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Autor: Gansser, Augusto

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Facts and theories on the Himalayas

By Augusto Gansser[1])

ABSTRACT

During the classical exploration in the 19th and early 20th centuries the ratio between facts and theories was 1:0.5. Plate tectonics changed it to 1:3 and with geophysics, geochemistry and structural analysis the ratio became 1:5.

The backbone of the High Himalayas is a crystalline core, involving the Lesser Himalayas in the W. Exposed are Precambrian structures and metamorphism, overprinted by a Himalayan phase, its intensity still highly disputed. Cambrian nonorogenic granites cut discordantly rocks with preserved Precambrian structures. New ages from 2,000 to 900 my confirm this fact. Himalayan PT have not cancelled all the Precambrian elements and thrusting along the MCT has transported some relic structures. The MCT forms a zone of imbrication or can expose a sharp contact.

Disputed is the fact of reversed metamorphism towards the MCT and above. The hot overthrust theory is contradicted by Jurassic palynomorphs just below the thrust. The Himalayan metamorphic overprint ends with the intrusion of leucogranites. They stress the 500 my intrusive gap from the Cambrian granites, a fact repeated in the North-Himalayan crystalline, diapiric domes; a gap filled with nonorogenic Tethyan sediments. Locally the crystalline/sediment contact can be downfaulted, negligible in the Garhwal Himalayas where basal sediments are over 5,000 m thick.

Theories to fact ratio increase when we approach the Indo/Yarlung suture (IYS), the obducted remnants of a large or small Tethyan ocean, outlining the collision between India and Tibet. Its timing, proven by intra-trappean Asian faunas of 67 my predates all previous assumptions, though collision was not synchronous and started earlier in the West-Himalayas. The regional outline is surprisingly constant, but the details vary considerably: West-Ladakh exposes 3 vertical opiolitic melange belts. Eastwards they are capped by a large (40 km) ultramafic body, which retains a normal cover of gabbros and volcanics. Further east it is transported 50 km northwards to the triple-junction at Tashigang, the most important but least known spot along the IYS. From here starts the Shyok suture and borders the Karakorum to the S as a deep fracture or a subduction.

In a postcollision phase ophiolite nappes were thrust southwards. Remnants are seen in the Spongtang nappe (40 km thrust), the Amlang-La nappe (80 km) and Shigatse nappe (30 km). Similar nappes are even known along the suture on the west side of the Indian shield with 30–50 km thrusts towards the E. In all nappes ophiolitic melanges, frequently with exotic blocks, form the base and ultramafic bodies the top.

North of the IYS follow the Andean-type Transhimalayan plutons, subdivided into Gangdese, Kailas, Ladakh and Swat plutons. They range from 100 to 40 my in age and border the complex Tibetan continental margin, by which they have been more or less contaminated. This is documented by many xenoliths from the Tibetan "basement". However, in the western Ladakh pluton, between the Shyok suture and the IYS, NS aligned xenoliths seem to resemble the basement of the Nanga Parbat spur.

Subsequent to the last intrusions, the Transhimalayas were strongly uplifted and eroded, producing an Oligocene molasse, from which the spectacular Kailas, the most sacred mountain in Asia, has been carved. All the great rivers in the wider Himalayas originate from the Kailas region, cut through the highest uplifts of the rising Himalayas and deposit their sediments in the Indus and Bengal fans, the largest submarine deltas known.

[1]) Via Rovello 23, CH–6900 Massagno.

ZUSAMMENFASSUNG

Während der klassischen Erforschung im 19. und anfangs des 20. Jahrhunderts war das Verhältnis zwischen Tatsache und Theorie 1:0,5. Die Plattentektonik änderte dies zu 1:3 und mit der Anwendung von Geophysik, Geochemie und Strukturanalyse zu 1:5.

Der Kern des hohen Himalaya besteht aus kristallinen Gesteinen welche im W auf den niederen Himalaya übergreifen. Aufgeschlossen sind präkambrische Strukturen und Metamorphose, überprägt durch eine himalayische Phase deren Intensität noch heftig diskutiert wird. Anorogene kambrische Granite intrudieren diskodant in Gesteine mit präkambrischen Strukturen. Isotopenalter von 2000 bis 900 my bestätigen diese Tatsache. Druck und Temperatur der himalayischen Phase haben die präkambrischen Elemente nicht völlig überprägt und die MCT Überschiebung hat teilweise Gesteine mit reliktischen Strukturen transportiert. Diese Überschiebung ist als Schuppenzone oder auch mit scharfem Kontakt aufgeschlossen.

Diskutiert wird auch die Tatsache der umgekehrten Metamorphose, aufgeschlossen gegen die MCT und darüber. Der Theorie einer «heissen» Deckenüberschiebung widersprechen jurassische Palynomorphe gerade unter der Hauptüberschiebung. Die metamorphe Überprägung wird durch die Intrusion der Leucogranite abgeschlossen. Diese belegen eine Lücke von 500 my seit der Intrusion der kambrischen Granite, eine Tatsache die wir auch aus den diapirischen Kristallindomen des Nordhimalayas kennen, eine Lücke deren Zeitspanne den anorogenen Sedimenten entspricht. Der Kontakt dieser Sedimente mit dem Kristallin kann lokal eine Bruchzone sein. Diese fehlt im Garhwal-Himalaya, wo die basalen Sedimente über 5000 m mächtig sind.

Das Verhältnis zwischen Theorie und Tatsache nimmt zu, wenn wir uns der Indo-Yarlung Sutur (IYS) nähern, mit aufgeschobenen ozeanischen Resten einer weiten oder engen Tethys, als Kollisionsnarbe zwischen Indien und Tibet. Die Datierung dieser Kollision mit 67 my, bestätigt durch intertrappische Faunen asiatischen Ursprungs, ist älter als alle bisherigen Annahmen, andererseits war die Kollision nicht synchron und begann früher im W. Regional ist die Sutur erstaunlich konstant, im Detail jedoch kompliziert: Im W Ladakh sind drei vertikal stehende Melange-Zonen aufgeschlossen. Ostwärts werden diese von mächtigen (40 km lang) ultrabasischen Körpern überlagert mit einer normalen Überdeckung von Gabbros und Vulkaniten. Weiter ostwärts wird die gesamte Serie 50 km nach N geschoben, zum Tripel-Punkt von Tashigang, dem wichtigsten und wenigst bekannten Teil der IYS. Von hier streicht die Shyok Sutur zur Südseite des Karakorum, als Tiefenfraktur oder Subduktionszone.

In einer Postkollisionsphase wurden Ophiolitdecken südwärts bewegt. Reste sind erkennbar in der Spongtangdecke (40 km Überschiebung), Amlang-La decke (80 km) und Shigatsedecke (30 km). Ähnliche Decken sind bekannt längs der Sutur auf der Westseite des indischen Schildes, mit 30–50 km Überschiebung gegen E (Quetta Teil). In allen Decken bilden die ophiolitischen Melanges, häufig mit exotischen Blöcken, die Basis, überlagert von ultrabasischen Massen.

Nördlich der IYS folgen die Plutone des Transhimalaya von andinem Typus, unterteilt in Gangdese, Kailas, Ladakh und Swat Plutone. Die 100–40 my alten Transhimalaya Plutone grenzen an den komplizierten tibetischen Kontinentalrand der die Granite teilweise chemisch beeinflusst hat. Den Beweis liefern die zahlreichen Xenolithe des tibetischen «Grundgebirges». Andererseits zeigen die Plutone des westlichen Ladakhs, zwischen der Shyok Suture und der IYS, N-S streichende Xenolithe, welche den Gneisen des Nanga Parbat Sporn gleichen.

Nach den letzten Intrusionen wurde der Transhimalaya stark gehoben und erodiert, was zur Bildung einer Oligocänen Molasse führte, aus der der spektakuläre Kailas, der heiligste Berg Asiens, geformt wurde. Alle grossen Flüsse des gesamten Himalayas haben ihren Ursprung in der Region des Kailas, durchbrechen die höchsten Erhebungen des wachsenden Himalayas und deponieren ihre Sedimente in den Indus und Bengal Deltas, den grössten bekannten submarinen Fluviatil-Ablagerungen.

Introduction

About 20 years ago the geological knowledge of the Andes was at the same level as the one of the Himalayas is today. At that time I gave a William Smith lecture in London on "Facts and Theories of the Andes". In the following account I will try to discuss Facts and Theories of the Himalayas, where I was able to witness the rapid progress of geological exploration since my first investigations 55 years ago. I introduced this theme at the fifth Himalayan Workshop in Milan, early in 1990, during the 20 minutes allotted time.

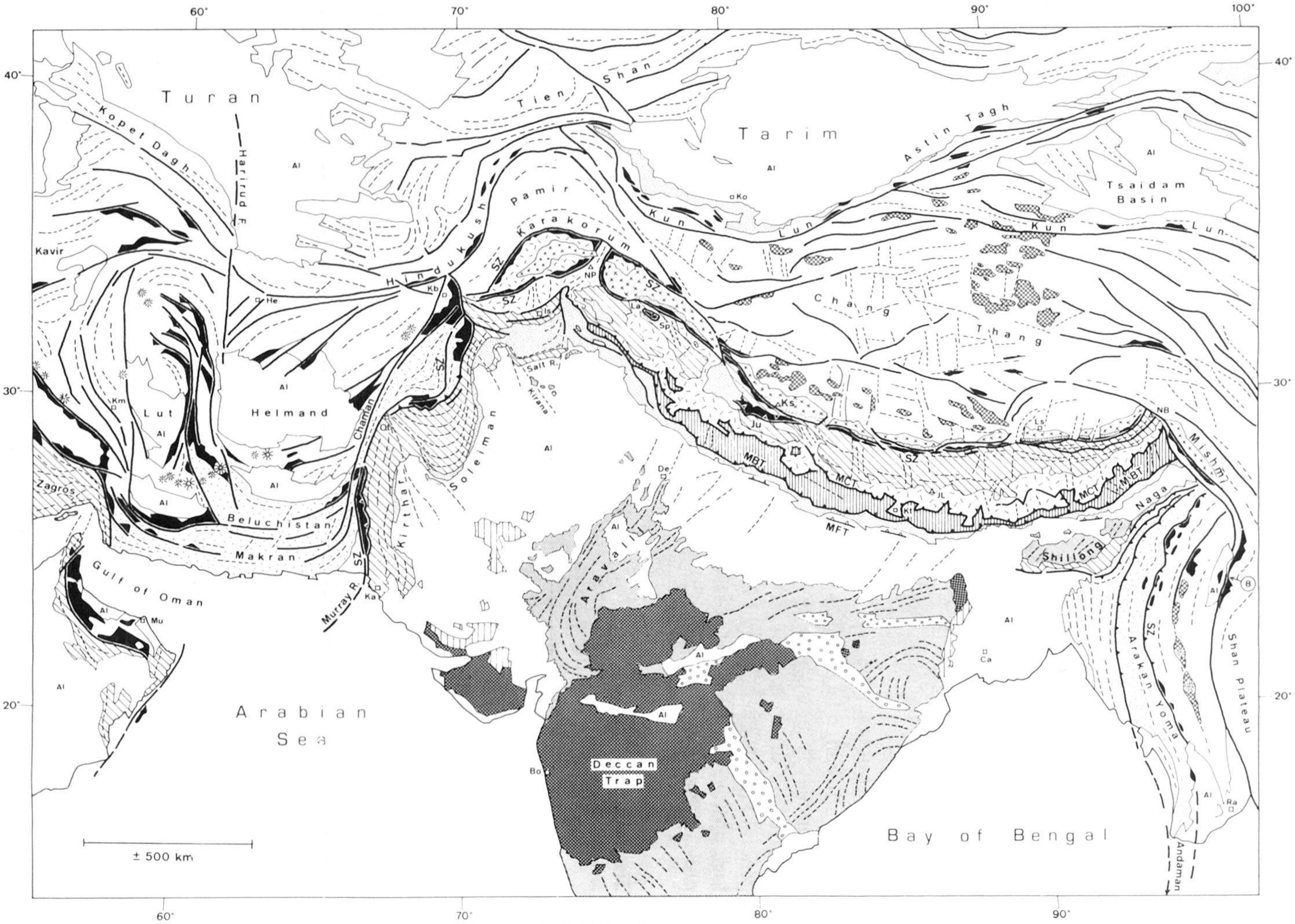
With the foundation of the Geological Survey of India in 1851, began the "golden age" of Himalayan exploration, involving teams of European geologists. Though modern travel facilities did not exist in those early days, there was plenty of time and contact with the field was much more intimate, compared to our hectic activities of today. The ratio between facts and theories was than about 1:0.5. The application of plate tectonics to the Himalayas changed this ration to 1:3 and with modern geophysics, including paleomagnetics, with geochemistry and detailed structural analysis, the ratio became 1:5. Even in the presentation of facts, such as in modern geological sections, we note theoretical interpretations hardly representing nature any more. In discussions in the modern volume "Tectonic evolution of the Himalayas and Tibet", John Ramsay states:... "I would suggest that this current fashion of making constructions to depth is not only mechanically unsound, but it does not accord with the observations of structural geometry"... and again ... "I fail to understand why some workers persist in using a model that is so much at odds with the undisputed observations ..." (RAMSAY 1988, p. 321).

In the following discussions I will deal with some selected Himalayan problems with a rather high facts versus theories ratio. Contrary to the Andes, some key areas in the Himalayas and adjoining Tibet are still prohibited to foreign geologists and this unfortunate situation is, at the time of writing, not improving. I will not enter into the general Himalayan geology. I have discussed the regional picture up to 1964, in "Geology of the Himalayas", (GANSSER 1964), and Patrick Le Fort has completed it to the present (LE FORT 1989). For the general geological outline I refer to Figures 1 and 2.

The crystalline core

The backbone of the highest mountain range in the world is its crystalline core, covered by shallow marine Tethyan sediments. Morphologically these crystalline rocks do not always coincide with the highest peaks (High Himalayas) and can outcrop in lower regions (Lesser Himalayas) such as in Pakistan west of the western syntaxis. The crystalline core exposes Precambrian structures involved in polymetamorphic events, suggesting various orogenic phases between 2,000 and 800 my. These have been overprinted by the Tertiary Himalayan orogeny without any intervening phases, apart from some epirogenic movements. The intensity of this Himalayan phase is still highly disputed. How much has the old structural pattern influenced the Himalayan tectonics? Here we have one of the major problems which can only be solved by many more field facts and critically applied age dating. Not so long ago some authors rejected any pre-Himalayan phases, (POWELL & CONAGHAN 1973). However, at present, facts are increasing about old, pre-Himalayan preserved structures.

The well known, anorogenic, 500 my old granites, (LE FORT et al. 1980, 1986), with their typical cordierite "guide" mineral, cut discordantly rocks with preserved Precambrian structures and metamorphism. Some of these structures expose a striking N-S alignement, visible in the Besham region of northern Pakistan. In spite of new Precambrian ages in this region, a dominant Himalayan overprint is still being considered, based on recent investigations by the British school, (TRELOAR et al. 1989). By reviewing the Precambrian, NNE aligned Aravalli trend, characterizing the northern edge of the Indian shield (ref. Figs. 1, 2, 8), discussed already by J.B. Auden 55 years



60°
70°
80°
90°
100°
40°
30°
20°
Turan
Kopet Dagh
Harirud F.
Tien Shan
Tarim
Astin Tagh
Tsaidam Basin
Kun Lun
Kun Lun
pamir
Hindukush
Karakorum
Kavir
Chang Thang
Lut
Helmand
Chaman
Soleiman
Salt R.
Kirana
Zagros
Beluchistan
Makran
Kirthar
Murray R.
Gulf of Oman
Arabian Sea
Aravalli
Deccan Trap
MBT
MCT
MFT
Mishmi
Naga
Shillong
Arakan Yoma
Shan Plateau
Andaman
Bay of Bengal
SZ
Al
He
Kb
Km
Ko
NP
Ju
Ks
La
Sp
Ls
NB
JL
Kt
De
Ka
Mu
Ca
Bo
Ra
± 500 km

ago (Auden 1935), it seems possible that this remarkable structural pattern may have influenced the structures of the Himalayan crystalline. Such trends are not only visible in the western Himalayas but can be recognized all along its trend, reappearing, as a last rejuvenation, in the youngest N-S directed fracture systems, (Valdiya 1976, 1980, 1981, Gansser 1983).

Subsequent to the consolidation along the Indo-Yarlung Suture (IYS) and as a compensation to the still northdrifting India, intracrustal thrusting developed during the late Oligocene-Miocene and produced the Main Central Thrust (MCT). Along this thrust, the central crystalline body, over 15 km thick and with a cover of 12 km of Tethyan sediments, moved 100–150 km to the south over Late-Precambrian metasediments of the Lesser Himalayas (Fig. 3). The MCT can be a complicated zone of imbrications (Schuppenzone) from which originated the Lesser Himalayan crystalline nappes (Almora type) and which brought the unnecessary term of "Vaikrita thrust" (Roy & Valdiya 1988), or the thrust can be knife-sharp, as in eastern Bhutan (Gansser 1983).

Still highly disputed is the widespread reversed metamorphism which can be observed, increasing from the Lesser Himalayas towards the MCT and above, within the main crystalline, and evidently the fact versus theory ratio is very high. The assumption of large recumbent folds (nappes) as a possible reason was suggested already in 1878 by Louis de Loczy in Sikkim, even before the discovery of similar nappes in the Alps. Unfortunately de Loczy published his results only 30 years later (de Loczy 1907). The gradual upwards change from the low-greenschist facies of the

Al Alluvial plain
Pre-Gondwana basement, Indian shield
Gondwana sediments on Indian shield
Mesozoic Platform sediments on Indian shield
Trap, Indian shield
Molasse-type sediments (Siwaliks of sub-Himalaya)
Lesser Himalaya
Crystalline of High Himalaya
Tethyan sediments (platform)
Flysch facies
Ophiolites incl. ophiolitic melanges and related pelagic sediments
Transhimalayan plutons
Tertiary and Quaternary volcanics
Quaternary volcanoes
Main thrust and fault zones
Lineaments (fold axis, sec. fault zones, fracture zones)

ABBREVIATIONS

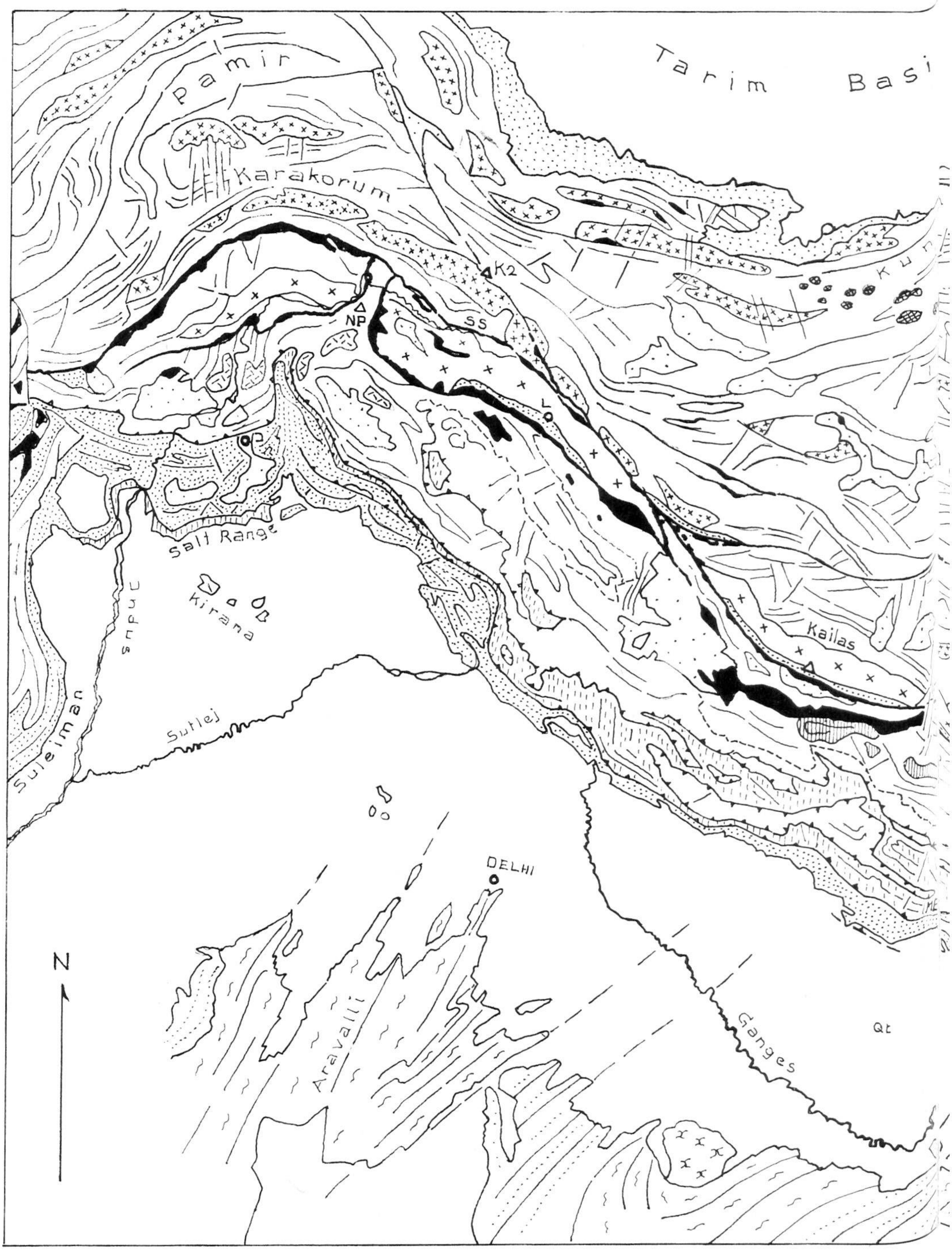
Bo	Bombay	Ls	Lhasa
Ca	Calcutta	Mu	Muscat
De	Delhi	NB	Namche Barwa Mt.
He	Herat	NP	Nanga Parbat Mt.
Is	Islamabad	Qt	Quetta
Jl	Jolmo Lungma (Everest)	Ra	Rangun
Ju	Jungbwa nappe	Sp	Spongtang Klippe
Kb	Kabul		
Ks	Kailas Mt.		
Ka	Karachi		
Kt	Kathmandu		
Ko	Khotan		
La	Ladakh		

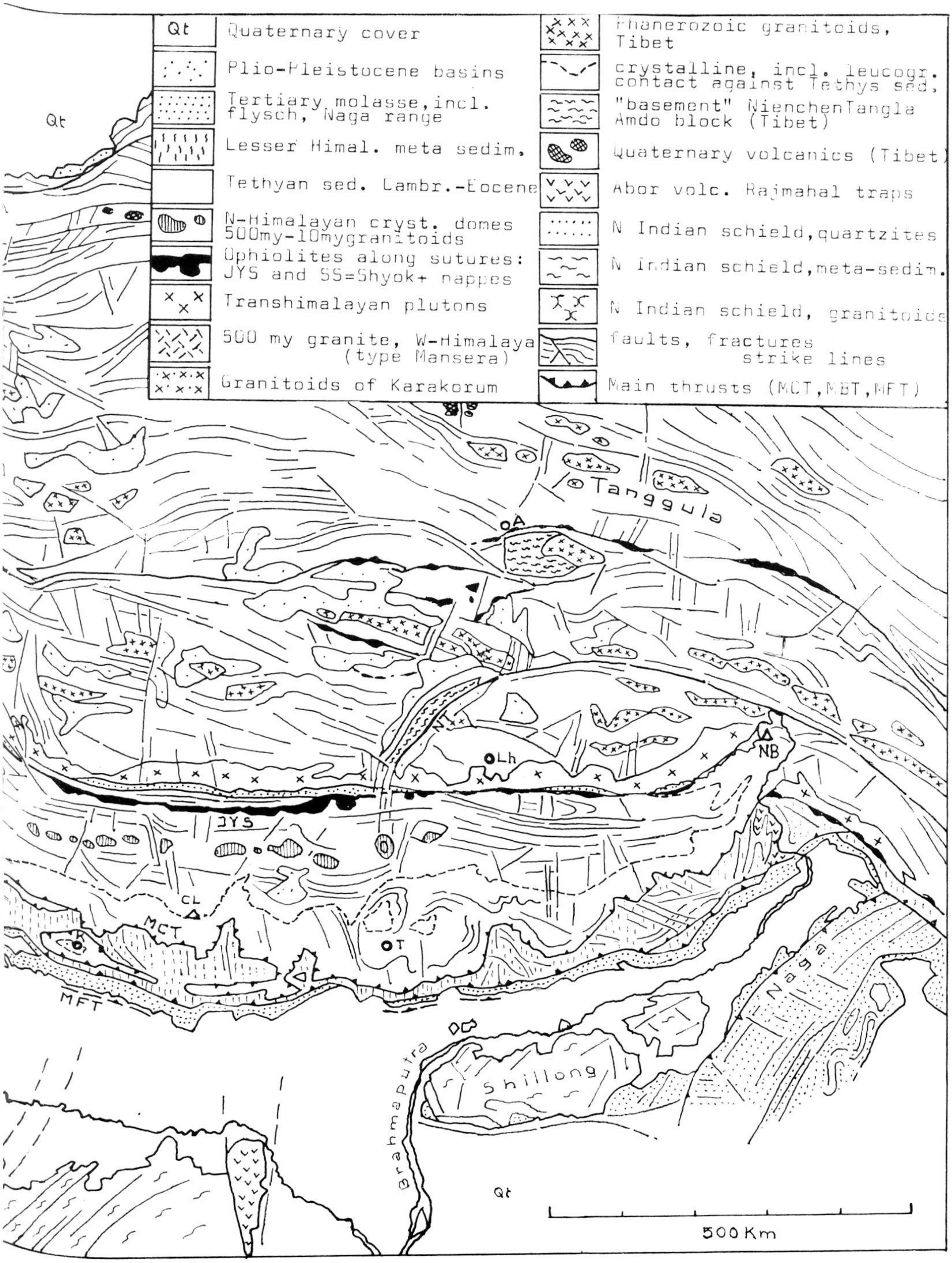
main structural units:

SZ	Suture Zone (Indus/Tsangpo)
MCT	Main Central Thrust
MBT	Main Boundary Thrust
MFT	Main Frontal Thrust

Outside wider Himalaya and Indian shield only structural trends, ophiolites and volcanoes are shown.

Fig. 1. *Geotectonic map of the wider Himalayan regions.* Geology up to 1980. From A. Gansser 1981.


Pamir
Tarim Basi
Karakorum
K2
Kun
NP
SS
Salt Range
Kirana
Indus
Kailas
Suleiman
Sutlej
DELHI
MB
Aravalli
Ganges
Qt
N


Qt
Quaternary cover
Plio-Pleistocene basins
Tertiary molasse, incl. flysch, Naga range
Lesser Himal. meta sedim.
Tethyan sed. Cambr.-Eocene
N-Himalayan cryst. domes 500my-10mygranitoids
Ophiolites along sutures: JYS and SS=Shyok+ nappes
Transhimalayan plutons
500 my granite, W-Himalaya (type Mansera)
Granitoids of Karakorum
Phanerozoic granitoids, Tibet
crystalline, incl. leucogr. contact against Tethys sed.
"basement" NienchenTangla Amdo block (Tibet)
Quaternary volcanics (Tibet)
Abor volc. Rajmahal traps
N Indian schield, quartzites
N Indian schield, meta-sedim.
N Indian schield, granitoids
faults, fractures strike lines
Main thrusts (MCT, MBT, MFT)
Qt
Tanggula
A
Lh
NB
JYS
CL
MCT
T
MFT
Naga
Brahmaputra
Shillong
Qt
500 Km

Dalings to the sillimanite bearing Darjeeling gneisses above became one of the classical sections exposing the Himalayan reversed metamorphism (Heim & Gansser 1939). Detailed studies in Nepal suggested rapid overthrusts of a hot crystalline sheet over the cool Lesser Himalayas, (Pêcher 1978, Pêcher & Le Fort 1986, Hodges et al. 1988). In the eastern Himalayas the sharp contact along the MCT exposes a remarkable jump in metamorphism from lower greenschist facies below to a higher amphibolite facies above. In the Tashigang section of eastern Bhutan conditions along the contact are further complicated by a less than 100 m thick wedge of practically unmetamorphosed, banded, siliceous, carbonate rocks which produced Middle to Upper Jurassic palynomorphs (Pantic et al. 1981, Gansser 1983). Between this layer and the main crystalline, at the very base of the MCT, outcrop several meters of phyllonitic, quartzitic, sericite schists with porphyroblasts of a fresh, unaltered biotite of a probably late generation. Below the Jurassic follow 4–5,000 m thick quartzites and phyllitic shales of the Late Precambrian Daling-Shumar group of the Bhutan Lesser Himalayas. The Jurassic sedimentary layers dip parallel to the MCT to the north, below the crystalline mass. Most surprising is the fact that some of the delicate dinocysts still show the preserved membrane, considering their position below a 15 km thick crystalline thrust-mass (Fig. 4). How can one reconcile the hot-iron overthrust theory? In spite of many well exposed sections along the 2,500 km long MCT, none of the theories related to the reversed metamorphism are so far convincing. Facts along its long exposure show however substantial differences between the eastern (sharp thrust), central (imbrications) and western (migration into foothills) Himalayas.

The intrusive gap

The Himalayan structural and metamorphic overprint ends with the intrusions of the leucogranites. These postgenetic intrusions are petrographically surprisingly homogeneous from the Nanga Parbat in the west to eastern Bhutan and beyond in the east. They are devoid of mafic xenoliths and intrude the upper part of the high Himalayan crystalline rocks and can reach the Cretaceous of the Tethyan sedimentary cover (Le Fort et al. 1987). Field facts indicate that many of the plutons and intricate dyke systems are associated with calcsilicate zones within the high-grade migmatites in the upper part of the high ranges (Dietrich & Gansser 1981) (Fig. 3). These carbonate zones may have some influence on the emplacement of the granites, particularly of the sill-like "lit par lit" intrusions, but not on the anatexis. Besides a very high Sr-ratio of 0.77, the Himalayan leucogranites are amongst the most $^{18}0$-enriched granites known, and must have originated by anatexis of a continental basement (Blattner et al. 1983). Whole rock isochron dating is difficult. From all line of evidence, the most likely age is Miocene and the intrusion may be synchronous to somewhat later than the thrusting along the MCT (Fig. 5).

◁ Fig. 2. *Structural map of the Himalayas and the greater part of Tibet.* Compiled from various sources including Landsat photos by A. Gansser. A = Amdo, I = Islamabad, K = Katmandu, L = Leh, Lh = Lhasa, T = Thimpu, CL = Chomo Lungma (Everest), K2 = (Chogori) with Karakorum fault zone, NB = Namche Barwa, NP = Nanga Parbat.

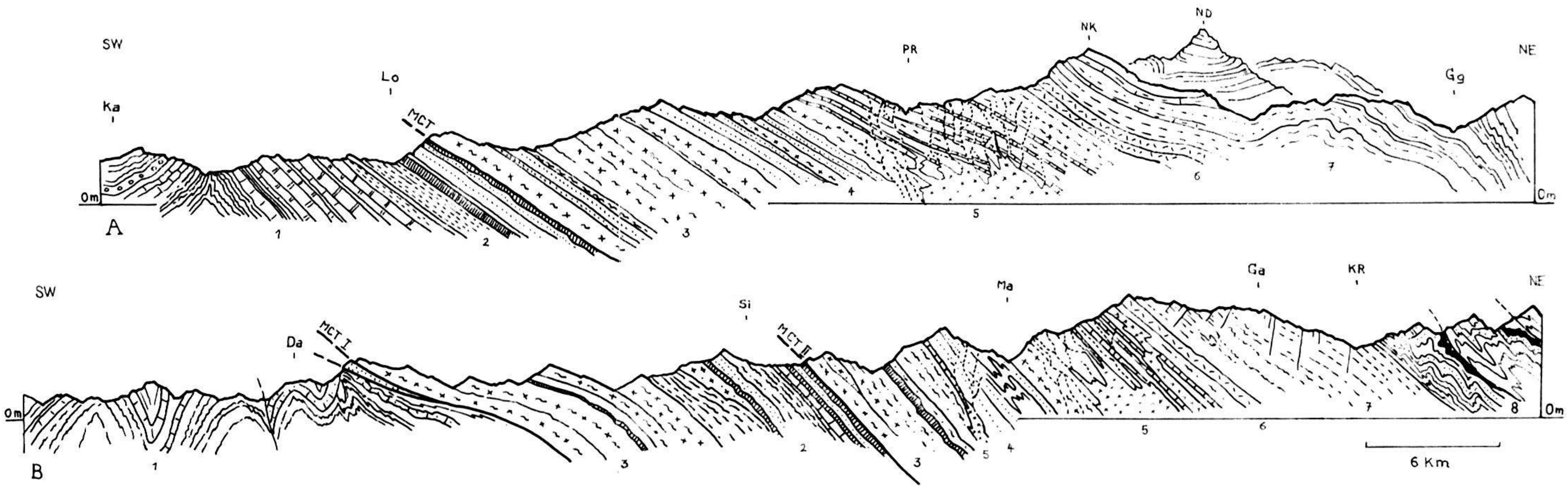


Fig. 3. *Geological sections through the MCT and the Crystalline Core of the Kumaon Himalayas* (Central Himalayas). (Redrawn from GANSSER 1964). Section A through Nanda Devi. Section B along Kali River (W border of Nepal), to Garbyang. 1. Precambrian sediments of Lesser Himalayas. Metamorphism increasing towards MCT. 2. Precambrian metasediments of Lesser Himalayas with schists, quartzites and amphibolites just below thrust, repeated in Sirdang area below MCT II. 3. Gneisses, partly migmatitic of lower part of crystalline core. 4. Metaquartzites and high grade schists in middle section of crystalline. 5. Leucogranites with dykes intruding zone of marbles, limesilicates and psammite-gneisses. The relation of leucogranites with the upper high grade carbonate zone of the main crystalline is widespread. A certain three-fold division of the main crystalline core is also evident in Nepal and the eastern Himalayas. 6. Typical biotite porphyroblast-schists, ending the main metamorphism of the crystalline core (Budhi schists). 7. Late Precambrian to Cambrian argillaceous Tethys-Himalayan sediments. 8. Folded and imbricated sediments from Ordovicium to Permian of the Tethys Himalayas. Da = Darchula, Ga = Garbyang, Gg = Goriganga (Valley), Ka = Kapkot, KR = Kuti River, Lo = Loharkhet, Ma = Malpa, ND = Nanda Devi (7,820 m), NK = Nanda Kot, PR = Pindari River, Si = Sirdang.

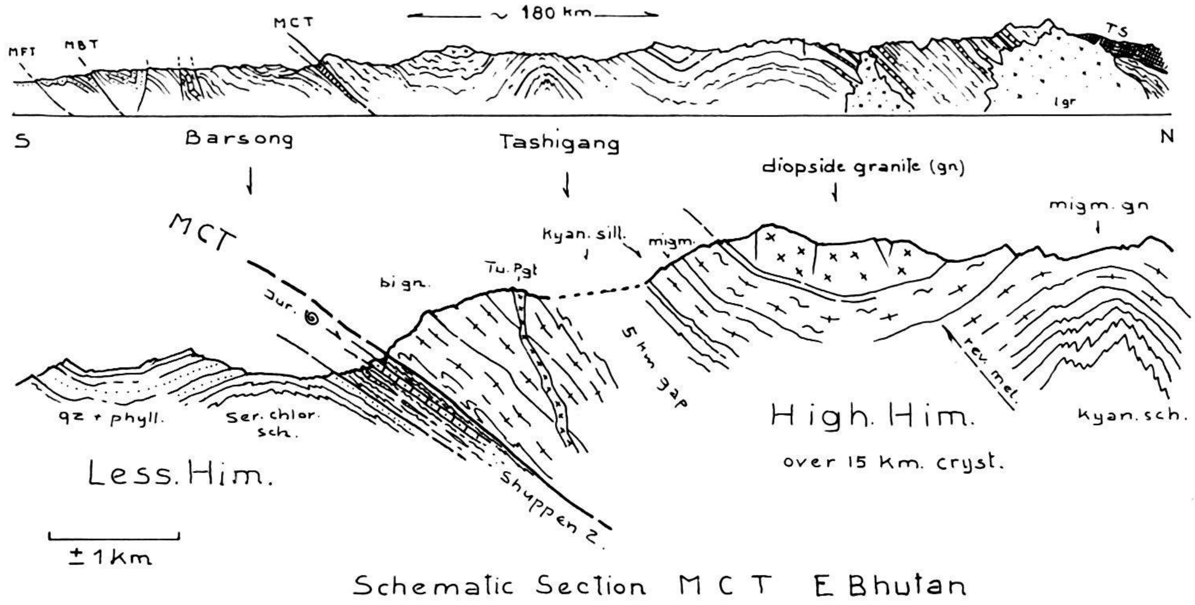


Fig. 4. *Section of MCT above Jurassic palynomorphs and a general section through the Bhutan Himalayas.* MFT = Main Frontal Thrust, MBT = Main Boundary Thrust, MCT = Main Central Thrust, lgr = leucogranite, intruding carbonate rich zone in crystalline. TS = Tethyan Sediments.

Comparing the Neogene leucogranite intrusions with the widespread 500 my old cordierite bearing, anorogenic granites, we realize the existence of a surprising intrusive gap of nearly 500 my in the Himalayan plutonism, a gap that coincides with the deposition of predominantly anorogenic Tethyan sediments, which range from Late Precambrian to Eocene. With a decreasing metamorphism they follow conformably above the main crystalline. In the Central Himalayas we note, actually contrary to VALDIYA (1988), over 5,000 m of concordant Late Precambrian to Cambrian argillaceous sediments (HEIM & GANSSER 1939), while in the Ladakh region as well as south of Lhasa, downfaulting to the north has sharpened the contact with an abrupt change in metamorphism (HERREN 1987).

The 500 my gap is again well displayed in the pearl-like chain of the "North Himalayan Plutons" (LE FORT 1988, 1989; GANSSER 1977), about 60 km to the south of the Indo-Yarlung Suture. They begin just to the west of Yamdrock Tso (south of Lhasa) with a 7,200 m high domal uplift of mostly Jurassic and Triassic sediments, intruded by leucogranites (unpublished observations by A. Gansser), followed by the granite dome of Kangmar further to the west. The field impression of the dome suggests a layered granite, intruded under stress and not an augengneis as mentioned by some authors. Its age was dated by Rb/Sr whole-rock with 480 my and the U/Pb methode on zircons gave about 520 my, thus straddling the famous 500 my. In spite of this, some contact metamorphism reached Jurassic sediments (BURG 1983) and I was shown in 1980 by Chang Chen Fa contact metamorphic Triassic marbles.

From here to the west we recognize about a dozen other crystalline domal uplifts until we reach the 7,700 m high Gurla Mandhata (Fig. 2). The domal highs are well visible on the Landsat photos and give the impression of a diapiric emplacement. Some of the domes, like the 6,500 m high Lhagoi Kangri, are made of porphyritic granite resembling the cordierite granite type and typical leucogranites. The relative abundance of these two types varies from one pluton to the other, but nearly all show the striking 500 my intrusive gap (LE FORT 1989). The Gurla Mandhata cristalline dome, similar to the other uplifts, though larger, is morphologically very young and displays along its flancs uptilted Quaternary terraces (Fig. 6). Further westwards, after a considerable gap of over 400 km, covered by the Plio-Pleistocene basin of Hundes with its

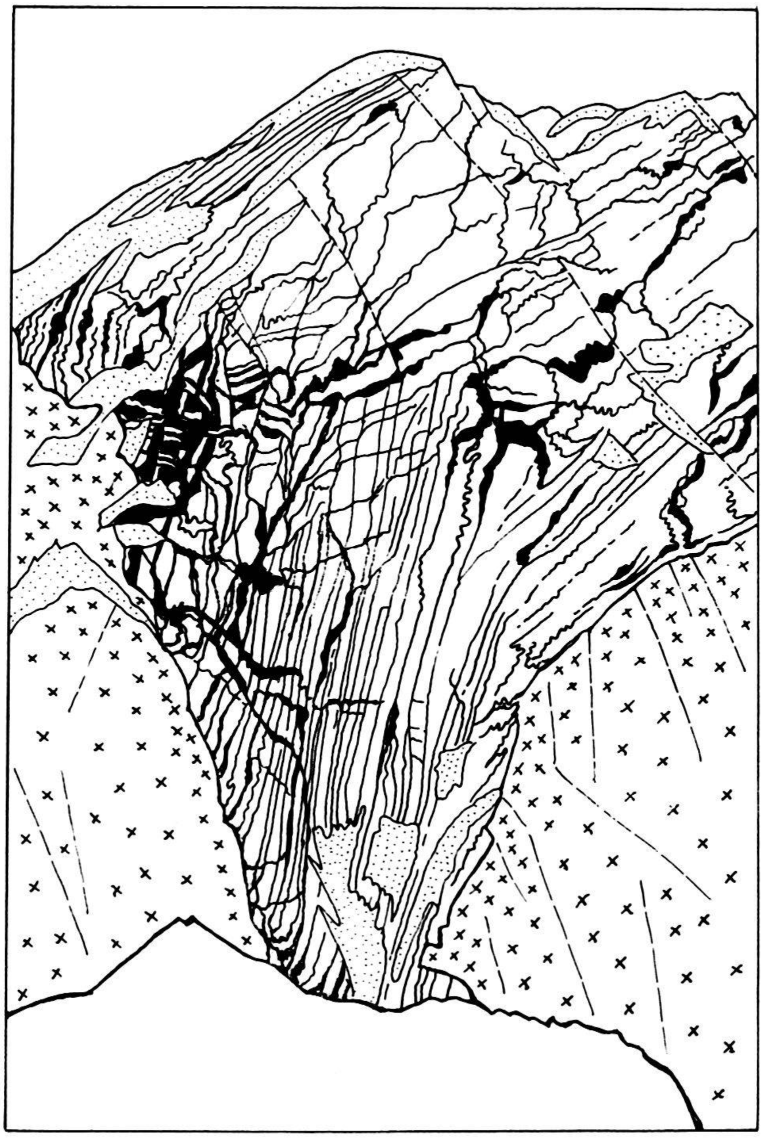


Fig. 5. *The 2,500 m high south wall of Nuptse (7,861 m), Everest area, exposing one of the most spectacular leucogranite intrusions known.* Crosses: leucogranite batholites, black: larger lenses, dykes and sills of leucogranites, broken lines: fracture-zones, fine stippled: ice and snow cover. The field facts suggest three intrusive phases: first were sills, mainly in the summit area and the lower main wall. They are followed by dykes and irregular lenses, which cut the sills. Finally the batholitic intrusions cut into the already existing sill and dyke phases. The contact on the eastern batholite seems slightly sheared. (After field observations and photograph by A. GANSSER.)

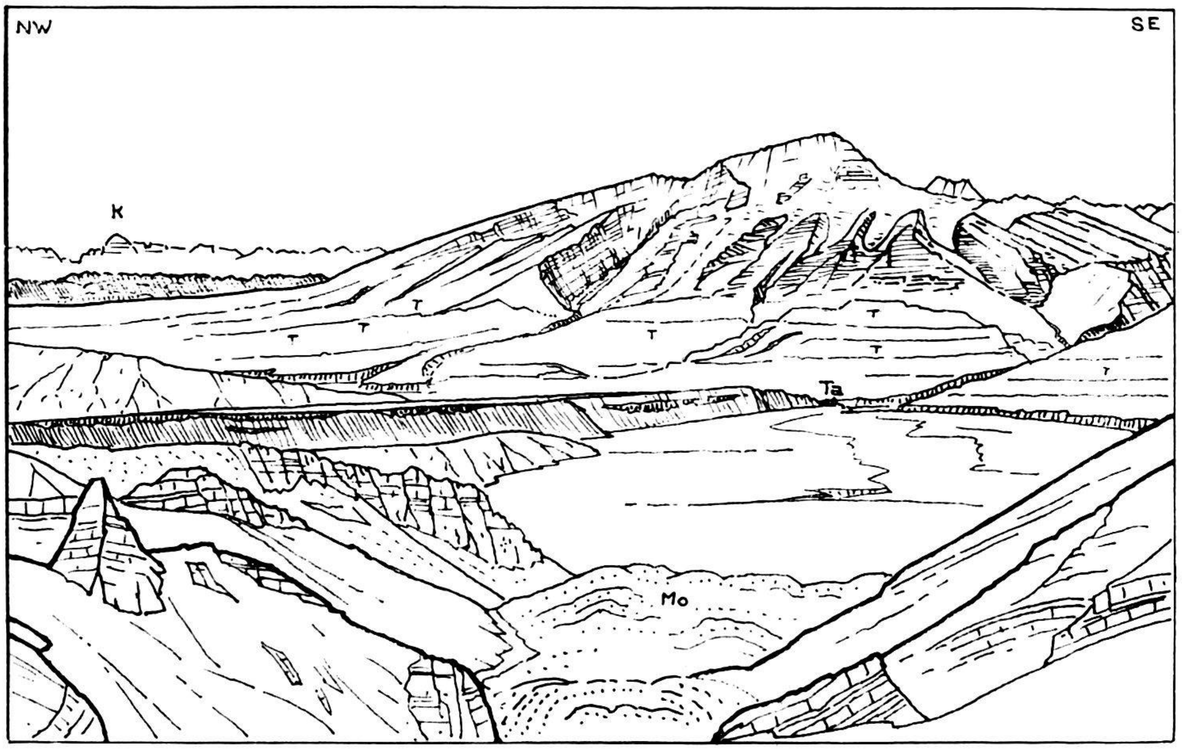


Fig. 6. *The Gurla Mandhata crystalline dome, 7,700 m high, seen from Tinkar Lipu, pass between westernmost Nepal and Tibet.* View towards NE. Ta = Taklakot Monastery at the end of a remarkable terrace. K = Kailas on the Transhimalaya with the ophiolitic Amlang-La nappe in front. T = Various terrace levels, partly tilted and related to the recent uplift of the Gurla Mandhata dome. In the foreground highly fossiliferous Triassic sediments and local moraines, MO. (Drawn from HEIM & GANSSER 1939).

remains of tropical mammals, uplifted to over 4,000 m, we meet the Tso Morari-Nimaling crystalline high in easternmost Ladakh. We may have here a continuation of the North Himalayan crystalline rocks (BERTHELSEN 1953, MASSON et al. 1990). Rb/Sr whole rock data from the coarse, muscovite-biotite Nimaling granite gave 460 my, still within the 500 my intrusive phase (STUTZ & THÖNI 1987). Leucogranites, however, have still to be discovered in this belt.

This characteristic 500 my plutonic gap is limited to the Himalayas and conditions change abruptly north of the Indo-Yarlung Suture. Within Tibet we recognize Phanerozoic granites of various ages. The largest body known are the plutons forming the Transhimalaya, intruded between Cretaceous and Paleocene (see below). To the north follow the early Cretaceous Bangong granites and the granites of the Amdo region of Cretaceous and Paleozoic ages and further north the Tanggula granite belt, forming the important watershed in Central Tibet. These still little known plutons are much more widespread than generally assumed and some expose perfect diapiric type domes surrounded by Jurassic sediments into which they intruded. Their upper age limit is probably pre Middle Cretaceous. Widespread are again the granites of the Kun Lun belt, bordering the Tsaidam Basin and ranging from Jurassic to Permian (Royal Soc. & Acad. Sinica 1988).

Recent volcanism, thermal springs and seismicity

Unrelated to these phases of plutonism, a Quaternary volcanism of potassium-rich andesites is widespread in Central Tibet (Deng 1978). On the Landsat photos we recognize well-preserved lava flows which originate from high volcanoes capped by small plateau glaciers or from smaller, well-preserved craters. No convincing theory explains the distribution and the origin of this striking volcanism and no counterpart is known in the Himalayas. A similar young volcanism is only known from the east, along the central ranges of Burma (Brunnschweiler 1966, Bender 1983) and again in the west with a group of well-preserved volcanoes at Dasht-e-Navar in northeastern Afghanistan (Bordet 1975). The Afghan ones are related to the large volcanoes of Kuh-e-Sultan, the 4,100 m high Taftan and Bazman further to the southwest in Beluchistan. The theories relaying these recent volcanoes to active subduction zones are contradicted by field facts. "The relation between earthquakes and recent volcanic activity seems equally unlikely as the relation of the young volcanic trends to their structural frame" (Gansser 1971, 333), (Fig. 1).

In contrast to the structurally unrelated recent volcanism, missing in the Himalayas, thermal springs are widespread in Tibet as well as in the Himalayas (Liao 1981, Tong & Zhang 1981, Wei et al. 1981) and here they are clearly structurally controlled. They follow important NS fracture zones, well displayed to the northeast of Bhutan, as well as major thrusts such as the MCT, which was active during the Miocene but is inactive at present (Fig. 7).

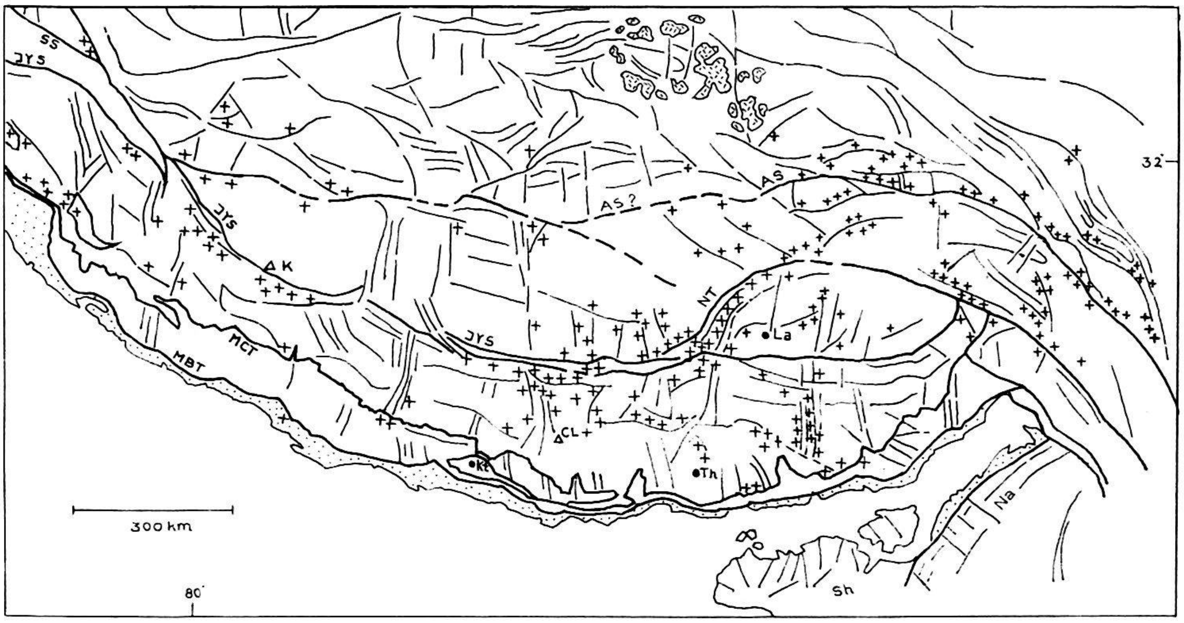


Fig. 7. *Thermal springs in the Himalayas and south Tibet (+), with main structural trends.* Only springs above 40° C are shown. The western syntaxis is not included. Note the relation to structural trends such as Nienchen-Tangla and the NS fracture zones (NE Bhutan). On the north-central zone of the map the Quaternary volcanism is indicated (crosshatches) with many hot spring not shown on the map. Main structural trends from S to N: MBT = Main Boundary Thrust, MCT = Main Central Thrust, IYS = Indo-Yarlung Suture, SS = Shyok Suture, NT = Nienchen Tangla range, AS = Amdo Suture?, CL = Chomo-Lungma, Everest, K = Kailas, Kt = Katmandu, La = Lhasa, Na = Naga range, Th = Thimpu, Sh = Shillong.

Such a structural relation is again much less evident in the distribution of the recent seismicity. Judging from the locations of epicenters alone, one could hardly reconstruct the regional Himalayan structural trends as we know them today. The MCT and the large Suture Zones are seismically inactive. The seismicity along the southern Himalayas in the region of the Main Boundary Thrust (MBT) and particularly along the Main Frontal Thrust (MFT), where the Siwaliks are thrust on Quaternary terraces, is not linear but rather concentrated in clusters suggesting NS trends. We must however realize, that precise information is still vague because of the limited seismic network stations. For the same reason, the interpretation of the gravity anomalies are equally vague, with the undercompensated excess mass of the High Himalayas versus the overcompensated deficit mass of the Indo-Gangetic plain, (Lyon-Caen & Molnar 1983, 1985, Molnar 1988). Theoretical interpretations flourish over the still uncertain geophysical facts. An exception are the detailed seismic investigations in relations to the

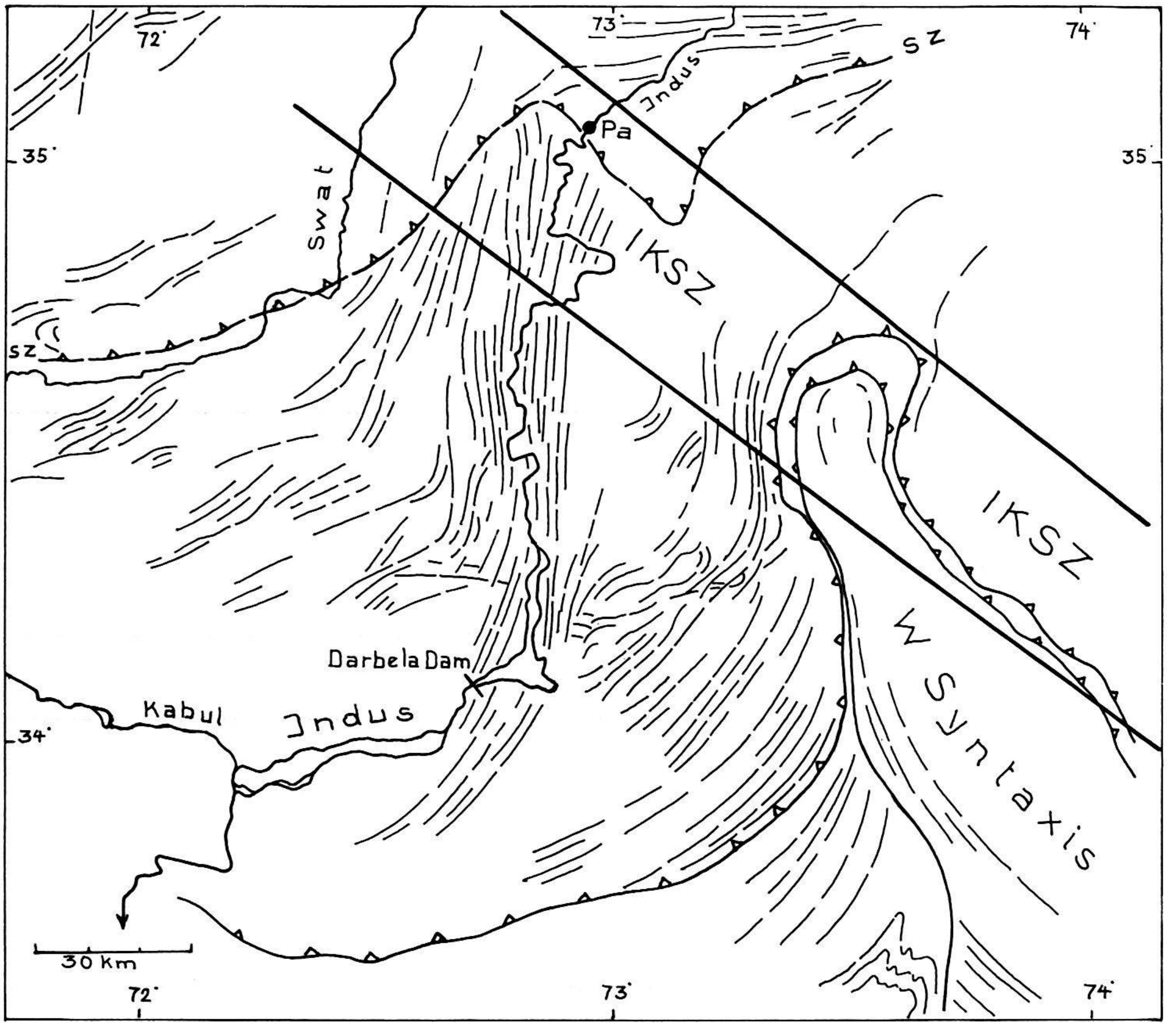


Fig. 8. *The Indus-Kohistan Seismic Zone (IKSZ) cutting the western syntaxis and the main NS directed structural trends.* IKSZ after Gornitz & Seeber (1981), structural trends from Landsat and field interpretations by A. Gansser. SZ = Indo Yarlung Suture or Main Mantle Thrust; Pa = Patan, site of 1974 large earthquake.

"famous" Tarbela dam crossing the Indus river (SEEBER et al. 1981). They show two seismically active trends running from southeast to northwest, in striking contrast to the western syntaxis, but still outlining an extension of the MBT (Fig. 8). This trend was called the Indus-Kohistan-Seismic-Zone by GORNITZ & SEEBER (1981).

The facts exposed in the famous Salt Range suggest that a large part of the western Himalayas is underlain by Late Precambrian salt deposits, which, forming a conspicuous detachment horizon, influence the tectonic style of the overburden. The lower part of the Hazara syntaxis, the folds of the Trans-Indus Salt Range and even the large Quetta arcs divided by the Quetta syntaxis show decollement tectonics which would explain the lack of correlation between the deeper seismic picture and the surface structures (SEEBER & ARMBRUSTER 1979). Larger salt horizons which would influence the tectonic style are missing east of the western syntaxis. Detailed seismic investigations like the one in connection with the Tarbela dam are needed in other parts of the Himalayas in order to lower the very high geophysical theories to facts ratio.

The Suture Zone

Theories over facts increase considerably when we approach the Indo-Yarlung Suture Zone. Outlined by ophiolites, often dismembered and incomplete, this belt nevertheless represents the most important obducted vestiges of a former ocean floor. The size of this ocean, its consumption and subduction are the most disputed items in Himalayan geology, but also for any Alpine or Andean type mountain range the world over. Expansion of a Tethyan ocean of over 6,000 km based on paleomagnetics and extreme plate tectonic reasoning, has been uncritically accepted by many authors dealing with the Alpine-Himalayan belt (KLOOTWIJK 1984, DEWEY & BURKE 1973). The increasing field facts on the other hand allow alternatives, such as only a narrow but deep Tethyan ocean. One proof could be the widespread ophiolitic melange belts with its exotic blocks, associated with ophiolites all along the Himalayan and Middle East Suture Zones, where continental subsidence seems to be the rule (GANSSER 1974). For interesting discussions related to the problems of large or narrow, shallow or deep oceans pertinent to the Middle East and Himalayan orogens I like to refer to the publications by STOECKLIN (1983, 1984, 1989). John Auden, who really knows Himalayan facts since over 60 years, ends his inspiring paper on "India's former crustal neighbours" by stating: "It would seem to the author that India has had a relatively close association with Eurasia throughout the Phanerozoic, notwithstanding the allowance which must be made for the crustal shortening during the formation of the Himalaya" (AUDEN 1981). A very comprehensive review on Late Paleozoic constraints on plate tectonic reconstructions is given by SMITH (1988).

In Oman we find the best example of an ophiolite emplacement onto a subsiding continental margin, one of the largest and best exposed ophiolite complexes in the world (COLEMAN 1981). A simplified picture looks as follows: An over 10 km thick thrust sheet, the Semail nappe, consisting predominantly of harzburgite, has been thrust on a strongly tectonized ophiolitic melange with huge exotic limestones bodies, the Hawasina belt, and this is thrust on the subsiding platform sediments of the Arabian continental margin. The originally widespread Semail nappe has been cut into large, disconnected segments and along the edges of this heavy overburden some of the Hawasina melanges have been remobilized diapirically and seem active even today (pers. obs. A. Gansser). According to COLEMAN (1981), the 95 my old Semail ophiolites could be traced to a spreading center within a very restricted part of the Tethyan sea. To the north and northeast of the steep continental slope of Oman, 3–4,000 m of sediments have been traced above an oceanic crust in the 3,000 m deep Oman sea. This rather abnormal situation could represent a yet unconsumed part of the Tethyan sea (COLEMAN 1981). However, it would not solve the emplacement of the Oman ophiolites.

From the well studied and excellently mapped ophiolite-geology of Oman we can learn much about the more intensely tectonized Himalayan ophiolites which have been involved in continental collision, a phase missing in the geological history of Oman. The Himalayan ophiolites, as obducted remnants of an ocean floor, outline the collision between India and Tibet. The timing of this collision has been set by applying various different methodes. A new convincing age of 67 my has been proposed based on the presence of Asian faunas in Indian intratrappean beds, and new isotope dating of the corresponding trap members (JAEGER et al. 1989). This age predates all previous assumptions, though collision was probably not synchronous and seems to have started earlier in the western Himalayas. However, while frogs, highly allergic to salt water, hopped happily from Asia to India, paleomagnetics tell us that India was still over 2,000 km to the south.

The regional outline and general composition of ophiolites along the main Suture, from the Middle East to Burma, are surprisingly constant, but details vary considerably: In western Ladakh the Indo-Yarlung Suture is represented by 3–4 vertical to steeply south-dipping slices of ophiolitic melanges. 180 km further to the east the melanges are covered by a 40 km large ultramafic body, which retains rests of a normal cover of gabbros and volcanics (FRANK et al. 1977, THAKUR & MISRA 1984). Further eastwards, this large ophiolite body is transported, along a faultzone, 50 km to the north, where it disintegrates into huge melange blocks at the triple junction of Tashigang, the most important but least known spot along the 5,000 km long Peri-Indian ophiolite belt. From here starts the Shyok Suture which further to the west borders the southern Karakorum as a suture or a deep fracture. North of this triple junction the eastern Karakorum is sheared off along the younger, dextral Karakorum fault, leaving large giant boudin-like granite bodies (Fig. 9). The region just south of the triple junction, along the northwestern Sutlej basin, shows some seismic activity, culminating in the Kinnaur earthquake of January 1975, the largest event known from the Tethys Himalayas in the last 50 years (NI & BARAZANGI 1985). Some of the ophiolitic melanges of the eastern Shyok Suture are sheared into the Nubra Valley and outcrop together with hot springs, the whole being overthrust to the southwest by the Karakorum crystalline rocks (RAI 1986, THAKUR et al. 1981). The connection of the Shyok ophiolites between the Shyok-Nubra junction and the region of Machalu in the lower Shyok river, from where the ophiolites continue into the Shigar Valley at Skardu, is still unknown (GANSSER 1980, SEARLE et al. 1989).

In a postcollision phase ophiolitic nappes, rooted in the Indo-Yarlung Suture, have been "thrust" to the south, onto Tethyan shallow marine sediments. Remnants are seen in the Shigatse nappe southwest of Lhasa with 30 km thrust, in the Amlang-La nappe, divided into the Kiogar (melanges) and Jungbwa (ultramafics) with 80 km thrust, the largest ophiolite nappe known in the Himalayas, the Spongtang nappe in Ladakh with 40 km thrust and the Dargai klippe in Kuhestan with 30 km thrust. All these remnants suggest that ophiolite nappes were widespread prior to erosion. Even along the Suture following the west side of the Indian shield, the Quetta-Las Bela branch, very similar nappes are thrust 40–50 km eastwards onto platform sediments covering the Indian

Fig. 9. *The important but little known Tashigang Triple-Junction.* Compiled from various sources on base of Landsat photographs by A. Gansser. IYS = Indo-Yarlung Suture, SS = Shyok Suture, with later superimposed Karakorum faultzone. Ophiolite belt (vertically hatched) with mafic and ultramafic intrusives (black), dismembered E of Tashigang. Melange belts shown by black triangles. Transhimalayan batholite, here Ladakh section (large crosses) and sheared off Karakorum granites (small crosses with dots). 500 my type granites in Tso Morari crystalline (cross-hatched). Basic to acide volcanics related to main batholites (open V). Kailas type molasse transgressing on batholites (black dots). Indus flysch (line and dot). Post Lower Paleozoic Tethyan sediments (oblique lines). North of Tashigang follow metasediments of the Pangong Tso group. Ta = Tashigang, Ch = Chusul, Pu = Puga with hot spring. PT = Pangong Tso, TM = Tso Morari, (Tso means lake, shown by wawy lines). Heavy lines show main faultzones and sutures. Thin lines show fracture zones and strike lines.

Precambrian shield (Fig. 1). In all the nappes mentioned above as we have already noted in Oman, ophiolitic melanges form the base and ultramafic bodies, often dismembered, the top. All the contacts are tectonic.

In the Las Béla ophiolitic belt to the south of Quetta, some melanges contain boulders of pink, porphyritic granite, strikingly similar to the Precambrian granites of the Cutch area of the Indian shield, over 500 km to the southeast (Gansser 1979). How can one introduce granites from a distant shield, which first had to be unroofed from its sediments, into an ophiolitic belt? This question touches the important point regarding the origin of the ophiolitic melanges. Equally questionable is still the mechanical process of thrusting ophiolitic nappes, consisting of highly incompetent melanges overloaded by competent ultramafic bodies. It seems theoretically impossible to thrust a melange mass, loaded by 3,500 km^2 wide and several km thick ultramafics, for at least 80 km on top of already folded Tethyan sediments, a fact we can observe in the Amlang-La region of the Central Himalayas. To some extent gravity gliding must have played an important role after the Transhimalaya and with it the Suture Zone began to rise during the Eo-Oligocene.

The emplacement of the Quetta-Las Béla ophiolitic nappes may be somewhat earlier than the Himalayan equivalents. They are covered transgressively by Lower to Middle Eocene shallow water limestones which pass westwards into a flysch facies of the Katawaz basin (Allemann 1979). Like its equivalent in Makran, the over 6,000 m thick flysch grades into molasse and is limited to the west by the Chaman-Arghandeh faultzone, where ophiolites appear again (Stoecklin 1989). This striking flysch belt ends in the Kabul region and is unknown in such a development in the Himalayas. Quite different is the 5–6,000 m thick late Cretaceous Shigatse (Xigaze) "flysch" following the Indo-Yarlung ophiolite belt (Burg 1983). The very well bedded clastics with some black shales, in which a Turonian ammonite was found during the 1980 Tibet symposium, begin with orbitolina limestones in the north and with Albian-Cenomanian radiolarites on pillow lavas in the south. Only a small part of the Shigatse formation conforms to a flysch facies.

Recently allochtonous ophiolites were reported along the eastern border of the Indian shield, in the outer (western) ophiolite belt in the Naga-Malipur sector and on the Andaman islands (Sengupta et al. 1990). Ophiolite nappes are thrust to the west (towards the Indian shield) onto Eo-Oligocene flysch. On the complicated ophiolite stack occur klippen of continental metamorphic rocks. The base, as in all the ophiolite nappes, consists of an ophiolitic melange.

Considering the regional aspect of the peri-Indian ophiolites, the authors argue that: "A trail of small ocean basins may have existed during late Mesozoic time along the periphery of the Indian continent facing Eurasia" (p. 442).

Ophiolite nappes as well as the ophiolites along the Suture Zone, with locally north directed counterthrusts (Shigatse belt, Burg 1983), are the obducted remnants of an oceanic crust. This is an undisputed fact. Disputed is however the question how much of this oceanic crust was actually obducted and how much has been subducted. Here we enter highly theoretical assumptions, and I like to cite Jovan Stoecklin who "wonders why subduction at the gigantic scale inferred by plate tectonics is not at least as evident in the geological structure as obduction, to which plate tectonics assign the role of a mere by-product" (Stoecklin 1989, p. 285).

The Transhimalaya

North and parallel to the Indo-Yarlung Suture follows the 2,500 km long Transhimalayan batholith, subdivided from E to W into the Gangdese, the Kailas, Ladakh and Swat plutons, the latter already west of the western syntaxis in Kohestan. Their age ranges from 100 my to 40 my with a more basic and also older composition frequently along its southern part. We note noritic gabbros, diorites, granodiorites and adamellites, younging from south to north with a predominance over the whole chain of granodiorites-tonalites. The low Sr-ratio shows a tendency to increase from south to north and in some sections from west to east (0.704–0.707, Le Fort 1989), and suggests for the long plutonic belt a partial melting of mantle material and consumption of a "large" amount of oceanic crust (Honegger et al. 1982). Here we may have one important, but otherwise rare, indication of a major subduction as origin for this extensive, linear plutonism. We face the same well known problem in the Andes, where very similar plutons of the same age and same composition are exposed over 9,000 km (Pitcher 1978). The main difference is however the fact that no collision has followed the Andean subduction. On the other hand the Pacific "foreland" of the Andes varies considerably. Along its northern section we note a Late Cretaceous to Eocene uplifted but not subducted ocean floor, the middle section exposes Precambrian basement and the partly drowned southern section shows some patches of meta-ophiolites, some of them outcropping on the opposite side (Gansser 1973, Dalziel 1989). These facts contrast with the southern border of the Transhimalayan batholite which is followed for its whole length by the ophiolites of the Indo-Yarlung Suture Zone. Despite such discrepancies, a very rough calculation of the plutonic rock volume of the two plutonic belts, down to a depth of 10 km, gives for the Andes 4,650,000 km^3 and the Transhimalaya 950,000 km^3, quite a similar volume considering the difference in the length of the two ranges.

Since large sections of the Transhimalaya are still little known, generalisations and uncritical statements such as the comparison to an island arc, flourish in the literature. With increasing field facts a more complex picture begins to emerge. We know that the Transhimalayan plutons intruded a highly heterogenous South-Asian continental margin and were contaminated by its continental crust, witnessed by the numerous xenoliths and the geochemical changes from south to north.

Rather unexpected structural complications related to continental contaminations were observed by Honegger and Raz while traversing the Ladakh batholith over the Largyap-La to the west of Leh (Honegger & Raz 1987). North of the pass the dominant granodiorites and biotite granites intrude a folded section of sandstones and schists overlain by 500 m thick white marbles with recognizable rests of Triassic/Jurassic megalodonts and lithiotis. These metasediments were overthrust to the south by a 5 km thick section of migmatitic gneisses, containing lenses of limesilicates. This outstanding section shows that an intense tectonisations, including thrusting, predates the batholitic intrusions. According to the authors the section resembles Karakorum lithologies (Honegger & Raz 1987). Similar white marble bands, though on a much smaller scale, were observed by the writer along the south flank of the Gangdese batholite in the Chabra Valley SW of Lhasa. These and similar new facts confirm a contamination of the Transhimalayan batholite by melting a highly complicated

Tibetan continental margin, subject to a strong (including thrusting) pre-batholitic but post early Jurassic orogenic phase.

Another type of pre-batholitic inclusions was observed by the writer to the east of Skardu, along the gorges of the Shyok and the Indus rivers. About 30 km to the southeast from the junction of the Indus and Shyok rivers, within the Indus gorge, the batholith intrudes a north-south striking antiform of black hornfels with white marbles and black shales which contain highly stretched (NS) dolomite and quartzite pebbles together with irregular shale fragments, the whole resembling a tectonized agglomeratic slate (Permo-Carboniferous?). This giant xenolith is intruded on its eastern flank by noritic gabbros and by younger biotite granites on its western side. The same granites also cut the gabbros in a nearby section. Frequent are also up to 1 km thick enclaves of north-south striking, intensely folded biotite gneisses and schists, locally migmatized, not unlike the "basement" of the Nanga Parbat further to the west. The crystalline xenoliths outcrop in the Shyok as well as in the Indus rivers towards Skardu. Again we note the intense, pre-plutonic tectonisation and metamorphism. The pronounced NS strike of the various enclaves within the batholith suggests contamination by the North Indian shield margin and its cover rocks, rejuvenated in the Nanga Parbat syntaxial uplift (Gansser 1980).

The new accumulating facts seem to suggest that large sections of the Transhimalaya are more complex than regionally accepted and that the distribution of the various plutons of different composition and age can be haphazardous. This would include the various outcrops of trachyandesites, forming a 500 m high dome at Teah monastery, of granophyres and even leucogranites, though chemically and mineralogically quite different from the High Himalayan type. All these rocks fringe the southern border of the batholith (Honegger & Raz 1987).

The phenomenal Kailas

Subsequent to the plutonic and volcanic activities, the Transhimalaya was suddenly strongly uplifted, producing an over 2,000 km long belt of a coarse molasse, transgressive on its southern flank. This molasse is best developed in the Central Transhimalaya with over 4,000 m of nearly horizontal sediments, from which the spectacular Kailas has been carved, the most sacred mountain in Asia (Allen 1982). With its 6,800 m elevation it is also the highest molasse mountain known (Fig. 10). The main uplift of the Transhimalaya, its erosion and the deposition of the molasse must have happened in a very short time. Age dates for the molasse are rather confusing. An Upper Cretaceous age is proposed for the transgressive red Basgo molasse in Ladakh (Garzanti & Van Haver 1988), which contrasts with our own observations of Eocene limestone pebbles in the Upshi and Pashkyum molasse, transgressing directly on the Ladakh batholite, suggesting an Oligocene age (Frank et al. 1977). The near-horizontal, thickbedded Kailas molasse transgresses with irregular granite boulders on the Kailas batholite, with an increase in better rounded, mostly dacitic and rhyolitic volcanic pebbles in the upper layers. Sr-isotope data from Kailas intrusives and volcanics yield a well-defined isochrone of 38,8 ± 1,3 my (Honegger et al. 1982).

Support for rapid uplifts of some sections of the Transhimalayan batholites was given by new $^{40}Ar/^{39}Ar$ and fission-track mineral ages from the Quxu pluton of the

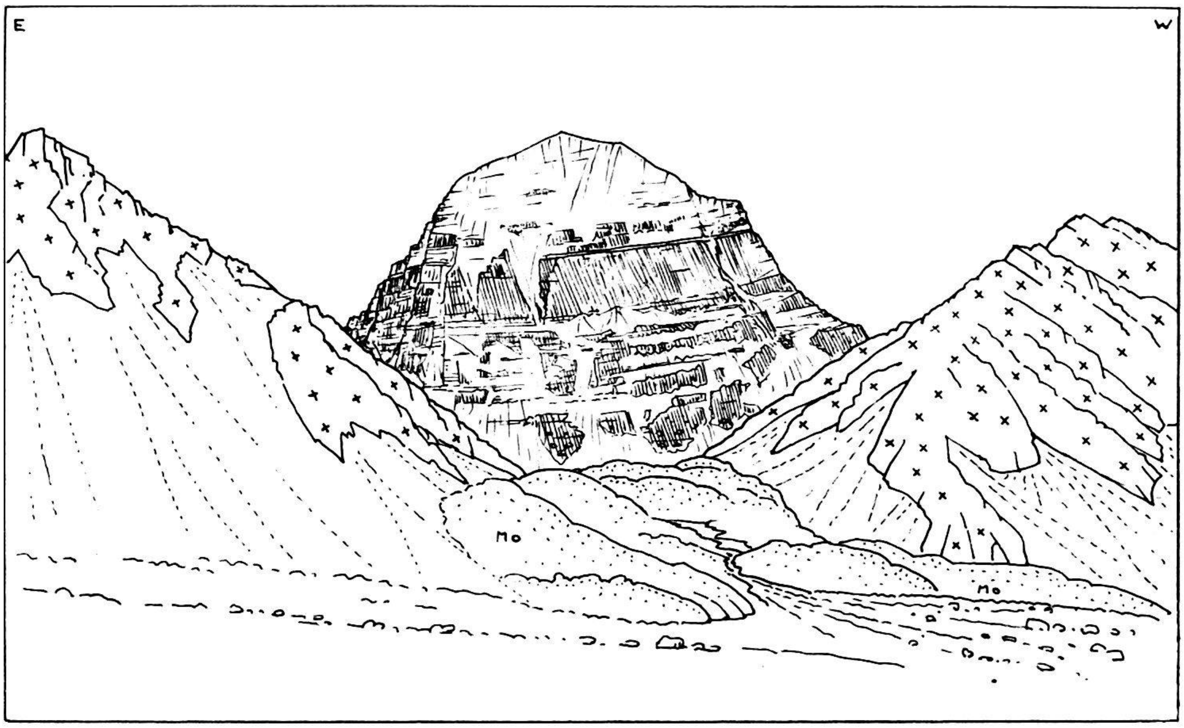


Fig. 10. *Kailas, the most sacred mountain in Asia (6,800 m), seen from the N.* The mountain is carved from over 4,000 m of near-horizontal molasse (Kailas molasse). At the transgressive base granite boulders occur (some up to 5 m^3), followed higher up by smaller granite boulders with increasing andesitic and trachytic pebbles which, well rounded, dominate in the upper layers. The mountain is framed by Transhimalayan granodiorites, tonalites and hornblende granites, on which the Kailas molasse transgresses. Mo = Moraines, partly on dead ice. Drawn after field information and photograph by A. GANSSER.

Gandese batholite (COPELAND et al. 1987). 3 km of uplift is reported in the late Oligocene/early Miocene with a peak of erosion at about 18 my. Based on regional morphology, thickness of the conglomerates and shape of the Kailas peak, it seems likely that the largest uplift must have occured in the Kailas region while the Himalayas were still a rudimentary range, dominated by the Transhimalaya.

The striking fact that all major Himalayan rivers originate from the Kailas region may be related to this early uplift. These rivers kept their courses for a long time, and once the Himalayas (and Tibet) have begun to rise during the morphogenic phase in Plio-Pleistocene times, the largest of these rivers cut deep gorges into the highest uplifts in the extremities of the Himalayan range. The Indus cuts through the Nanga Parbat uplift, where we find the largest difference in elevation known in the world, and the Yarlung Tsangpo is cutting the 7,800 m high Namche Barwa uplift with very steep, glaciated peaks, flanking the river, 5,000 m below, in the most spectacular and still little known gorge ever carved into a mountain range (Fig. 11).

Even in the Alps do we note a rapid rise of a Transhimalayan I-type pluton during the Oligocene in the well known Bergell massive. Intruded 30 my ago into a well built Alpine nappe edifice, unroofing of at least 8 km of overburden caused a rapid morphogenic rise. The highly glaciated mountain was strongly eroded and large granite boulders swiftly transported to the south, forming the fanglomeratic Como molasse.

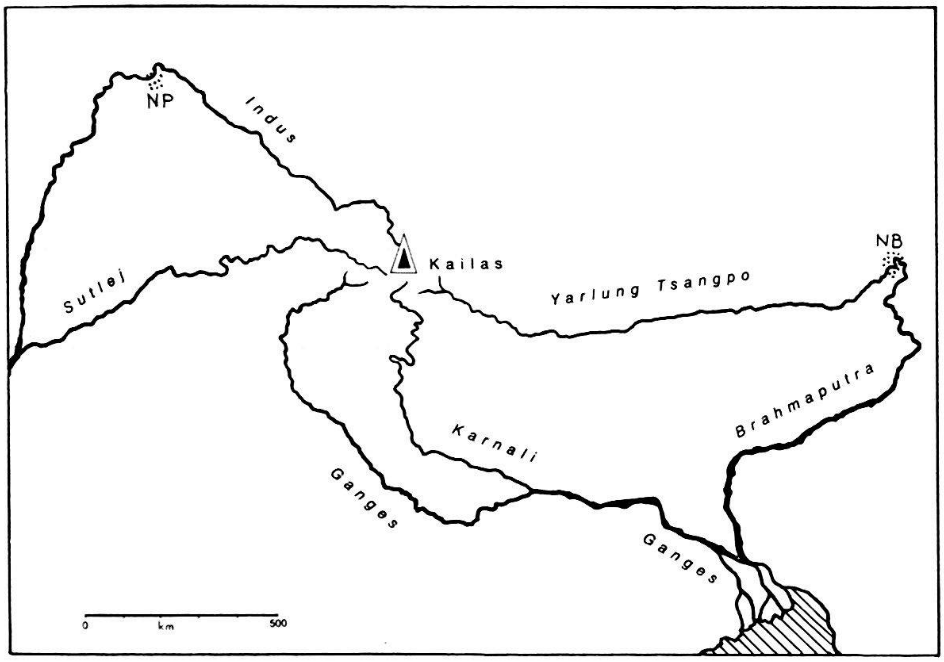


Fig. 11. *All the main Himalayan and Transhimalayan rivers originate from the Kailas.* The largest ones cut through the highest uplifts in the two extremities of the Himalayas, the Indus through the Nanga Parbat and the Yarlung Tsangpo (Brahmaputra) through the Namche Barwa culmination (Stippled area).

This molasse overlies well bedded, foraminiferal silts of Middle Oligocene age. Fission-track ages suggest that the tonalites and granites in the Como molasse can be reassigned to a vertical position of 6 km above the present morphology of the 2–3,000 m high Bergell massive (WAGNER et al. 1979). Here too, like in the Kailas region, we realize that uplift, erosion and deposition have happened nearly at the same time. It is an interesting question to find out how regional the so far localized Oligocene event has been in the Alpine-Himalayan orogen.

The extreme speed of uplift, erosion and deposition has been also evidenced in the study of Leg 116 in the Bengal fan where the youngest cooling ages of detrital K-feldspars and muscovites are indistinguishable from the stratigraphic ages of the host sediments. The sudden uplift and subsequent rapid erosion of the Transhimalaya in the Oligo-/Miocene must be responsible for the bulk of the older sediments of the Bengal fan. I doubt somewhat the author's suggestion that the area adjacent to the Main Central and Main Boundary thrusts has been a major source area since 9 million years. Vertical uplift rather than thrusting seems to produce the necessary relief (COPELAND & HARRISON 1990).

The morphogenic phase

After the late Tertiary progressive high-temperature metamorphism and the subsequent intrusion of leucogranites into the High Himalayas the orogenic phase is overprinted by the morphogenic event, with pulses of strong uplifts leading to the final shape of the mountains. It is a characteristic Himalayan fact that this high-grade metamorphism affected mainly the Precambrian poly-metamorphic rocks of the Higher Himalayas but only locally its younger sedimentary cover. An exception are some local "heat domes", discovered in the western Zanskar range of Ladakh, where infolded Lower Mesozoic sediments were overprinted by the Late Tertiary progressive metamorphism (HONEGGER 1983, KÜNDIG 1988). Away from these centres the metamorphism decreases rapidly to the prehnite-pumpellyite facies and then disappears completely, a fact well known in the highly fossiliferous Tethyan Himalayan sediments.

Many theories try to explain the fact that a high temperature phase triggers uplifts. None is so far convincing, this is particularly the case in our region, where we must realize that the morphogenic phase is not only restricted to the Himalayas but involves the whole Tibetan block. This surprising fact shows that an area of 2,500,000 km^2 has been uplifted 3–4,000 m during Pleistocene time and that this uplift is still going on. We have not yet been able to calculate this regional uplift and must base our information on morphological and glaciological interpretations as well as on the facts that tropical fauna and flora are found at present in Pleistocene sediments at 4–5,000 m elevation (HSU 1978, LI et al. 1981, XU 1981).

The fact that such an enormous area has been lifted during the Pleistocene above the snow-line, rises the problem of the intensity of the glacial cover. The extreme view is postulated by KUHLE (1985, 1988), who, based on various expeditions, comes to the conclusion that Tibet was covered by an inland-ice cap comparable to the present-day Greenland. This view is vividly contested by Monique Fort and Edward Derbyshire (pers. comm. during various discussions). "One critical question throughout this huge region, for example, concerns the criteria for discrimination of glacial from non-glacial diamictons" (DERBYSHIRE 1990).

The present relics of the numerous Tibetan lakes with well preserved strandlines, proving a progressive dessication, suggest that after the main ice-age, lakes must have covered large portions of Tibet. Already during his 1927–1935 expeditions, Eric Norin suggested large dead-ice bodies, preserved in depressions after the melting of a substantial but not complete ice cover, responsible for the formation of large lakes (NORIN 1946, 1982). These lakes must be distinguished from those formed in north to south directed grabens, related to the extensional tectonics of the same morphogenic phase.

Theories and facts enter even into old Tibetan sagas: The theory, found in ancient block prints (OLSCHAK 1979), tells of great floods covering the whole of Tibet in ancient times, and how a famous Buddha of that time took pity on the flooded land and with his sword cut a deep swath through the mountains of southeastern Tibet and thus let the water out. The facts show us that at this spot we find the spectacular gorge where the Yarlung Tsangpo cuts through the Namche Barwa uplift.

Contrasting with Tibet, large lakes are rare in the Himalayas. Smaller lakes are related to the last glacial stage and many are dammed by end-moraines or lateral glaciers in the upper part of valleys. Lakes dammed by landslides are generally very short-lived. Still, all the lakes play a substancial role in shaping the morphology of the rapid rising Himalayas. The sudden break-through of dammed lakes is a frequent phenomenon and its catastrophic floods can cause important morphological changes in a few hours which otherwise take hundreds of years. Remnants of such lakes with their light colored sediments, can be observed today in upper river courses as well as high on valley slopes (BÜRGISSER et al. 1982).

We are still missing convincing uplift rates for the morphogenic phase of the Himalayas. Comparative precise levelling as has been applied in the Alps is not yet possible. The Alpine profile shows the surprising fact that the present maximal uplift rate does not coincide with the topographic high, but is clearly displaced to the south and coincides with the deepest exposures and the lowest level of the Moho (Gubler et al. 1981). From all evidence, such as the very rough morphology, the high elevation and the distribution of the elevated terraces, we may reasonable assume that in the Himalayas the maximal uplift-rates coincide with the highest elevations. Fission-track ages from the 8,000 m high Nanga Parbat massive give an uplift rate of 4.5 mm/y, about 5 times the Alpine maximum (Zeitler 1985).

The facts of the step-like distribution of terraces in all the steep valleys of the High Himalayas, which show a wild, fanglomeratic composition, strikingly different from the Siwalik molasse in the south, suggest that the uplift occured in very strong pulses, interrupted by relative calm periods. A large amount of detrital material has been accumulating within the Himalayas in various intermontane basins and along the depression of the Yarlung Tsangpo valley (Le Fort 1989). This material reflects the earlier phases of the morphogenic uplift. All these deposits are at present well exposed in the spectacular canyons cut into the horizontal Pleistocene deposits of Hundes, famous for their tropical mammals now at 4,000 m elevation. An enormous volume of detritus is now transported from the fast rising Himalayas by the large rivers which originate from the Kailas, the "navel of the world". The holy Ganges flows with the largest amount of suspended mud ever measured. All these sediments from the growing Himalayas finally end in the sea, in the Indus and Bengal fans, the largest submarine deltas in the world.

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