scale of 1:677'000 (Plate 1). The French Spot satellite images and the 1:250'000 U.S. Army map of India and Pakistan have been used as the topographical base and for toponyms.

The first part of this study describes the stratigraphy and magmatism of the Protolith of the Himalayan range in a chronological order and separately for the main tectonic units (Chapter 2, Fig. 3). The second part deals with the tectonic units, their emplacement and the related metamorphism, magmatism and synorogenic sedimentation. A tectonic model is presented in a concluding chapter.

2. Pre-Himalayan tectonics, sedimentation and magmatism

The Lesser Himalaya

The Lesser Himalayan units, the Lower Crystalline nappe, the Kishtwar, Larji-Kullu-Rampur units and their equivalent, the Chail nappes, the Jaunsar nappe and the Simla-Runkum nappe are composed of a Proterozoic sedimentary sequence deposited on the northern margin of Gondwana and are associated with, or intruded by 1'870-1'900 Ma S-type granites (Frank et al. 1995, Valdiya, 1995). The Ordovician granites, widespread intrusives in the High Himalayan Haimanta or Phe formation, are lacking. In Fig. 3 and 4, the author proposes a synthetic stratigraphic column ranging from early Proterozoic to an Eocambrian age, mainly based on review papers by Brookfield (1993), Frank et al. (1995, 2001), Miller et al. (2000), Srikantia & Bhargava (1998). This sedimentary sequence belongs to the northern part of the North and Central Indian Purana basin. No elements of its basement, the Archean Indian shield, has been observed in the Himalaya (Valdiya, 1995).

The Rampur Formation (Jhingran et al. 1952)
(Proterozoic)

The Rampur Formation is considered to be the basal and probably also oldest formation in the Himalaya. It consists of massive beds of white quartz-arenites alternating with thin layers of sericite and chlorite schists, locally associated with metarhyolites and metabasaltic dikes and lava flows (Rampur basic volcanics, 1'800 ± 13 Ma, U-Pb ages on single zircon, Miller et al. 2000). For Miller et al. (2000), it is not clear whether the Rampur formation quartzites are unconformably overlying the Bandal granitoid complex (Srikantia and Bhargava 1998, Sharma, K.K. & Rashid 2001) or whether the granitoids intrude these Quartzites (Sharma, V.P. 1977, Guntli 1993). The emplacement of silicic volcanites and of S-type per-

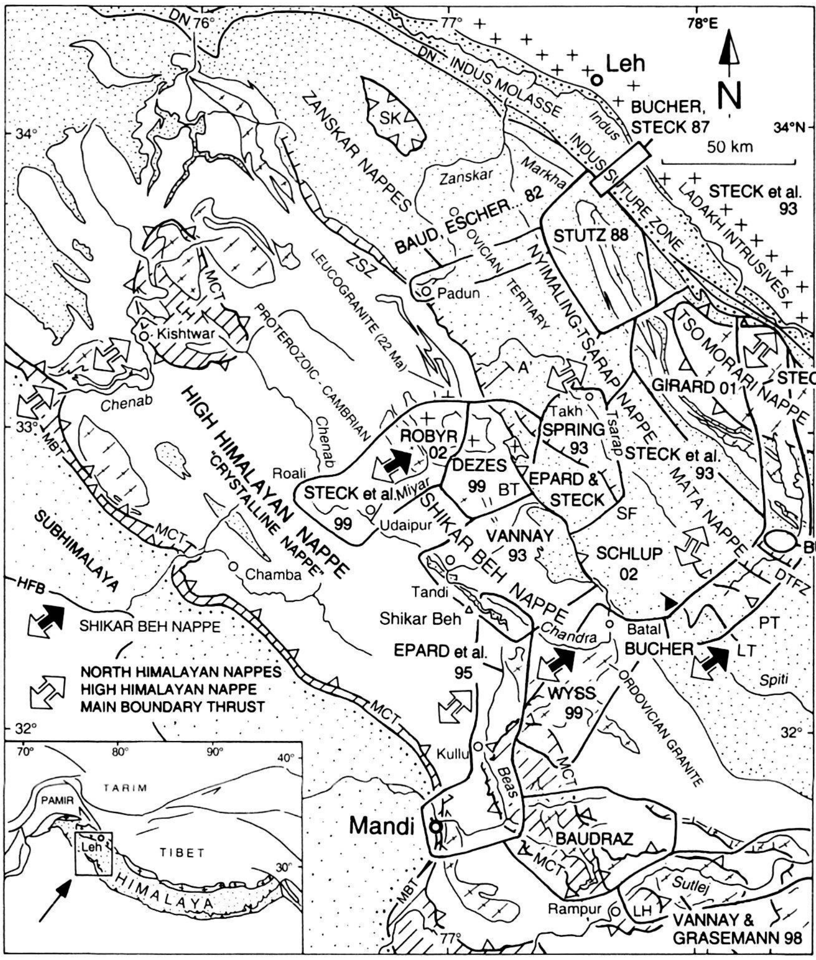

Fig. 2. Geological sketch map of the NW Indian Himalaya based on the area studied by geologists from the University of Lausanne since 1979. The compilation of other regions represented on the geological map (Plate 1) is mainly based on the work of earth scientists from Arizona, Grenoble, India, Milan, Poitiers, Oxford, Turin, Vienna and Zurich.

aluminous granitic rocks occurred around 1.86-1.84 Ga (Miller et al. 2000, Bandal and Sainj granite, Rampur window: 1'800 ± 70 Ma, Rb-Sr whole rock age of 4 samples, metarhyodacite, Rampur window: 1'840 ± 16 Ma, single zircon $^{207}Pb/^{206}Pb$ evaporation technique, Kober 1987, Klötzli 1997; Wangtu granitoid, Lesser Crystalline nappe: 1'866 ± 10 Ma, U-Pb zircon age by Singh et al. 1994). The striking similarities in terms of geological setting, geochemical characteristics and age between Bandal orthogneisses of the Rampur Fm. and the Wangtu Gneisses of the Lower Crystalline nappe suggest that they were formed under similar tectono-magmatic environment during the Paleoproterozoic period. The Rampur Formation represents a northern equivalent of the Aravalli crystalline.

Garsha and Berinag Formations
(Garsha Slates, Thöni 1977, Rampur Formation, Frank et al. 1995)
(Proterozoic)

The Garsha and Berinag formations are composed of quartzites and grey-green phyllites exposed in the Tons and Yamuna valleys and in the Simla klippe and are interpreted as lateral equivalents of the Rampur Formation.

The Shali Formation (Oldham 1888, Pilgrim & West 1928)
(synonyms: Sirban, Deoban, Tejam etc. Oldham 1888; Chail, Pilgrim & West 1928)
(Lower and Middle Riphean)

The Shali Formation, is a massive Mid Proterozoic carbonate platform up to 2000 m thick, composed of calcschists, blue-grey dolomite and limestone with stromatolites: *Kussiella, Collonella* and *Conophyton* of a early to middle Riphean age (Sinha 1972, Valdia, 1989, 1995). It forms the top of the older portion of the Lesser Himalayan sequence (Thöni 1977). In the Shali window, the limestones and quartzites of the Shali Formation are transgressed by the Eocene nummulitic limestones of the Subathu Formation.

The Simla Slates (Medlicott 1864, Pilgrim & West 1928)
(synonyms: Hazara Slates, Dogra slates, Wadia 1934)
(late Riphean-Vendian)

The late Riphean and Vendian Simla and Dogra Slates

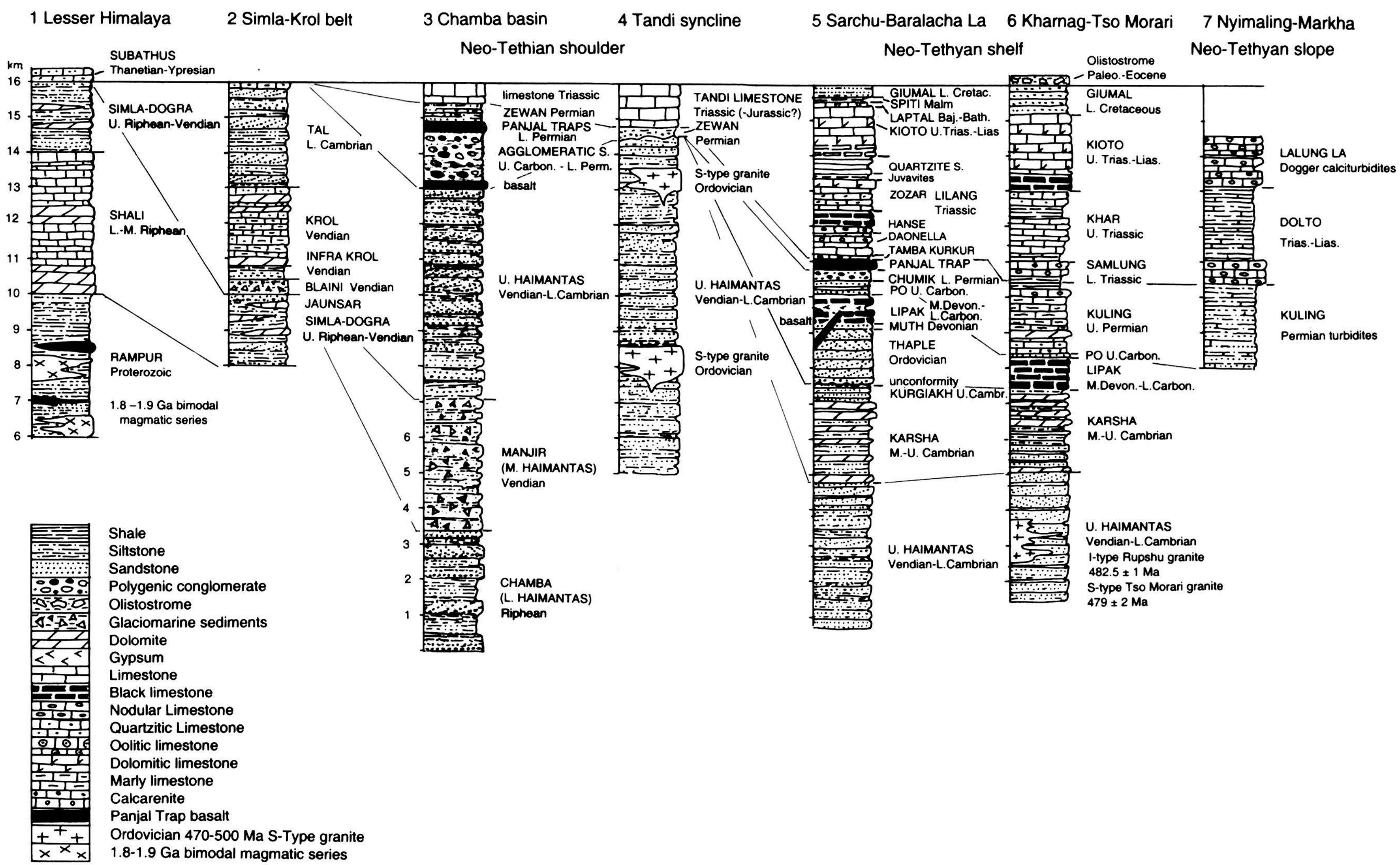

Fig. 3. Compilation of stratigraphic sections of the Lesser and High Himalaya based on stratigraphic sections as well as on biostratigraphic and radiometric ages by the following authors: Auden (1934), Azmi & Pancholi (1983), Bagati (1991), Bhatt et al. (1983), Bhatt & Mathur (1990), Brookfield (1993), Draganits et al. (2002), Frank et al. (1995, 2001), Fuchs (1975), Gaetani et al. (1990), Gansser (1964), Garzanti et al. (1986), Girard & Bussy (1999), Hayden (1904), Hughes & Jell (1999), Kumar et al. (1987), Miller et al. (2000), Pilgrim & West (1928), Ranga Rao et al. (1982), Rattan (1974, 1978, 1985), Spring (1993), Srikantia & Bhargava (1979, 1998), Steck et al. (1993), Stutz (1988), Stutz & Steck (1986), Tripathi et al. (1984), Vannay (1993).
Note that the Late Cretaceous Chikkim limestones are missing in these sections. Erosion relicts of the Late Cretaceous foraminiferal limestone are exposed near Takh on the Tsarap river and on the Chikkim mountain in the upper Spiti valley (Plate 1).

consist of over 1'000 m of grey, green, and dark slates, phyllites and siltstones, with locally a thin intercalation of a green limestone. In the Simla-Runkum nappe the nummulitic limestones transgress the Simla Slates.

The Jaunsar Formation (Jaunsar Series, Oldham 1883, Pilgrim & West 1928) (synonyms: Jagas, Nagthat, Auden 1934) (late Riphean-Vendian)

The Jaunsar Formation, called the Jaunsar Series by Pilgrim & West (1928), are composed of about 500 m of quartzites, slates of dark or light green-brown or brown colour, purple phyllites and conglomerates and a few intercalation of carbonaceous phyllites. Pilgrim & West (1928), distinguished in the Simla region the Jaunsar Series forming a thrust sheet between the Simla unit in the foot wall and the Chail unit in the hanging wall, where as Frank (personal communication) considers this series to be a concordant stratigraphic unit in the upper part of the Simla slates. Pant & Shukla (1999) interpret the correlative Nagthat succession as a progradational tide-dominated Proterozoic succession. After Valdia (1995) the paleocurrents in the Nagthat Fm. are mainly NE-directed.

The Blaini Formation (Pilgrim & West 1928) (Vendian)

The Blaini Formation is composed of up to 200 m of diamictite pebbly mudstone alternating with slates of a probable Vendian age (< 700 Ma, Rb-Sr ages on detrital micas, Wolfgang Frank, personal communication). The Blaini Formation rests on the Simla Slates with a clear unconformity (Pilgrim & West, 1928, Frank et al. 2001). These sediments are interpreted as glaciomarine sediments or tillites. Frank (1995) considered the Blaini Formation as a lateral equivalent of the Neo-Proterozoic Manjir Conglomerate of the Haimantas or Phe Formation of the High Himalaya. A thin layer of pink carbonates overlies the pebbly mudstones.

The Krol Formation (Auden 1934) (Vendian)

The Blaini boulder beds are stratigraphically overlain by about 170 m of the black fine-grained sandy slates of the Infra-Krol Formation and up to 1'500 m of limestone and dolomite of the carbonate platform of the Krol belt (Audin 1934, West 1939, Gansser 1964, and Sinha 1987). Stromatolites being the only macrofossils, a Vendian age (Wolfgang Frank, personal communication) is more probable than the Permo-Triassic ("Phanerozoic") age suggested by the above authors. Valdia's conclusion (1995), that the carbonates of the Krol Fm. represent a lateral equivalent of those of the Shali Fm., is not supported by other geologists.

The Tal Formation (Middlemiss 1887) (Early Cambrian)

The sediments of the Tal Fm. are restricted to the Nigali Dhar area. A striking change in deposition took place after the deposition of the calcareous Krol sequence, with the younger

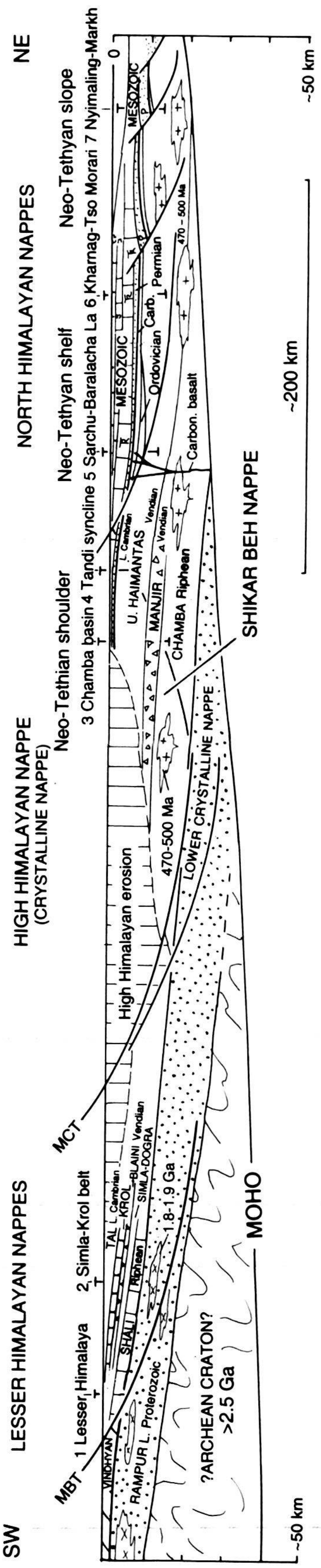

Fig. 4. NE-SW palinspastic section through the NW Indian Himalaya. The palinspastic section was constructed using the stratigraphic sections of Fig. 3 and shortening estimates of ~100 km for the N-Himalayan nappes, of over 300 km for the High Himalayan nappes and of less than 200 km for the Lesser Himalayan nappes. This reconstruction illustrates the geometry of the N Indian flexural passive margin before the continental collision of India and Asia.

beds consisting exclusively of detrital, mostly quartzitic rocks. Auden (1934, Gansser, 1964) distinguished a Lower and Upper Tal, which overlie with an angular unconformity the Krol carbonates. The Lower Tal is up to 1'000 m thick and is characterized by dark, often calcareous graywackes, carbonaceous and micaceous shales and some quartzites. The Upper Tal is up to 2'000 m thick and consists mainly of fine-grained (average grain size of 0.5 mm) arkosic quartzites. The Tal Fm. has yielded Tommotian to Botomian (Early Cambrian) conodonts (Azmi & Pancholi 1983), small shelly fauna (Bhatt et al. 1983, Bhatt & Mathur 1990), brachiopods (Tripathi et al. 1984) and trilobites (Kumar et al. 1987). Early Cambrian trilobites *Xela mathurjoshi* and *Redlichia noetlingi* around the limit of the Lungwangmiaon and Tsanglangpuian, have been identified by Hughes & Jell (1999) in the Lower Tal of the Kumoan Himalaya.

The Lower Crystalline nappe (synonym: Bajaura nappe, Thöni 1977)

The Lower Crystalline nappe is an alpine strongly metamorphosed and deformed unit exposed at the base of the Main Central Thrust in the Kishtwar and Rampur windows. It is composed of mylonitic augengneisses, garnet- and sericite-phyllites, quartzites, graphitic schists and marble layers of the Bajaura Formation and minor concordant sheets of metabasites and Proterozoic granitoids (Wangtu granitoid north of Rampur: 1'866 ± 10 Ma, U-Pb zircon age, Singh et al. 1994). The sediments differ from those of the overlying Haimatas or Phe graywackes. The occurrence of the Proterozoic granites suggests this unit belongs to the Lesser Himalaya rather than to the younger High Himalaya sequence, in which the old granites are missing. The metasediments may be lateral equivalents of the Rampur Formation.

Conclusion on the stratigraphy of the Lesser Himalaya

The units of the Lesser Himalaya, including the Lower Crystalline nappe, are composed of an uniform and typical stratigraphic sequence of a Proterozoic to Early Cambrian age (~2'500–530 Ma) intruded (or underlain?) in its lower part by ~1'850 Ma granitoids and basalts. An early to middle Proterozoic age of the Lesser Himalayan sequence is also suggested by the presence of 1.7–2 Ga detrital zircons (U-Pb-ages, Parrish & Hodges 1996). The sediments of the Lesser Himalaya are transgressed by the Eocene nummulitic Subathu Limestone (Middlemiss 1887, Gansser 1964). During the Tertiary Himalayan thrusting the lesser Himalayan sequence was detached from a same sedimentary basin (Purana) of the North Indian continent (Valdiya 1995).

The High Himalaya

The tectonic units of the High Himalaya (from S to N: the High Himalayan nappe or "Crystalline nappe", the Shikar Beh nappe, and the North Himalayan nappes, including the Tso Morari nappe) are characterized by elements of a single sedimentary sequence of a Late Precambrian to Paleogene age. The sequence may be divided in:

The Gondwanan sediments and related magmatic rocks of Neo-Proterozoic to Early Permian age deposited or emplaced on the northern margin of India which at that time was part of the Gondwanan supracontinent.

The sediments of the Neotethyan shelf and the Neotethyan slope, were deposited on the N Indian margin between the Late Permian opening of the Neotethyan ocean and its closure at the Paleocene India – Asia continental collision some 65-50 Ma ago (Patria & Achache 1984, Jäger et al. 1989, Garzanti et al. 1987, Rowley 1996).

The stratigraphic sections illustrated in Fig. 3 have been compiled from work by Hayden (1904), Gansser (1964), Stutz & Steck (1986), Stutz (1988), Garzanti et al. (1987), Brookfield (1993), Gaetani et al. (1990) Gaetani & Garzanti (1991), Saklani (1993), Spring (1993), Vannay (1993), Epard et al. (1995), Frank et al. (1995) and Wolfgang Frank (personal communication), Steck et al. (1993, 1998, 1999). Gansser (1964) wrote of the Spiti section: "It is this conformable sedimentary sequence of Spiti, from Precambrian onwards, which reflects a calm epeirogenic pre-Alpine history of the Tibetan Himalaya". In addition, Srikantia & Bhargava (1998) recognised the similarity of the stratigraphic columns of the High Himalaya that they grouped together in their Tethys Himalayan Tectogen. This sedimentary and magmatic sequence is crosscut in the Zanskar shear zone by 22 Ma leucogranites (Dèzes et al. 1999).

The Gondwanan Series

Haimantas (Griesbach 1891, Frank et al. 1995)
(Synonyms: Phe Formation (Nanda & Singh 1977), Lolab Fm. (Kumar et al. 1984), Shumahal Fm. (Srikantia & Bhargava 1983), Kunzam La Fm./Debsa Khas Mb. (Kumar et al. 1984), Jutogh Series (Pilgrim & West 1928), Batal Fm. (Srikantia et al. 1980), Vaikrita Series (Griesbach 1891).
(Riphean-Early Cambrian)

Frank et al. (1995) divide the Haimantas into the Lower, Middle and Upper Haimantas. Later, Draganits et al. (1998) proposed the subdivision Chamba Fm., Manjir Fm. and Phe Fm. as equivalents of the three divisions of Frank et al. (1995).

The Lower Haimantas (Chamba Formation, Rattan 1973) (Riphean?)

The Lower Haimantas includes the Blahai and Chamba Fm. and the Pukhri Slates (Rattan 1973). The Lower Haimantas, of a probable Riphean age, represents a more than 5'000 m thick monotonous sequence of meta-pelites, meta-siltstones and meta-graywackes or micaschists with subordinate interbedded carbonaceous layers. The formation shows an overall coarsening-upward trend and sedimentary structures like graded bedding, load casts and flute casts point to a turbitite-type depositional environment (Draganits et al. 1998). The Lower

Haimantas are intruded by the 476 ± 12 Ma old Kaplas, Dalhousie and Mandi granites and the 912 Ma Chur granite (Frank et al. 1995).

The Middle Haimantas (Manjir Conglomerates, Rattan 1973, Manjir Formation, Draganits et al. 1998)
(Vendian?)

The Manjir Conglomerates are up to 3'000 m thick and separate the Lower from the Upper Haimantas. They were designated the Middle Haimantas by Frank et al. (1995). They consist of pebbly diamictites interpreted as glaciomarine sediments, easily recognized by their boulder slate appearance. The matrix supported, polymodal, poorly sorted, angular and rounded clasts, up to 1 m in diameter, are dispersed in a chaotic manner. The clasts consist mainly of quartzites, graywackes, slates and subordinate granites and gneisses. ^{40}Ar-^{39}Ar ages < 700 Ma on detrital white micas in the NW Himalaya (Frank et al. 1995) and 0.8-1.0 Ga U-Pb ages on detrital zircons from the Nepal High Himalaya suggest a Vendian age for the Manjir Formation. Wolfgang Frank (personal communication) considers the glaciomarine Manjir boulder beds of the High Himalaya to be a lateral equivalent of the Blaini Fm. of the Lesser Himalayan sequence, thereby implying that the Lower Haimantas represents a lateral equivalent of the Simla slates. Like the Blaini Formation, the Manjir Formation is overlain by a thin dolomite and limestone layer. SE of the Chamba region, the Manjir boulder slate passes gradually into locally graded meta-graywackes and meta-sandstones intercalated with slates similar to the matrix of the underlying Manjir Formation.

The Upper Haimantas (Draganits et al. 1998)
(Vendian-Early Cambrian)

The Upper Haimantas is up to 9'000 m thick and consists of monotonous graywackes, slates to sandstones with one or two 50m- to 100 m-thick characteristic graphitic quartzite horizons and thin carbonate layers or horizons with carbonate concretions (Frank et al. 1995, Steck et al. 1999). A shallow water detrital marine environment is indicated for the Haimanta sediments by the rhythmic alternation of sandstone and siltstones, the presence of hummocky cross stratification and ichnofossils. Common sedimentary structures, such as graded bedding, load casts, flute casts, chevron marks and groove marks, indicate a turbidite type depositional environment (Draganits et al. 1998). No identifiable fossils have been found in the Haimantas to confirm their generally acknowledged Neo-Proterozoic age. Ordovician granitoids dated at 500 Ma are widespread in the Lower and Upper Haimantas (Le Fort et al. 1986, Pognante et al. 1990, Frank et al. 1995, Girard & Bussi 1999). The 912 Ma-old Chur granite represents a unique age for a granitoid of the Himalaya that intrudes the Lower Haimantas in the Chur peak area (Frank et al. 2001). The Himalayan Cambro-Ordovician magmatism will be discussed in a separate chapter below.

The Karsha Formation (Nanda & Singh 1977)
Synonyms: Parahio Series (Spiti, Hayden 1904), Kunzam La Fm. (Srikantia et al. 1980), Rangamal Fm. (Kashmir, Srikantia & Bhargava 1983)
(Middle and Late Cambrian)

There is a gradual change in the carbonate supply between the Upper Haimantas and the Karsha fms. The lower boundary of the Karsha Formation is arbitrarily defined by the first occurrence of dolomite-bearing beds. In the Kurgiakh valley in southern Zanskar, Garzanti et al. (1986) subdivide the formation into the Mauling (~400 m thick), the Thidsi (200-300 m thick) and the Teta (70-160 m thick) members. A similar sequence is reported by Vannay (1993) from the Baralacha La region.

The arenaceous Mauling member is composed of very fine-grained sandstones and micaceous siltstones similar to those of the Upper Haimantas. Trace fossils characteristic of the Early Cambrian, such as *Rusophycus* isp., *Cruziana* isp., *Arthraria* isp. and *Planolites* isp., as well as synaeris cracks, indicate shallow marine conditions (Stutz 1988, Vannay 1993). The carbonates are ferriferous dolomite with locally hemispheroidal or tabular stromatolites, bioturbation and phosphatic shells.

The carbonaceous Thidsi member comprises thick amalgamated beds of rusty-weathering grey dolomites, locally separated by pyritic greenish shales.

The Teta member is composed of grey nodular stromatolite limestone and marls, sometimes dolomitic, alternating with black schists. The presence of rare trilobites (*Goniagnostus spiniger, Diplagnostus planicauda, Eoshengia sudani?*) indicate the age of the Thidsi member of the Zanskar valley to be Middle Cambrian (Changhian) (Huges & Jell 1999). Like the Haimantas, the entire Karsha sequence was deposited in a shallow water marine environment (Garzanti et al. 1986).

The Kurgiakh Formation (Garzanti et al. 1986)
Synonyms: Rangamal Fm. in Kashmir (Srikantia & Bhargava 1983)
(Late Cambrian)

Garzanti et al. (1986) named a sequence of pelites and sandstones, stratigraphically overlying the Karsha Formation in the Kurgiakh Valley, the Kurgiakh Formation. He subdivided them into a 150 m-thick fossiliferous lower Surichun Member and an upper 150 m-thick silty-sandy Kuru Member. A rich late Middle Cambrian trilobite fauna has been identified in the middle Surichun member (*Goniagnostus aculeatus, Lejopyge armata, Hypagnostus correctus, Linguagnostus* cf. *tricuspis, Clavagnostus* sp., *Agnostid indet., Fuchouia indet., Schmalenseeia amphionura, Damesops sheridanorum, Torifera* sp., *Goniagnostus spiniger, Diplagnostus planicauda, Eospengia? sudani*, Hughes & Jell 1999). The trilobite-bearing beds of the Surichun member consist of black to greenish-grey bioturbated or parallel-laminated pelites. Silty and nodulose dolomites are intercalated in lenticular beds gradually decreasing in thickness upward. Tuffitic layers are present. The lower part of the 300 m-thick Kuru member consists of thin-bedded, greenish-grey siltstones with turbidite sedimentary structures. The middle part comprises thick-bedded (up to 6.5 m) dark greenish-grey sandstones and the upper part consists of a fining-upward megasequence made of amalgamated and multiply graded sandstone beds of gradually decreasing thickness. According to Garzanti et al. (1986), the Karsha carbonate platform passes by gradual deepening into the turbiditic sedimentation of the Kurgiakh Formation, which indicates active tectonic subsidence that largely exceeded the sedimentation rate.

Thaple Formation (Hayden 1904, Nanda & Singh 1977)
Synonyms: Kashmir: Riskobal Fm. (Srikantia & Bhargava 1983), Ladakh-Zanskar: Thango Fm. (Kanwar & Ahluwalia 1979), Spiti: Shian Quartzites, Pin Fm. (Goel & Nair 1977), etc. (Ordovician)

The Thaple Fm. consists of mainly red, sometimes white or green conglomerates and sandstones. The conglomerates overlie equivalents of the Kurgiakh or Karsha Formation with angular unconformity (Pin and Parahio valley, Hayden 1904, Pt. 6, Upper Kamirup Valley, Epard & Steck, in press). The thickness of the Thaple Fm. varies from 250 m to 1'500 m and synsedimentary normal faults suggest a tectonic relief related to extensional tectonism (Spring 1993, Vannay 1993, Steck et al. 1993). Fossils such as corals, crinoids, brachiopods, trilobites indicate an Ordovician to Earliest Silurian age (Hayden 1904, Ranga Rao et al. 1982 and Bagati 1990, 1991). Sedimentary structures such as high-angle crossbeds indicate a fluvial, deltaic depositional environment. Polymictic pebbles of the underlying partially eroded Haimantas, Karsha and Kurgiakh formations occur. The outcrops of the Thaple conglomerates and the overlying white Muth quartzites are restricted to a narrow basin which can be followed from the Kurgiakh valley in Zanskar in the NW, through the Baralacha La, Upper Chandra Valley region and the Spiti valley to the SE. Another correlative sequence is exposed in the Liddar valley of Kashmir, where the Ordovician sediments are formed by pink, purple, green and grey quartz arenites, siltstones and shales (Rishkobal Fm. Srikantia & Bhargava 1983). The whole Gondwanan sedimentary sequence is undifferentiated on the geological map due to the absence of a complete and detailed map of the Kashmir basin.

The Ordovician magmatism

Widespread magmatic activity ranging from and peaking at 500-470 Ma intrudes the Proterozoic and Early Cambrian sedimentary sequence of the High Himalayan units (Le Fort et al. 1986, Mehta 1977, Trivedi et al. 1986). Most of the available radiometric data are Rb-Sr ages that must be used with caution. Precise U-Pb ages on zircon and monazite have been determined in the NW Himalaya by Girard & Bussi (1999: S-type Tso Morari granite, 479 ± 2 Ma, I-type Rupshu granite, 482.5 ± 1 Ma) and Pognante et al. (1990: 472 ± 9 Ma, Temasa granite). No Ordovician granites have been recognized in the Lesser Himalaya. A low-pressure contact metamorphism, with an assemblage of quartz, plagioclase, biotite, white mica, garnet, staurolite, sillimanite, andalusite, has been described by Guntli (1993) in the southern contact aureole of the Ordovician Kaplas granite, Tavi valley, where it has been undisturbed by alpine deformation. A zone of dark and fine-grained hornfels is exposed around the Rupshu granite (Girard & Bussy 1999). Hornfelses with quartz, plagioclase, muscovite, biotite and andalusite in metapelites and diopside, grossularite and wollastonite in metamorphosed Karsha dolomites and limestones, are observed near the Nyimaling granite in the Kanjatse peak area (Baud et al. 1982). The presence of a small quantity of probable contemporaneous basic intrusions, that include rocks at Tso Morari and in the Miyar and Tos Valleys, indicate a bimodal magmatism, but no radiometric ages of the basic rocks are available. Basic dikes with a Tertiary eclogite facies mineral assemblage are widespread in the Tso Morari granite gneiss (Berthelsen 1953). Meta-olivine gabbros are described by Pognante & Lombardo (1989) from the Miyar valley and by Wyss (1999) from the Tos valley, as being a magmatic assemblage of olivine, clinopyroxene, orthopyroxene, spinel, plagioclase (core An 72, rim An 47), biotite, ilmenite and magnetite. The rocks in the Tos Valley are overprinted by a probable Tertiary M1 amphibolite-granulite facies transition assemblage of Cpx, Opx, spinel, garnet, amphibole, ilmenite and magnetite at a pressure of 10 kbar and 700°C and later by an M2 amphibolite facies regional metamorphism (Wyss 1999).

A major, continental-scale tectonic event is required to generate such a large magmatic belt. Girard & Bussy (1999) suggest it is a late stage event in the evolution of the Pan-African orogen. Geotectonic reconstructions traditionally consider that only the extreme south of the Indian plate, situated at a distance of over 3000 km from the Himalaya, was affected by the Pan-African compressional events (e.g. Stern, 1994). As we do not know what kind of crust was situated north of India before the opening of the Paleo- and Neo-Tethyan oceans, the relation of this calc-alkaline magmatism to a zone of subduction can not be excluded. However, the association of the 500 Ma bi-modal calc-alkaline magmatism at a deep tectonic level with syn-sedimentary extensional structures in the Ordovician Thaple sediments now in a high tectonic level of the High Himalayan sedimentary sequence coupled with the fact that we have never observed old pre-Himalayan fold structures in the presently studied NW Himalaya, or an old regional metamorphism testifying of a Pan-African orogeny, as proposed by Srikantia et al. (1977), Mehta (1977, 1978), Garzanti et al. (1986) or Marquer et al. (2000), require another mechanism of magma generation. Wyss (1999) suggests that magmatic underplating in a large zone of extension in the N Indian border of the Gondwana plate is a possible mechanism of this magma generation.

The Muth Formation (Stoliczka 1965)
Synonyms: Wazura and Muth Formations (Srikantia & Bhargava 1983), Kenlung Formation (Nanda & Singh 1977)
(Devonian)

The white Muth quartzites are ~80 m thick and constitute an important marker-horizon, which may be followed from Kashmir to Nepal (Gansser 1964). A littoral foreshore environment is suggested for their deposition by the flat, parallel stratification and wave and current ripples (Elliott 1986), by a bimodal granulometry of the sands (Brookfield 1993) and aeolian dune cross-beds structures (Gaetani et al. 1986). Fossils are extremely rare in this mature quartz-arenite. A Lower Devonian age is generally acknowledged because of its stratigraphic position. Draganits et al. (2001) discovered abundant trace fossils in the Lower Devonian Muth Formation of the Pin Valley in Spiti. The ichnoassemblage consists of *Palmichium antarcticum*, *Diplichnites gouldi*, *Diplodichnus biformis*, *Taenidium barretti*, *Didymaulichnus* cf. *lyelli*, *Didymaulyponomos* cf. *rowei* and *Selenichnites* isp.

The Lipak Formation (Hayden 1904)
Synonyms: Kashmir: Syringothyris Limestones (Middlemiss 1887), Aishmuquam Formation (Srikantia & Bhargava 1983), Zanskar: Tanze Formation/Members A+B (Nanda & Singh 1977)
(Middle Devonian-Early Carboniferous)

The Lipak Formation stratigraphically overlies the Muth quartzite from the Spiti Valley through the Kunzum La, Chandra valley and Baralacha La region. It is essentially composed of a sequence, up to 250 m thick, of calcarenites, limestones and evaporites (gypsum) with conodonts of Middle Devonian (Givetian) to Early Carboniferous (Tournaisian) age (Draganits et al. 2002), and was deposited on a low energy platform with lagoons (Hayden 1904, Vannay 1993). Synsedimentary normal faults intruded by basaltic dikes are common in the Baralacha La region. This Baralacha La dike swarm is related to a major Carboniferous transtensional structure (Vannay 1993).

The Early Carboniferous continental basalts (Vannay & Spring 1993)

The basaltic dikes in the Baralacha La region (Baralcha La dike swarm) have tholeiitic to alkaline compositions and they correspond to a comagmatic suite, which evolved mainly by fractional crystallisation processes. They are not feeder dikes for the tholeiitic Permian Panjal traps, which have a different continental flood basalt composition (Vannay & Spring 1993). It was not possible to date the metabasalts radiometrically, because they have a Tertiary greenschist facies overprint (albite, chlorite, biotite, stilpnomelane, actinolite, epidote, titanite).

The Po Formation (Hayden 1904)
Synonyms: Kashmir: Fenestella Series (Middlemiss 1910), Ganeshpur Formation (Srikantia & Bhargava 1983), Zanskar: Tanze Formation/Member C (Nanda & Singh 1977)
(Late Carboniferous)

Hayden (1904) introduced the term Po Series for a 220 m-thick sequence of sandstones, siltstones and black shales that stratigraphically overlie the Lipak Formation. According to Gaetani et al. (1990), these sediments were deposited in a shallow marine high-energy environment with an important terrigenous component. Bivalves and plant fossils indicate an Early Carboniferous age (Tournesian-Visean?, Hayden, 1904, Gothan & Sahni, 1937, Gaetani et al. 1986, 1990). No diagnostic fossils have been found in the upper black shale member.

The Ganmachidan Formation (Srikantia et al. 1980)
Synonyms: Kashmir: Agglomeratic slates (Middlemiss 1910), Pindobla Formation (Srikantia & Bhargava 1983), Zanskar: Ralakung Formation/Phitsi Member (Nanda & Singh 1977), Chumik Formation (Gaetani et al. 1990), Spiti: Losar Diamictites (Ranga Rao et al. 1982)
(Early Permian)

Quartz arenites, conglomerates and black shales of the Ganmachidam Formation are about 150 m thick and overlie the Po black shales and siltstones with an angular unconformity (Hayden, 1904, Fuchs, 1982, Vannay, 1993). In the correlative Losar diamictites of the Upper Spiti valley, Ranga Rao et al. (1987) identified fossils of Early Permian age and a similar Early Permian (Sakmarian) age has been attributed by Gaetani et al. (1990) to the Chumik Fm. in the Lingti valley, SE Zanskar. The formation is divided into a lower member composed of quartz arenites and conglomerates and an upper member of a polygenic conglomerate, sand- and siltstones and black shales. The Ganmachidam Fm. corresponds to a sequence of coarsening upward sediments corresponding to a distal fluvial deposit or a littoral delta.

The Panjal Traps (Lydekker 1878)
Synonyms: Panjal Volcanics, Panjal Unit, Ralakung Volcanics (Singh et al. 1976), Sankoo Volcanics (Gupta et al. 1983), Phe volcanics (Srikantia et al. 1980)
(Late Carboniferous-Early Permian)

The Panjal Traps represent important continental flood basalts that in Kashmir (Lolab valley, Erin valley and Gulmarg) reach a thickness of 2'500 m deposited under subaerial, marginal marine to terrigenous conditions (Pareek 1983). Their thickness is gradually reduced to the SE and the last Panjal traps are observed SE of the Baralacha La in the Upper Chandra valley (Lydekker 1878, Vannay 1993). The Panjal Traps display relatively primitive tholeiitic and alkaline compositions (Nakazawa & Kapoor 1973, Singh et al. 1976, Bhat and Zainuddin 1979, Honegger et al. 1982, Gupta et al. 1983, Pareek 1983). These rocks originated from an "enriched" P-MORB-type magma, which underwent a limited magmatic evolution by fractional crystallisation with probable crustal contamination (Thompson et al. 1984, Hawkesworth et al. 1990). The volcanic activity began in the Late Carboniferous, producing several hundred meters of intermediate to acid pyroclastics and welded tuffs (Pareek 1983), called the "agglomeratic slate", which overlies Carboniferous shales and shallow water limestones. Stratigraphic relations indicate an age between the Artinskian and Kungurian for the main lava flows (Kapoor 1977, Nakazawa et al. 1975).

The Yunam granite (Spring et al. 1993)
(Early Permian)

A porphyritic granitic dike, 2-15 m thick, crosses the Yunam valley south of Sarchu. The granitic dike has an alkaline to subalkaline composition and yielded an Early Permian U-Pb age on zircon of 284 ± 1 Ma. This alkali granite intrusion may be related to the Early Permian Panjal Trap magmatic event.

The Neotethyan shelf

A strong thermal subsidence of the N-Indian margin started after the eruption of the Panjal Traps concomitant with the Late Permian marine transgression and the opening of the Neo-Tethys ocean (Gaetani & Garzanti 1991, Garzanti 1993, Stampfli et al. 2001).

The Kuling Formation (Stoliczka 1865)
Synonyms: Kashmir: Zewan Beds (Middlemiss 1910), Zewan Formation (Nakazawa et al. 1975 Nakazawa et al. 1981, Srikantia & Bhargava 1983), Lahul: Sarchu Formation (Nanda & Singh 1977), Spiti: Productus Shales (Hayden 1904)
(Late Permian)

Stoliczka (1865) proposed the term Kuling Shales for a sequence of black shale, marls and calcarenites deposited on the Early Permian conglomerates of the Spiti valley. Farther NW these shales overlie the Early Permian Panjal Traps. The Kuling calcarenitic shales were later subdivided in the lower Gechang Member composed of quartz arenites, calcareous bioclastic sandstone, siltites and black shale, and upper Gungri Member composed of siltites and black shales by Srikantia et al. (1980), a nomenclature adopted by many geologists (Fuchs 1982, 1987, Ranga Rao et al., 1982, Baud et al. 1984, Nicora et al. 1984, Gaetani et al. 1986, 1990, Vannay 1993). In the Spiti Valley and the Baralacha La region, the lower member has a thickness of about 65 m and the upper member about 25 m (Vannay 1993). The thickness of the formation rapidly increases to some 100-1000 m in more distal regions of the N Indian shelf with an increase in limestone and dolomite sedimentation (Stutz & Steck 1986, Stutz 1988, Steck et al. 1998). A rich brachiopod fauna with *Lamnimargus himalayansis, Spirifirella rajah* indicate a Early Dzhulfian (middle Tatarian) age for the Gechang Member of the Kuling Formation (Hayden 1904, Nakamua et al. 1985, Gaetani et al. 1990). The correlative Permian Zewan Formation exposed in the Guryul ravine and near Palgham east of Srinagar, was deposited with a stratigraphic gap on the Panjal Traps and has yielded late Midian, Dzhulfian and early Changhsingian ages (Nakazawa et al. 1975, Baud et al. 1996).

The Lilang Group (Hayden, 1904)
(Triassic)

The Spiti valley is a classic area of exposure for the Triassic Lilang Group, about 1'200 m thick, that forms the carbonate platform of the Neo-Tethyan Indian shelf. Most of the stratigraphic horizons are dated by fossils (Hayden 1904, Gansser 1964, Srikantia 1981, Fuchs 1982, Bhargava 1987, Gaetani et al. 1986, Jadoul et al. 1990 and Garzanti et al. 1995). The conodonts of the Triassic sequence of the Spiti valley have been described by Garzanti et al. (1995) whose nomenclature is very similar to the classic stratigraphic subdivisions proposed by Hayden (1904).

The Tamba Kurkur Formation (Srikantia 1981)
(Scythian-Anisian)

The Permian/Triassic boundary is marked by a major break in sedimentation, of up to several My, and is represented by a lateritic horizon in Spiti and an angular unconformity (Hayden 1904, Bhatt et al. 1980, Srikantia 1981, Garzanti et al. 1995). East of Srinagar in Kashmir (Nakazawa et al. 1975, Baud et al. 1996) and Lossar in the Spiti Valley (Hayden 1904, Hugo Bucher personal communication), an alternation, about 14m thick, of centimetric-decimetric black shale and limestone layers ("chocolate limestone") the Scythian and Anisian *Otoceras*, *Ophiceras* and *Hedenstroemia* beds and about 20 m of Nodular limestone overlie the unconformity with the underlying Permian *Productus* Shale (Kuling Formation). They are followed by the competent Niti Limestone (Diener 1908), the Middle Triassic "Muschelkalk" of an Anisian to early Ladinian age that is about 8 m thick.

The Hanse Formation (Srikantia et al. 1980)
Synonyms: Kashmir: Khreu Formation (Nakazawa et al. 1975), Zanskar: Zangla Formation/Middle Member (Nanda & Singh 1977), Garhwal-Kumaun: Kuti Shales (Heim & Gansser 1939)
(late Ladinian-late Carnian)

The Upper Triassic begins with the Hanse Formation that is about 350 m thick and consists of alternating regularly stratified dark limestone, dolomite and marl layers deposited under pelagic to semi pelagic conditions with an important detrital contribution. *Daonella* sp. (Daonella shale and limestone, Hayden, 1904, Bhargava, 1987) indicate a late Ladinian to Carnian age (Hayden, 1904, Srikantia et al. 1980, Gaetani et al. 1986, Garzanti et al. 1995).

The Nimaloksa Formation (Srikantia et. 1980)
Synonyms: Spiti: Tropites Beds (Hayden 1904, Fuchs 1982), Sanglung Formation (Bhargava 1987)
(late Carnian-early Norian)

The Hanse Formation is conformably overlain by 300 m of Carnian to earliest Norian limestone and dolomite with terrigenous intercalations. Its upper massive member, with some megalodontids, also called the Zozar Formation (Gaetani et al. 1986), forms 150 to 350 m high cliffs in the Zanskar area.

The Alaror Group (Garzanti et al. 1995) or Quartzite Formation (Gaetani et al. 1986)
(Norian)

The Norian Quartzite Series (Gaetani et al. 1986, Jadoul et al. 1990) are traditionally subdivided into the 100-200 m-thick Juvavites Beds, the 15–30 m-thick Coral Limestones, the 90-160 m-thick Monotis Shale, and the 30-100 m-thick Quartzite Series, originally defined by Hayden (1904). These classical lithostratigraphic subdivisions, display an upward increase in sandstone with a coral-bearing carbonate band in the middle (Bhargava 1987). Crossbed structures in the quartzite layers are useful polarity markers for structural work.

The brown coloured Norian Juvavites Beds are muddy terrigenous to calcareous shelf sediments with grainstones and oolitic ironstones in its middle part. Bioclasts, commonly concentrated in storm lags, include pelecipods, crinoids, brachiopods, corals, gastropods, ostracods, algae and *Juvavites*. They represent a good marker horizon.

The Coral Limestones form a discontinuous marker unit of grey nodular bioclastic limestones, with interbedded ferruginous siltstones, phosphate nodules and arkoses.

The Monotis Shale is composed of shelf mudrocks, arenites and storm deposited sandstones.

The Quartzite Series consists of fine-grained grey arkoses and green and pinkish quartzarenites with dolomitic to phosphatic clasts, bioclasts and some times Megalodons.

The Kioto Formation (Hayden 1904)
(late Norian-Liassic-Aalenian)

The competent subtidal Kioto limestones and dolomites are 400–900 m thick, contain abundant *Neomegalodon* in some beds, and form spectacular cliffs throughout the NW Himalaya from the Spiti valley to the Zanskar area. They were deposited on a carbonate platform, ranging from late Norian, Liassic to Aalenian in age (Gaetani & Garzanti 1991).

The Laptal Beds (Heim & Gansser 1939)
(early Callowian)

The top of the Kioto platform is truncated by a major unconformity and after a period of at least 10 m.y. was progressively onlapped by the Ferruginous Oolite of the Laptal Formation during the early Callovian global sea level rise (Haq et al. 1987, Gaetani & Garzanti, 1991). The Laptal Beds are characterized by fossiliferous ironstone intervals enclosing a coarsening-upward shale-sandstone sequence deposited on a storm-controlled inner shelf. In the regions where the Laptal Beds are missing, the surface of the Kioto carbonates often shows a zone of red alteration.

The Spiti Shale (Stoliczka 1865)
(Oxfordian-early Berriasian)

After a period of reduced sedimentation and frequent gaps in the late Callovian to early Oxfordian, the Laptal Beds were followed until the early Berriasian time by deposition of offshore pelites, the Spiti shale, on the slowly subsiding N Indian shelf. The thickness of the Spiti Shale varies between 10-30 m in NW Zanskar and 200 m in the Spiti area to the SE (Gaetani & Garzanti 1991).

The Giumal Sandstones (Stoliczka 1865)
(Early Cretaceous)

The offshore Spiti Shale is overlain by the Aptian and Albian Giumal Sandstones, which recorded the multiphase progradation of deltaic clastics on the Zanskar shelf. The Giumal Sandstones form a 200-300 m-thick sequence of grey locally cross or graded-bedded, fine-grained sandstones inter-bedded with black shale. An Early Cretaceous (Valanginian-Albian) volcanic extensional event is indicated by abundant volcanic detritus and local basaltic lavas of alkaline and tholeiitic suites in a large part of the N Indian passive margin, from Zanskar in the NW to Nepal in the SE and correlates with the 115 Ma old Rajmahal Traps of north-eastern India. This magmatism is related to an Early Cretaceous break up episode that preceded the final opening of the Indian ocean (Garzanti et al. 1987, Garzanti 1993, Gaetani & Garzanti 1991).

The Chikkim Formation (Stoliczka 1865)
Synonyms: Zanskar: Fatula Limestone (Gaetani et al. 1985)
(Cenomanian-Campanian)

During the Cenomanian, the outer continental terrace was covered by 100 m light grey to multi-coloured pelagic foraminiferal limestone that formis the white Chikkim cliff in the upper Spiti valley (Stoliczka 1865, Hayden 1904) and the multicoloured Fatula Limestone in Zanskar (Gaetani et al. 1985). This early Late Cretaceous sedimentation marks the onset of the opening of the Indian ocean and the N directed drift of India (anomaly 34, 80 Ma, Campanian, Patriat et al. 1982, Patriat & Achache 1984).

Kangi La Shale (Fuchs, 1977)
(Synonym: Goma Shale, Fuchs, 1977)
(Late Cretaceous)

In Zanskar, the Fatula Limestones are overlain by the Upper Cretaceous Kangi La (Goma) Shales, a 400-600 m-thick sequence of dark grey marls, calcareous siltstones and sandstones in the upper part that was deposited in a bathyal to sublittoral environment (Baud et al. 1984, Garzanti et al. 1987).

Stumpa Quartzites (Gaetani & Garzanti 1991)
(Danian)

The Paleogene succession begins with 10-100 m of white, brown-weathered Stumpa quartzarenites, onlapping an underlying unconformity (Garzanti et al. 1987). These coastal sandstones have a Danian age (Gaetani et al. 1986).

The Shinge La Formation (Garzanti et al. 1987)
(synonyms: Spanboth Limestone, Fuchs 1982, Dibling Limestone, Garzanti et al. 1987)
(Paleocene)

The carbonate sedimentation on the N Indian shelf ends in the Late Paleocene with the 200 m-thick open shelf Dibbling Limestone and oceanward Shinge La pelagic limestone, that is up to 500 m thick. The latter formed on the outer part of the continental terrace and was unconformably overlain by 0-120 m of nummulitic Kesi Limestone. These sediments are capped by an early Eocene hardground (Garzanti et al. 1987).

The Kong Formation (Garzanti et al. 1987)
(synonym: Kong Slates, Fuchs 1982)
(Ilerdian-Ypresian)

The Kong Formation is composed of marine slates and siltstones rich in very fine-grained volcanic detritus with nummulites and assilinas of an Ilerdian and early Eocene (Ypresian) age. These sediments record the erosion of obducted oceanic crust and the collision of the Indian passive margin with Asian active margin. These observations corroborate the paleomagnetic data, which suggest continental collision at about 50 Ma (Patriat & Achache 1984)

Paleogene Olistostrome

To the south of Dat in the Karnagh region, the Cretaceous Giumal Sandstones are overlain by debris-flow conglomerates containing limestone pebbles of Cretaceous to Paleocene age (Fuchs 1986, Garzanti et al. 1987, Steck et al. 1993).

The Neotethyan slope

The Lamayuru Formation (Frank et al. 1977, Fuchs 1977)
Synonym: Lamayuru Flysch (Frank et al. 1977, Fuchs 1977), Markha Unit (Baud et al. 1982).

The sedimentation on the N Indian slope is characterized by a heterogeneous sequence of turbiditic calcarenites and marls with rare fossils, strongly deformed during the Himalayan collision (Stoliczka 1865, Lydekker 1883, Frank et al. 1977a, Fuchs 1977, Bassoulet et al. 1980, Bassoulet et al. 1983, Stutz & Steck 1986, Stutz 1988). Near Lamayuru, the Lamayuru Flysch is composed of a repeated alternation of grey to black siltstone and calcareous grey siltstone with frequent olistolites, olistolite breccias that contains Jurassic microfossils (Bassoulet et al. 1983). The Lamayuru Flysch is exposed all along the Indus suture, from the Dras valley in the NW to the Tso Morari region in the SE (Fuchs & Linner 1996). In the Markha valley, Stutz (1988) distinguished and described different formations that range from Early Permian to Late Cretaceous in age: they include calcareous grey schists of the Luchungtse Formation, over 200 m thick, of a probably Permian age, over 200 m of calcarenites and shales of the Late Triassic to Early Jurassic Dolto Formation and 160 m of calcarenites and calcirudites with phosphorite concretions of Middle Jurassic to Late Cretaceous age. On the Geological map (this paper), the Lamayuru Formation includes sediments of a Permian to Late Cretaceous age of the Neotethyan slope. Georges Mascle (personal communication) has suggested Carboniferous sediments near Karzok Gompa may also belong to these rocks. Virdi et al. (1978) described Permian conodonts from the Taglang La region that may also be included. According to Fuchs & Linner (1996), the Lamayuru Formation of the Shingbuk La region is followed by dated Cretaceous clastic flysch with a few foraminiferal marl beds and nummulitic limestones at the top. Honegger (1983) observed alkaline basaltic sills and volcanites of a Triassic age in the Lamayuru Flysch of the Suru Valley region.

Conclusions on the composition and history of the Pre-Himalayan North Indian continental margin

A palinspastic section of the North Indian continental margin and typical stratigraphic sections are proposed in Figs. 3 and 4. The 2.4-3.2 Ga old rocks of the Archaen craton are exposed in the southern part of the Indian subcontinent (Le Fort et al. 1986). In N India they probably form the basement for the early Proterozoic siliciclastic sediments and bimodal magmatic series of the Aravalli range and the Lesser Himalaya. Archean rocks have never been found in the Himalayan range. The Lesser Himalayan units are mainly composed of Proterozoic sediments and magmatic rocks. In N India, they are overlain by the Middle and late Proterozoic sediments of the Vindhyan Basin a southern equivalent of the Riphean, Vendian to Early Cambrian Shali limestones, Simla-Dogra slates, glaciomarine Blaini boulder slates, Krol limestone and dolomite and Tal sandstone of the Lesser Himalaya and Simla-Krol belt. In the Shali and Simla region they are overlain with an angular unconformity by the Paleocene-Eocene nummulitic Subathu limestone and slates (Pilgrim & West 1928, Auden 1934, Gansser 1964, Brookfield 1993). The tectonic units of the High Himalaya, the Shikar Beh nappe, the High Himalayan nappe or Crystalline nappe and the North Himalayan nappes, are composed of a similar stratigraphic sequence of late Proterozoic to Late Cretaceous age, locally overlain by younger Cenozoic sediments, related to the closure of the Neo-Tethys ocean. The most difficult task is the reconstruction of the geological environment of the early Proterozoic siliciclastic sediments and bimodal magmatic series of the Lesser Himalaya, exposed in the Kishtwar and Larji-Kullu-Rampur windows and in the strongly deformed Lower Crystalline, Chail and Simla-Runkum nappes of alpine age. The siliciclastic sediments were intruded in a lower part by 1.84 Ga granitic and 1.80 Ga mafic magmatic rocks. The Nd depleted mantle model ages on the peraluminous granitic rocks extend to 2.63 Ga, indicating recycling of the older crust and Early Proterozoic to Late Archaen sources (Miller et al. 2000). It is difficult to know, whether this sequence suffered any Proterozoic (Grenville?) orogenic event. Frank et al. (1995) correlate the Vendian Blaini tillite and the overlying Kroll carbonate platform of the Lesser Himalaya with the Manjir tillite and the Upper Haimantas detrital sediments of the High Himalaya. The abundance of fossils in the Phanerozoic makes for very precise stratigraphic interpretation. Fig. 4 proposes a palinspastic cross-section of the Late Triassic

Neotethyan margin of NW India. The principle features of this reconstruction are the following:

1. In contrast to the Alps, where two major angular unconformities cutting through folded and metamorphosed older rocks testify of the Caledonian and Variscan orogenic events, in the Himalaya, no Paleozoic compressional structures are observed. Gansser's conclusion (1964): "It is this conformable sedimentary sequence of Spiti, from Precambrian onwards, which reflects a calm epeirogenic pre-Alpine history of the "Tibetan" Himalaya" that is valid for the whole stratigraphic sequence of the High Himalaya.
2. The early Proterozoic Rampur Formation forms the basement of the Riphean to Early Cambrian sedimentary sequence in the Lesser Himalaya and the Lower Crystalline nappe.
3. The Riphean to Early Cambrian sedimentation of the High Himalayan domain was a long lasting anorogenic detrital accumulation that is over 10 km thick in the Haimanta sequence on the N Indian border (Frank et al. 1995).
4. The glaciomarine pebbly diamictite of the Manjir Formation (Middle Haimantas) represents an important stratigraphic marker horizon of a Vendian age in this monotonous sequence. The Blaini boulder beds in the Lesser Himalayan units are considered to be the lateral equivalent of the Manjir boulder beds in the High Himalayan units (Frank et al. 1995, Draganits et al. 1998).
5. Strong erosion and thermal uplift are indicated by the angular unconformity at the base of the Ordovician Thaple conglomerates. The lower crust is intruded by Ordovician bimodal calc-alcaline but mainly granitic magmatic rocks at 500 Ma (Girard & Bussy 1999, Wyss et al. 1999). At this time, the Cimmerian blocks, like South Tibet and Afghanistan were still attached to the N Indian continental margin. This Ordovician extensional event may be related to the Paleo-Tethys rifting (Stampfli et al. 2001).
6. Early Carboniferous synsedimentary normal faults and a basaltic intraplate magmatism are related to transtensional movements in the N Indian margin suggesting an aborted Carboniferous rift preceding the main Permian Neo-Tethys rifting (Vannay 1993, Vannay & Spring 1993).
7. The emplacement of the Middle Permian Panjal Trap continental flood basalts preceded the opening of the Neo-Tethys ocean. The Cimmerian blocks, Afghanistan and S Tibet, progressively separate from N India. A strong thermal subsidence of the N Indian flexural margin with the formation of the Permian-Cretaceous carbonate platform that began in Middle Permian time (Vannay 1993, Stampfli et al. 2001).
8. The Neo-Tethys margin of N India possesses the geometry of an upper flexural margin (Fig. 4, Wernicke 1985, Voggenreiter et al. 1988). The rift shoulder is exposed in the Pir Panjal range, between the Mesozoic Tandi syncline and the Chamba basin (Gaetani & Garzanti 1991, Steck et al. 1993, Vannay 1993, Stampfli et al. 2001).
9. During the Early Cretaceous, abundant volcanic detritus mixed with quartzose siliciclastics in the Albian shelf sand bodies of the Giumal Sandstone and by a local occurrence of basaltic lava testify to a major volcanic event affecting the northern Indian margin, from Ladakh to Nepal (Bordet et al. 1971, Raina & Bhattacharyya 1977, Sakai 1983, Gaetani et al. 1985, Garzanti et al. 1987). This Early Cretaceous rifting may be a precursor of the NE-directed drift of the Indian plate in the Late Cretaceous. In the Campanian, India began moving away from Africa and synchronously a convergent plate boundary developed along the southern Eurasian margin (anomaly 34, 80 Ma, Senonian; Norton & Sclater 1979, Patriat et al. 1982). The sedimentary record of the period of convergence is exposed in the youngest (Ypresian and early Lutetian) sediments of the North Himalayan nappes of the Zanskar region (Zangla and Lingshed nappes, Garzanti et al. 1987, Gaetani & Garzanti 1991, Rowley 1996). According to Jaeger et al. (1989) and Rage et al. (1995) terrestrial faunas of the Cretaceous/Tertiary boundary age (65.7 ± 2 Ma) in India are similar to coeval faunas of Eurasia and have been inferred to imply collision by 65 Ma. The 55 Ma age of the Tso Morari eclogites suggests that in the NW Himalaya, the subduction of the Indian crust below Asia is of the same age (55 ± 7 Ma Sm-Nd age on grt-gln-whole rock, 55 ± 12 Ma Lu-Hf age on grt-cpx-whole rock and 55 ± <17 Ma U-Pb age on alanite, De Sigoyer et al. 2000). The rapid drop of the convergence velocity from about 15 cm/a to 5 cm/a approximately 50 Ma ago in the early Eocene (Ypresian) (Patriat & Achache 1984) may be another consequence of the continental collision of India with Asia.
10. The time of ophiolite obduction is determined by the first arrival of volcanic and debris from ocean crust from the obducted ophiolites and the accreted Dras arc in the Early Eocene Chulung La Formation of the Zanskar shelf (Garzanti et al. 1987) and the latest Paleocene and Eocene Subathu Formation of the Indus-Ganga fore arc basin (Najman & Garzanti, 2000). Before this time, all detritus deposited on the N Indian shelf was derived from the Indian passive margin to the N (Garzanti et al. 1987). At the time of the Early Cretaceous deposition of volcanic detritus in Giumal sandstones, the N Indian margin was still separated from the active Eurasian margin by the more than 2000 km wide Neo-Tethys ocean. The occurrence of Maastrichtian to Ypresian fossils, in the ophiolitic melange underlying the Spongtang ophiolite klippe, proves that the ophiolite obduction onto the Indian passive margin ended in the late Paleocene (Colchen & Reuber 1987). Thus the classic hypothesis of a Cretaceous continental collision and ophiolite obduction (Searle 1983, 1986) must be revised.