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Abstract Volume

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Palaeomagnetic Results of Cretaceous/Tertiary Sediments from the Zanskar Range

TALK

E. APPEL*, A. PATZELT* & C. CHOUKER**

Palaeomagnetic investigations have been carried out on Tethyan sediments from the NW Zanskar Range. A total of 470 oriented core samples from 52 sites were taken from five stratigraphic units of Middle Cretaceous to Lower Eocene age (Shillakong Fm, Marpo Lms, Stumpata Qz, Dibling/Lingshet Lms, Kong Fm).

A characteristic remanence (ChRM) could be isolated for most sites through detailed thermal and alternating field demagnetization and multi-component analysis. All ChRM directions are similar, independent from the geological age. Negative fold tests for the different units indicate that the ChRM represents a post folding remanence. Isothermal remanence (IRM) acquisition and thermal demagnetization of a saturation IRM identify pyrrhotite as the dominating ferrimagnetic mineral and carrier of the ChRM. The pyrrhotite remanence is probably a thermoremanent magnetization which was blocked when low-grade metamorphism decreased below a temperature of about 300°C.

The coinciding ChRM directions suggest that the age of remanence acquisition is identical for all stratigraphic units. According to a negative conglomerate test from the Kong Fm, the remanence must be younger than Lower Eocene. The ChRM inclination suggests that the remanence was acquired at about 20°N. However, crustal shortening between the Zanskar Range and stable India does not allow to estimate the remanence age from the apparent polar wander path of India.

The ChRM declination shows a counterclockwise rotation of 26.5° since remanence acquisition. Dependent on the remanence age, no rotation or a slight counterclockwise rotation relative to the stable India can be concluded. This does not fit to the general pattern of palaeomagnetic results from neighbouring areas within the western syntaxis of the Himalaya, from which a clockwise rotation relative to stable India is expected for the Zanskar Range.

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Trace Element Modelling of Pelite-Derived Crustal Melts (Zanskar, North India)

TALK

M. AYRES*

The anatectic migmatites and leucogranites of the High Himalayan Crystallines (HHC) south of the Zanskar Normal Fault (ZNF) provide an excellent opportunity to test crustal melting models. Isotopic analyses of Himalayan leucogranites from other regions have shown that they are the product of crustal melting and that their source rock most likely consisted of the metapelites and metapsammites exposed in the HHC or lateral equivalent[1]. The cause of melting has been variably assigned to frictional heating along the Main Central Thrust (MCT) with or without the interaction of fluids[2], hot over cold thrusting along the MCT[3] or decompression melting as a result of rapid uplift along the ZNF (or lateral equivalent) in conjunction with rapid erosional unroofing. These possibilities can be distinguished by detailed field studies integrated with analytical geochemistry. Preliminary field work in Zanskar clearly indicates the importance of the ZNF in controlling the emplacement of some leucogranites though its significance in determining the melting process remains equivocal.

Preliminary whole-rock major element and trace element X-ray diffraction data obtained for eight leucogranites from the Zanskar region have been used to test crustal melting models. The trace elements Rb, Ba and Sr are of particular use in modelling the processes involved during the melting of a pelitic source since they are all thought to reside predominantly in major phases. Three types of incongruent melting reactions are thought to occur at the onset of melting for a pelitic source :-

1) Vapour-absent melting of muscovite.

2) Vapour-present melting of muscovite.

3) Vapour-absent melting of biotite.

The results obtained for the Zanskar leucogranites indicate that vapour-absent melting of muscovite was the predominant melting reaction. This result is in agreement with data tested in the melting model for other Himalayan leucogranites[4].

This study aims to further our understanding of the melting processes involved by analysing the distribution of trace elements and rare earth elements between leucosome phases (in-situ granitic melts) and melanosome phases (restitic selvedge) of anatectic migmatites, and leucogranite bodies (e.g. Gumburanjun, E Zanskar) which have migrated from their source. It is hoped that these data can be combined with PT estimates to ascertain whether the melting style (i.e. equilibrium versus disequilibrium) varied with depth and temperature.

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Paleodrainage Patterns and Basin Evolution of the NW Himalaya

TALK

M.E. BROOKFIELD*

During the late Tertiary the NW Himalaya rose rapidly due to crustal shortening, thickening and differential erosion. At the same time adjacent basins subsided accumulating thick prisms of sediments which were continually compressed, uplifted and eroded as thrust sheets migrated over them. The interplay of tectonism with erosion by changing river systems is particularly apparent in the Pamir arc, which indented Asia only within the last 20 ma, involving almost 1000 km northward thrusting of already assembled collision belts over the Tadjik marginal basin.

The age and nature of the foredeep sediments of the Tarim and Tadjik basins have been used to infer pulses of contemporary tectonism in the mountains. NET rates of erosion derived from radiometric and fission track dating, sediment budgets and river drainages can be compared with GROSS rates of uplift derived from fossil faunas and floras. These studies show that each range has an independent history of uplift and erosion within the framework of generally increasing late Tertiary uplift. And so has each basin. Deposition in basins is determined by the courses of the major rivers which have NOT remained constant. The thickness of sediment accumulating in marginal basins and the isostatic uplift of ranges depends on when rivers changed their courses, on when and how much temporary storage occurred within intermontane basins, and the time at which the intermontane barriers were breached and their sediments eroded.

Establishing the Cenozoic courses of the major rivers of Central and Southeast Asia shows that coarse clastic sediment pulses can not be used to infer increased tectonism in adjacent ranges. they may simply reflect river capture. Though this places constraints on the tectonic history of collision, it also provides and opportunity to reconstruct the landscape as well as orogenic evolution of the mountain belt.

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U-Pb Determinations and Tectonic History in the Kali Gandaki Region (Annapurna Himal, West-Central Nepal)

TALK

R.L. BROWN*, J.H. NAZARCHUK* & R.R. PARRISH**

The Main Central Thrust (MCT) is a crustal scale, ductile-brittle shear zone that spans the contact between the Greater Himalayan metamorphic sequence (GHMS) and the underlying Lesser Himalayan sedimentary sequence (LHSS). The GHMS is separated from the overlying Tibetan sedimentary sequence (TSS) by the Annapurna detachment fault (ADF). The MCT and ADF have been studied in detail along the Kali Gandaki - Ghaleti Khola near Dana and in a drainage west of Dhumpu, respectively.

Within the MCT shear zone, three phases of ductile deformation are observed in GHMS lithologies: D1 structures are isoclinal folds outlined by compositional layering and an S1 foliation preserved as inclusion trails in garnet; D2 structures are the product of southwesterly directed progressive deformation at kyanite grade and consist of a pervasive foliation (S2), a down dip stretching lineation, tight to isoclinal folds and shearing fabrics, all of which have been subsequently deformed by southwesterly verging folds and crenulations; D3 locally formed chlorite-grade mylonite shears near the base of the GHMS. In the LHSS four ductile deformation events, with characteristics similar to those in the GHMS, are overprinted by a fifth phase of brittle deformation.

The effects of ductile shearing on the MCT are most pronounced in the pelitic gneiss unit of the GHMS where the dominant fabric is very planar, gneisses are medium grained, and the hinge lines of D1 and D2 folds are oriented parallel to down dip stretching lineations. Associated with ductile shearing in the hanging wall of the MCT is a strain gradient. This is demonstrated by the rotation of D1 and D2 hinge lines from a down dip orientation near the base to nearly horizontal in the more central portion of the GHMS; there is also an upwards coarsening of gneisses, fabrics are less planar, and the angle between S1 and S2 increases. Abundant top-to-the-southwest shear sense indicators related to movement on the MCT are observed, but well developed mylonites either did not form or are obscured by the extensive recrystallization found in the GHMS. These annealed fabrics formed at middle crustal conditions and suggest a period of static recrystallization prior to exhumation and reactivation of the basal shear zone at upper crustal levels. Similarly, the ADF is characterized by recrystallized leucogranites with top-to-the-northeast normal sense ductile shear fabrics which are superimposed by a discrete zone of brittle deformation.

Single and multi-grain fractions of monazite and thorite from two igneous rocks within the GHMS have been dated using the U-Pb isotope system. An undeformed, coarse grained pegmatite, which cuts across S2 in the highly strained pelitic gneiss unit within the MCT shear zone, has an interpreted crystallization age of 21.8 +/- 0.5 Ma. Above the high strain of the MCT shear zone, a

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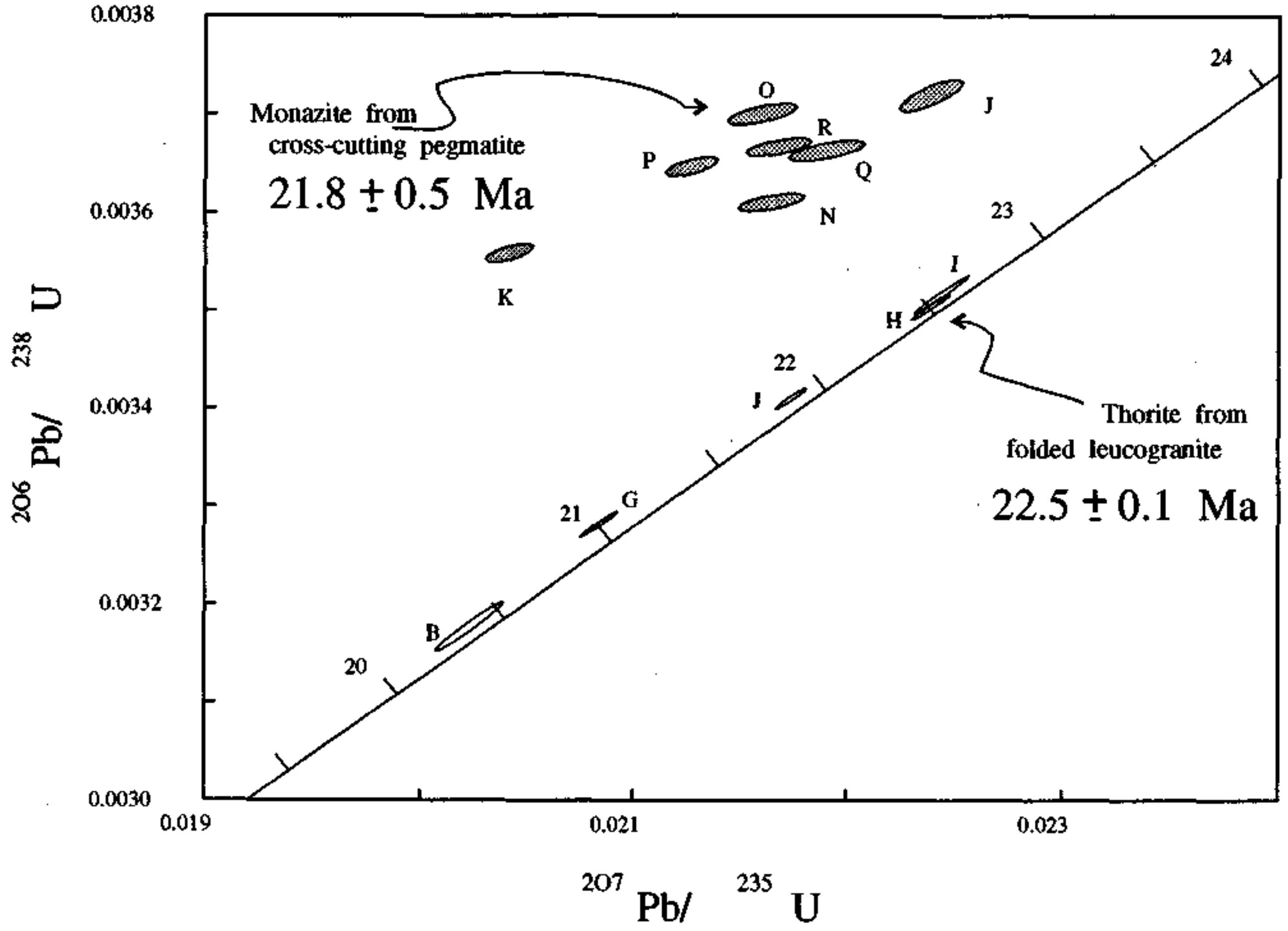

multiply deformed leucogranite body in the calc-silicate gneiss unit which exhibits interference patterns between D1 and D2 folds and contains the S2 foliation has an interpreted crystallization age of 22.5 +/- 0.1 Ma.

The new structural and U-Pb data presented here imply the following temporal relationships in the Kali Gandaki region: 1) peak metamorphism, anatectic melting, and leucogranite emplacement occurred at about 22.5 Ma; 2) at least some of the D1 deformation and all of the D2 deformation associated with the MCT occurred between 21.8 and 22.5 Ma, and therefore, both deformation events are Himalayan in age; 3) ductile deformation on the ADF probably happened after 22.5 Ma; 4) at 21.8 Ma ductile deformation on the MCT and possibly on the ADF had ceased, followed by a period of extensive static recrystallization as the GHMS cooled; 5) a subsequent pulse of movement formed chlorite-grade shears in the GHMS and a biotite-grade crenulation in the LHSS; and 6) more recently, reactivation of both the MCT and ADF has superimposed brittle fabrics on ductile shear fabrics.

The Kongur Shan Normal Fault: An Example of Mountain Building Assisted by Extension (Karakorum Fault, Eastern Pamir)

TALK

M. BRUNEL*, N. ARNAUD**, P. TAPPONNIER***, Y. PAN**** & Y. WANG****

The northernmost segment of the Karakorum fault is an active normal dextal wrench fault that bounds the Muji Tashgorgan Plio-Quaternary basin. The KongurShan (7719m) and Mustaghata (7545m) form great antiformal domes, 25 Km wide, elongated along a direction N 110.They are growing "en échelon" on the Eastern side of the Karakorum fault (1).

The Kongur antiform folds a large regional overthrust between a volcanic arc complex and a thick (probably Permo-Carboniferous) sedimentary sequence underneath. The sediments (red-violet to greenish-grey sandstones, shales, slates and calcschists) are affected by cascades of recumbent, north-facing isoclinal folds, some of them reaching kilometric sizes.

The allochtonous amphibolite volcanic arc complex, is described in the Oytag Akezi area, 200 km south of Kashgar, on the north flank of the KongurShan antiform. The 3 or 4 thousand meters thick allochtonous sequence, possibly Upper-Middle Paleozoïc, consists mainly of metabasalts, garbenschiefer amphibolites, granodiorites, gabbros and greywackes, all thrusted above the folded and schistosed green and red sandstones formation probably of Upper Paleozoic age. Shear senses in mylonitic gabbros (greenschist facies) at the base of the amphibolites are consistent with emplacement of the arc complex as a NNE vergent thrust-sheet. Biotites in the sole contact of the nappe yields Ar/Ar Jurassic ages of 146±0.7 Ma but limited Quaternary displacement is also suggested. Preliminary U/Pb ages imply also Lower Jurassic metamorphism in the Mustaghata core. The core of the Kongur antiform is made of augengneisses and leucogranites, garnet micaschists, and chloritoid schists. Overall, the allochtonous metabasites and the foliation in the gneisses wrap the antiformal dome but there are local complexities. Biotite schists form a tight, NW-SE trending syncline and near-horizontal lineation show clear evidence of right-lateral shear. The Kongur antiformal structure is interpreted as a growing ramp anticline thrusted northwards by the Main frontal Pamir thrust (MPT) system, over the 10 000 m thick Tarim Plio-Quaternary sediments. The Kongur massif, on the restored cross section, therefore appears like a gigantic crustal structure 20 to 30 Km high; the total horizontal shortening is estimated to exceed a hundred kilometres.

To the West and Southwest, the Kongur anticline is bounded by active slip normal faults, which contribute to shape the topography of its western face. West dipping, mylonitic gneisses at least 1000m thick with downdip lineation characterize a normal fault zone within which plastic deformation of quartz agregates and development of shear bands and C-S structures indicate a down to the west, shear sense along the western flank of the Kongur antiform. This normal faulting occurs under greenschist metamorphic facies conditions allowing crystallization of quartz-chlorite-muscovite.Those gneisses are cut by the steeper, active normal fault, a situation reminiscent of the Miocene North-Himalayan normal fault.at Everest.To the South, the Mustaghata (7545m) anticline is the twin structure of the Kongur, and gneisses there have given Jurassic ages with U/Pb method on zircons, probably dating the protolith of the gneisses.

Ar/Ar ages obtained on micas, use of K feldspar Ar/Ar modelling with the multi-domain theory and fission tracks ages performed on apatites lead to the proposal of a major contrast in the cooling history of the Kongur-Shan gneiss antiform at 2 Ma (2) The dated minerals crystallized or have been reequilibrated during the greenschist facies metamorphism that

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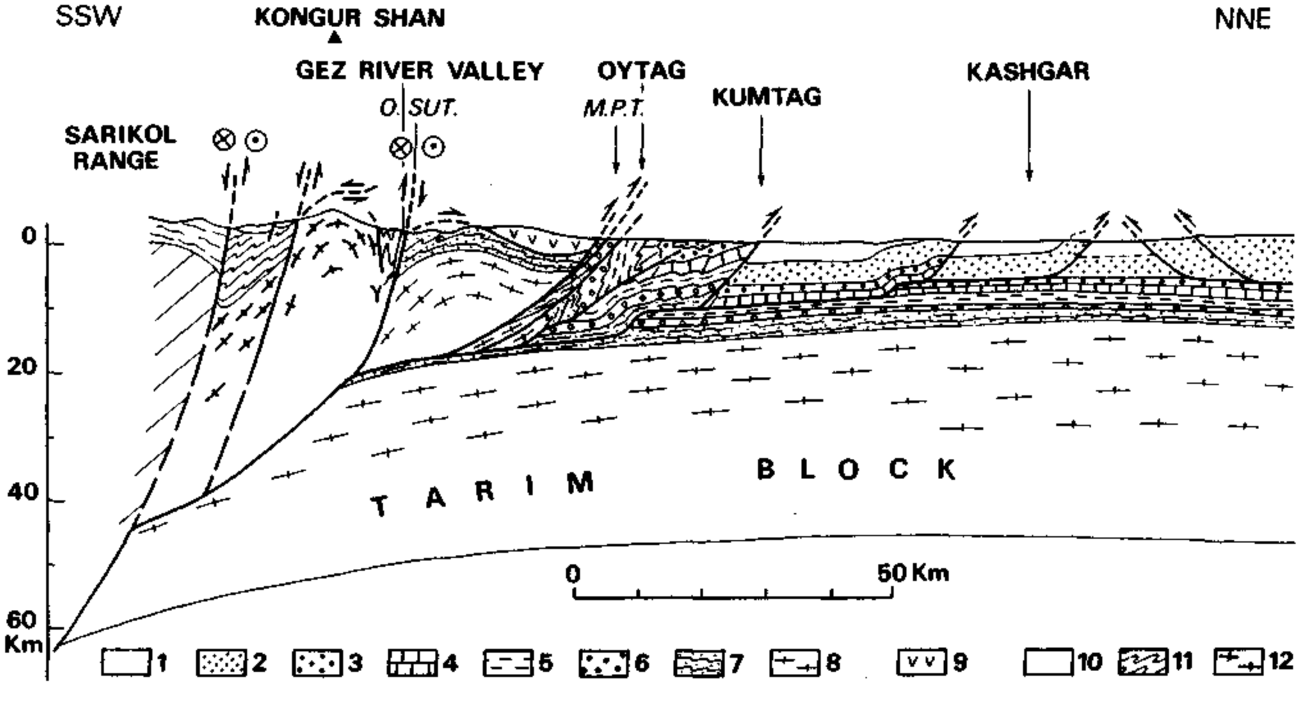
prevailed during normal faulting. The cooling deduced from those therefore records cooling after metamorphism and denudation associated with the normal fault movement. It is clear also, that the sudden increase in cooling rate (from 50°C up to 150-250°C) at 2 Ma. does not match only simple cooling subsequent to metamorphism in the normal fault but is related to a drastic change in denudation related cooling.

For these reasons, it is suggested that the cooling rates record an important increase in normal denudation at 2 Ma. Assumming a minimum geothermal gradient of 30°C/Km these cooling rates after 2Ma. record a maximum value for footwall uplift of the normal fault at rates of 3-5 Km/Ma. Similar rates at other localities suggest that the recovery time of isotherms after uplift is short, and that these rates are also minimum values. Finally, from measurement of the dip-slip component on recent fault scarps,(Liu Qing et al.,1992), concluded to a comparable average value of 1-4 Km/Ma.of relative uplift in the late Quaternary.

Tectonic observations and rates of uplift estimates imply that the Kongur-Mustaghata structures, which represent growing, "en échelon" ramp anticlines, at the scale of the crust, can be explained by Southwestward subduction of the Tarim. As is in the Himalayan example we assist to the coeval development of the frontal Pamir thrust and the rear Muji-Tashgurgan normal fault. In each of these cases, an important delay: almost 20 Ma.is observed between the onset of convergence and associated thrusting and the development of extensional deformation and normal fault. We suggest that an important amount of crustal thickening is necessary before it can induce the development of normal fault.

Kongur-Shan appears as an exceptional example where normal faulting contibutes to create relief and should be regarded as the type example of orogenic extension.



1-Plio-Quaternary; **2**- Miocene-Oligocene; **3**-Eocene; **4**-Cretaceous; **5**-Jurassic; **6**- Triassic; **7**-Devono-Carboniferous and Paleozoïc; **8**-Tarim Precambrian basement.
9-Amphibolitic nappe
10-Plio-Quaternary of the Muji Basin; **11**-KongurShan micaschists; **12**-KongurShan gneiss.

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The Panjal Sea, Kashmir Hazara Microcontinent and Hercynide Geology of Northwest Himalaya in Pakistan

M.N. CHAUDHRY*, M. GHAZANFAR* & J.N. WALSH**

This paper discusses the tectonic significance of the Permian Panjal Volcanics of Kaghan Valley on the basis of an overview of geology, field relations and associated rocks. It is proposed that more than 400 km long rift related, generally terrestrial Panjal suite developed into an incipient ocean, the Panjal Sea with continental to oceanic transitional to oceanic crust in Kaghan area. Major element, trace element and R.E.E. characteristics appear to corraborate this conclusion.

North of this incipient ocean lay the Kashmir Hazara microcontinent. The permian Panjal Sea which developed during rifting of Gondwanaland closed during Triassic when the overlying Malkandi limestone was deposited and Neo Tethys started opening to the north of the Kashmir-Hazara microcontinent.

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Late Orogenic Extension in the High Himalaya: The Thakkhola Hemi-Graben (Nepal)

M. COLCHEN*

The Thakkhola hemi-graben is located at the northern side of the Nepalese High Himalaya (Dhaulagiri and Annapurna Ranges). It is filled with thick (900 m) detritical series of probably Plio-Pleistocenous age (Tetang and Thakkhola formations) *(1)*.

Several fault systems are recognized in the Mesozoic formations, which constitutes the basement of the southern part of the Thakkhola hemi-graben :

- **a N020-N040 system**, set of plurikilometric normal faults of regional extension, which are well exposed in the western part of the basin. The fault planes dip 80 to 85° to the east, with striae pitching 15° to 30° to the north. These faults are associated with sinistral oblique-slip ones. The amplitude of the displacement decrease from north to south : it varies from 4 km (vertical slip) and 8 km (horizontal slip) at the north to some tens of meters 50 km to the south.
- **others fault systems** are recognized : N180-170, N070-090, N115, N150-160° normal and strike-slip faults. These faults are subvertical, with minor vertical slip.

Four directions of extension are recognized :

- a WNW-ESE which fits with the Thakkhola hemi-graben formation with N020-040 normal faults,
- a N-S, with N150-160 normal faults,
- a NE-SW, with N150-160 normal faults,
- and a W-E, with N180-170 normal faults.

Two directions of compression :

- a NNW-SSE to N-S with N020-040 sinistral and N150-160 dextral strike-slip faults,;
- a E-W with N020-040 dextral and N120-150 sinistral strike-slip faults.

(1) FORT M, FREYTET P. and COLCHEN M. (1982).

In conclusion :

The superposition of the several striae assemblage on a same fault plane reveal a polyphasic faulting in extension and compression alternately.

The disconformity between the Thakkhola fm. and the mesozoic fm. of the basement, both folded and faulted, is the indication that a part of this faulting predates the Thakkhola hemi-graben formation.

Concerning this hemi-graben, is proposed the following chronology of the faulting from the Late Paleogene to the present time :

1) a WNW-ESE extension characterized by N020-040 normal faults ;
2) a NW-SE to N-S compression with the N020-040 sinistral strike-slip faults and N150-160 dextral strike-slip faults ;
3) a ENE-WSW to E-W compression with the N020-040 dextral and N070-090 sinistral strike-slip faults ;
4) a E-W extension with the N180-160 normal faults observed in the Thakkhola fm. and the Quaternary fm.

This faulting is in keeping with the geodynamic evolution of the northern himalayan domains, consequence of the continental hypercollision between India and Asia :

- the extension of the upper plate above the North Himalayan shear zone ;
- the Miocene dextral shearing between Himalaya and Tibet.

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Field Study of the Western Karakorum Axial Batholith Along the Karambar Valley (Northern Pakistan)

TALK

F. DEBON* & N.A. KHAN**

The detailed study of the Karakorum axial batholith undertaken by different teams for the last ten years has shown its composite character. Different plutonic units, dominantly ranging in age from Cretaceous to Miocene, have been recognized. However, their inventory is far from being over, and their extent and relationships remain often ill-defined.

Our 1992 field trip in the Karakorum range was mainly devoted to the Karambar valley (N. Pakistan), the choice of which was based on several grounds: - the Karambar valley offers a complete and easily accessible N-S section of the western axial batholith, perpendicular to its elongation; - this section, hitherto poorly known (review *in* Casnedi, 1984), cross-cuts a cartographic plutonic "blank", about 120 km long, separating two already investigated N-S sections of the batholith, namely the Yasin-Darkot and the Hunza-Batura sections. The study concerns a section around 40 km long, 28 of them for the batholith itself.

Along the Karambar valley, surrounding rocks of the batholith are essentially made up of metapelitic formations, usually trending WNW-ESE. Metamorphism is dominantly developed south of the batholith, where biotite-garnet metapelites are cross-cut by a conspicuous swarm of diversified leucocratic dykes that could be held responsible for their transformation into migmatites of the injection type. This migmatitic zone is about 4 km wide. More to the south, around 6 km far from the batholith, dykes almost completely disappear and metamorphism decreases abruptly (phyllites, slates).

At its northern and southern margins, the batholith intrudes metapelites along sharp, normal and steep contacts, roughly concordant at map scale. Metasedimentary xenoliths, a metre up to several decametres in thickness, are frequent close to either margins, particularly along the southern one where they occur within a zone some 700 m wide. Metasedimentary rocks seem to be completely lacking in the internal part of the batholith. The huge screen which, more to the west, divides the batholith into two branches, does not reach the Karambar valley.

Three major types of plutonic rocks can be distinguished along the section studied: (1) strongly foliated biotite-amphibole granodiorite, often rich in mafic enclaves, sometimes blastomylonitic, representing the westward continuation of the well-known mid-Cretaceous calc-alkaline "Hunza Granodiorite" (HG); (2) diversified foliated amphibole-biotite granite, locally porpyritic, corresponding to the mid-Cretaceous subalkaline "Darkot Pass Granite" (DPG); (3) various and more or less foliated fine grained rocks of acidic and intermediate composition (FGR). From north to south, the arrangement of the different units is: HG + metapelitic xenoliths (~ 0.2 km) / DPG, often porphyritic, + FGR + HG (~ 0.5 km) / DPG, often porphyritic, (~ ≤ 1.5 km) / DPG + FGR (+ HG) (~ ≥ 3.5 km) / FGR + HG (often as angular enclaves within FGR) (~ 5.5 km) / HG (~ 16 km) / HG + metapelitic xenoliths (~ 0.7 km). The different units usually display sharp and sinuous contacts. HG was emplaced before FGR, whereas FGR and DPG could be coeval.

On the whole, the section shows a very complex imbrication between the Hunza and Darkot Pass plutonic units, as also between them and the fine grained igneous group (FGR), of uncertain affinity.

Numerous leucocratic dykes of various composition cross-cut the batholith. At least part of them were emplaced during or before the deformation(s) responsible for the foliation of their host granitoids. Their study, in relation with deformation and metamorphism, both within and out of the batholith, remains to be done and should be of particular interest.

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TALK

Extensional Exhumation of High-Grade Metamorphic Rocks in the Zanskar Himalaya

M. DRANSFIELD*

One process leading to the exhumation of lower crustal, high-grade metamorphic rocks is by extensional unroofing along the footwall of large-scale, low-angle normal fault zones. Such extension is often sited along orogenic belts, where it is associated with compressional tectonics. Detailed mapping and sampling, combined with analysis of macro- and micro-structure, petrology and PT data, is being used to study the evolution of rock fabrics and metamorphic pathways, and the history of compression and extension recorded in the footwall metamorphic rocks of these large-scale normal faults. Field work has been conducted in two orogenic belts; the Scandinavian Caledonides, in western Norway and the Himalaya, in Zanskar, northern India. This presentation will concentrate on the Zanskar area.

High-grade metamorphism in the High Himalayan Crystalline Unit resulted from thrust- and fold-related crustal thickening within the Indian plate following the collision of India and Asia during the Eocene. The existence of a large-scale, laterally extensive, normal fault zone bounding the northern side of the High Himalayan Crystalline Unit is now well established, from Zanskar in the north-western Himalaya to eastern Nepal/Tibet. However, the details of the exhumation of the high-grade metamorphic rocks, in the footwall of the normal fault zone, remain poorly understood. In Zanskar, the normal fault is continuously exposed along strike for over 150km and places sillimanite-grade gneisses of the High Himalayan Crystalline unit against anchimetamorphic Tethyan sediments. Its dip varies between 20 and 45° NE. The Zanskar normal fault zone is one expression of the extension that affects a large proportion of the Crystalline Unit in this area. The fabrics recorded by different grades of metamorphic rocks in the footwall represent an evolution from compressional to extensional tectonics and exhumation through different crustal levels.

Early, compressive nappe, domal and fold structures are preserved mainly in the highest-grade rocks, in the core of the Crystalline Unit - high amphibolite facies gneisses and migmatites. Extension begins in amphibolite facies, shown by the presence of sillimanite growing along NE-directed extensional S-C fabrics. The later foliation, stretching lineations, polyphase folding and boudinage structures, in the gneisses, schists and deformed leucogranites can all be interpreted as extensional fabrics, evolving from pure to simple shear structures as exhumation proceeded. Late, greenschist facies mylonites, mainly associated with the fault zone itself, show many discrete shear zones and abundant, simple-shear-related kinematic indicators, revealing a consistent top to the NE, or normal, sense of displacement. The final stage of exhumation is accompanied by the formation of mesoscopic, brittle, normal faults and pseudotachylite veins. Petrological and thermobarometric data will be used to quantify this exhumational history.

A combined pure and simple shear model is suggested for the area. The simple shear domain of the upper and middle crust has overprinted the pure shear domain of the lower crust as the rocks were exhumed and cooled. The Main Central Thrust and the Zanskar Normal Fault Zone appear to have been active simultaneously. The extension is thought to be a result of gravitational collapse of the Himalayan topographic front, leading to the formation of the Zanskar Normal Fault Zone and contributing to the exhumation of the metamorphic rocks below the fault.

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Cooling History of the MCT-Process in the NW-Himalayas in the Light of Geochronology, Thermal Modelling and Palaeogeography

TALK

W. FRANK*, B. GRASEMANN*, P. GUNTLI & Ch. MILLER*****

GEOCHRONOLOGY: In the Crystalline nappe of the NW-Himalayas amphibolite facies temperatures ceased from 25-23Ma onwards. $^{40}Ar/^{39}Ar$ plateau ages of white micas from the Higher Himalayan Crystalline (HHC) along the Chenab river S of Kishtwar typically yield cooling ages around 22-21Ma. Biotites frequently yield ages (appr. 300°C) about 16Ma, locally also younger ones. A rapid cooling phase is only indicated for higher temperatures, but was obviously not active for the whole 500°C-300°C interval. From this cooling pattern it can be inferred that the Main Central Thrust (MCT) process started not later than 23Ma.

Up to now reliable cooling ages from the metamorphosed Lesser Himalayan unit (LH) are nearly missing. From several reasons it is difficult to obtain reliable ages from these units. The Proterozoic granitic rocks usually have not reached total equilibrium in alpine times. Slates and schists without major Ca-bearing mineral phase are unsuitable for Rb/Sr-dating. Excess ^{40}Ar (up to $1x10^{-4}cm^3$ STP/g) is ubiquitous in these units. Therefor the few reliable data from these units have an important significance. The youngest ages in the Larji-Kulu-Rampur window indicate formation ages for the very low metamorphic zones of about 12Ma.; biotites from this area may have passed their blocking temperature later than 10Ma. Locally the HHC W of Kishtwar window suffered a reheating from below, an interpretation based on Ar/Ar data on biotites around 7-8Ma.

Youngest ages in the LH are derived from 1860Ma granite gneisses in Garwahl along the Bhagirathi river below the Vaikrita thrust (main MCT). $^{40}Ar/^{39}Ar$-plateau ages of 4.5Ma were measured on phengites from these rocks. Several other results on micas from this region with different methods support a cooling history from 10Ma onwards.

THERMAL MODELLING: Two-dimensional finite-difference thermal modelling of the overthrusting of the HHC over the LH establishes that the shape of cooling curves for samples from the footwall and hanging wall are very sensitive to the actual displacement history. The cooling curves deduced from mineral ages in the hanging wall are steeper between 25-15Ma and become shallower in more recent time. Samples form the footwall show a temperature rise between 25-10Ma followed by rapid cooling. These patterns can be numerically modeled assuming an initial displacement of about 10mm/a and crustal thickening of 10km, which produces an elevated geothermal gradient and warming of the footwall. From appr. 15Ma onwards the hanging wall was exhumed at a rate of about 1mm/a. The rapid cooling of the samples in the footwall at around 10Ma can be explained by an exhumation rate of about 1.5mm/a or higher, which was caused by rapid uplift near extensional faults.

PALAEOGEOGRAPHY: The thermal history of the HHC is closely connected with the detailed palaeogeographic position of the different units at the former border zone between the LH and HHC units. It has important consequences if the present southern front of the HHC was near to the leading edges of the overthrust along the MCT or far behind it.

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From our geochronological data of the Proterozoic sequences, from field work in the Lahul/Chamba region and the similarities between the Simla Slates and the Haimantas we reject the widely accepted interpretation that the Simla Slate - Krol sequence was deposited on the Early to Middle Riphean Shali - Deoban carbonate platform. We propose an alternative model in which the Simla - Krol sequence was deposited in the southern continuation of the vast clastic Haimanta sedimentary pile, which often exhibit a flyschtype character and got their clastic material from a northern region.

We assume that the northern Chail series (without carbonates) or the Jutoghs and their equivalents (Lower Crystalline nappe in the sense of G. FUCHS) may have been the former basement of the Simla Slates.

In a first phase of the MCT process the Simla/Krol sequence together with the main HHC began to move along a nearly horizontal thrust plane with ramps. In a second phase the thin leading edge of the overthrust unit (i.e. the Simla/Krol unit) was overridden by the main mass of the HHC and parts of the Chail units, forming now some kind of a giant duplex structure.

This interpretation has several consequences apart from palaeogeographic and lithostratigraphic aspects: the thrust distance between the HHC and LH should be extended by the order of 100km. This special setting and the geometry of the initial MCT-process greatly facilitates the evolution of the reversed metamorphic sections. The present stacking: Chail units / Lower Crystalline nappe / HHC may have developed for some Ma in the first stage by thrusting hot material on already warm substrate and the reversed metamorphism developed in the associated shear regime of considerable thickness. The geochronological results of the cooling pattern are in better correspondence with this new model than with a very rapid thrusting of hot on cool elements.

Contribution to the Geology of SE Zanskar, Lahul, Chamba – the Sangtha – Dharamsala Section

TALK

G. FUCHS* & M. LINNER**

It is significant that there exists no sharp boundary between the Lamayuru Unit and the Zanskar shelf series (FUCHS, 1986). In the Khurnak syncline the complete Precambrian-Eocene succession is exposed. The Triassic series exhibit distinct Lamayuru facies. Though blue limestones gain importance towards the S the euxinic facies persists in the Norian series till Marang La. The thrust of this pass demarkates a change in facies, and therefore indicates at least several kilometers of transport. In the N we find the euxinic Norian and a lenticular red riff body at the base of the Kioto Limestone, whereas in the S the greenish-grey Monotis Shales are succeeded by the Quartzite Beds and then the Kioto Limestone follows. In the Tsarap Valley a complex, partly sheared syncline contains Jurassic-Cretaceous series up to the Kangi La Formation (Campanian).

The Sarchu Shear Zone, comparable to the Zanskar Shear Zone (HERREN, 1987), influenced the pre-existing structures on both sides. In the N the vergence is generally SW, but in the vicinity of the shear zone folds are directed NE. In the S the huge recumbent folds in the Palaeozoics are the product of dragging near the shear zone. There is also a hiatus in the grade of metamorphism - it is much higher in the footwall. During the activity of the shear zone the conditions changed from ductile shear to steep planes with cataclasis.

In the fold belt of Lahul we find Haimantas (Phe) and Parahio (Karsha) Formation with a few Palaeozoc synclines. The Tandi Syncline still is an enigma. It consists of carbonates of Jurassic age (PICKET et. al., 1975) bordering Precambrian Haimantas without a trace of any Palaeozoic or Triassic formations. The fold, however, is directed NE and not plunging SW.

In Chamba the age of the Manjeer Conglomerate is a major problem. From the Sach Pass section FUCHS (1975) did not hesitate to correlate with the Agglomeratic Slate (Up.Carb.). FRANK found the boulder slates underlying Haimantas and therefore suggests a Late Precambrian age (pers.comm.). In fact we substantiated the observation: At Tindi (Chandra Valley), the Chobia Pass, and ENE Barmaur the Manjeer Conglomerates are overlain by Haimantas. From the lithology of the conglomerates and their association with carbonates and black slates there is no doubt that there is only one such series in Chamba, and that the "intra-Haimanta" conglomerates are connected with the Manjeer Conglomerates of the Kalhel Syncline. There they are associated with fossiliferous Late Palaeozoic and Triassic sediments and the Panjal Trap. Thus we favour a Late Palaeozoic age of the Manjeer Conglomerates, which implies overthrusting of Haimantas in the area SE of the Sach Pass.

The Early Palaeozoic Granite intrudes Haimantas in the Dhauladhar Range. Between the Crystalline Nappe and the Murrees of the Tertiary Zone in Dharamsala basic volcanics, Eocene Subathus, and a scale of Shali Limestone and black slates are squeezed and inverted.

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Geological Traverse from Chitral to Karambar (E Hindu Kush to W Karakorum) Preliminary Geological Results

TALK

M. GAETANI*, A. NICORA*, L. ANGIOLINI* & P. LE FORT**

In the easternmost Hindu Kush, Hindu Raj and W Karakorum, the following units may recognized from south to north:

1) The Axial Batholith forms two distinct branches in this region. They are separated by a band of metasediments already described east of this zone as the Darkot Group, of Permian age pro parte. Possible Mesozoic fossils have been obtained. The Yarkhun river only cuts through the northern branch where two types of granitoid have been recognized: (i) a dark amphibole-biotite granodiorite to biotite, rich in mafic enclaves, often foliated, resembling the Hunza granodiorite of mid-Cretaceous age, (ii) a porphyritic biotite ± amphibolite granite, often strongly deformed, more abundant to the north of the section, where it intrudes into the metasedimentary formations with a diffuse contact. This second type, resembling the subalcaline mid-Cretaceuos Darkot pass granite, is intimately associated with the first, a situation similar in some way to that of the Karambar section (see Debon & Khan Abstract).

2) North of the Axial Batholith mostly sedimentary rocks crop out, usually arranged in three stacks, thrusted southwards. The crystalline basement of the middle stack has been discovered. It is made up of a medium grained biotite granite, largely eroded in a glacial basin, due to its very strong alteration and brittle deformation. To the south, the granite intrudes the dark metapelites of Chikar. The sedimentary succession is directly trangresssive on the granite with conglomerates and siltites, in which Early Ordovician acritarchs have been detected (M. Tongiorgi, Pisa). The succession continues upwards with a terrigenous unit, hundreds m-thick, with rare dolomitic intercalations in which Talent et al. (1981) found Middle-Upper Ordovician conodonts. The first significant carbonate unit consists of about 150 m of yellow well bedded dolomites, with peritidal depositional characters. Supposed age: Devonian. A mixed terrigenous carbonate unit, locally extremely rich in corals, brachiopods and bryozoans follows. Field identification: Middle Devonian and Frasnian. Upwards about 100 m of grey wackestone-crinoidal packstones follows, with solitary corals. Supposed age: Carboniferous. The lower part of the Permian is terrigenous and it is correlatable with the Gircha Fm. of the Hunza region. Then a mixed carbonate-terrigenous succession, several hundreds m-thick follows, locally crowded with brachiopods, corals, bryozoans, conodonts, gastropods, bivalves and especially fusulinids. For details refers to Angiolini et al.

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(Poster Section). After an erosional surface, with local emersions and a thin terrigenous unit, a huge peritidal dolomitic formation, 700 m, thick follows. The paleontological control is poor and we suppose it represents the Upper Permian and may be the Triassic up to the Early Jurassic. We have no informations about most of the Mesozoic. The southernmost thrusted slice may have at its top the Reshun Conglomerate with *Orbitolina*-bearing pebbles.

3) A system of sinistral strike-slip faults, SW-NE oriented, the Tirich Mir Fault, brings in contact grey pale dolomites, with low metamorphic grade. Phantoms of ? Devonian and Triassic fossils have been found. Most significant are mafic metatuffs and various detrital volcanogenic levels, dark red to dark green, interbedded with the sediments.

4) With faulted contact, the huge, several km-thick Wakhan Slates follows. They are intruded by granitoid bodies made up in general of biotite-amphibole porhyritic granite. A single granitoid pluton (Chatteboj), with a strong contact aureole, was found also intruded in the unit 2). All these granitoid bodies could pertain either to the northern granitoid belt running from Tirich Mir to Khunjerab, in which Cretaceous ages have been obtained, or to the Batura group of Eocene age.

The Himalayas Seen from Bhutan

A. GANSSER*

Most of the publications on the wider Himalayas deal with the western and central part with easier access, better exposures, climate and lesser political restrictions. This changes drastically from Sikkim to the east with difficult field conditions, over 10 m rain in Assam and restrictions for foreign investigators. It is the domain of the geologists of the Geological Survey of India , their eccellent work only partly published and without regional maps. My own experience in this area,apart of an investigation of satellite photos covering the wider Himalayas, are expeditions into the Bhutan Himalayas from 1963 to 1977.

The geology of Bhutan represents the eastern Himalayas and differs in many aspects from the more western regions. The over 17 km thick central crystalline thrustsheet is more widespread and exposes throughout a remarcable reversed metamorphism, increasing northwards with large intrusiones of leucogranites. It decreases suddenly towards the Tibetan border with the transgressive tethyan sediments, which also occur in some isolated basins on top of the crystallines. No tethyan faultzone exists in the north and the earliest fossils,after decreasing metamorphism, suggest an Ordovician age. The Lesser Himalaya forms a narrow band but opens eastwards into a large, northwards directed spur with complicated internal tectonics, emphasized by slices of over 1000 my old granitoids in late Precambrian sediments,dominated by 5000 m thick quartzites. From this spur all along the eastern Lesser Himalayas outcrops a steep narrow band of Permo-Carboniferous , coal-bearing Damudas, bordering along the MBT the constant belt of Siwaliks, interrupted only along the western Bhutan foothills,overthrust by the Lesser Himalaya. This coincides with a remarcable shallowing of the Brahmaputra basin with Shillong elements outcropping only 35 km to the south of the MBT, the narrowest spot of the whole Himalayan foreland.

All the elements from Bhutan can be followed through the eastern Himalayas until the East Himalayan "syntaxis". The narrow Damuda belt opens along the Siang river (NS directed Brahmaputra), with the incoming Permian Abor volcanics, the equivalent of the West Himalayan Panjal traps, both volcanics restricted to the west and east end of the Himalayas. The Abor volcanics form a complicated north plunging antiform with a window of marine Eocene in the Siang gorge, its size similar to the Hazara-Kashmir "syntaxis" in the west. The equivalent of the Nanga Parbat uplift in the east Himalayas could be the Namche

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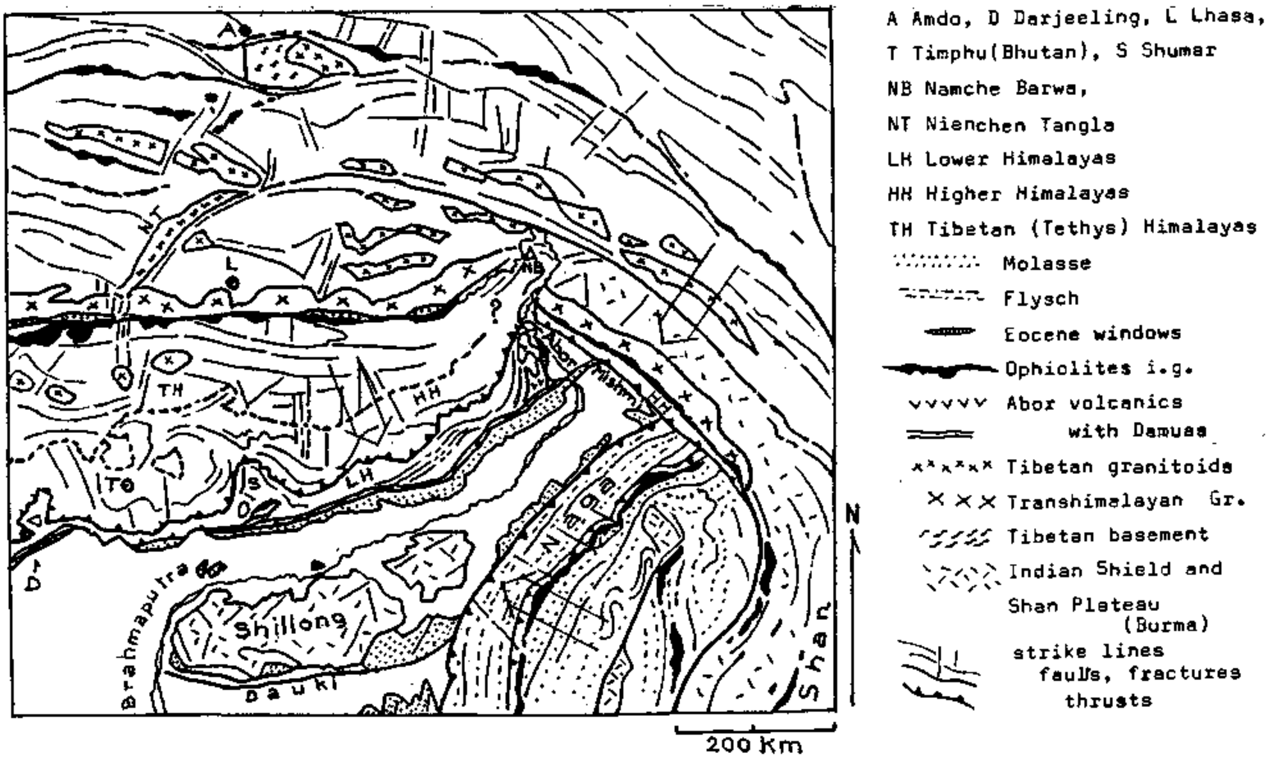
Barwa high, though the structural connections with the Abor spur are still vague. The Himalayas do not end with the respective syntaxis but with remarcable fault and thrustzones, the Sarobi and Chaman faults in the west, the Mishmi thrust in the east. Both Himalayan ends and the respective continuations along the west and east border of the Indian shield are strikingly different. The west is characterised by widespread evaporites, outcropping in the salt range, forming an important decollement horizon . They are responsible for the discrepancies between surface and subsurface structures. Evaporites are so far unknown in the eastern Himalayas except for some late Precambrian-Cambrian gypsum horizons in the Shumar spur of the Lesser Himalaya in southeast Bhutan. A 6000 m thick Eocene flysch belt grading into a younger molasse followes the allochtonous Quetta and Las Bela ophiolites,thrust on the west border of the Indian shield.
A similar flysch zone, here with exotic blocks, is related to the allochtonous Naga ophiolites of the Indo-Burman ranges. They are thrust towards the Shillong and Mikir massives of the eastern Indian shield. No similar flysch development is known from the main Himalayan range. The outstanding,southeast striking Mishmi thrust which overrides even Quaternary sediments, cuts all the main Himalayan elements as well as all the Indo-Burman ranges. The complete tethyan Himalaya has disappeared between a thin crystalline belt and the still enigmatic Tidding ophiolite zone, which continues into the western border of the Burmese Shan plateau. The Tidding zone is southwestwards overthrust by granites reminiscent of the Transhimalaya.

THE WIDER EASTERN HIMALAYAS



It is most conpicuous how the eastern Himalayas, the Mishmi hills as well as the Indo-Burman ranges encroached for hundreds of kilometers from the north, the northeast and the southeast on the Shillong shield and its northeastern continuation under the Assam basin, with several thousand meters of Neogene and Quaternary sediments. In spite of recent seismicity, trending north-south in the middle of the basement, this northeastern continuation of the Indian shield has remained fixed.

A Complete Section Through the Paleozoic to Mesozoic Indian Continental Margin (Spiti Himalaya, N India)

E. GARZANTI*, F. BERRA*, F. JADOUL* & A. NICORA*

The complete Paleozoic and Mesozoic stratigraphy of the Northern Indian continental margin was reconstructed from several detailed sections measured in 1992 along the Pin and Parahio Valleys, in the Kibber-Chikkim area and along the Kunzam La-Losar-Kiato profile.

A very thick succession of shallow-water fine-grained sandstones and pelites, with only a few intercalated dolostone beds at the top, was deposited in the Late Precambrian? and Cambrian. A thin biocalcirudite marker horizon was found in the Kunzam La area 485 m below the top of the unit. Similar carbonate beds occur also in Pin Valley.

Next, a major break is marked by a low-angle unconformity, best exposed north of Kunzam La and ascribed to the Late Pan-African orogenic pulse, overlain by an up to 783 m thick redbed "molasse" of Ordovician age. The following unit is still arenaceous in the Takche area, and becomes more calcareous eastwards. At Muth it is 243 m thick and contains several limestone intervals, ironstone beds in the lower part and patch reefs at the top. It is overlain by 224 m of pure (eolian?) white quartzarenites, followed in turn by alternating hybrid dolomitic arenites and pure quartzarenites (55 to 92 m). At Losar this upper interval is much thicker (about 250 m) and characterized by restricted to open marine facies, including biocalcarenites and coral patch reefs. Fossiliferous, storm-deposited arenaceous limestones (61 m at Muth), passing upward to dolostones and shale (64 m at Muth) were deposited in the Early Carboniferous; this succession is followed by white gypsum layers in the Losar area.

The Upper Paleozoic was characterized by major tectonic activity, leading to extreme topographic irregularities sealed by the Upper Permian Kuling Formation. In the Spiti Valley, the latter unit overlies a very thick terrigenous section, consisting of tidal quartzarenites and shales (well over 353 m thick at Losar), *Fenestella*-bearing shales (about 100 to 150 m thick at Losar), orange-weathering quartzarenites (123 m thick at Losar) and brownish sandstones, paraconglomerates and black pelites with dropstones (around 300 m thick at Losar and well over 150 m also at Lingti). In the Pin Valley, instead, the Upper Paleozoic section is largely eroded, and the Kuling Fm. disconformably overlies Silurian arenites to Devonian quartzarenites separated by paleofaults (Parahio Valley), or Lower Carboniferous limestones (Pin Valley).

The Kuling Fm. (63 to 95 m thick) consists of 0.4 to 35 m thick basal conglomeratic arenites, comprising ironstone layers at the base and top, overlain by black phosphatic pelites rich in Spiriferid and Productid brachiopods (52 to 93 m thick). In the Parahio Valley the basal arenites are only 0.4 to 2.1 m thick, whereas in the Pin Valley

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the basal breccia and hybrid arenites increase in thickness from 1.2 to 6.5 m (Muth), to 17.5 m (Guling).

The Triassic succession begins with the sharp paraconformable base of the Upper Griesbachian to Upper Anisian Tamba Kurkur ammonitic limestones (33 to 54 m thick). The ironstone-bearing, ammonite-rich condensed limestones occurring at the top of the unit are overlain by the *Daonella* Shale (42 m thick at Muth) and next by the *Daonella/Halobia* Limestone (85 m thick at Muth), whithin which the Ladinian/Carnian boundary lies.

The Carnian succession is very thick, and comprises the shelfal Grey Beds (206 m thick), upper Lower Carnian at the base (*Austriacum* Zone), and the shallow-water *Tropites* Limestone. This unit, organized in several terrigenous/carbonate shallowing-upward cycles, can be lithologically subdivided in a lower carbonate member (158 m thick), a middle largely terrigenous member (172 m thick, increasing northward to 205 m), and an upper carbonate platform member (103 m thick, increasing northward to 158 m). The upper member yielded uppermost Carnian conodonts at its base. Facies distribution patterns invariably point to northward deepening of the Spiti passive margin.

The sharp paraconformable base of the overlying Norian-Rhaetian succession is marked locally (Hal village) by breccias/conglomerates, overlain by storm-deposited quartzose limestones and bioclastic siltstones and sandstones, in turn followed by thick ironstone layers, marly limestones with rare ammonoids and locally abundant vertebrate ribs, passing upward to calcareous siltstones (109 to 187 m thick). Next, a 16 to 22 m thick limestone interval, locally yielding corals, brachiopods and lithoclasts, is followed by grey pelites, greenish sandstones, micritic limestones and local ironstones (134 to 148 m thick). These three units broadly correspond to the "*Juvavites* Beds", "Coral Limestone" and "*Monotis* Shale" of previous Authors, which however are difficult to recognize and trace laterally, due to poor original definition and strong lateral variability of facies. The overlying "Quartzite Series" (47 to 51 m thick), is characterized by quartzarenites, hybrid sandstones and bioclastic limestones. The upper boundary with the Kioto Limestone, marked by appearance of large bivalves (Alatochonchids, Megalodons) is transitional.

The latter mainly Lower Jurassic unit (over 600 m thick) consists of thick-bedded subtidal limestones; in the Kibber area huge oolite bars occur in its middle-upper part. The overlying Laptal Fm. (15 to 30 m thick) is characterized by quartzose calcarenites and ooidal limestones with ostreids and belemnite beds at the top. Next, the Ferruginous Oolite Formation consists of a lower grey marly interval yielding bivalves and belemnites (20 to 30 m thick), capped by an ironstone layer (0.8 to 2.2 m thick), passing upward to the Spiti Shale. Black shales with hybrid storm beds rich in Inoceramids and belemnites (*Belemnopsis gerardi* Beds, over 30 m thick) are followed by black shales yielding abundant Late Jurassic ammonoids (Chidamu Beds), which are invariably folded and overlain by black shales with intercalated sharp-based quartzose sandstones (Lochambel Beds, about 100 m thick).

The Giumal Group consists of a lower interval of quartzose bivalve-rich sandstones (54 to 73 m thick), overlain by black pelites and subordinate sandstones (116 to 133 m thick), and by locally glauconitic subarkoses yielding a few volcanic rock fragments, up to very coarse-grained at the top (32 to 67 m thick). Next, a thickening-upward cycle of reddish bioturbated subarkoses with intercalated glauconitic and bivalve-rich layers (31 to 32 m thick), is overlain by black pelites, volcanic arenites and glauconitic layers (55 to 59 m thick). At Chikkim, the top of the unit consists of three thickening and coarsening-upward cycles (56 to 64 m thick), capped by biocalcirudites and black pelites (25 m thick).

The basal bed of the overlying Chikkim Limestone is rich in small phosphatic pebbles, belemnites and bacterial mats, and displays a strongly bioturbated sharp paraconformable base. This mid-Cretaceous pelagic unit, 65 m thick and containing planktonic foraminifers and locally echinoids, is followed by at least 200-300 meters of folded Kangi La Marls of Late Cretaceous age, which represent the youngest term of the Spiti succession.

Initial Rising of the Himalaya as Deduced from Petrography of Syncollisional Redbeds (Muree Supergroup, Pakistan, and Chulung La Formation, Tethys Himalaya, India)

TALK

E. GARZANTI* & S. CRITELLI**
Based on fieldwork and sampling in Hazara-Kashmir by
P. BOSSART*** & R. OTTIGER***

The northern spur of India began to collide with the Transhimalayan arc-trench system around the Paleocene/Eocene boundary (Early Ilerdian; Garzanti et al., 1987).

Flexural response to loading by the overriding Asian accretionary prism caused strong subsidence on the northern edge of the Indian Plate, where collisional basins were rapidly filled by huge amounts of detritus derived from the slowly rising proto-Himalayan chain.

Onset of continental collision is recorded on the Indian margin by a basal unconformity, which is overlain by shallow-marine limestones with intercalated quartzarenitic layers occurring both in the Patala Fm. (Northern Pakistan) and in Lithozone C at the top of the Dibling Fm. (Northern India). This temporary increase of pure quartzose detritus in the very first stage of collision might be ascribed to flexural uplift of a peripheral bulge located on the Indian craton to the south, with erosion of older sedimentary and crystalline rocks.

The sudden arrival of abundant quartzolithic detritus, including serpentineschist rock fragments and chromian spinels derived from both island-arc and mid-ocean ridge ultramafic rocks, indicate that both the Murree and Chulung La redbeds were fed from the Tethyan suture in the north (Garzanti et al., 1987; Bossart & Ottiger, 1989).

This major petrographic change is recorded just below (Hazara-Kashmir) or directly above (Tethys Himalaya) calcarenitic layers dated at the *Fasciolites ellipsoidalis* Zone. Such small time lag (possibly 1 m.y.) may be ascribed to slightly diachronous collision, beginning earlier in the northwestern Nanga Parbat area (latest Paleocene), and progressively later (earliest Eocene) to the east.

It is noteworthy that, among all Tertiary clastic wedges shed from the Himalayan suture belt, the greatest mineralogical differences are observed between the Murree and Chulung La redbeds (Tab. 1), which were both deposited in collisional basins fed from proto-Himalayan reliefs, at the same time, and in very similar sedimentary environments.

Detrital modes of the Chulung La Formation are feldspatolithic, volcanic-rich and quartz-poor, and thus identical to "magmatic arc" sandstones. Since they compare closely with syn-collisional clastics derived from and deposited within the Ladakh arc-trench system (Garzanti & Van Haver, 1988), it can be safely concluded that the Chulung La delta was fed entirely and directly from the obducting Transhimalayan accretionary prism.

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Conversely, detrital modes of the Murree Supergroup plot in the middle of the "recycled orogen" provenance field. Even though erosion of calc-alkalic and ophiolitic rocks incorporated in the Transhimalayan arc-trench system is indicated, low-grade metapelitic detritus was predominant particularly in the Middle Ilerdian to Cuisian lower part of the Balakot Formation (Kunhar River section).

It is difficult to ascribe this feature of the Murree redbeds to an unknown metapelitic source terrane located to the north of or within the suture zone, and it is not conceivable that Mesozoic continental rise pelites of the Indian margin (western equivalents of the Lamayuru Unit of Ladakh) could have undergone metamorphism, uplift and erosion in virtually no time after collision. Abundant phyllite rock fragments were thus most likely derived from proto-Lesser/High Himalayan reliefs made of mildly metamorphosed supracrustal Indian margin rocks, possibly mainly Late Proterozoic to Cambrian pelites overprinted by Pan-African metamorphism. Petrographic evidence suggests that this fold-thrust belt began to be uplifted just south of the Tethys Himalayan Zone since the onset of collision, separating the Chulung La "piggy back" basin from the Murree foreland basin.

Direct stratigraphic superposition of Late Paleocene limestones on top of Precambrian carbonates in the Hazara Syntaxis is consistent with a palaeogeographic position much closer to the Indian craton with respect to the Tethys Himalayan succession, which consists of thick Paleozoic and Mesozoic sediments deposited on the southern shores of Neo-Tethys. Moreover, the overall petrographical affinity between the Murree Supergroup and younger orogenic sandstones largely derived from the High Himalaya argues in favour of a common source, which evolved during the Tertiary from lower- to higher-grade metamorphic rocks.

Throughout the Murree Supergroup itself, from the Ilerdian-Cuisian part of the Kunhar River section to the Lower Miocene Murree redbeds of the Rawalpindi area, detrital modes in fact changed gradually. Slight increase of detrital feldspars and polycrystalline quartz through time points to progressive deepening of erosion into infracrustal crystalline rocks, until in the late Early Miocene (Burdigalian) a huge hot wedge of Indian crust was rapidly uplifted and carried hundreds of km southward along the MCT. Rise of the Himalayas at this time of major palaeogeographic change, coincides with major changes in detrital modes of sandstones, recorded from the Siwalik foreland basin (Parkash et al., 1980) to as far as the accretionary wedges of Nias and Makran (Moore, 1979; Critelli et al., 1990).

	N	Qt	F	L	Qm	P	K	Qp	Lvm	Lsm	Lm	Lv	Ls
SIWALIKS	29	57	7	36	88	12		11	0	89	63	0	37
NIAS	24	73	11	16	86	9	5	17	23	60	35	29	36
MAKRAN	62	56	10	34	83	12	5	9	36	55	31	37	32
CHULUNG LA	**18**	**24**	**26**	**50**	**44**	**55**	**1**	**5**	**93**	**2**	**2**	**96**	**2**
INDUS GROUP	26	24	34	41	41	45	14	8	68	25	13	70	17
MURREE GROUP	**28**	**68**	**5**	**26**	**92**	**8**	**1**	**21**	**27**	**52**	**39**	**28**	**33**

Table 1 - Detrital modes of Tertiary sandstones derived from the Himalayan suture belt. Note that the Chulung La Fm. and coeval Indus Group feldspatolithic sandstones are much less quartzose and rich in volcanic detritus than the Murree Group and other quartzolithic "recycled orogen" clastic wedges.

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Structural and Thermal Constraints on the Tectonic Evolution of the North-Western Margin of the Nanga Parbat-Haramosh Massif (Pakistan)

TALK

M.T. GEORGE*

In the Haramosh region of northern Pakistan, the Kohistan island arc is separated from the Indian crust of the Nanga Parbat-Haramosh massif (NPHM) by a 2.5 km-wide, steeply inclined ductile shear zone containing intercalated lithologies derived from both terranes. A combined structural, geochemical and geochronological study across this zone has helped to constrain the thermal and tectonic evolution of the region.

The youngest stage of magmatism within the eastern part of the Kohistan batholith is characterised by biotite granite sheets (Confluence granites) emplaced at 50-30 Ma and younger muscovite granite sheets (Parri granites) at ~26 Ma. These are geochemically distinct, with the Confluence granites comprising a range of granitic compositions with high Sr and Ba abundances and the Parri granites forming granite sheets enriched in Rb. Undeformed granites in both suites have $(^{87}Sr/^{86}Sr)_i$ in the range 0.7045-0.7054 and $\varepsilon_{Nd}(T)$ of +0.1 to +2.7, suggesting that both groups may be derived from juvenile arc sources.

The Kohistan granite sheets can be traced into the shear zone at Sassi, where they are generally intensely deformed and mylonitised, although locally the sheets cross-cut shear fabrics and intrude intercalations of Indian crust material. Whilst none of the sheets appear to have intruded far into the NPHM, these relationships indicate that the Kohistan granite sheets postdate the initial collision of the northern Kohistan terrane with the Indian continent. The isotopic evidence from the undeformed granite sheets suggests that significant underthrusting of northern Kohistan by the Indian continental crust may not have occurred until after 26 Ma. Within the shear zone, deformed granite sheets show a marked increase in $(^{87}Sr/^{86}Sr)_i$ (0.7075-0.7784), with decreased $\varepsilon_{Nd}(T)$ (-13 to -26). These trends are thought to be due to a combination of sub-solidus fluid infiltration and assimilation of crustal material, with fluids or material derived from the adjacent, isotopically evolved NPHM crust.

Structual data were collected from a 24 km-long section along the western margin of the NPHM. The main shear fabrics within the belt are at greenschist grade and rework the earlier amphibolite-grade metamorphic assemblages. Kinematic indicators demonstrate an east-side up

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movement sense, with a strong component of dextral-slip. Since the foliation dips moderately to steeply west, the shear zone has a normal fault geometry, characterised by a north-westerly motion of the Kohistan arc relative to the NPHM.

The timing of movements within the shear zone have been constrained using mica geochronology on deformed lithologies within the zone. Rb-Sr muscovite-WR ages lie in the range 12-28 Ma, and reflect variable post-metamorphic cooling through the 500°C closure temperature. Rb-Sr biotite-WR and biotite-feldspar ages are 11 and 24 Ma, and have locally been reset to 6 Ma, probably during the retrograde shearing within the zone. Interestingly, leucogranites and their metamorphic country-rocks within the adjacent part of the NPHM have Rb-Sr ages of 2.8-7.7 Ma (muscovite) and 1.4-3.4 Ma (biotite), related to recent uplift and leucogranite intrusion within this part of the NPHM. The absence of such young mica ages within the shear zone bordering the Kohistan arc indicates that in the Haramosh area, the major, recent uplift of the NPHM was not accommodated along the western margin of the NPHM, as occurred further south. The disparity in mica ages between the shear zone and the NPHM, and the lack of any consistent age variation within the NPHM, may indicate a relatively passive uplift of this part of the massif.

Thrusting, Normal Faulting and High Himalayan Leucogranite Relationships in Central Himalaya

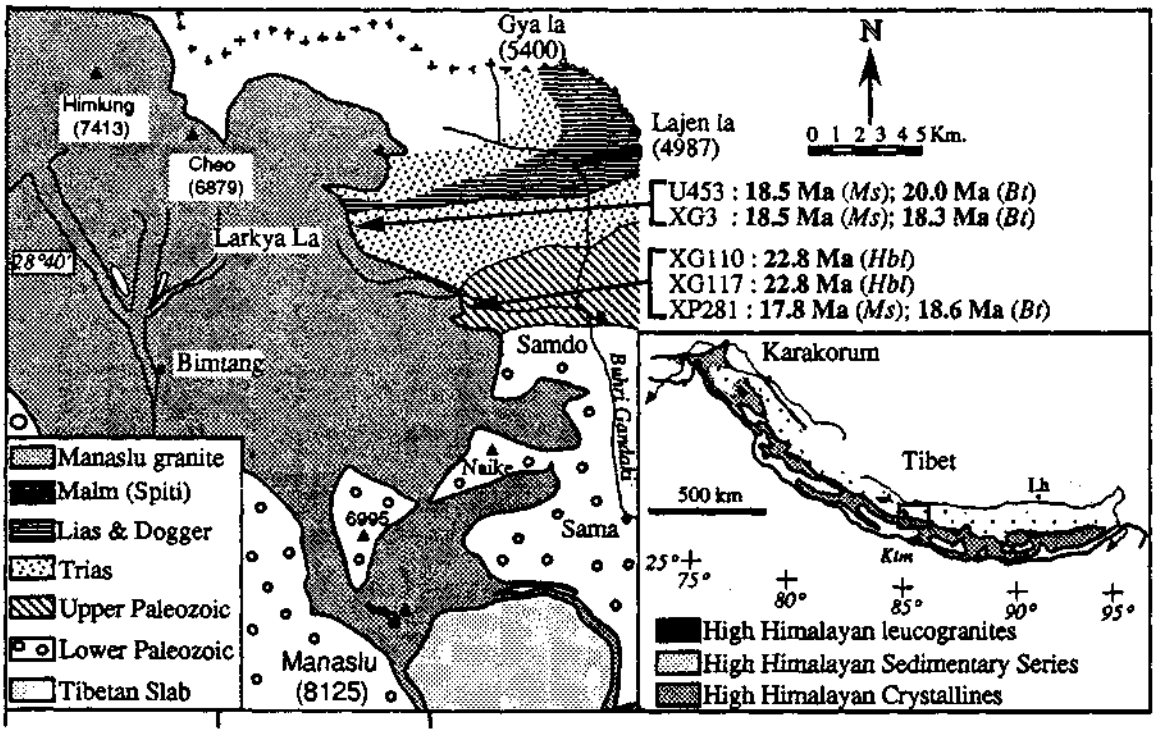
S. GUILLOT*, P. LE FORT*, A. PÊCHER* & K.V. HODGES**

The late Oligocene-early Miocene orogenic evolution of the Central Himalaya is dominated by the development of the Main Central Thrust and the contemporaneous movement of the South Tibetan Detachment system (STDS) at the top of the High Himalayan Crystalline (Pêcher et al., 1991; Burchfiel et al., 1992). In this structural regime, the High Himalayan leucogranites are emplaced at the hanging wall of the STDS.

Structural, metamorphic and geochemical data in the Manaslu area provide new contraints for the evolution of the High Himalaya.

In a previous study (Guillot et al., 1991) we emphasised the great depth of emplacement of the Manaslu leucogranite based on thermo-barometrical estimations in the contact auréole. It suggests the extension towards the south of the North Himalayan nappes, for a minimum of 70 km and a minimum thickness of 7 to 10 km during Miocene time.

Structural investigations in and around the pluton (Guillot et al., 1993) indicate that the emplacement of the pluton is related to tension gash system opened during the dextral wrenching of the South Tibet.



Geological sketch maps showing the study area in Central Himalaya and a simplified map of the Manaslu pluton with sample localities and 40Ar/39Ar ages in the upper contact auréole. Lh : Lhassa, Ktm : Kathmandu

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A geochemical contouring of the massif allows us to confirm the structural and magnetic scheme. The model of emplacement of the Manaslu granite could be extended to other High Himalayan leucogranites, like the pods of the Suru valley in Ladakh (Gapais et al., 1992), the Badrinath-Gangotri pluton in Garhwal (Scaillet et al., submitted) or the lenses of the Nyalam area (Burg et al., 1984), as a consequence of the beginning of the eastward extrusion of Tibet.

New $^{40}Ar/^{39}Ar$ data from the contact auréole of the Manaslu indicate that intrusion was active at least prior to 23 Ma and support the 25 Ma interpretation of the monazite reported by Deniel et al. (1987) for the crystallization age of the pluton. These data require that the STDS was active several million years earlier than in the Everest region (Hodges, 1992) and suggest an important movement along this zone between 25 and 20 Ma in the central part of the Himalaya.

Evidence of rapid cooling in the upper part of the pluton and in the contact auréole at around 18 Ma may indicate a second phase of extension dominated by movement on normal faults structurally above the STDS.

The understanding of the Himalayan leucogranite behavior appears very important in the knowledge of the Himalayan orogenic evolution : on the example of the Manaslu massif in Central Nepal we suggest the evolution of the strain pattern, with no evidence of lateral extrusion before 25 Ma, then with obvious extension from 25 to 20 Ma followed by a tectonic denudation of the High Himalayan beginning at around 18 Ma. The uplift of the High Himalaya recorded in sedimentary strata in the Bengal fan (Amano & Taira, 1992) and the rapid cooling of the Gandese belt at around 20 Ma (Harrison et al., 1992) also support the hypothesis of an important Miocene extensional event.

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Melting and Metamorphism in the Himalayan Orogen

N. HARRIS*

The thermal evolution of the crust during continental collision is closely related to deformation, yet the relative controls exerted by orogenic collapse and thrust tectonics on metamorphism in thickened crust is controversial. In the High Himalaya, both inverted metamorphism and partial melting in the Tibetan Slab have been ascribed to thrust tectonics and fluid infiltration. However, such models are inconsistent with the spatial relationship between the MCT and high-grade metamorphism, the field evidence for extensional tectonics during emplacement of leucogranite melts, and the evidence from both trace-elements and stable isotopes that precludes wet melting in the hanging-wall of the MCT. Uplift associated with extensional tectonics provides a mechanism for anatexis (under vapour-absent conditions) but thermal contrasts between juxtaposed sediments during uplift are insufficient to provide an adequate heat source.

Inverted metamorphism of the High Himalayan Crystalline Series is probably a consequence of dissipative heating associated with active thrusting[1]. Sufficient temperatures may be generated to cause fluid-absent metamorphism of muscovite-bearing protoliths, but significant melting by this process is unlikely since anatexis will strongly reduce shear stress on the thrust fault. Thrusting appears to have been distributed across the 10-15 km sequence of metasediments known as the High Himalayan Crystallines. Thus the MCT, as is generally represented, is one of several high-strain zones that separates supracrustals of contrasting isotopic, and metamorphic, characteristics. Either as a consequence of incipient melting, or as a result of transfer of thrusting southwards onto the Main Boundary Thrust, the hanging wall of the MCT was weakened and normal faulting was initiated. Orogenic collapse at ~20 Ma resulted in decompression melting, and emplacement of leucogranite melts into, or proximal to, the South Tibetan Detachment Zone.

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Kinematic Analysis of Folds Within the Chail Rocks of Garhwal Himalaya (India)

TALK

B.C. JOSHI*, V.K. SINGH* & P.S. SAKLANI*

The rocks of the Chail Group consists of schists, metabasics and migmatites in Pokheri area of the Garhwal Himalaya is tectonically bounded by the Jutogh Thrust (MCT II). The rocks exhibit F_1, F_2 and F_3 folds formed by D_1, D_2 and D_3 phases of deformation respectively. The flattening percentage, homogeneous strain ratio, shortening percentage and relationship of wavelength/amplitude ratio of these mesoscopic folds were determined with respect to the Jutogh Thrust (MCT II). The kinematic analysis of mesoscopic folds demonstrates that the amount of flattening of F_2 folds was maximum near the thrust but it gradually decreased away from the thrust.

The F_2 (syn-tectonic) folds developed near the Jutogh Thrust (MCT II) were marked by higher values of flattening from 50 to 85%, shortening from 50 to 70%, apparent strain ratio from 0.1 to 0.25 and low attitudes of quarter wavelength/amplitude ratio from 0.26 to 0.40. Whereas away from the thrust the flattening ranges from 20 to 50%, shortening from 30 to 45%, apparent strain ratio from 0.25 to 0.65 and quarter wavelength/amplitude ratio from 1.25 to 2.25. F_2 folds produced due to D_2 phase (syn-tectonic) show higher intensity of deformation than F_1 and F_3 folds produced by D_1 phase (pre-tectonic) and D_3 phase (post-tectonic) of deformation. The D_2 phase of deformation was related to formation of the Jutogh Thrust (MCT II).

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Paleoatmospheric Consequences of CO_2 Released During Tertiary Regional Metamorphism in the Himalayan Orogen

TALK

D.M. KERRICK*, K. CALDEIRA* & L.R. KUMP*

Fluxes of metamorphic CO_2 to the atmosphere have been suggested to be climatically important (Fyfe, 1986; Varekamp et al., 1992; Touret, 1992). Using an overly simplified model of decarbonation of a 1 km-thick carbonate layer, Fyfe (1986) concluded that atmospheric CO_2 content could have been significantly affected by the Tertiary Himalayan orogenesis. However, the validity of the suggestion that metamorphic CO_2 has significantly affected the atmosphere critically depends upon a number of factors; i.e., duration of prograde metamorphism, abundance and composition of CO_2 source rocks, and escape of CO_2 to the Earth's surface. The Himalayan orogenic belt affords an excellent case study for analysis of these variables in determining the quantities and fluxes of CO_2 released by metamorphic decarbonation and graphitization.

The Eocene was the warmest epoch of the Cenozoic, with published estimates of Eocene atmospheric CO_2 content ranging from two to six times the current value. The Early Eocene (50–55 Ma) global warming may have been produced by the greenhouse effect arising from elevated CO_2 contents. Our calculations of CO_2 consumption by silicate weathering show that metamorphic CO_2 releases of ca. 10^{18}/Ma could readily account for inferred Eocene atmospheric CO_2 contents and, consequently, Eocene warming.

Because of the lack of evidence for Eocene metamorphism in the central and eastern portions of the orogen, we focused on Eocene metamorphism in the western portion of the orogen (i.e., Zanskar and westward). Duration of prograde metamorphism was constrained by the timing of the India-Tibet collision (50–65 Ma) and the peak of prograde regional metamorphism (ca. 40 Ma). Due to lack of published estimates of the proportions and bulk compositions of metacarbonate and graphitic lithologies in the western Himalayan orogen, we coerced selected colleagues (J.A. DiPietro, M.S. Hubbard, K.P. Hodges, and M.P. Searle) into providing "guesstimates" of the proportions of such lithologies. In our computations we assumed marl as the model metacarbonate source rock and that 5 wt % of CO_2 was released during prograde metamorphism (Ferry, 1982). With a conservative assumption that carbonate rocks constitute ca. 10% (by volume) of the western Himalayan orogen (J.A. DiPietro, M.P. Searle), and that CO_2 was generated at a constant rate during the prograde event, we estimate that ca. 10^{19} moles/Ma of metamorphic CO_2 were produced at depth. Assuming 0.5% (by volume) of carbonaceous lithologies, CO_2 released from the graphitization of carbonaceous material is estimated to be ca. 10^{18} moles/Ma. These calculations assumed that CO_2 was linearly released during prograde metamorphism; however, because extensive devolatilization of marls and carbonaceous lithologies occurs during progradation through the lower greenschist facies (Ferry, 1982; Labotka et al., 1988), CO_2 production may have been two to four times more rapid than these estimates.

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The possibility of escape of metamorphic CO_2 to the atmosphere is indicated by the global correlation between the distribution of major zones of seismicity and carbon dioxide discharged from hot springs (Barnes et al., 1978). Release of metamorphic CO_2 to the atmosphere would have been impeded by retrograde carbonation and carbonate vein formation in the shallower (lower grade) portions of the orogens. However, in light of large fluid/rock ratios, significant expulsion of CO_2 to the atmosphere may have occurred by focused fluid flow along the Main Central Thrust (MCT) in the Himalayan orogen. Transient expulsion of large amounts of metamorphic volatiles is expected to have accompanied seismic activity along the MCT.

Geochronologic analyses reveal a remarkable similarity in peak metamorphic ages (40–50 Ma) for many areas within the Tethys and Circum-Pacific orogens, thus supporting the concept of a major, world-wide Eocene regional metamorphism. This metamorphic culmination was contemporaneous with increased Eocene atmospheric CO_2 and associated global warming. World-wide Eocene regional metamorphism could well have generated $\geq 10^{20}$ moles CO_2 /Ma at depth. Even if only 1% of the total metamorphic CO_2 produced escaped to the Earth's surface, there would have been significant paleoclimatic consequences.

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Field Study and Geochemical Evolution of the Kargil Plutonic Complex (Ladakh, NW India)

TALK

Y. LEMENNICIER* & I. REUBER**

The Kargil Plutonic Complex (KPC) is intrusive in the volcano-sedimentary formations of the Dras arc which are considered, by all authors, as an eastern extension of the Kohistan arc series.

During summer 1991, we have mapped in detail an area of approximately 100 Km2, just west of Kargil. Based on the field observations (see map), we have been able to disinguish two units separated by a thrust, striking N140° with a steep SW dip. This thrust has been already described by Sharma (1990, "Kirkichu Thrust"), near the Chanigund village where it is a submeridian fault. In all the mapped area, the thrust reactivates an older large shear-zone followed by metadolerites and by a large lens of metapelitic gneiss. The cleavage in the gneiss is nearly vertical, striking N110°E to N150°E, and shows a stretching lineation with a weak plunge between 0° and 20° in either direction.

The SW unit is essentially composed by the Somau granodiorite, which intrudes the Dras1 formations (Reuber,1989). An acicular amphibole-bearing diorite, intrudes the granodiorite on its eastern side. The Somau granodiorite (103±3 Ma by U-Pb method on zircon: Honegger,1982), is characterised at the outcrop scale by a penetrative cleavage, underlined by biotite and amphibole. Foliation spreads from N110° to N140° with a steep NW dip. However, it has not been possible to define clearly, in the granodiorite as in the gneiss, the shear sense of movement.

The NE unit is composed by several plutons of varied composition, from granite to cumulative gabbro, intrusive into Dras1 formation. The most important one is the Rinak pluton which displays a quartz-gabbro rim and a quartz-diorite center. In these plutons, the fabric corresponds to a rather fuzzy magmatic foliation.

An andesitic dyke-swarm cutting all the older structures, is affected by a late reactivation of the N 140° thrust. The statistical best orientation of the dyke walls is N40°E, subvertical.

A geochemical study based on 19 new analyses including 10 andesite dykes, completed by published data (Honegger,1982; Sharma,1990), leads to the following conclusions:

(i)- the Dras I volcano-sedimentary formation defines a tholeiitic trend of immature Island Arc type;

(ii)- the KPC plutonics, intrusive in Dras I defines, as a whole, a subalcaline trend with calkalcaline affinities;

(iii)- the andesitic dyke swarm displays a calkalcaline trend of mature arc with continental affinity.

Thus we can follow, in the Dras Arc, a magmatic evolution from oceanic IAT to continental calkalcaline arc magmatism. This evolution meets the conclusions previously obtained by G. Reibel (1984). Considering the deformation differences between the Somau granodiorite on one side and the NE plutonics on the other one, leads us to suggest that the Arc-Eurasia collision occured during the plutonic activity of this arc.

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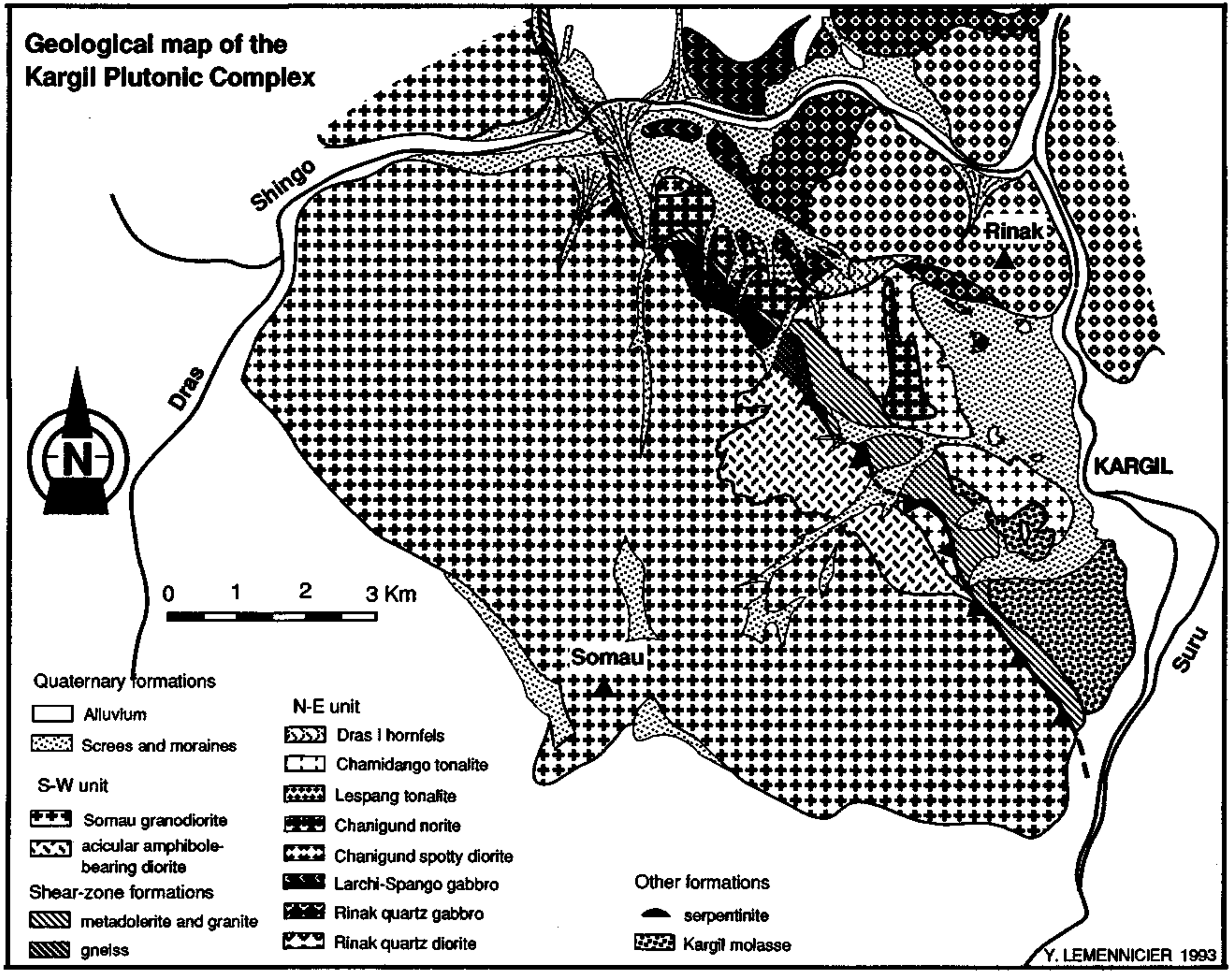

Geological map of the Kargil Plutonic Complex

Contribution to the Geology of Eastern Ladakh – the Upshi – Sangtha Section

TALK

M. LINNER* & G. FUCHS**

The Indus Molasse consists mainly of continental conglomerates, sandstones and shales. The anticline of Miru brings up the Eocene flysch (Jurutse). At the base of the younger molasse red pelites are significant. Along the Indus Suture the Dras-Nindam and Ophiolitic Melange zones are partly squeezed out. There are only lenticular bodies composed of serpentinites, lavas and tuffs of an alkali basalt series, carbonates, flysch sandstones and shales (eg. E Rumtse).

In the Lamayuru Unit we found an anticline, where the Mesozoic euxinic pelites and limestones are stratigraphically underlain from top to bottom by a chlorite-arkose schist horizon, carbonates and dark phyllites, and the Karsha Formation. This shows that the Lamayuru Unit, at least in its southern parts, is still underlain by Zanskar rock series. Thus the Lamayuru series were deposited on the continental slope. The chlorite schists may indicate the Panjal volcanic event - STUTZ (1988, p43) also mentioned chlorite schists in the fossiliferous Kuling Formation. To the latter the marbles and quartzites of Taglang La correspond, which form the core of a syncline. In the Debring region the Haimanta (Phe) Formation is overlain by thick quartzite or carbonate-dark phyllite series, which are interfingering in various ways. This resembles the Devonian series of Dolpo (Nepal), where mature sands (Muth) were deposited side by side with platform carbonates and even basin sediments (Tilicho Pass Fm.). Thus we suspect Devonian series also in Zanskar, whereas the upper part of the carbonate series probably represents the Lipak (Lower Carboniferous). A conspicous horizon of basaltic metavolcanics corresponds geochemically to the Panjal Trap. Also the doleritic dikes which occur in different formations show affinity to the Panjal Trap and may be understood as feeders.

The metamorphism of the Nimaling sedimentaries increases from WNW towards ESE. In the metapelites the chlorite zone is succeeded by the biotite zone and the garnet zone. In the latter two zones blasts of plagioclase, biotite respectively garnet occur. For the garnet zone metamorphic conditions of T = 450-480°C and P = 3-3.5kbar were determined from the paragenesis Gar-Bi-Chl-Mu-Ab-Cc-Q. Towards the SW the metamorphism decreases.

Along a counter thrust the granites from the core of the Nimaling Dome override the described sequence and divide the dome into two wedges. This deformation is younger than the regional metamorphism. In the southern wedge the granite is succeeded by Haimantas (Phe), Parahio (Karsha) Formation, Devono-Carboniferous carbonates, Po, Kuling and the Mesozoic series. This succession shows metamorphism only of the chlorite zone.

Stutz, E. (1988): Mém. Géol. (Lausanne); No.3, 149p.

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Higher Himalayan Metamorphism and its Relation to Main Central Thrust

TALK

R.M. MANICKAVASAGAM*, A.K. JAIN*, A. ASOKAN* & S. SINGH*

In NW-Himalaya, the Main Central thrust (MCT) separates the Higher Himalayan Crystalline (HHC) belt of the hanging wall from the Lesser Himalayan Proterozoic foreland (LH) of the footwall, now exposed in the Kishtwar window. The footwall side of the MCT is made up of carbonaceous phyllite, quartzite and mica schist having garnet, biotite, muscovite, chlorite, feldspar and quartz. The mineralogy indicate that metamorphism ranges from chlorite to garnet grade condition. Towards northeast and southwest, the base of the hanging wall along MCT consist of staurolite, kyanite, biotite, muscovite, quartz and feldspar, indicating staurolite-kyanite grade metamorphism.

Thermobarometric and garnet zoning data obtained from hanging wall and footwall side of MCT suggest the following:

1. Staurolite-kyanite grade rocks just adjacent to Kishtwar window of the hanging wall show a garnet core temperature and pressure of ~550°C and ~7.50 kb. The rim temperature show an increase of ~100°C without much change from core pressure. Garnet show homogeneous zoning except near the rim, where X_{sp} and X_{alm} show slight enrichment. The development of homogeneous zoning appears to be because of faster growth accompanied by diffusion in increased temperature condition. Clockwise temperature path suggest that this zone has developed during subsidence and uplift stage in the ductile shear regime. Moreover, the insignificant change in pressure probably indicates that this zone seems to have been remained static relatively, when compared to the faster uplift of higher grade rocks in the hanging wall. The faster uplift of the higher grade rocks are evidenced from the reduced rim temperature and pressure of ~650° C and ~4.00 kb. Temperature increase in staurolite-kyanite grade is interpreted to have been developed because of the thermal relaxation of the higher grade rocks during uplift, before the movement along MCT.

2. The footwall rocks occurring just below MCT, show rim temperature and pressure of about 560°C and 7.00 Kb. S-shaped mineral inclusions in garnet suggest syntectonic growth, showing normal growth zoning. The P-T data and garnet zoning indicate that the footwall rocks have not been affected by heating either during the thermal relaxation stage of the hanging wall or thrusting along MCT.

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An Oxygene Isotope Traverse through the High Himalayan Crystallines (HHC) (Langtang Valley, Central Nepal)

TALK

J.A. MASSEY*

Although several Himalayan studies have considered stable isotopes, most have concentrated on the High Himalayan Leucogranites (HHL), with only token analyses made of the underlying HHC, the proposed source of these granites. In this study, a comprehensive traverse through the HHC is reported with analyses from both the metamorphic material and, at the top of the section, the Langtang HHL, with the aim of providing constraints on the metamorphic and magmatic history of the HHC, and in particular to constrain fluid processes.

Most HHL, Langtang included, show $\delta^{18}O_{(whole-rock)}$ 11-13‰ and $^{87}Sr/^{86}Sr_{20Ma}$ 0.74-0.77, although a few cases show $\delta^{18}O$ down to 9‰ (Mustang and Bhutan) and higher $^{87}Sr/^{86}Sr_{20Ma}$[1]. In the case of the Makalu and Mustang HHL a correlation between lower $\delta^{18}O$ and increased $^{87}Sr/^{86}Sr_{20Ma}$ may exist. HHC analyses are rare although ranging from ~9-13‰[1]. Analyses of the HHC in Langtang again reveals a range of $\delta^{18}O$ from ~8.5-13‰, and with a correlation between low $\delta^{18}O$ and high $^{87}Sr/^{86}Sr_{20Ma}$. However this range is not found throughout the section, and indeed the HHC can be divided into blocks which are isotopically distinct for both O and Sr. Correlation of these distinctions with metamorphic and structural variations supports the suggestion that the HHC in Langtang consists of tectonically separated blocks of crust, and allows delineation of the possible contributions of different parts of the HHC to Himalayan magmatism.

More detailed consideration of mineral separate material provides further information on temperature, equilibrium and fluid effects. In the lowest part of the HHC (kyanite-grade), the small variation in lithologies and hence in expected initial isotopic variations, limits the usefulness of isotopes in constraining prograde processes. However heterogeneity of $\delta^{18}O_{minerals}$ suggests largely internal buffering of isotope compositions. In addition, high temperature fractionations (in agreement with temperature estimates using mineral chemistry methods) combined with the observation of common muscovite, preclude any extensive fluid influx which would have resulted in melting at such temperatures (>700°C). Quantitative diffusion modelling indicates that uplift must have taken place in an anhydrous, closed system.

At the top of the section (sillimanite-grade), isotopic concordance between varied lithologies (metabasites, pelites, calc-schists) suggests substantial isotopic homogenisation to values in equilibrium with either metamorphic or magmatic fluids. In addition disequilibrium fractionations recorded in the granites are not explicable by simple diffusional exchange and may require the presence of fluids during retrogression. At the very latest stages meteoric fluids have locally percolated along

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brittle chlorite-grade fractures. The upper parts of the section also contrast with the base in showing evidence for a much more prolonged syn and post-peak deformation history[2] and hence a connection between fluid processes and deformation may be inferred.

[1] summary in : France-Lanord & Le Fort 1988, Trans.Roy.Soc.Ed. 79,183-195 (& refs therein).
[2] Reddy et al.1993, Spec.Publ. Geol.Soc.London, in press.

Triassic Rifting and Tethyan Paleoenvironment of a NE-Gondwanan Passive Margin (Thakkhola, Nepal)

TALK

U. v. RAD*, J.G. OGG**, S.B. DÜRR*** & J. WIEDMANN***

The Mesozoic sediments of the Thakkhola (central Nepal) were deposited on a broad eastern north Gondwanan passive margin at mid-latitudes (28-41°S) facing the Southern Tethys ocean to the north. The facies is strikingly similar over a distance of several thousand km from Ladakh in the west to Tibet and to the paleogeographically adjacent Northwest Australian margin (Exmouth Plateau, ODP Legs 122/123) and Timor in the east. Late Paleozoic rifting led to the opening of the Neo-Tethys Ocean in Early Triassic times. An almost uninterrupted, ca. 2 km-thick sequence of syn-rift sediments was deposited on a slowly subsiding shelf and slope from Scythian (Early Triassic) to late Valanginian times when breakup between Gondwana (NW Australia) and Greater India formed the proto-Indian Ocean.

The sedimentation is controlled by (1) global events (eustasy; climatic/oceanographic changes due to latitudinal drift; plate reorganization leading to rift-type blockfaulting) and (2) local factors, such as varying fluviodeltaic sediment input, especially during Permian and late Norian times. Sea level was extremely low in Permian, high in Scythian to Carnian and low again during Rhaeto-Liassic times. Third-order sea level cycles were distinguished in the Scythian and late Norian to Rhaeto-Liassic.

During the Permian pure quartz sand and gravel were deposited as shallowing-upward series of submarine channel or barrier island sands. The high compositional maturity is typical of a stable craton-type hinterland, uplifted during a major rifting episode.

During the Scythian a 20-30 m thick, composite, condensed sequence of nodular "ammonitico rosso"-type marlstone with a "pelagic" ammonite-pelecypod- calcisphere-ostracode-fauna was deposited (Tamba Kurkur Formation). This indicates rapid tectonic subsidence and sediment starvation during the transgression of the Neo-Tethys ocean.

After a hiatus (?), a 400 m thick sequence of fining-upward, filament-rich wackestone/shale cycles was deposited in a bathyal environment (Mukut Limestone Formation, Carnian). This is overlain by about 300 m of sandy shale and siltstone intercalated with quartz-rich bioclastic grain- to rudstone (Tarap Shale Formation, late Carnian-Norian).
The upper Norian to (?lower) "Rhaetian" Quartzite Formation (Thini Formation, 250 m) consists of (sub)arkosic sandstones, rich in K-feldspar and pure quartz arenites, indicating different sediment sources. The fluviodeltaic sandstones are intercalated with silty shale, coal, bioclastic limestone (including algal bindstone and mollusc floatstone), as well as mixed siliciclastic-bioclastic rocks. The depositional environment was marginal-marine to shallow-subtidal. The fluviodeltaic influence

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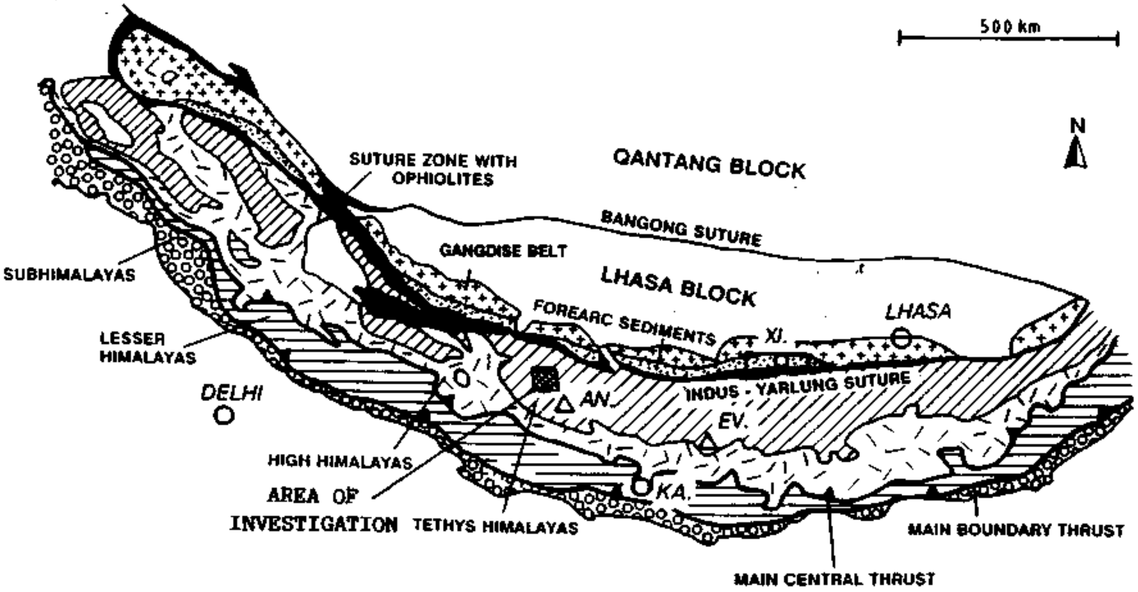
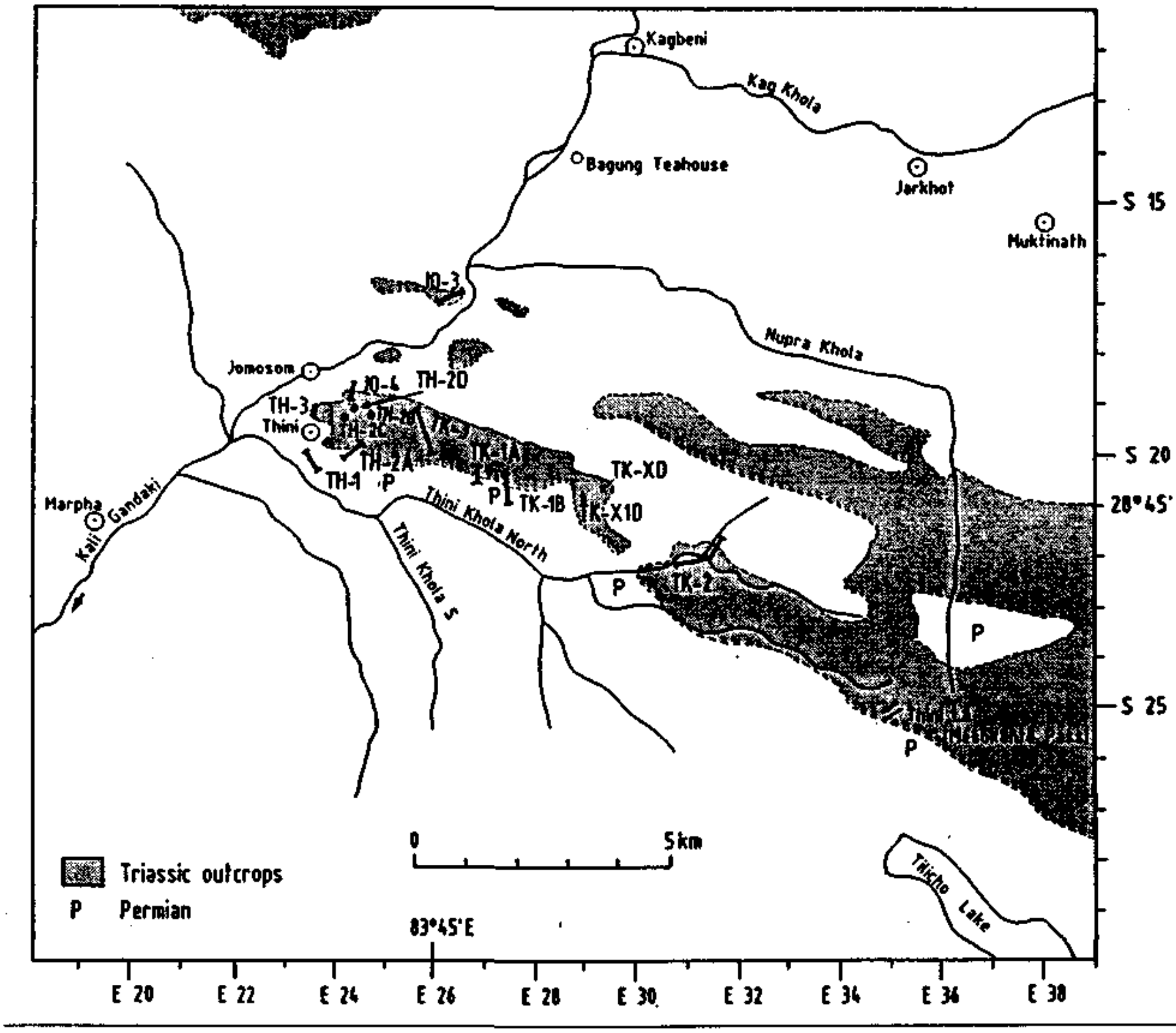
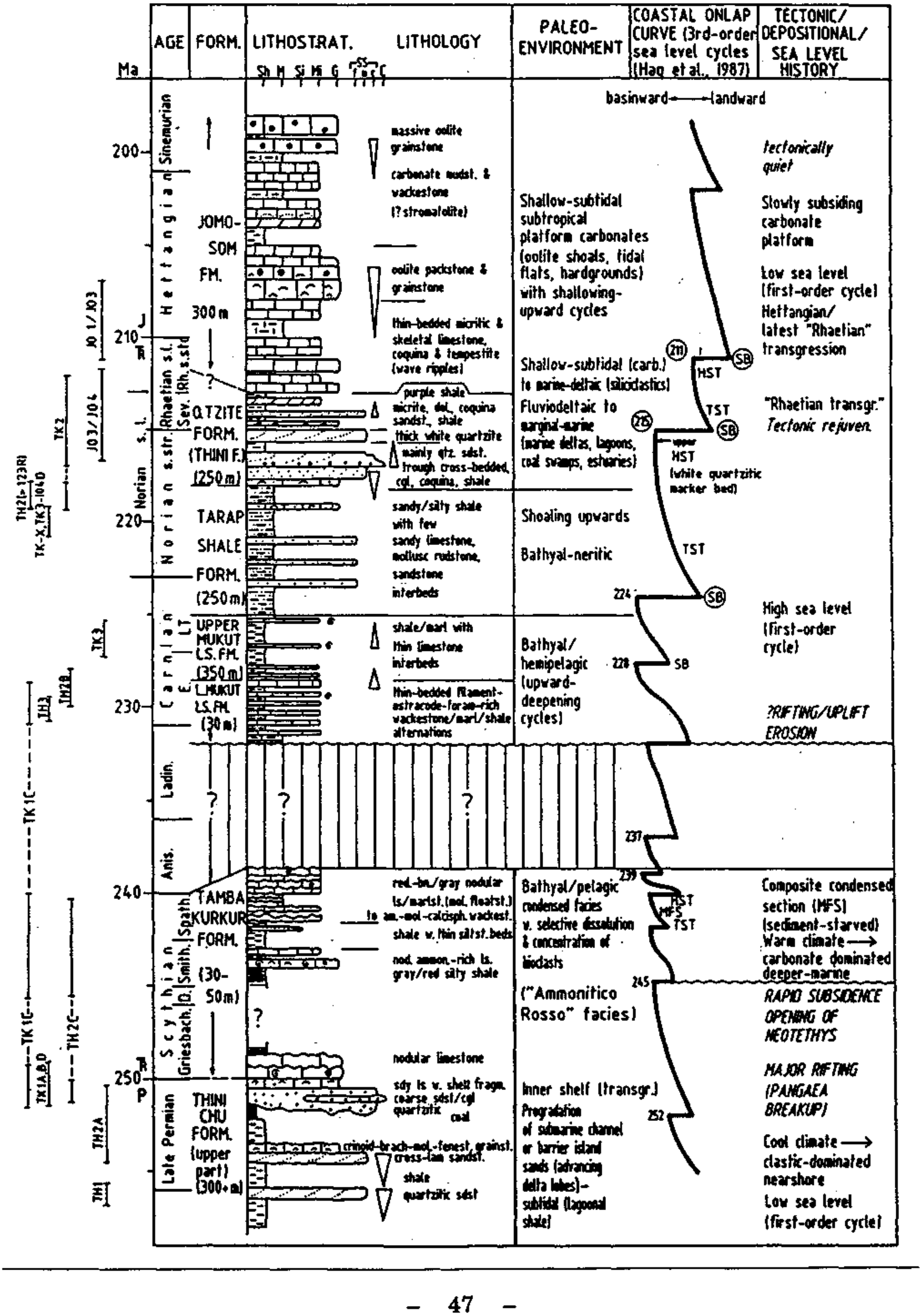
decreased towards the overlying Rhaeto-Liassic carbonates of the Jomosom Formation (correlative to the Kioto Limestone). During that time the region entered tropical paleolatitudes resulting in platform carbonates and local reefs (e.g. at Exmouth Plateau).





TRIASSIC STRATIGRAPHY, THAKKHOLA (NEPAL)



A Boron and Tourmaline Point of View of the Central Nepal Himalaya

S.M. RAÏ* & P. LE FORT*

The Himalayan range is known for the wide occurence of tourmaline, sometimes in large quantities; in fact we have found it in all formations of the Central Nepal Himalaya, from the Midlands to the Tibetan sedimentary series. We have undertaken a systematic survey of the boron content and tourmaline compositions of all types of rocks along a general section through the range in the Annapurna-Manaslu region.

The boron content of the whole rock varies from less than a ppm to more than 1000 ppm. Some formations are rather boron-rich such as the "Lesser Himalayan" granites or the upper Midland formations. Others vary from one sample to another, such as the Manaslu granite (from 12 to 664 ppm). In the Midlands formations, the boron content seems to first increase with the grade of metamorphism, from chlorite to garnet-grade, and then to lessen up to kyanite, a decreasing trend that clearly continues in Formation I of the Tibetan Slab.

Although a number of boron-bearing minerals such as danburite have been found in Nepal, most of the boron is contained in tourmaline. However, micas, and especially biotite, may reveal up to several hundreds of ppm of boron.

One can distinguish mainly two types of occurence of tourmaline: in the ground mass of rocks, or in the granitic paragenesis of aplitic to pegmatitic dykes. The latter only show up above the MCT.

Tourmaline in Central Nepal has a highly variable chemical composition that can be mostly described in terms of dravite-schorlite-(elbaite) end members (figures). These variations seem to be linked:

- to the composition of the host rock
- to the grade of metamorphism
- to the position in the structural edifice

The chemical composition of tourmaline obtained by microprobe analysis in the various rock types indicates Mg-rich tourmaline (dravite) in calcic gneiss, marble and restite, against Fe-rich tourmaline (schorlite) in granite and tourmalinite (fig a). Other rock types are mostly distributed between the dravite and schorlite end members, with little increase in the elbaite content. Tourmaline from the aplopegmatitc dykes also varies largely in composition, depending on the lithology of the host rock: the more pelitic the latter, the more dravitic the tourmaline.

In the Midlands there seem to be a rather good correlation between the grade of metamorphism and the composition of the tourmaline: from chlorite to kyanite inverted grade, there is a decrease in the elbaite (Al) and schorlite (Fe) contents (figure b). We have not found similar systematic variations in the zonation of the tourmaline. The zonation trend, related to small (a few %) variation in the chemistry, is usually homogeneous within a sample but varries randomly from one sample to another. This suggests that tourmaline grew rather rapidly during metamorphism.

For the granitic dykes intruding the Tibetan Slab and the overlying Annapurna formation, there is a global trend of evolution of the tourmalines from a dravitic composition in the Formation I to a very schorlitic (and more elbaitic) composition in the Annapurna limestones (figure c). This evolution encompasses a structural section of more than 10 km and may reflect the changes in the tectonometamorphic conditions.

Altogether, boron and tourmaline, minor in abundances, trace the fossil path of fluids; they are distinctively sensitive to the chemical and physical constraints of the Himalayan building.

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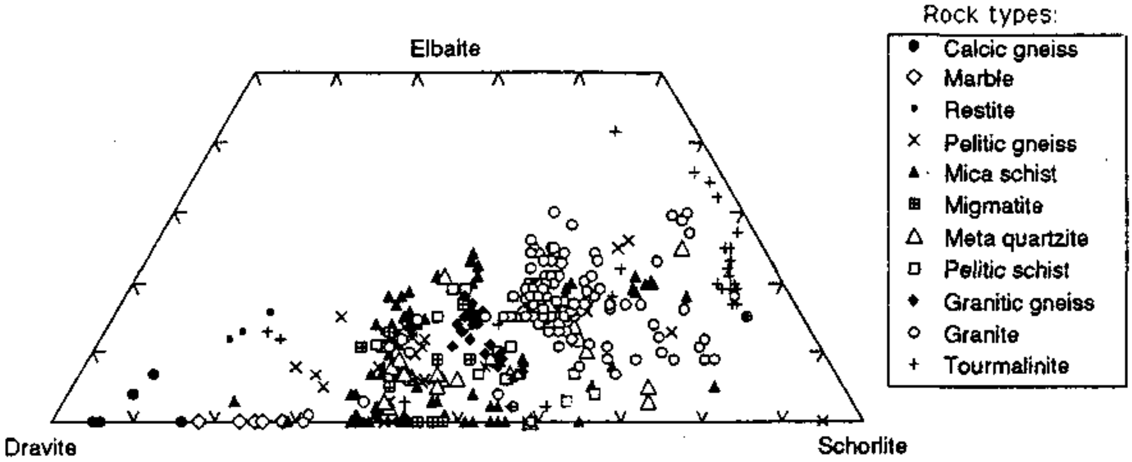

Fig. a. End member compositions for tourmalines from various rock types in Central Nepal.

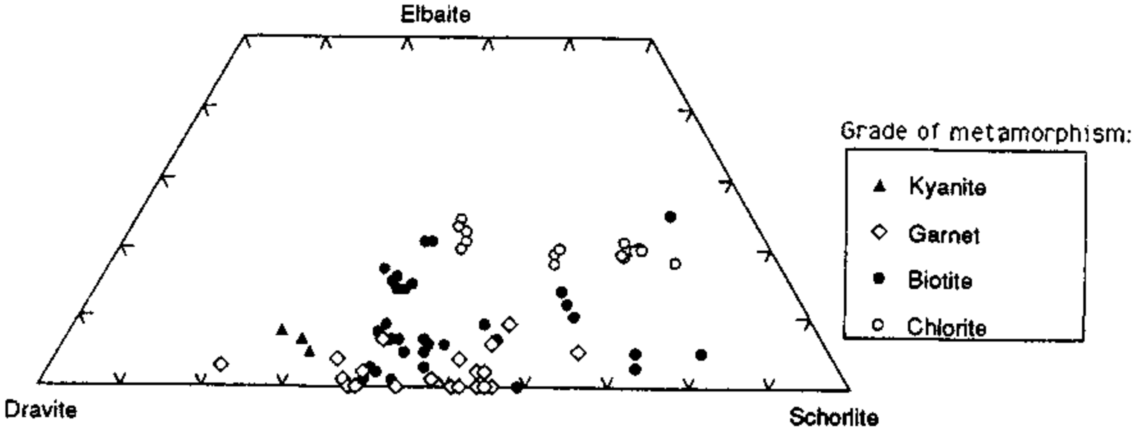

Fig. b. End member compositions for tourmalines in Midland Formations, Central Nepal.

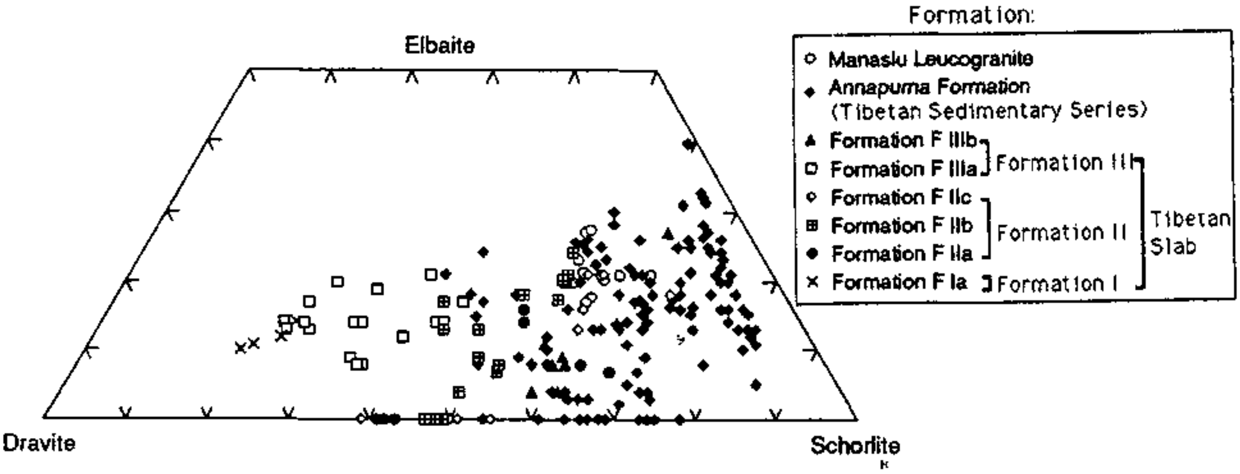

Fig. c. End member compositions for tourmalines from aplopegmatite dykes in Central Nepal.

Structure, Metamorphism and Cooling History of the Central Karakoram (North Pakistan)

TALK

M.P. SEARLE*

ABSTRACT. Prior to the Eocene (ca. 50 Ma) collision of the Indian and Asian plates, the southern margin of Asia in the Karakoram region was dominated by a series of Andean-type plutonic belts (Hushe gneiss, Muztagh Tower gneiss, K2 orthogneiss) and regional low-pressure andalusite, staurolite and garnet-grade metamorphism (M1). Crustal shortening, thickening and regional metamorphism following collision occurred between 50-37 Ma and has been dated by a U-Pb zircon age from the Mango Gusar two-mica leucogranite which cross-cuts syn-metamorphic fabrics in the country rocks. Thermobarometry of kyanite and sillimanite-grade rocks indicates peak metamorphism (M2) at around 700°C and 8-9 kbars. Temperatures increase northwards along the Baltoro glacier transect towards the contact with the Baltoro granite where *in situ* partial melting begins in the sillimanite gneisses. Post-metamorphic folding of M2 isograds was associated with deep crustal gneiss domes and initiation of the Main Karakoram Thrust in the south. Post-M2 thermal relaxation followed from 37-25 Ma after which localised high heat concentrations at the base of the thickened crust caused widespread crustal melting and intrusion of the Baltoro granite at 25-21Ma. A high-temperature, low-pressure thermal aureole (M3) along the northern contact of the Baltoro monzogranite-leucogranite is synchronous with the 21±0.5 Ma U-Pb zircon crystallisation age of the granite. The Mitre contact aureole contains the assemblage: andalusite+cordierite+biotite+muscovite +chlorite+plagioclase+quartz and indicates pressures less than 3.5 kbars. The increase of T along the southern contact of the Baltoro granite is interpreted as the thermal upwarping of pre-37 Ma M2 isograds by 21 Ma M3 contact metamorphic isotherms. In the southern Karakoram pressures up to 10 kbars were attained by 37 Ma ago meaning that around 37 km of overburden has been eroded since the Eocene-Oligocene boundary giving a time-averaged exhumation rate of 0.95mm/year. The 21 Ma Baltoro granite crystallised at temperatures above 750°C and pressures above 10 kbars equating to depths of burial between 26-35 km. The exhumation or unroofing rate, which includes processes of uplift and erosion is between 1.2-1.6mm/year. Subduction of Indian continental crust and mantle lithosphere northwards beneath the Karakoram and Tarim Basin continental crust southwards beneath the KunLun and the northern Karakoram has created a lithospheric-scale pop-up structure with its axis of maximum uplift aligned along the Karakoram.

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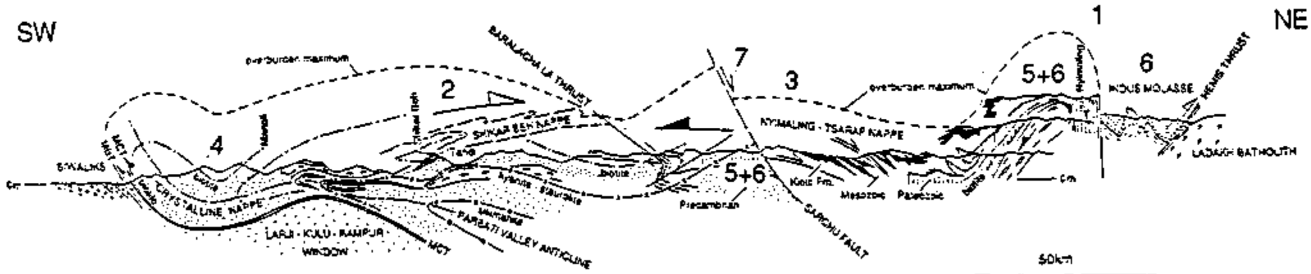
Geological Transect Across the Northwestern Himalaya in Eastern Ladakh and Lahul – A Model for the Continental Collision of India and Asia

TALK

A. STECK*, L. SPRING*, J.-C. VANNAY*, H. MASSON*, E. STUTZ*,
H. BUCHER*, R. MARCHANT* & J.-C. TIÈCHE*



Chronology of the Tertiary Himalayan structures

1-	Continental collision, underthrusting of India below Asia and initiation of the Nyimaling-Tsarap Nappe	(Eocene)
2 -	NE vergent Shikar Beh Nappe	(Eocene)
3 -	SW vergent Nyimaling-Tsarap Nappe	(Eocene)
4 -	SW vergent "Crystalline Nappe" (MCT and MBT)	(Oligocene-Miocene)
5 -	Dextral transpression	(Oligocene)
6 -	NE vergent folding	(Miocene)
7 -	Late extension	(Miocene)

The detailed geological mapping and structural study of a complete transect across the north western Himalaya, allow to describe the tectonic evolution of the north Indian continental margin during the Tethys ocean opening and the Himalayan Orogeny.

The Late Paleozoic Tethys rifting is associated with several tectonomagmatic events. In Upper Lahul and SE Zanskar, this extensional phase is recorded by Lower Carboniferous synsedimentary transtensional faults, a Lower Permian stratigraphic unconformity, a Lower Permian granitic intrusion and middle Permian basaltic extrusions (Panjal Traps). In eastern Ladakh, a Permian listric normal fault is also related to this phase. The scarcity of synsedimentary faults and the gradual increase of the Permian syn-rift sediments thickness toward the NE, suggest a flexural type margin.

The collision of India and Asia is characterized by a succession of contrasting orogenic phases. South of the Suture Zone, the initiation of the SW vergent Nyimaling-Tsarap Nappe corresponds to an early phase of continental underthrusting. To the S, in Lahul, an opposite underthrusting within the Indian plate is recorded by the NE vergent Tandi Syncline. This structure is associated with the newly defined Shikar Beh Nappe, now partly eroded, which is responsible for the high grade (amphibolite facies) regional metamorphism of South Lahul.

The main thrusting of the Nyimaling-Tsarap Nappe followed the formation of the Shikar Beh Nappe. The Nyimaling-Tsarap Nappe developed by ductile shear of the upper part of the subducted Indian continental margin and is responsible for the progressive regional metamorphism of SE Zanskar, reaching amphibolite facies below the frontal part of the nappe, near Sarchu. In Upper Lahul, the frontal parts of the Nyimaling-Tsarap and Shikar Beh nappes are separated by a zone of

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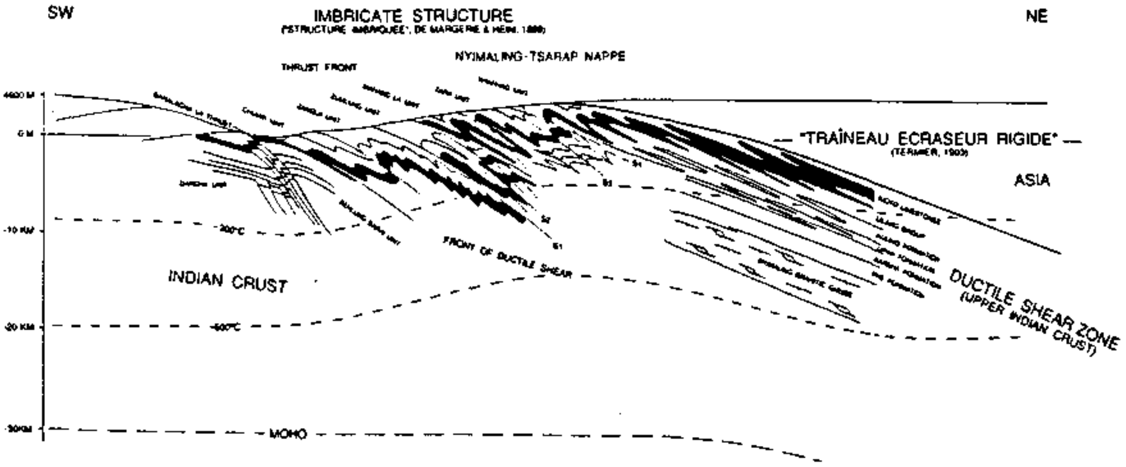

The Nyimaling-Tsarap Nappe (situation before backfolding, extension, uplift and erosion).

low grade metamorphic rocks (pumpellyite-actinolite facies to lower greenschist facies). At high structural level, the Nyimaling-Tsarap Nappe is characterized by imbricate structures, which grades into a large ductile shear zone with depth. The related crustal shortening is about 87 km.

The root zone and the frontal part of this nappe have been subsequently affected by two zones of dextral transpression and underthrusting: the Nyimaling Shear Zone and the Sarchu Shear Zone. These shear zones are interpreted as consequences of the counterclockwise rotation of the continental underthrusting direction of India relative to Asia, which occured some 45 Ma ago, according to plate tectonic models.

Later, a phase of NE vergent "backfolding" developed on these two zones of dextral transpression, creating isoclinal folds in SE Zanskar and more open folds in the Nyimaling Dome and in the Indus Molasse sediments.

During a late stage of the Himalayan Orogeny, the frontal part of the Nyimaling-Tsarap Nappe underwent an extension of about 15 km. This phase is represented by two type of structures, responsible for the tectonic unroofing of the amphibolite facies rocks of the Sarchu area: the Sarchu high angle Normal Fault, cutting a first set of low angle normal faults, which have been created by reactivation of older thrust planes related to the Nyimaling-Tsarap Nappe.

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Metamorphism and Melting within the Nanga Parbat Syntaxis (Pakistan)

TALK

P.J. TRELOAR*, J. WHEELER & G.J. POTTS****

Metamorphism within the Indian Plate gneisses within the Nanga Parbat syntaxis reached kyanite-bearing granulite facies in which the assemblage quartz-plagioclase-orthoclase-garnet-biotite-kyanite (or sillimanite) -rutile was stable. Calculated peak metamorphic conditions were at about 10 kbar and 800°C achieved after a period of prograde metamorphism along a P-T path with positive slope. A leucogranite melt is intimately associated with the main fabric, within the plane of which is contained a south trending lineation. This melt is considered to be an *in situ* anatectic melt derived by vapour absent melting during the main phase of south verging thrusting. Melt reaction topologies imply that such melting should be decompressive in nature and this may imply that late stages of the peak metamorphism were consistent with some unroofing of the metamorphic pile. Similar trends of regional metamorphism during pressure increase with some decompression at the metamorphic peak have been documented elsewhere in the Pakistan Himalaya.

That all these fabrics are folded by the large scale folds that dominate the Nanga Parbat syntaxis, and which date from syntaxial growth, as well as being cut by large garnet-tourmaline bearing leucogranite sheets poses a problem. Do these anatectic melts date from a peak metamorphic phase that substantially predates syntaxial evolution or do they document early stages in that evolution? The lineation data within the layered anatectites is critical here, as it indicates that the fine scale anatectic layering dates from a different tectonic environment from that of the syntaxial growth, that of southward thrusting rather than east-west shortening. Thus we infer the presence of two melt phases within the syntaxis. The first, under granulite facies conditions, dates from the main phase Himalayan metamorphic-deformation event which, elsewhere in Pakistan, reached its peak during the Eocene although reasons of structural geometry indicate that this could have been somewhat delayed within the Nanga Parbat region. The second is Neogene in age and is related to decompressive vapour-absent melting during active uplift and unroofing of the syntaxis.

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Earthquake Hazard of the Himalayan Front

TALK

R.S. YEATS*

Great earthquakes of M>8 struck the Himalayan front of India and Nepal in 1897, 1905, 1934, and 1950, leaving seismic gaps between the 1934 and 1905 earthquakes and west of the 1905 shock that were only partially filled by earthquakes in 1803, 1833, 1869, and 1991. None of these great earthquakes has any documented surface rupture, although the 1905 event was accompanied by growth of folds at the Himalayan front. However, there is abundant evidence of young folding and faulting, including back-thrusting, and these structures must be the surface expression of a décollement moving unmetamorphosed strata over the Indian shield. Beneath much of the Sub-Himalaya, the décollement is too shallow and thus too weak to generate M>8 earthquakes, and the source must then be farther north, perhaps as far north as directly beneath the MCT, where the décollement may enter basement rocks. A major problem is the geological evidence for earthquake segment boundaries. These may follow Indian-shield discontinuities like the Hardwar Ridge and may be expressed at the surface by changes in tectonic style from imbricate thrusting to blind thrusting and development of duns. A second problem is the absence of evidence for great earthquakes prior to 1897. Civilized societies in the plains south of the Himalaya apparently did not record great events for the preceding 2000 years. On the other hand, the Taxila earthquake of A.D.25 in the northern Potwar Plateau of Pakistan may have been a great earthquake, and seismic risk to northern Pakistan may be as great as it is farther east despite the presence of Precambrian salt at the décollement farther south. The absence of Precambrian salt in Hazara and in ranges around the Peshawar basin suggests that the Precambrian salt basin terminates northward in the Himalayan foothills and therefore does not lessen seismic risk in Pakistan.

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Geology of the Himalayan Foothills from the Perspective of the Attock – Cherat Range

R.S. YEATS* & A. HUSSEIN**

The Attock-Cherat Range contains boundaries between very different pre-Mesozoic terranes. South of the Hissartang thrust, the Kala Chitta Range and Potwar Plateau foreland fold-thrust belt comprises an unmetamorphosed Phanerozoic sequence with Ordovician to Carboniferous missing; Indian-shield rocks are overlain by Eocambrian evaporites. This correlates easily with subsurface cratonic rocks of the Punjab plains south of the Salt Range. North of the Khairabad (Panjal) thrust, late Precambrian continental-margin clastics (Manki Slate, Tanawal Quartzite) are overlain by a relatively complete Paleozoic and Mesozoic section which does not correlate well with the shield but is similar to sequences in Kashmir and Afghanistan. These strata are metamorphosed and intruded by granitic rocks, and they can be mapped northward across the Peshawar basin and Swat to the suture zone (MMT). Between the Khairabad and Hissartang thrusts are two problematical thrust plates. The northern plate is dominated by a late Precambrian flysch sequence (argillite, sandstone, and rare limestone, very weakly metamorphosed) named the Dakhner Formation; this is traced NE into the Hazara Formation. The Dakhner resembles the more highly metamorphosed Manki Slate farther north, but it lacks counterparts to the Tanawal Quartzite, Shahkotbala Limestone, Uch Khattak Limestone, and Shekhai Limestone characteristic of the Precambrian north of the Khairabad thrust. The fossiliferous Lower Paleozoic sequence overlying the Precambrian of the Peshawar basin is absent south of the Khairabad thrust, where the Dakhner is overlain directly by Paleocene strata and locally by Jurassic or Cretaceous rocks. Similar relationships are seen in the Kherimar Hills and Hazara. The southern thrust sheet consists of Darwaza Limestone, Hissartang Quartzite and associated redbeds, and Inzari Limestone overlain by Paleocene. The Darwaza to Inzari sequence lacks fossils and does not correlate easily with the lower Paleozoic of the Peshawar basin or with any other sequence, including that of the Salt Range. The Mesozoic and Tertiary of these thrust sheets correlate with the fold-thrust belt to the south even though the older rocks do not, indicating that the Dakhner, Darwaza-Inzari, and Kala Chitta sequences were juxtaposed in pre-Paleocene and possibly pre-Jurassic time. The lack of evidence for Eocene collision suggests that the major encounter of the Attock-Cherat Range was between India and one or more microplates, and this encounter may have been largely strike slip on the western margin of the Indian plate.

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The Permian Succession of the Baroghil Area (E Hindu Kush)

POSTER

L. ANGIOLINI*, M. GAETANI* & A. NICORA*

During the 1992 pakistani-italian expedition from Chitral to Karambar a complete Paleozoic succession was discovered and analysed. In particular the Permian part of the succession is extensively exposed in the Baroghil-Showar Shur area. There was the great opportunity to visit the Baroghil section, which was studied by Hayden in 1914 and then only shortly visited by Talent and Takhirheli in 1973. The area was then strictly closed because of the Afghan war.

Three stratigraphic sections for about 2000 m of development have been measured along the Permian part of the Paleozoic succession, with at least 250 samples collected.

The Lower Permian overlies Lower Carboniferous crinoidal packstones and it is represented by a quartzarenitic to litharenitic unit, at least 600 m-thick. This unit has been named Gircha Fm., because of its correlatability with the Gircha Fm. of the Hunza region.

Then a mixed carbonate-terrigenous succession, several hundreds m-thick follows, named Lashkargaz Fm. It consists of four members; the first, mostly terrigenous, contains Sakmarian conodonts (*Adetognathus paralautus*) and brachiopods (*Globiella* cf. *G. rossiae, Elivina tibetana, Spirigerella* sp., *Cleiothyridina ailakensis*) at the top. The second member consists of fusulinids packstones and limestones locally crowded with oncolites, corals and gastropods. The third member is only 40-50 m-thick and consists of siltites and arenites. The fourth member chiefly consists of limestones with chert rich in fusulinids, conodonts (*Sweetognathus whitei, Gondolella bisselli, Gondolella* cf. *G. idahoensis, G. intermedia, Anchignathodus* sp., *Iranognathus* sp.), brachiopods (*Costiferina* sp., *Marginifera* sp.), corals and bryozoans. Marly limestones may be present. The age of the fourth member is Artinskian to Bolorian on the basis of conodonts.

At the top of the Lashkargaz Fm., above an erosional surface, the Gharil Fm. crops out. It consists of red microconglomerates and arenites with phosphate nodules.

Then a huge peritidal dolomitic formation, 700 m-thick follows. In the lower and middle part of this formation Upper Permian small foraminifers (*Dagmarita chanackiensis, Paraglobivalvulina* sp., *Globivalvulina* sp., *Langella* sp., *Climacammina* sp.)have been detected, whereas in the upper part foraminifers and algae are present and may suggest an Early Jurassic age.

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The Paleozoic succession is repeated at least three times within three thrust sheets, with slightly different facies in the Baroghil area. On the contrary we have poor informations about most of the Mesozoic.

In contrast to the Upper Hunza and Shimshal valleys (Karakorum), where deep-water sediments are present from the Midian upwards, in the upper Yarkhun-Karambar area the shallow water environments seems to persist throughout the Permian. Correlations may be inferred with the Helmand Block in Central Afghanistan.

Stratigraphic and Paleogeographic Evolution of the Carnian-Norian Succession in the Spiti Region (Tethys Himalaya, India)

POSTER

F. BERRA*, F. JADOUL*, E. GARZANTI* & A. NICORA*

During the 1992 expedition to Spiti Valley we studied in detail the Carnian- Norian units (Tropites Beds, Alaror Group) in Pin, Parahio and Spiti (Kiato) valleys. Here we present the preliminary results of the facies analisys.

Stratigraphic distribution of lithofacies allowed recognition 45 carbonatic, terrigenous and ironstone sedimentary events, correlated through in the area between Kiato and Muth.

"Tropites Beds". The unit is subdivided into three members. The lower one (maximum thickness 165 m) shows high-frequency pelites- carbonates cycles (2/20 m thick) arranged in two possibly third- order shallowing upward cycles (70-95 m thick) with oolites and oncolites carbonates at the top are present. The middle member (maximum thickness 207 m.) is characterized by a mainly terrigenous central part. It consists of terrigerous-shallow water carbonate cycles better developed in the lower and upper portion. A phosphate horizon divides the succession in two third-order shallowing-upward cycles. The upper member is almost exclusively carbonatic with mainly low to high energy subtidal platform environments with common oolitic-calcarenitic bodies (maximum thickness of 158 m at Kiato). In the lower part bryozoan debris and dolomitic stromatolitic limestones occur, whereas open platform oolitic grainstones are predominant in the upper part. The upper member displays transgressive-regressive evolution.

The "Tropites Beds" is characterized by more proximal environments in Pin Valley (Muth). Thickness and terrigenous detritus increase in the Parahio Valley, whereas more external and relatively deeper facies have been recognized toward the NW (Kiato).

Preliminary foraminifera and conodont biostratigraphic results confirm (Bhargava, 1987) a mid to late Carnian age for the two lower members (Epigondolella echinata) and a Norian age for the third member, (Metapolygnatus nodosus at the top the middle member).

Alaror Group (Srikandia et al.,1981). This group (Quartzite s.l. of Jadoul et al.,1990) includes the "Juvavites Beds", "Coral Limestone" ,"Monotis Shales" and the "Quartzite Series" of Fuchs (1982). The lower boundary is paraconformable to disconformable and marked by breccias (Hal village). The lower part ("Juvavites Beds" and "Coral Lst.") reaches a maximum thickness in the Kiato area (150-160 m). Hybrid arenites and siltites contain major limestone intercalations in the middle part and at the top (Coral Lst.). One minor and one major ironstone layers are well developed in the Pin Valley. This marker is less evident in Parahio Valley, and it disappears northward where it passes to pelites with phosphatic nodules (Kiato). This transgressive layers are followed by pelitic interval locally containing calcareous beds full of vertebrate ribs or bioclastic calcarenites with ammonoids. Two shallowing-upward cycles are recognized: the first is comprised from the top of "Tropites Beds" to the base of the major ironstone/phosphatic material. The second cycle, reaching up to the "Coral Limestone", mostly consists of bioturbated marls and siltstones.

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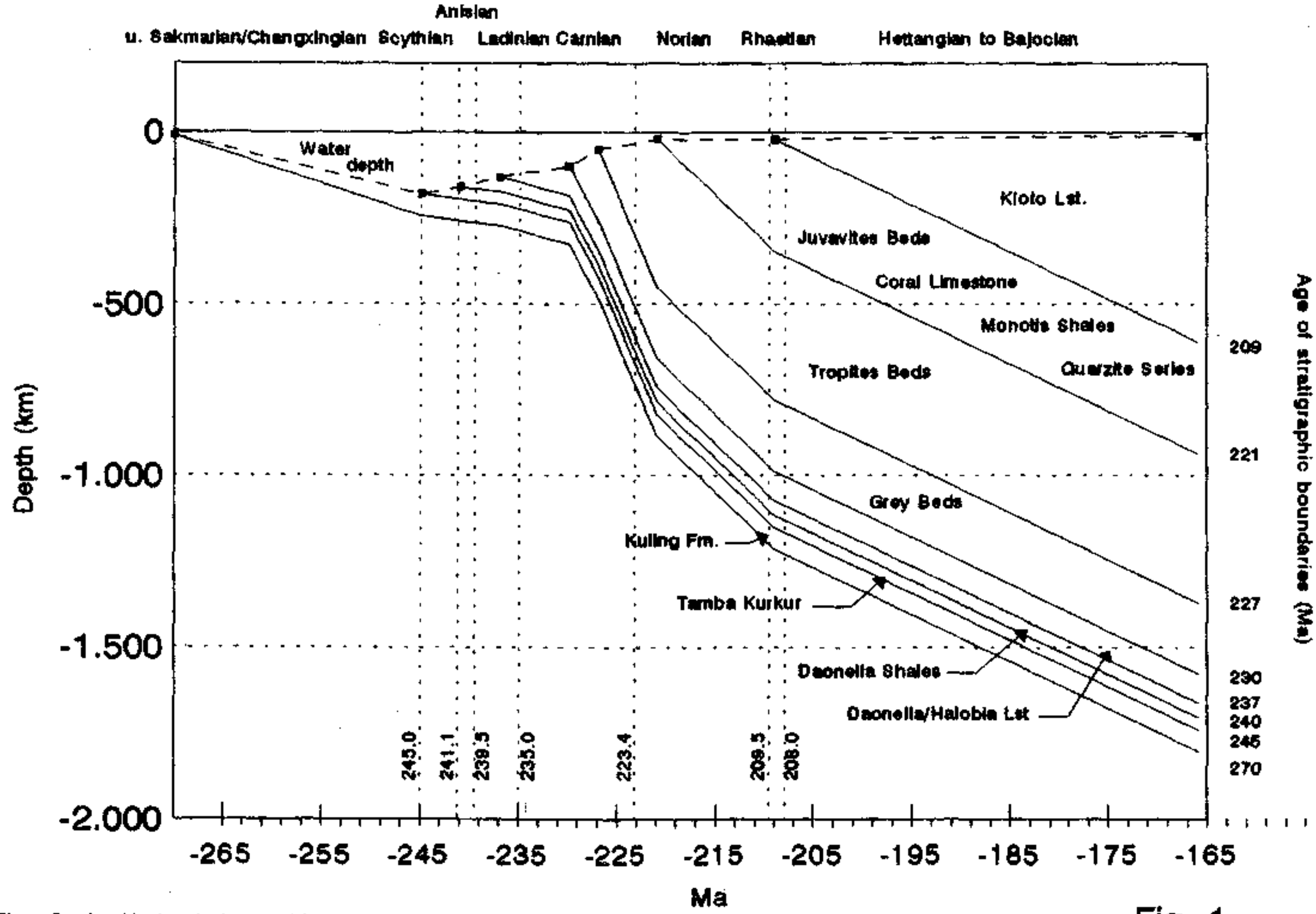
The "Coral Limestone" is discontinous in the Pin Valley where it is commonly replaced by bioclastic calcarenites-rudites; in the Kiato section it is represented by bioturbated dark limestones.

Facies analisys testifies the transition from shelfal and hybrid deposits to offshore pelitic sediments towards the N whith deposition in deeper environments.

The upper part of the Alaror Group is an overall shallowing- upward cycle, passing from pelites to increasingly sandstones layers and finally to about 50 m hybrid quartzarenites, locally containing Megalodons ("Quartzite Series s.s."). Sedimentary evolution from the upper member of the "Tropites Beds" to the top of the Alaror Group compares closely with the western Zanskar succession (Zozar Fm. and "Quartzite Series s.l".).

The Late Triassic succession of Spiti points out to high subsidence rates (fig.1) documenting a stage of tectonic extention affecting the Indian passive continental margin: this episode appears to be a geodynamic marker all along the Tethys Himalaya from Zanskar to Nepal (Garzanti et al.,1992).



Time Scale: Harland et al., 1990

Fig. 1

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The Tectonic Evolution of Fault Systems with Strong Lateral Variations in Tectonic Style: The Trans-Indus Ranges (Northern Pakistan)

POSTER

P.M. BLISNIUK* & G. SAHEED**

The main focus of this ongoing study is the structural evolution of fault systems with lateral variations in tectonic style between compression and transpression. Such fault systems have been recognized in many mountain belts. However, due to the complex pattern of deformation their formation is still poorly understood, and the tectonic interpretation of regions affected by this kind of deformation is difficult.

The Trans-Indus Ranges are part of the young and still active frontal thrust system of the NW-Himalayan foreland fold-and-thrust belt which is characterized by the occurrence of several pronounced structural re-entrants and promontories. Studies of such structurally complex fault systems in actively deforming regions are important because they can provide information that is usually not available in older mountain belts but necessary to understand the mechanics of their formation. A particularly attractive aspect of the ongoing project is the young age of deformation in the study area (< 1 Ma ?), which allows a very precise quantitative assessment of the rates of deformation. Furthermore, thermal and tectonic overprinting which has occurred in many older mountain belts is absent, and exposure is excellent in most of the region.

Preliminary results of a first field season in the Trans-Indus region (11/91 to 1/92) indicate that the emergence of the Trans-Indus Ranges was controlled by a system of frontal ramps that form the centers of re-entrants and promontories, and lateral or oblique ramps that form their edges. The construction of balanced cross-sections shows that the total shortening along the frontal ramp segment represented by the western Khisor Range is on the order of at least 10 km. This suggests that the deformation along the lateral and oblique ramps is characterized by a strike-slip component of similar magnitude. Pronounced bends of structures in the Khisor Range near the transition zones to adjacent regions of transpressive deformation suggest that vertical axis rotations occur in these areas. Structures show an apparent clockwise rotation near the western end of the Khisor Range, which is truncated by a right-lateral strike-slip fault, and an apparent counterclockwise rotation near its eastern end, which seems to be truncated by a left-lateral strike-slip fault. The sense of the apparent rotations is therefore compatible with the assumed relative motions along the lateral terminations of the Khisor Range. Alternatively, the observed bends could simply reflect a complex ramping geometry, in which case vertical axis rotations would not have occurred at all. Present fieldwork (12/92 to 3/93) therefore includes sampling for a paleomagnetic investigation to test these hypotheses.

With the exception of the results of our previous investigations in the Trans-Indus Ranges, quantitative data on the deformation in that region are not yet available. The main goal of our study therefore is a qualitative analysis of the structural style of deformation, and a quantitative assessment of the total deformation.

The area presently represented by the Trans-Indus Ranges was part of the Himalayan foreland basin and received synorogenic deposits during Late Neogene folding and thrusting further north, and was subsequently deformed as part of the hangingwall of the younger frontal thrust system in the south. The onset of deformation in the Trans-Indus region should be reflected by decreasing sedimentation rates of the more distal facies with a source area further north, and subsequent nondeposition and erosion, or deposition of proximal deposits that have the Trans-Indus Ranges as source area. Ongoing research therefore integrates sedimentological and chronostratigraphic studies of the synorogenic deposits with structural investigations in this area.

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The structural portion of this work includes detailed field mapping to provide constraints on the style of deformation. This mapping also is the basis for the construction of balanced cross-sections that are needed to quantify the total amount of shortening along the Trans-Indus Ranges. The chronostratigraphic studies will include paleomagnetic age determinations of young synorogenic molasse deposits, and fission track dating of volcanic ashes within that sequence. These studies will provide information on the age ranges and deposition rates of syntectonic sediments. Together with sedimentological mapping of syndeformational unconformities, facies changes and paleocurrent analyses these results will constrain the temporal and spatial character of deformation in the NW-Himalayan foreland.

The Cambro-Ordovician Orogenic Cycle in the Himalayan Chain: Comparison and Relationships with the Evolution of the Continental Margin of Eastern Gondwana (Antarctica and Australia)

POSTER

R. CASNEDI*

During the Cambrian, the Himalayan domain was bordering one of the major continental masses forming the Gondwana supercontinent. In fact the western border of the Indian-Australian block was separated from an Asiatic fragment (Tibet microplate) by a wide continental shelf with connected outer basin. Terrigenous to carbonate peritidal facies recorded a transgressive trend, in a passive continental margin setting. Consequently, in the middle-late Cambrian, turbidites and basaltic tuffites were poured in a deep water basin, in front of an arc-trench system (Kurgiakh Formation) The sedimentary sequence was uplifted and transformed into chain (Late Pan-African event?) and thereafter eroded giving alluvial fan conglomerates and braid-plain sandstones in middle Ordovician time (Thaplè Formation).

A similar carbonate lower to middle Cambrian deposition characterised the eastern continental margin of Gondwanaland. In both the Ross Orogen (Antarctica) and Delamerian Orogen (South Australia), the sequences contain thick, Archeocyath-bearing carbonates called the Shackleton Limestone and the Normanville Group, respectively. Even if there is no evidence of regional continuity, these rocks prove the existence of a continental shelf flanking this sector of the Cambrian Gondwana. Shelf-continental slope-island arc refers to the sediments and associated intrusive and extrusive rocks of Australia, New Zealand, Tasmania and Antarctica.

The orogenic cycle began with the sinking of the shelf, followed by turbidite systems, locally interbedded with tuffaceus material (Kurgiakh Formation in Himalaya, Kanmantoo Group in Australia, Priestley Formation, Sledgers, Mariner and Robertson Bay Groups in northern Victoria Land-Antarctica and other equivalent sequences). The terrigenous sedimentation was supplied either from detritic discharges coming from the continental block and from the carbonatic shelf. A great part of the continental margins of Gondwanaland were consequently uplifted and eroded. Ordovician post-orogenic molasse-like and alluvial deposits cover unconformably the remnants of the chain (Thaplè Formation in Himalaya, Brown Ridge Conglomerate-Crashsite Quartzite-Leap Year Group in different domains of Antarctica).

The correspondence of events caused a surprising affinity and correlation among the Cambro-Ordovician sequences even located at the opposite borders of Gondwanaland. The persistence of faunas of warm climate in carbonate shelf environment, gives moreover paleogeographic constraints: both the regions remained within the tropical carbonate development zone.

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Lateral and Frontal Structure of the Dun of Dang (Siwalik Belt, Western Nepal) – Geodynamic Correlation with a 3D Numerical Model of a Critical Wedge Taper

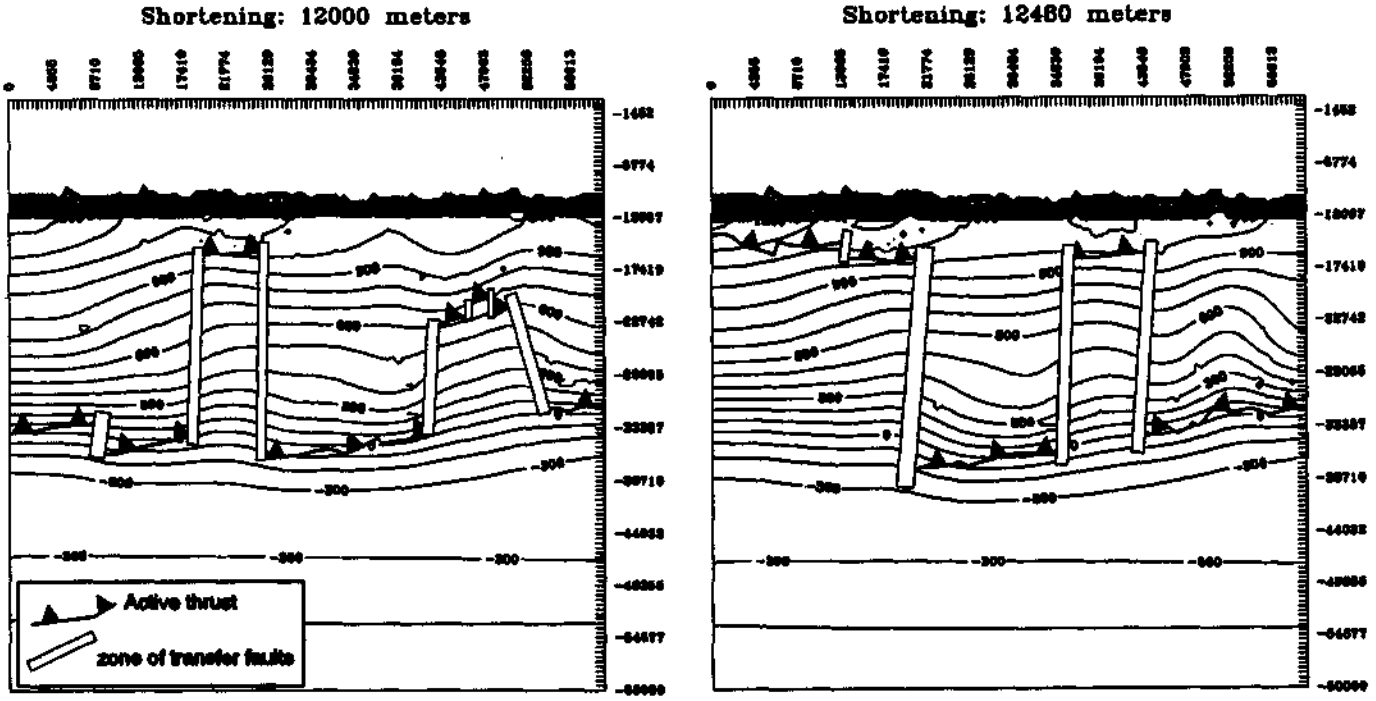
POSTER

E. CHALARON*, J.L. MUGNIER* & G. MASCLE*

The Siwaliks foreland basin fringes the Himalayan range along more than 2000 Km. In Nepal, several thrusts are defined in this basin. From North to South several thrusts outcrop:

1) the M.B.T., thrusting over the Siwaliks sediments.
2) the Main Dun Thrust (M.D.T.).
3) the Main Frontal Thrust (M.F.T.).

In western Nepal, the M.D.T. can be divided in two major thrusts which outcrop in the Bheri valley (M.D.T. 1) and in the Babaï valley (M.D.T. 2). Each of them thrusts over Upper Siwaliks sets (Pliocene-Pleistocene). The M.F.T. comes into contact with the Quaternary of the Teraï plain. A virgation of the structures that displaces southward the M.D.T. 2 is shown in the western part of the dun of Dang. Therefore this area is displaced piggy back by the M.D.T. 2.



Topographic maps and active thrusts after 12 and 12.48 Km of shortening. In an accretionary wedge in steady state, different thrusts may be actived in same time and create zones of transfert.

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A 3D numerical modelisation is proposed to study the evolution of an intracontinental accretionary wedge. It is based on the couple of a kinematic forward model, a mechanic model, an isostatic compensation model and an erosion / sedimentation model. This modelisation shows that during its evolution, an accretionary wedge reaches successively two states: a transitional and a steady state. During the first one, the tectonic evolution is managed by geometric and mechanic parameters and a forward and / or a backward propagation sequence occurs. The steady state is a continuous of the basal decollement propagation and of internal thrust reactivation. The geometric parameter which controls the evolution is the local topography induced by the couple of tectonic history of each tectonic sheet and erosion / sedimentation. Nevertheless one part of the wedge may prompt the basal decollement and another part may prompt a more internal tectonic sheet creating by this way some zones of transfer faults. The structure of the western part of the dun of Dang and the overthrusting of M.D.T. 1 & 2 on Upper Siwaliks sediments is explained by a pre-localised deformation controlled by the geometry of the underlying flat at the beginning of the deformation and its solicitations by several events during the steady state tectonic evolution of the foreland basin.

Late Orogenic Extension in the High Himalaya The Thakkhola Hemi-Graben (Nepal)

POSTER

M. COLCHEN*

The Thakkhola hemi-graben is located at the northern side of the Nepalese High Himalaya (Dhaulagiri and Annapurna Ranges). It is filled with thick (900 m) detritical series of probably Plio-Pleistocenous age (Tetang and Thakkhola formations) *(1)*.

Several fault systems are recognized in the Mesozoic formations, which constitutes the basement of the southern part of the Thakkhola hemi-graben :

- **a N020-N040 system**, set of plurikilometric normal faults of regional extension, which are well exposed in the western part of the basin. The fault planes dip 80 to 85° to the east, with striae pitching 15° to 30° to the north. These faults are associated with sinistral oblique-slip ones. The amplitude of the displacement decrease from north to south : it varies from 4 km (vertical slip) and 8 km (horizontal slip) at the north to some tens of meters 50 km to the south.
- **others fault systems** are recognized : N180-170, N070-090, N115, N150-160° normal and strike-slip faults. These faults are subvertical, with minor vertical slip.

Four directions of extension are recognized :

- a WNW-ESE which fits with the Thakkhola hemi-graben formation with N020-040 normal faults,
- a N-S, with N150-160 normal faults,
- a NE-SW, with N150-160 normal faults,
- and a W-E, with N180-170 normal faults.

Two directions of compression :

- a NNW-SSE to N-S with N020-040 sinistral and N150-160 dextral strike-slip faults,;
- a E-W with N020-040 dextral and N120-150 sinistral strike-slip faults.

(1) FORT M, FREYTET P. and COLCHEN M. (1982).

In conclusion :

The superposition of the several striae assemblage on a same fault plane reveal a polyphasic faulting in extension and compression alternately.

The disconformity between the Thakkhola fm. and the mesozoic fm. of the basement, both folded and faulted, is the indication that a part of this faulting predates the Thakkhola hemi-graben formation.

Concerning this hemi-graben, is proposed the following chronology of the faulting from the Late Paleogene to the present time :

1) a WNW-ESE extension characterized by N020-040 normal faults ;
2) a NW-SE to N-S compression with the N020-040 sinistral strike-slip faults and N150-160 dextral strike-slip faults ;
3) a ENE-WSW to E-W compression with the N020-040 dextral and N070-090 sinistral strike-slip faults ;
4) a E-W extension with the N180-160 normal faults observed in the Thakkhola fm. and the Quaternary fm.

This faulting is in keeping with the geodynamic evolution of the northern himalayan domains, consequence of the continental hypercollision between India and Asia :

- the extension of the upper plate above the North Himalayan shear zone ;
- the Miocene dextral shearing between Himalaya and Tibet.

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Deformation History and Structural Pattern Within an Exploration Concession in the Eastern Potwar Basin (NE Pakistan)

POSTER

R.W. DELL'MOUR* & M. RODGERS*

Structural Data gained from field work carried out in 1992, Satellite TM interpretation and seismic interpretation provides the basis for a Tectono-Kinematic interpretation of a small portion of the Eastern Potwar Plateau (Fig. 1).

The Potwar Basin is part of the Central Fold Belt of Pakistan, the northern portion of which forms part of the Himalayan foreland fold and thrust belt. This deformed belt is a product of the ongoing collision between the Eurasian and Indian plates which forms the northernmost element of the Indus Basin. Compressional deformation throughout the Himalayan foreland is taking place as the Indian Shield is overridden by sediments along its northern margin. In the eastern Potwar deformation is distributed along a broader zone of northeast/southwest trending, tight to overturned anticlines separated by broader synclines.

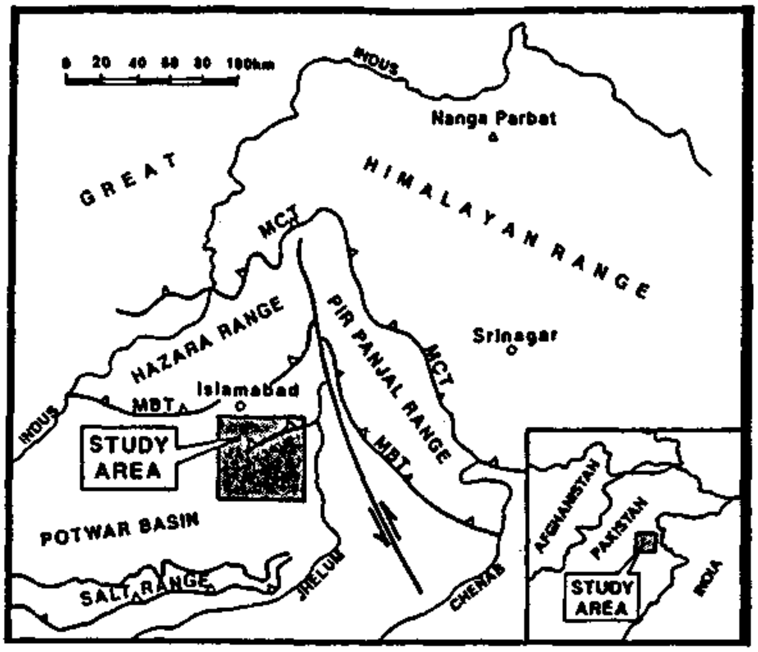

Fig. 1 Tectonic overview of the study area

Three phases of deformation have been observed within this compressional stress field (Fig. 2):

Phase 1: Thrusting and folding WNW/ESE
Phase 2: Strike-slip faulting (W)NW/(E)SE
Phase 3: Strike-slip faulting NE/SW

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Intensity of deformation increases to the NW as expressed by the more intensely sheared and compressed Riwat anticline. The easternmost Kallar anticline shows only minor deformation of the crest owing to southeast directed thrusting which does not appear to have significantly disturbed the stratigraphic sequence.

The most extensively developed thrust zone has been observed on the eastern limb of the Buttar anticline although the poorly developed outcrop exposure prevents accurate identification on the Satellite images. South-easterly directed thrusting over several hundreds of metres is likely and lithologic indicators in the kataclastic zone suggest probable detachment within the Kamlials or Chinji Formations.

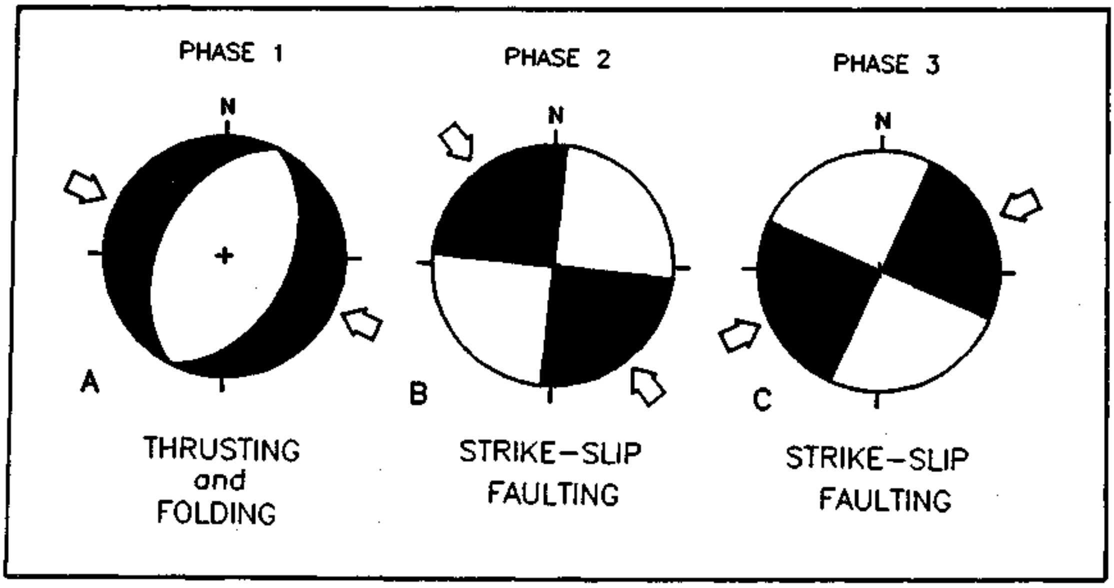

Fig. 2 Beach Ball diagram showing the deformation type and direction of compression: black = compression; white = extension (Angelier 1979).

A Geology Lesson in Manang Moutaineering School in Nepal

POSTER

U. HERLEC* & A. JAMNIK**

Insufficient knowledge and inexperience of participants of the Himalayan expeditions claimed by many Sherpas's lives. The native Nepalese living in higher areas have admirable qualities for mastering high altitudes and enduring extreme efforts, but they need instruction in alpine techniques for transition from the classical period of himalaism to more and more extreme climbing. They should be qualified to be able to succesfully accompany expeditions as well as to become reliable mountain guides for tourists - trekkers. Basing on the idea of Aleš Kunaver (leader of many Himalayan expeditions), in 1975 Slovenia (former part of Yugoslavia) started a cooperation with Nepalese Mountaineering Association (NMA), preparing the project of mountaineering school with its basic aim to educate the Nepalese as well as interested trekkers and tourists in mountaineering. In 1979 the construction got started in western Nepal, in the zone of Gandaki, district of Manang. The school is situated beside the Sabche Kola, on the picturesque trekking route around Annapurna (second most frequently visited in Nepal), close to Ongre airport and Manang.

Part of the course the Slovenian instructors are giving to Nepalese trainees is the basic knowledge of rock and mountain genesis. Apart from explaining the natural processes and possible danger caused by erosion, our aim is also education in basic geology and preservation of the nature.

The present knowledge on Himalayan geology has been limited to highly specialized expert groups and can be found mostly in professional publications. We think that basic knowledge on geology should be presented to broader public. For instance, on the trail near Muktinath we can see a lot of ammonites called "saligrami". For native guides and interested tourists a geological guidebook would be usefull for learning and observing the principles of fossilization, tectonics, geomorphology etc. Very useful are the photo views with sketches of geological interpretations. In lastest courses we included the published data on geology of the Annapurna range. With further investigations, new results and wider international cooperation of interested proffesionals we could write a book and organize courses on geology not just for natives but also for trekkers and interested geologists. Vicinity of the airport, accomodation in the Mountaineering school and relatively dry climate in the monsoon periode are advantages for people who are not familiar with high mountain hiking. They could obtain a lot of experience in mountaineering and geology.

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Constraints on the Timing of High Himalayan Unroofing, as Deduced from Detrital Garnets from Sediments of the Kasauli Formation (Lesser Himalaya, N India)

POSTER

Y. NAJMAN*, P. CLIFT*, M. JOHNSON* & A. ROBERTSON*

The Subathu, Dagshai and Kasauli Formation sediments are of Lower Tertiary age and document the early stages of India-Eurasia continental collision. Deposited on Indian plate basement rocks in front of the orogen, they became deformed into the Lesser Himalayan thrust stack as the orogen migrated south. The limestones and mudstones of the Subathu Formation are of Palaeocene-Mid Eocene age. They are of shallow marine origin and were deposited between initial and terminal continental collision. The red Dagshai Formation and the grey Kasauli Formation sediments are Mid Eocene-Upper Oligocene and Lower-Mid Miocene aged, respectively. They are sandstones and mudstones, interpreted as fluvial, foreland basin sediments, with palaeocurrent directions indicating flow from the north-west, away from the rising orogen.

Fragmented and complete detrital garnets have been found in the Dagshai and Kasauli Formations. Electron microprobe analytical traverses were made across Kasauli Formation garnets and the results plotted on Ca-Mg-Fe and Mn-Mg-Fe triangular diagrams and compositional profile diagrams. The results were then compared with the work of Arita (1983), Metcalfe (1990) and Staubli (1989) who analysed garnets in the Lesser Himalaya Main Central Thrust zone (footwall) and the High Himalayan Crystallines (hangingwall). All workers found that the garnets in the MCT zone showed 'bell-shaped' compositional profiles which were absent in samples from the Higher Himalayan Crystallines. Presumably this reflects the higher grade of the latter.

Although the detrital garnets from the Kasauli Formation show bell-shaped profiles, and therefore resemble those found in the MCT zone, this does not necessarily mean that the MCT zone was the source for the Kasauli Formation, as similar composition garnets could be present in the Indian craton. It does however, suggest that the high-grade High Himalayan crystallines were not unroofed until post-Kasauli times i.e. post Early-Mid-Miocene. This date for 'unroofing' is in agreement with other workers e.g. Amano and Taira (1992).

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Examples of the Campanian to Paleocene Sedimentary Record of the Northern Indian Shelf (Tethys Himalaya)

POSTER

H. PFLÄSTERER*, J. SCHALLER* & H. WILLEMS*

Four study areas of the northern Indian continental margin (Tethys-Himalaya) are presented. The sections are situated in southern Tibet and Ladakh and comprise a range from Campanian to Paleocene each. From west to east the following localities have been investigated.

Zanskar Shelf (Ladakh): the basal Kangi La Formation (Campanian to Maastrichtian) is built of marly/silty sediments and is characterized by a shallowing upward sequence due to the increasing sedimentary input. The shallow-water carbonates of the Marpo limestone follow in the Upper Maastrichtian. The Stumpata Quartzite composed of quartz arenitic coastal sandstones represents the Lower Paleocene, above which open marine conditions develop once more (Dibling Limestone).

Tingri (Tibet): the top of the basinal sediments of the Gamba Group (Upper Albian to Upper Santonian) is followed by the Zongshan Formation (Upper Santonian - Middle Maastrichtian), which is interpreted as highly pelagic facies of the outer shelf. After a hiatus in the Lower Maastrichtian, sandstone turbidites and siliciclastic-carbonatic resediments of the Zhepure Shanpo Formation (Middle Maastrichtian - Lower Paleocene) are deposited. They are superimposed by sandstones of the Jidula Formation in the Lower Paleocene. After this siliciclastic input, a stable carbonate platform has built up in the Middle Paleocene. The so-called Zhepure Shan Formation (Montian-Lutetian) comprises marine carbonates rich in fossils.

Gamba (Tibet): in parallelism to Tingri the basinal sedimentation of the Gamba Group (Upper Albian to Campanian) can be seen in the lowermost part of the section, it derived its name from this type locality. The succeeding Zongshan Formation prohibits the gradual shallowing of the area: pelagic carbonates pass into limestone/marl alternations, which in turn shift to fossiliferous limestones with intercalated rudist reefs. The top of the Zongshan Formation consists of a striking Rhodolite facies, which is superimposed by quartz arenitic sandstones of the Jidula Formation of the Cretaceous/Tertiary boundary. These sandstones represent the maximum of the regressive development. Marine limestones (Zongpu Formation) of Middle Paleocene to Ilerdian age follow above.

Tüna (Tibet): covering the Gamba Group, the newly introduced Tüna Formation is comparable to the Zongshan Formation in the type locality of Gamba, but different in detail. The overlaying Jidula Sandstones are similar to these of Gamba, marine fossiliferous limestones of Paleocene age follow.

The comparison of the different working areas of Ladakh and Tibet reveals similarities of the controlling mechanisms of sedimentation. Small-scale transgressions and regressions are superimposed by a large-scale shallowing upward trend in the Upper Campanian to Maastrichtian. The transition from flyschoid (Kangi La Formation, Ladakh) and pelagic sediments (Gamba Group and lower parts of the Zongshan and Tüna Formation in Tibet) to limestone/marl alternations and shallow water carbonates is significant. The maximum of the regression is shown by the deposition of marine coastal sands (Stumpata, resp. Jidula quartz arenites). They are followed by marine sediments in all areas investigated.

Global factors (eustasy) are therefore supposed for the build up of these depositional features.

Temporary and local disturbances are visible in the area of Tingri: resedimentation and turbiditic intercalations are due to tectonic events in the Middle Maastrichtian.

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Stratigraphic and Structural Framework of Himalayan Foothills (Northern Pakistan)

POSTER

K. R. POGUE*, M.D. HYLLAND** & R.S. YEATS***

The integration of new paleontological, stratigraphic, and structural data permit analysis of the pre-Himalayan configuration of the Indian plate passive margin in northern Pakistan. Thick sections of Paleozoic metasediments exposed in the Peshawar basin were preserved in half grabens created during Late Paleozoic rifting. Rift highlands were largely stripped of Paleozoic cover in Swat where Permian metabasalts overlie the Proterozoic Manglaur Formation and in the Attock-Cherat Range where Jurassic and Cretaceous rocks overlie the Proterozoic(?) Dakhner Formation. In the absence of a fossiliferous Paleozoic section, lithologic correlation of Proterozoic units is crucial to retrodeformation and estimates of Himalayan shortening. The Proterozoic Salt Range Formation, Hazara (Dakhner) Formation, Manki Formation, Gandaf (Salkhala) Formation, and Karora Group are interpreted as a formerly continuous northward-deepening sequence.

The Khairabad and Nathia Gali - Hissartang faults divide the foothills region into three stratigraphically distinct structural blocks. The northern block consists of the Proterozoic Gandaf and Manki Formations overlain by younger Proterozoic(?) formations and fossiliferous Paleozoic and Mesozoic strata. The metamorphic grade in the northern block gradually increases northward from lower greenschist facies near the Khairabad fault to upper amphibolite facies in central Swat. The central block consists of weakly metamorphosed Proterozoic Hazara (Dakhner) Formation and locally Cambrian and younger Paleozoic(?) strata overlain by Cretaceous and Paleogene marine strata. The southern block consists of unmetamorphosed fossiliferous strata of Triassic to Eocene age. Proterozoic rocks in the subsurface of the southern block are probably transitional between the evaporite dominated Salt Range Formation and the shallow marine clastics of the Hazara (Dakhner) Formation.

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Triassic Stratigraphy and Facies Evolution (Tethys Himalaya, Thakkhola, Nepal)

POSTER

U. v. RAD*, J.G. OGG**, S.B. DÜRR*** & J. WIEDMANN***

1. Triassic stratigraphy

See Abstract of talk "Triassic rifting and Tethyan paleoenvironment..."

2. Triassic facies evolution and global tectonic/eustatic events

Three main factors governed the patterns of Triassic through Middle Jurassic facies along the eastern Tethyan margin of Gondwana: paleolatitude, relative sea level, and regional tectonics.

Northwest Australia and the adjacent Himalayan margin lay at about 40°S during the Middle Triassic, drifted steadily northward into tropical latitudes to reach 20°-25°S in the Rhaetian to Early Jurassic, then again returned to temperate latitudes in the Middle Jurassic. As a result, shallow-water carbonate platforms are favored during the Rhaetian and Early Jurassic: Aghil Formation in Karakorum, Kioto Formation in Ladakh, Jomosom Formation in Central Nepal, Pupuga Formation in southern Tibet, reef limestone on the Wombat Plateau and in Timor. Such shallow-water carbonate facies are rare during the Middle Triassic to early Norian times or during the Middle Jurassic when most of these regions were in temperate latitudes. In addition, the influx of terrigenous clastics was also governed by the climatic regime, with increased clay input under tropical chemical weathering conditions and increased detrital components favored under subtropical monsoonal or seasonal temperate climatic conditions where physical weathering is important.

Throughout this northward drift in paleolatitudes, Northwest Australia was always further from the equator than the Himalayan and Karakorum regions which were in the most tropical latitudes. As a result, the facies are generally more calcareous on the Himalayan margins than on the Northwest Australian margin, and shallow-water carbonate deposition may continue into the Middle Jurassic in the more tropical latitudes (e.g., Ladakh and Pakistan).

Following a rapid deepening in the basal Triassic (Griesbachian transgression), the margins display a progressive shallowing. This culminated in deltas prograding over Middle Triassic to Carnian mudstone on the Northwest Australian shelf and over Norian shallow-shelf sediments on the Himalayan margin. A mid- to late-Carnian episode of rift tectonics is indicated by the formation of fault-bound basins on the Australian margin and by volcanics in the Ladakh region; this may have contributed to the increased influx to terrigenous clastics during the Norian.

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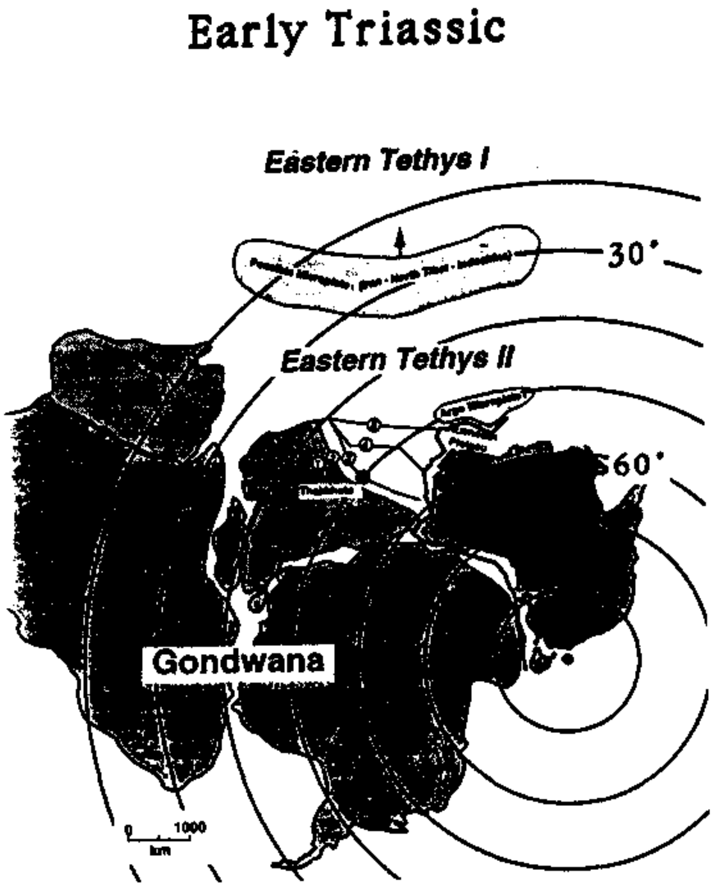
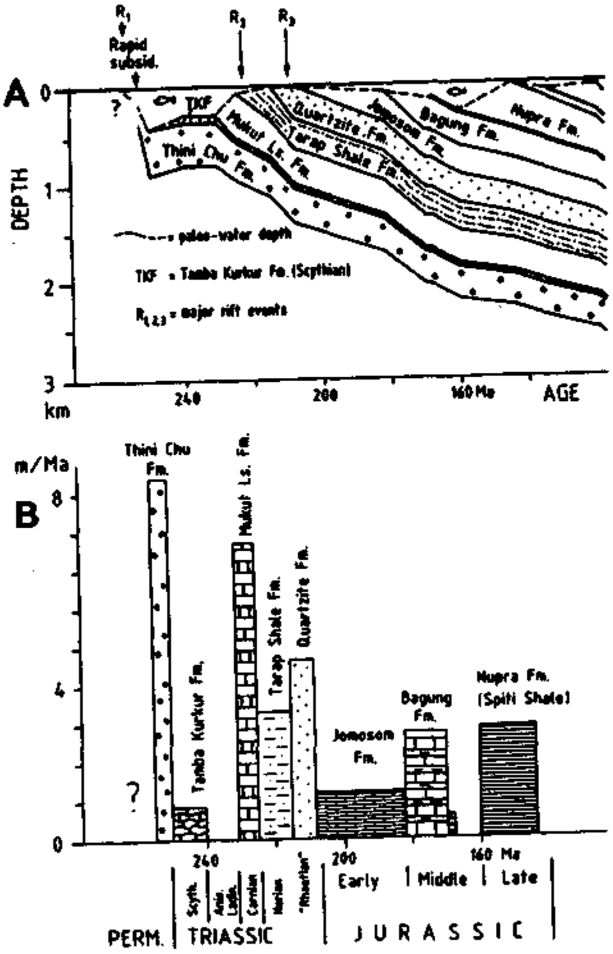
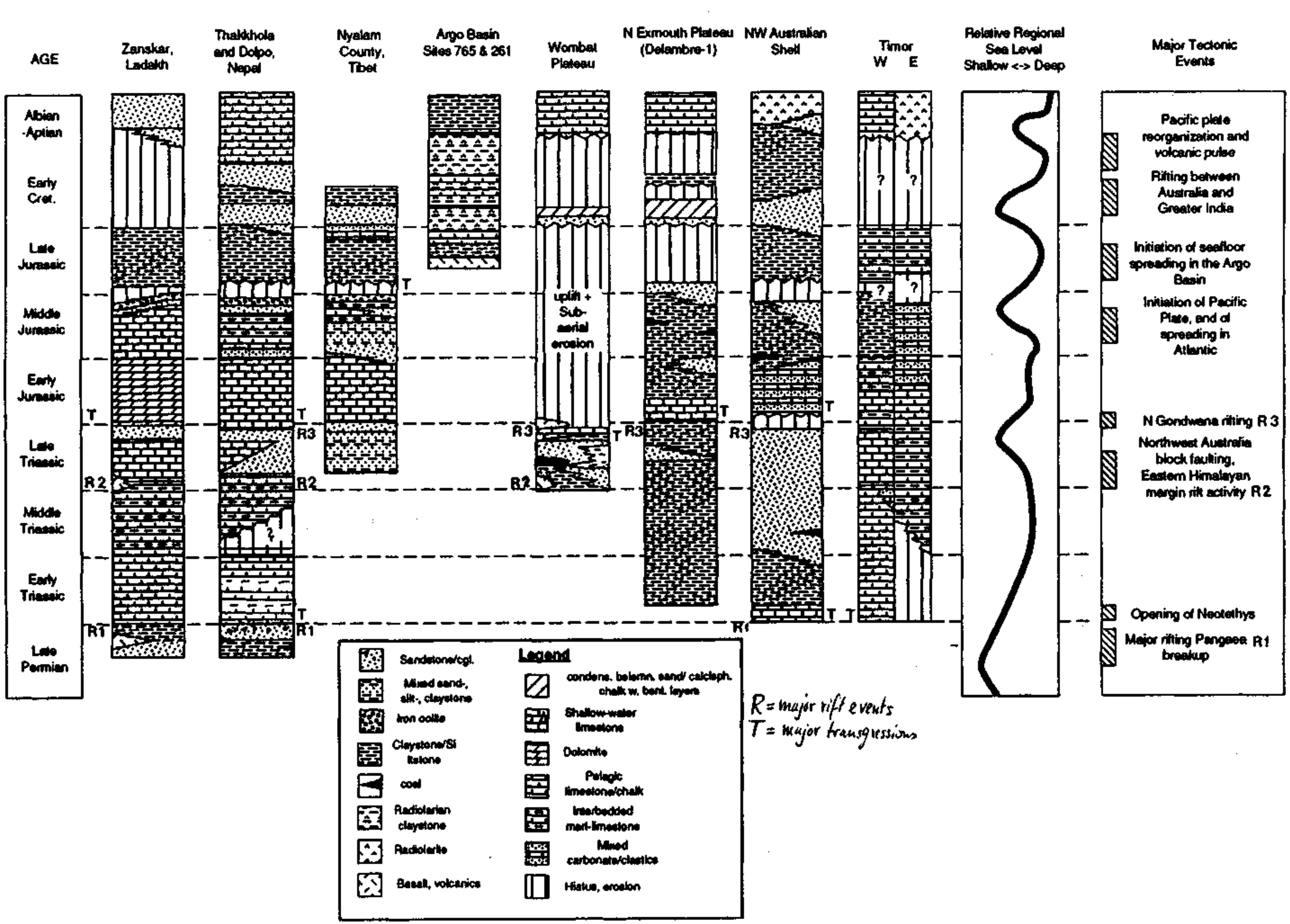
A sequence boundary of global significance ("215 Ma") was observed at Wombat Plateau: it is underlain by upper Norian fluviodeltaic floodplain to coal swamp deposits (highstand systems tract) and overlain by lower "Rhaetian" lagoonal marl/limestone cycles (transgressive systems tract) and upper Rhaetian reefal limestones (highstand systems tract). Tentatively, we correlate this major "215 Ma" sequence boundary to the top of the thick quartzitic marker bed of the lower Quartzite Formation, overlain by the shale- and carbonate-rich upper Quartzite Formation (transgressive systems tract).

A geohistory diagram of the Upper Permian to Jurassic strata in the Thakkhola shows the paleobathymetry, subsidence history and sedimentation rates. Global sea level was low in the late Permian and during Norian-Rhaetian time. Rapid tectonic subsidence after the late Permian rifting events caused substantial deepening of the margin to bathyal depths causing sediment starvation (Scythian to Carnian). Subsidence and sedimenta late Permian, Carnian and late Norian/"Rhaetian" times, whereas condensed sequences (< 1 m/Ma) and/or hiatuses straddle the Scythian to Ladinian stages. Apart from this unusual interval the burial curves indicate steady subsidence accentuated by rifting events, as typical for the early syn-rift history of passive margins.





Mesozoic Stratigraphy of Himalayan and Northwest Australian Margins



R = major rift events
T = major transgressions

Geological Outline of Neelum Valley (Azad Kashmir, NE Pakistan)

POSTER

M. Schouppe* & D. Fontan*
with the collaboration of A.K.M.I.D.C.**

More than fourteen hundred square km area is being intensively mapped at the scale 1:50.000, between the Neelum river and the watershed separating the Neelum Valley from the Kaghan Valley. New ground is broken in the sense that it is the first time that a systematic regional mapping is undertaken in a zone, which is often forbidden to foreigners due to the political instability between the Indian and the Azad Kashmirs. Geological data collected since 1991 greatly improve the understanding of the Higher Himalayan Crystalline (HHC) of Neelum Valley and relatively complete previous field observations made by other authors near the Hazara Kashmir Syntaxis.

Stratigraphy

In the HHC unit of Neelum we have distinguished a **basement** and a **cover**.

The **basement** comprises a thick sedimentary sequence intruded by leucocratic garnet-bearing granitoids of pre-Himalayan age (presumably Early Paleozoic). The sedimentary rocks consist of a monotonous alternance of psammitic to pelitic schists with minor intercalations of impure marble. The contact between the granitoids and the schist is generally tectonized. Evidence of intrusive contacts are still observable: spotted schists with andalusite relics and skarn in the Jagram-Kalapani area and magmatic contact in the Shardi-Surgun-Gumot area.

Basaltic dykes cross-cut at low angle the regional banding of the basement.

The **Cover** has been divided into three units (from bottom to top):

- unit A: a siliceous sequence made of impure quarzites associated with minor metaconglomerates, and a thick sequence of kyanite-bearing paragneisses.
- unit B: an alternance of impure marble (frequently ruby-bearing), calcschist, and amphibolite.
- unit C: a thick sequence made of graphite-bearing garnet micaschists.

The conctact between the basement and the cover is believed to be an old tectonised stratigraphic unconformity. The question remains open due to the lack of well accessible outcrops.

Metamorphism

The regional Himalayan metamorphism of the studied area has been shown to be of Barrovian type (from *biotite-chlorite zone* to *sillimanite zone*) with an early eclogitic stage present only in the Shardi-Surgun-Gumot area.

In the cover sequence of the Shardi-Surgun-Gumot, a typical kyanite-staurolite assemblage of high temperature amphibolitic facies, is wide-spread developed. Beside this assemblage, a few relics of previous prograde metamorphism are present. Some chlorite crystals, discordant on the schistosity, attest for a not intensive retrometamorphism in the green schist facies.

The sedimentary sequence of the **basement**, well developed in the Jagram-Kalapani area, shows a metamorphic zonation consisting in a biotite-chlorite zone, a kyanite-staurolite zone and a sillimanite zone.

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Rocks with biotite-chlorite assemblages were encountered near Kundalshahi. These assemblages may represent relics of a prograde phase of Barrovian metamorphism or a pre-Himalayan low grade phase associated with the emplacement of the granitoids.

Kyanite-staurolite bearing assemblages are not common on the field. The typical assemblage consists in white mica, biotite, garnet, epidote and amphibole. Kyanite and staurolite, visible only in thin section, are associated with the spotted schists. They growth on old andalusite grains, already replaced by white mica and quartz. This suggests that the time of re-equilibration to the amphibolitic condition was relatively short.

Sillimanite appears in the sedimentary sequence with anatectic rocks (agmatites) as small needles or flakes. It is associated with the first appearance of K-feldspar.

In the granitic rocks, the old magmatic white mica is partially or totally replaced by fibrous sillimanite. In the migmatitic gneisses, sillimanite coexists with kyanite and an incipient melting appears in small (dm) shear zones .

In the Shardi-Surgun-Gumot area, basaltic dykes cross-cutting the migmatitic gneisses are characterised by eclogitic assemblages (omphacite + garnet). These eclogitic assemblages are only preserved in the centre of the dykes. Sometimes, they are partly replaced by later discordant growth of hornblende and biotite and along the border zone, by green schist assemblages.

Eclogites, in the same metamorphic setting, have been found also outside the mapped area. They appear in the Lilian Basti area (Kaghan Valley) as strongly deformed pillow lavas and, in Kel area, as dykes cross-cutting migmatitic rocks.

Eclogitic assemblages are not found in the Jagram-kalapani area where the basaltic dykes show an amphibolitic paragenesis with relics of the magmatic texture.

The fact that eclogitic assemblages have been found in the Shardi-Surgun-Gumot area and that they are absent in the Jagram-Kalapani area, suggest a different metamorphic P-T-t path for both of them.

Structure

The basement- and the cover rocks of the Higher Himalaya Crystalline of Neelum Valley illustrate the prevalent ductile nature of a complex Himalayan deformation. Four successive phases of folding have been distinguished on the field in both mapped areas ("Jagran-Kalapani" area and "Shardi-Surgun-Gumot" area).

An over spread penetrative schistosity (S1), derived from the preferred orientation of platy and acicular minerals lies subparallel to the banding. It is probably related to a large ductile shear at deep level, associated with isoclinal and intrafolial foldings (F1). This first phase (F1) developed an East oriented stretching lineation (L1) well expressed in some granites and amphibolites of the "Jagran-Kalapani" area.

A second phase (F2) folded isoclinally the main schistosity and the banding. This phase brought off the transposition of the basement and cover sequence initiated by F1.

Later, a third phase of tight folding crenulated the main schistosity to develop a crenulation cleavage S3, 15° to 25° oblique to the banding.

The geometry of all these structures is disturbed by the fourth folding phase, which produced open folds repeated with a wavelength of several kilometres. Their axial planes are subvertical and strike NE-SW. From place to place, the fold axes are subhorizontal, gently plunging to the NE or to SW. This suggests further gentle deformations expressed in the rocks with a very large wavelength (>20 km).

We mention finally a set of small early deformations including kinking of the previous structural planes, different fracture sets and local subhorizontal thrust planes, constantly characterised by a displacement of the roof to the SW.

Geochronology of the Indus Gorge and Astor Valley Sections through the Nanga Parbat Syntaxis: Constraints on Uplift History

POSTER

P.J. TRELOAR*, J. WHEELER, G.J. POTTS**, D.C. REX*****
& A.J. HURFORD****

The Indus Gorge provides a constant altitude east-west section across the north-trending Nanga Parbat syntaxis. The Astor Valley, to the south, provides a second section, this one NW-SE trending, through the syntaxis, although not a constant altitude one. The syntaxis is a structural half window, within the core of which Indian Plate gneisses are updomed from beneath a cover of overthrust volcanics of the Kohistan-Ladakh island arc complex. These sections provide an opportunity for detailed, structurally constrained, sampling for both P-T-t path analysis and geochronology. Here we present data from these traverses that enable us to constrain the uplift history of the syntaxis. 120 samples were collected for analysis by hornblende and mica Ar-Ar and K-Ar techniques, and by zircon and apatite fission track techniques. When those data of Zeitler (1985), Zeitler and Chamberlain (1989), Smith et al (1992) and George et al (1993) are included we have a copious, closely spaced data set.

1) A marked break in cooling ages occurs across the western margin of the syntaxis. This margin is marked by the Raikot-Sassi Fault Zone, a complex fault system with an overall oblique sense of displacement that includes both right lateral and thrust type displacements. The data imply that significant displacements have occurred along this zone within the last 1 to 2 Ma.

2) The eastern margin is marked by neither a significant fault zone nor a marked step in cooling ages. Instead cooling ages gradually decrease westward across the margin into the syntaxis, a decrease explained by exhumation during the growth of a large scale antiformal fold located within the syntaxis.

3) Within the Indus Gorge section, hornblende and mica Ar-Ar ages are both younger within the western half of the syntaxis than in the eastern half. This is consistent with the recognition of a series of domal structures within the syntaxis not all of which grew synchronously. Within the Indus Gorge section, the data are consistent with the growth of an antiform within the eastern part of the section before 5 Ma ago, and the subsequent

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growth of a similar structure, at ca. 3 Ma ago, in the western part of the section. Neither zircon nor apatite ages show this age difference from east to west, indicating that folding may have become of secondary importance to uplift controlled by faulting along the eastern margin after about 2 Ma ago. Locally hornblende and monazite ages indicate T>500°C as recently as 9-10 Ma and in the case of muscovite Rb-Sr ages as recently as 5 Ma. Some of these very young ages may be due to localised thermal perturbations due to melt emplacement.

4) Within the Astor Valley section, a different cooling profile is recorded with mica ages increasing towards the west, a pattern shown less well by the fission track ages. The tectonic siginifance of this variation is, as yet, uncertain.

Although a combination of early folding followed by later oblique slip thrusting along the western margin may explain the uplift and cooling history of the Indus Gorge section, it may be unwise to extrapolate this model without qualification to the rest of the syntaxis, as shown by the data from the Astor Valley. The internal structure of the syntaxis is best modelled as a series of nested domes. Folds within the Indus Gorge plunge south, whereas those within the Astor Valley plunge north. More detailed geochronology is required to demonstrate the extent to which these developed diachronously as well as their temporal relationships to thrusting along the western margin.

Total exhumation and overall uplift rates are difficult to quantify given the vertical telescoping of isotherms due to rapid uplift and unroofing, and the emplacement, as recently as 2 Ma ago, of leucogranite dykes and bodies to high structural levels. However, due to the constant altitude of the Indus Gorge section, the antecedent nature of the river and the magnitude of the unroofing indicated by the cooling history data, we feel confident that exhumation amounts approximately equal bulk uplift amounts. As such, it is hard to escape the conclusion that fold amplification was exponential, or that recent uplift rates have been as high as 6mmyr^{-1}, as suggested by Zeitler (1985).

Late-Stage Extension Along the Main Mantle Thrust (Pakistan, Himalaya): New Field and Microstructural Evidence

POSTER

K.J. VINCE* & P.J. TRELOAR*

Recent geochronological work on metamorphic rocks from the Besham area of North Pakistan has yielded evidence of re-activation of the Main Mantle Thrust as a zone of late-stage crustal extension. This has been accommodated in the footwall and hangingwall by displacement along a set of E-W striking normal faults. This trend is roughly parallel to that of the Main Mantle Thrust. Local variations in strike occur as a result of folding of the Main Mantle Thrust into a minor syntaxis around the Besham region. The E-W trending normal faults cut across all the earlier ductile and brittle structures produced by south-verging deformation and are therefore late-stage.

E-W trending south-dipping normal faults in the Indian Plate rocks of the Main Mantle Thrust footwall exhibit topside to the south movement. Extensional fabrics displace the northerly dipping ductile shear fabric of the footwall rocks that were formed as a result of the collision between the Indian plate and Kohistan Island arc although, on a smaller scale, some extension was accommodated by brittle re-activation along fabric surfaces. These can be interpreted either as Riedel shears associated with the earlier south-verging thrusts or, surfaces along which extensional collapse of the entire metamorphic pile occurred. Riedel shears are also associated with a few of the E-W trending faults.

The Kohistan Island arc forms the hangingwall of the Main Mantle Thrust. E-W trending normal faults occurring in the ultramafic rocks can be divided into two groups according to their movement: topside to the south, similar to the footwall and topside to the north. The latter are developed parallel or sub-parallel to the shear fabric of the hangingwall rocks. This is not as well developed as the fabric of the footwall sequence but implies clear north-verging extension. Many minor extensional faults are associated with the larger scale faults in the Kohistan ultramafics.

A second set of normal faults, striking N-S, are associated with the late deformation which folded the Main Mantle Thrust into a minor syntaxis producing an antiform in the Besham region. This east-west directed extension was more pronounced in the hangingwall of the Main Mantle Thrust than in the footwall and is attributed to outer-arc extension of the developing fold.

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Structural History of the Sedimentary Cover of the North Karakorum Terrane in the Upper Hunza Valley (Pakistan)

POSTER

A. ZANCHI*

The Karakorum terrane belongs to the peri-Gondwanian blocks rifted from Gondwana during Permian and accreted along the southern Eurasian margin before collision with the Indian plate. The Karakorum block is located between two mayor suture zones: the Shyok Suture Zone to the South and the Rushan-Pshart suture to the North.
The Karakorum microplate includes a thick sedimentary cover, which is mainly Paleozoic in the western termination and Permian to Cretaceous in the central and eastern area. In the Hunza valley the cover consists of a thick pile of poorly metamorphic Permian-Cretaceous sediments cropping out north of the Karakorum Axial Batholith (KAB).
The sedimentary cover of the North Karakorum terrain is composed of three main structural units: the Guhjal, Sost and Misgar Units characterized by different stratigraphic and tectonic evolution. Folds and thrust surfaces generally trend E-W in the Sost and Misgar Units, whereas they are clearly NW-SE in the Guhjal Unit.
Several deformational events have been recognized on the basis of structural and geological analyses. A "mid-Cretaceous event" is testified by the folded succession cropping out below the Cretaceous Tupop and Darband Formations in the Sost Unit. Mid-Cretaceous granodioritic intrusives, some of which have been dated at about 100 MA, crossing previously formed schistosity, have been observed in the region. Important post-Cretaceous thrusting is testified by the deformation of the Cretaceous sediments and also by stacking of Eocene intrusives in the Yashkuk area. North vergent tectonic transport seems to be followed in time by south vergent thrust motion. Complex strike-slip faults are successively active, and are due to the prosecution of indentation phenomena between India and Eurasia. Metamorphic conditions range between very low and low grade which is reached in the deepest part of the Ghujal Unit. Andalusite is generally widespread around the intrusives, indicating low pressure conditions,
Field work was carried out in during two field seasons (1991-1992), leading to the preparation of a preliminary geological map which is presented in the poster section. Three main geological transects from the KAB to the Misgar Unit have been reconstructed: 1) from Shimshal village to the Khunjerab pass through the Boesam and Chapchingal Pir, 2) along the Hunza and nearby valleys (Shikarjerab, Abgarch and Khudabad valleys) and along the Yaskuk glacier and the western part of the Chapursan valley.

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