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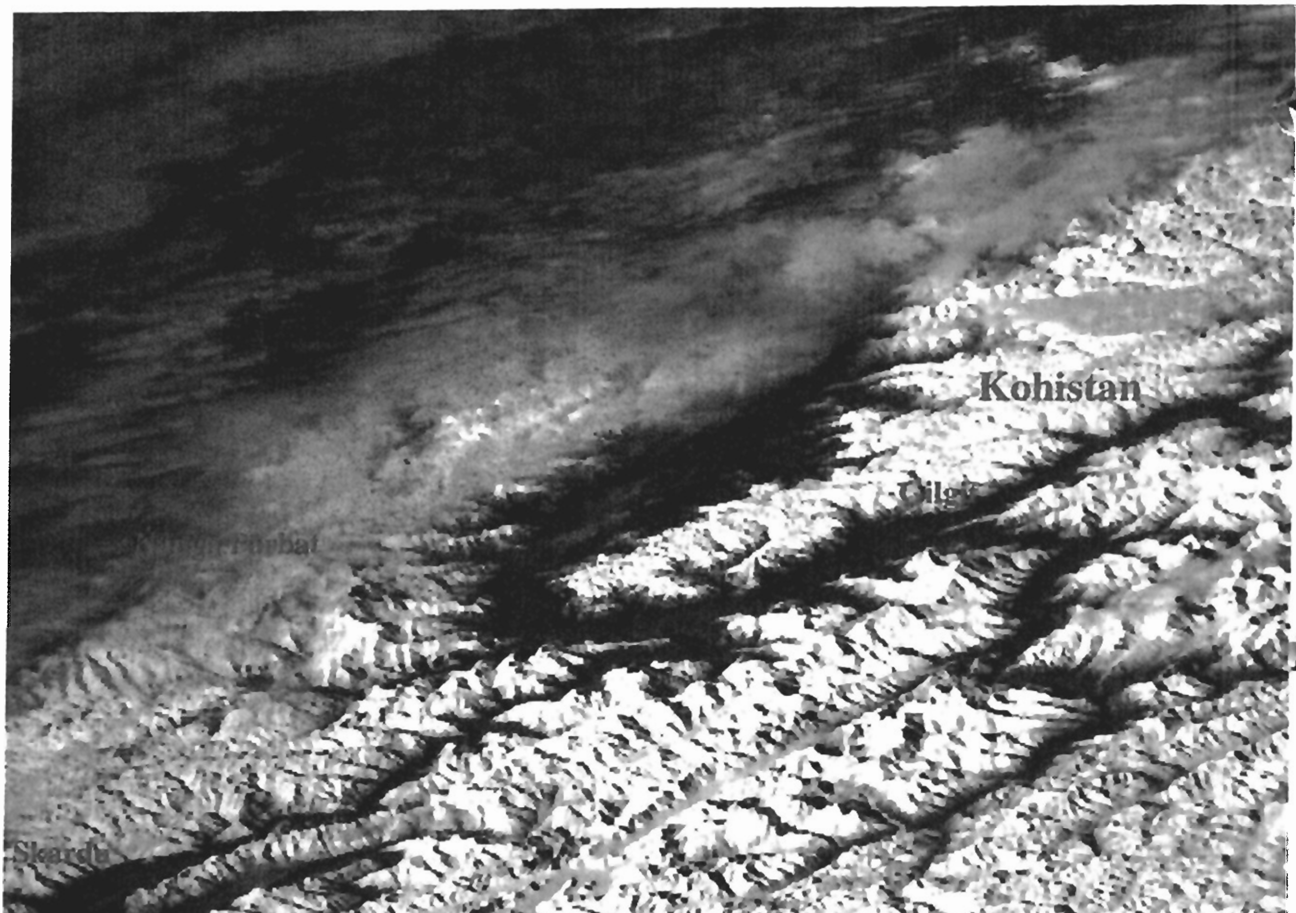
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Olistostromal blocks in metamorphosed Saidu mélange, Malakand agency, North Pakistan

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In Swat, the Indus suture zone contains melanges of diverse origins: the Shangla blueschist mélange, Charbagh greenschist mélange, and Mingora ophiolitic mélange [1]. The subduction-related Shangla blueschist and mélange contain blocks of bluescist, serpentinite, piedmontite schist, greenschist, metadolerite, metagreywacke and metachert in a sedimentary matrix. The Charbagh greenschist mélange is mainly a very large block of greenschist which is best interpreted a single exotic block in the Shangla mélange. The obduction-related Mingora ophiolitic mélange is composed of tectonized blocks and clasts of serpentinite, emerald-bearing talc-carbonate, greenstone, metapyroclastic, metagabbro, metachert and metasedimentary rock in a talc-carbonate matrix. The structurally underlying Indian shelf rocks [2] are Precambrian Manglaur schist (mostly quartz - mica - garnet schist), Carboniferous to Triassic Alpurai Group (calc - mica - garnet schist), and Triassic Saidu Formation (graphitic phyllite and marbles). These units and the Mingora mélange, but not the Shangla mélange, were metamorphosed between the latest Cretaceous and late Eocene [3].

New field work in the area southeast of Malakand Pass (Fig. 1), where the Saidu Formation is widely exposed structurally beneath the Dargai ultramafic complex, suggests that this unit contains large olistrostromal marble blocks and is in whole or in part a sedimentary matrix mélange. Immediately under the Dargai complex, ultramafic fragments are sheared into graphitic schists of the Saidu Formation. However to the east near Kharkai village the Saidu Formation is composed of 2 members. The lower one is the graphitic schist previously described as the only unit of the Saidu Formation and the upper one mainly a quartz - muscovite - talc schist and minor quartz - biotite schists with lensoid inclusions of gray to black marble (Fig. 2). Block dimensions up to 500 m by 50 m are present. The contact between the members is gradational over more than 10 meters. The marble is equigranular, coarse-grained and sugary textured. Much of it is internally brecciated in fragments with the same composition as their matrix. A few fragments contain some mica. These fragments are slightly flattened, but not dramatically strained. Massive, unbrecciated marble layers extend into the marble bodies in various orientations, commonly not parallel to the contact between the marble and the adjacent schists. The quartz - muscovite - talc schists contain small amphibolite layers that may be metavolcanic and a few horizons that look like possible meta-tuffaceous material. This upper member of the Saidu Formation does not resemble any of the units previously mapped in the region.

The Saidu, including the marble lenses, is multiply folded. The several blocks are the noses of tight asymmetric folds overturned toward the SSW. The best documented fold west of Palai has an axis trending S70°E, plunging 30° and an axial plane dipping about 45° to the north. Another lens is made up of 4 boundin shaped fragments. No connection, such as attenuated limbs have been observed between blocks, although several blocks appear to occupy the same horizon in at least one case. Contacts between the marble blocks and the enclosing schists are mostly sheared.

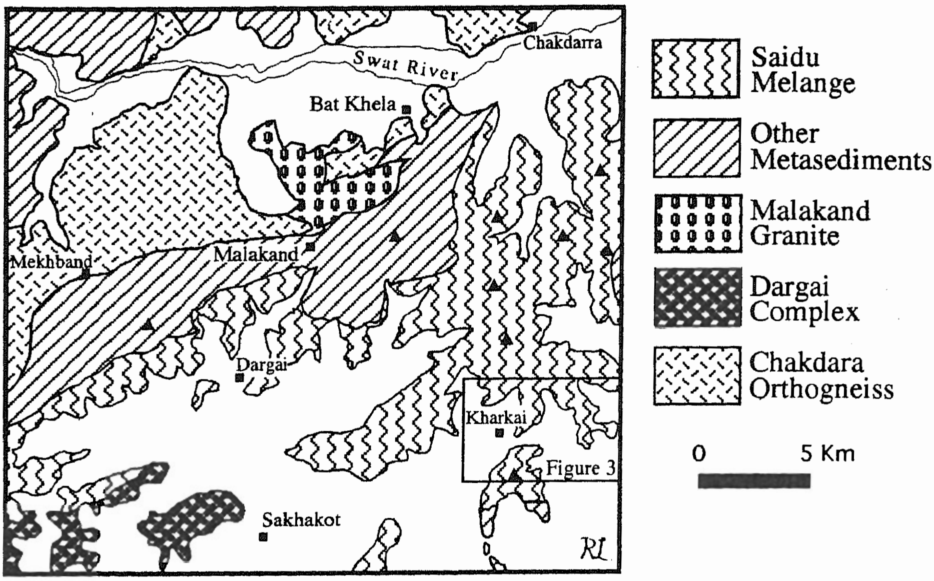

Fig. 1. Geology of the Malakand pass area.

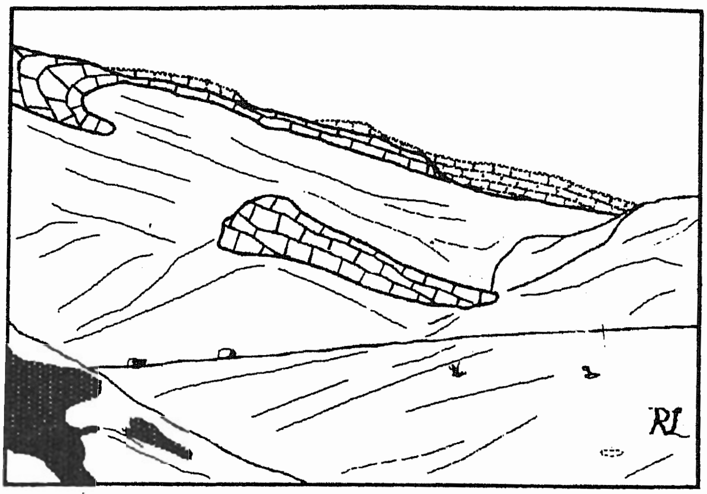

Fig. 2. Drawing from photo of marble blocks in quartz - muscovite - talc schist matrix between Kharkai and Palai, Pakistan. Small foreground block has no connection to large folded block at top of ridge.

Our best interpretation of this upper member of the Saidu is that it is a shelf/rise sedimentary accumulation with olistostromal limestone blocks derived from reefal limestone bodies on the outer edge of the adjacent Gondwana shell. Much of the internal breeciation may be derived from debris deposits on the reef. Lack of major strain of these features suggests that the folds in which the bodies are found developed under conditions in which the limestone was a competent unit relative to the enclosing clastic materials.

We suggest that the Saidu Formation is a metamorphosed olistostromal (sedimentary type) mélange analogous to the "Oman Exotics" of Hawasina complex of Oman mountains [4]. The "Oman Exotics" form isolated masses from boulder size to 1000 m thick Middle to Upper Permian and Upper Triassic fossiliferous limestones that crop out within imbricated thrust slices beneath the Semail ophiolite in the Oman mountains. They are commonly associated with a substrate of alkalic and transitional tholeiitic basalts and are interpreted as a series of reef - associated carbonate buildups deposited in part on oceanic islands or seamounts close to the site of initial rifting of the Oman continental margin. These blocks slid into the deep sea sediments being deposited to the north. Most of these features are present in the Saidu Formation, but obscured by metamorphism.

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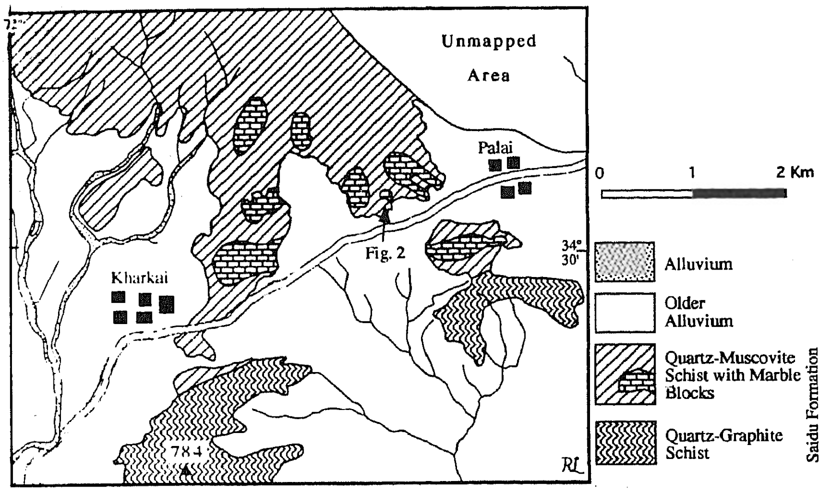

Fig. 3. Geologic map of the Kharkai area, Pakistan. Location of Figure 2 shown by arrow.

Geochemical discrimination amongst the basinal, island-arc related, and oceanic-island volcanic - hypabyssal components of the Bela ophiolite-mélange complex, Pakistan

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The Bela - ophiolite-mélange complex (BOMC) of Pakistan is a late Cretaceous (circa 66 Ma) supra-subduction zone composite ophiolite. Its abundant mafic volcanic and hypabyssal rocks are divisible into three distinct suites: an (ensimatic) volcanic island-arc (suite 1) dominated by low-Ti tholeiites; a back-arc basinal assemblage (suite 2) containing high-Ti rocks; and high-Ti alkaline basaltic rocks (suite 3). Each rock suite possesses characteristic features in its bulk-rock major-, trace-, rare earth - element and mineral chemistries. Compared to rocks of suites 1 and 2, the suite 3 rocks are high in LREE, Zr, Nb and Zr/Y, and low in Cr, Zr/Nb, Y/Nb and Ti/Nb. The suite 2 rocks contain $>$10,000 ppm Ti. The suite 1 are low-Ti rocks with Ti below 7,200 ppm. In their Zr/Y, suite 1 $<$ suite 2 $<$ suite 3. In terms of Cr content, suite 3 $<$ suite 1 $<$ suite 2. The spatial distribution of the three suites within the BOMC defines a northern (north of latitude 26°50' N) island-arc terrane characterized by IAT, and a southern basinal terrane containing BABB. The alkaline basalts may represent oceanic seamounts, and occur at a few isolated sites in both northern and southern terranes. Some OIB are emplaced in younger sediments overlying the ophiolite. As exceptions to the general distribution, a few tectonic blocks of high-Ti basalt crop out in the northern terrane. A few low-Ti basalts are located in the southern terrane. Representitive massifs with a completely intact ophiolite stratigraphic sequence include the Lake Baran massif in the arc terrane and the Bora Jhal massif in the basinal terrane. Chromite ore deposits in the basinal peridotites from the Bora Jhal massif possess lower Cr/(Cr+Al) due to lower degrees of partial melting in the mantle source; in contrast, the extensively developed chromite deposits in the arc terrane possess high Cr/(Cr+Al), indicative of more refractory source mantle rocks and higher degrees of partial melting.

Geology and appraisal of mineral resource potential of Lasbela - Khuzdar ophiolites, Balochistan, Pakistan

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Ophiolites in Pakistan are found exposed in the Las Bela - Khuzdar, Muslimbagh, Zhob and Waziristan - Khost regions. These are interpreted as disrupted fragments of the oceanic crust and upper mantle of the Tethyan ophiolites belt.

In the Las Bela - Khuzdar area a suit of ophiolites is exposed at intervals in north - south direction for about 500km along the western margin of Indo-Pakistan plate. Lack of contact metamorphism indicate that rocks of the ophiolitic suite was cool and in a solid state at the time of emplacement on the existing positions. Stratigraphically, they are Maastrichian in age and were emplaced along the western margin in early Tertiary period. The southern end of the ophiolitic belt west of Karachi merits special attention as it continues into the Arabian sea and may have formed an important part of Murray ridge.

The ophiolites consist of ultramafic rocks, gabbro, sheeted dykes, pillow lavas - and pelagic sediments, commonly as dismemberment fragments/thrust slivers of variable dimensions surrounded by mélange containing unmapable disoriented blocks of pillow lavas, diabase, serpentinite, limestones, marble, clastic sediments and exotic blocks of alkali granite. However, the well documented complete ophioilites with continuous conformable section from lowermost hurzburgite passing upward through hurzburgite, dunite, gabbro, sheeted diabase, pillow lavas, and pelagic sediments occur in Sonaro - Drakalo area of Khuzdar district. The contact between these rocks is rather gradational. Gabbroic rocks grade up from pyroxenite and wherlite into pyroxene rich gabbro and include locally plagiogranite rocks. Slivers of metamorphic green chlorite schist occur locally at places immediately below the ophiolite masses.

Mafic sills of alkaline - tholeiitic composition intruded in the abyssal siliceous sediments are present closly associated with mafic volcanic rocks but, invariably, their contact is faulted.

The lower contact of the ophiolites with the Mesozoic sediments is faulted and characterized by a conspicuous crushed zone. Eocene - oligocene sediments dominantly limestone and minor shale, overlie the ophiolitc rocks. Further southward the upper contact is concealed by the Quaternary sediments of the Bela plain.

The ophiolite belt is interesting from an economic point of view. There are mineral occurrences related to the ophiolite complex. These include chromite deposits in serpentinitized peridotite, manganese and Fe-Cu sulphide in basalt, and some secondary mineral occurrences of magnesite, asbestos and lateritic nickle. Marble, granite, and sheared and calcified variety of serpentinite are of significant importance as decorative stones.

Facies and microfacies analysis of Kawagarh Formation of Hazara Basin, Pakistan

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The Upper Cretaceous in the Hazara Basin is marked by a transgression which deposited Kawagarh Formation (Latif, 1970; Shah, 1977). At the type locality (lat. 33° 45′ 30" N; long. 70° 28′ 30" E) the Kawagarh Formation is composed of dark mart, cleaved calcareous shale and nodular argillaceous limestone. The section of the Kawagarh Formation at the type locality is incomplete due to folding and faulting. A study of four sections of Kawagarh Formation of Hazara Basin at Jabri, Changla Gali, Giah and Borian is presented and discussed as following:

The Kawagarh Formation near Jabri (lat. 33° 55′ N; long. 73° 1.5" E) is composed of light brown to chocolate, whitish grey to light grey and pinkish grey limestones. The basal portion contains thinly laminated dirty to earthy grey and rusty grey marls interlayered with arenaceous limestone (Ahsan et al., 1993). The formation here is divided into eight facies which are composed of glauconitic arenaceous mudstone facies, mixed arenaceous limestone/marl facies, mud to wackestone facies, mixed grainstone to mudstone facies, wackestone to mudstone facies, mixed grainstone to mudstone facies, mudstone facies and mixed dolomitic limestone facies.

The Kawagarh Formation at Phangla Gali (lat. 33° 55′ 30" N; long. 73° 22′ 30" E) consists of medium to dark grey limestone which weathers to off whitish grey, yellowish grey and light grey shades. Earthy grey, rusty to yellowish grey and splintry mart (20.52m thick) is present at the top. However, eight marly horizons intercalated within the limestone also occur. The formation is composed of four facies which are dolomitic arenaceous mudstone facies, packstone - dolomitic packstone-dolospar and mad facies, mixed wackestone packstone-marl facies and marl facies (Ahsan et al., 1994).

The Kawagarli Formation at Giah (lat. 34° 6′ 30"; long. 73° 21′ 26") is white to light grey, bluish grey and dark grey limestone (Chaudhry et al., 1992). It is composed of four facies which contain mixed dolomitic limestone - dolospar facies, biomicrite facies, sandy biomicrite facies, sandy dolomitic limestone facies - sandy dolospar facies. Towards top it contains coarse grained detrital qüartz.

The Kawagarh Formation at Boriati (lat. 34° 9′ 15" N; long. 73° 17′ 15" E) is composed of light to dark grey, light yellowish grey, whitish maroon, reddish maroon to maroonish grey limestone (Ahsan et al., 1993). The formation consists of four facies which contain mixed wackestone-packstone-dolomite facies, mixed mudstone to wackestone facies, mixed mudstone-wackstone facies and mixed mudstone-wackestone intraclast bearing wackestone-dolostone facies.

The sections of the Kawagarh Formation at Jabri and Changla Gali which are located southwards of the Nathiagali Fault contain fair amount of marls and arenaceous limestone. Arenaceous limestone and marl constitute 23.13m of lower part of the Jabh section. The Changla Gali section is composed of alternations of marl and limestone horizons. The sections situated to the north of the Nathia Gali Fault do not contain marls or limestones of significant clastic matter. The sections south of the Nathia Gali Fault which contains fair amount of the marl were deposited at relatively shallower depths of around 80 to 100 m since they lack benthic fauna and contain pelagic foraminifera. However, the sections to north of the Nathia Gali fault which lack marl were deposited towards the very shelf edge at about 200 to 250 m as indicated by the presence of Oligostegina. Carbon oxygen isotope studies of selected samples show that it was deposited in warm water conditions.

It has been determined that the Indian plate established its first contact with Kohistan arc at about 67±2 Ma (Bard et al., 1979). It resulted in uplift of shelf and lateritization of the Kawagarh Formation in Maastrichtian (Chaudhry et al., 1994). The burial of Kawagarh Formation started with deposition of shelf carbonates and shales in Thanetian and continued upto deposition of Murree Formation. The total thickness of sediments is about 3800m. The deposition of Siwaliks is not certain in the studied area. The maximum temperature was about 125°C and pressure reached about 0.9 kb.

Non ferroan microcrystalline calcite is penecontemporaneous to the bioclasts. The Mg^{++} - bearing solutions from Chichali Formation deposited authigenic dolomite during burial. The ferroan recalcification of dolomite, groundmass and some bioclasts is associated with final uplift and is due to influx of reducing waters. Microstylolites were developed at a pressure of about 0.9 kb.

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Magmatism south of the Indus suture, lower Swat, Pakistan

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The lower Swat magmatism is dominated by the so called Swat granite, which intruded the Manglaur Formation and is unconformably overlain by the Alpurai schists (Fig. 1). Its age of emplacement has been assumed to be similar to that of the Manserah granite, which gave a Rb-Sr total - rock isochron of 516±16 Ma age (Le Fort et al., 1980). We present results of petrological, geochemical and geochronological studies of the Swat granitoids in the northern part of the Loe Sar dome and Alpurai regions (Fig. 1).

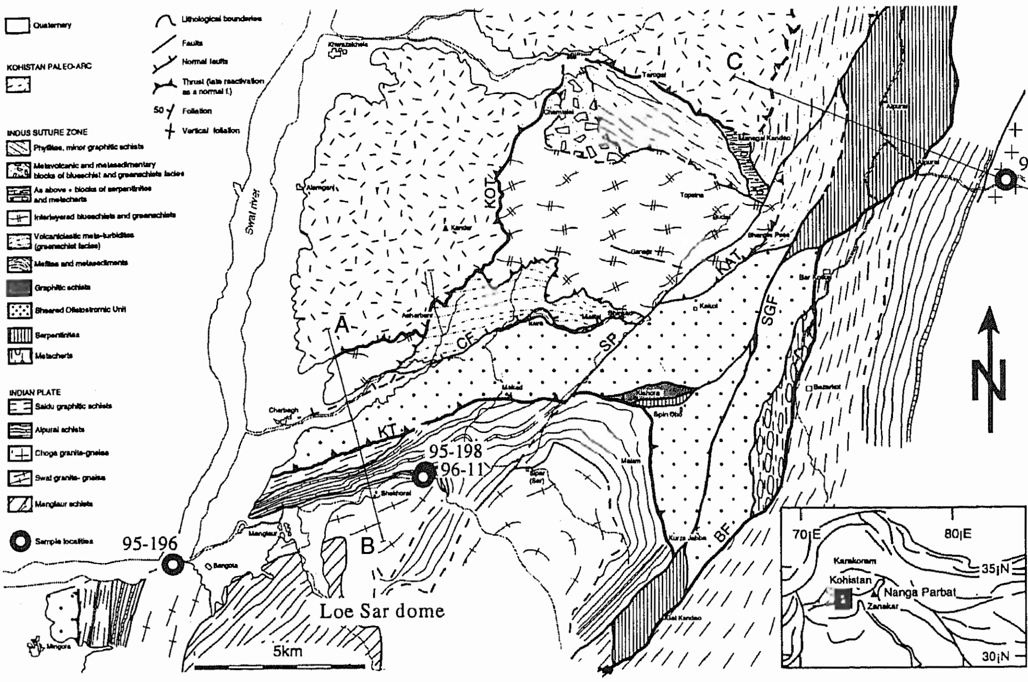

Fig. 1. Sample localities.

At the northern edge of the Loe Sar dome the granitoids occur as two sill-like bodies. We investigated the upper sill at the northern edge of the dome. It exhibits dominantly augen and flaser type textures which show alkaline composition. U-Pb single zircon dating of sample 95-198 (Fig. 1) yielded 268+7/-3 Ma. Preliminary dating of sample 95-196 confirms the Permian age, which we interpret as the time of magmatic emplacement. The body is intruded by alkaline syn - to post - kinematic pegmatitic dykes, which are truncated and sheared at the contact with the overlying Alpurai schists (Fig. 2a). U-Pb zircon dating gave an age of 29.2±0.2 Ma interpreted to represent an intrusion age. This date establishes also the maximum age for shearing. Scarce kinematic indicators suggest a thrust sense of movement. Thus, the Tertiary alkaline volcanism appears to be associated with regional thrusting (see also Le Bas et al., 1987) rather than rifting as proposed by Kempe and Jan (1980).

Taking into account field observations and age data we suggest an intrusive rather than an unconformable nature for the contact between the Swat granite gneiss and the Alpurai schist. This interpretation is based on i) the existence of a fine-grained fabric at the border of the granite gneiss, ii) the occurrence of xenoliths of garnet - amphibolite that may have been derived from the Alpurai schists and iii) the Permian age of the granite, which has intruded Middle Carboniferous to Permian beds at the base of Alpurai schists (Marghazar Formation of DiPietro et al., 1997). Regional shearing at ca. 30 Ma is responsible for the truncation of the pegmatitic dykes at the Swat granite gneiss/Alpurai schists interface and has obscured the original intrusive character of this contact.

Based on similar stratigraphic position with respect to the Alpurai schists, the Choga granite gneiss (Fig. 1, 2a,b) of the Alpurai region has been commonly assigned to the Swat granitoids. Microprobe analyses of major mineral phases in sample 95-211, however, are different from those of samples 95-198 and 95-196, which originate from the northern part of the Loe Sar dome (Fig. 1). This observation is corroborated by a U-Pb zircon age of 468±5 Ma obtained for Choga granite, which we interpret as an intrusion age. Based on similarities in major mineral geochemistry, we consider the Choga granite to be related to the granitoids in the core of the Loe Sar dome (lower sill).

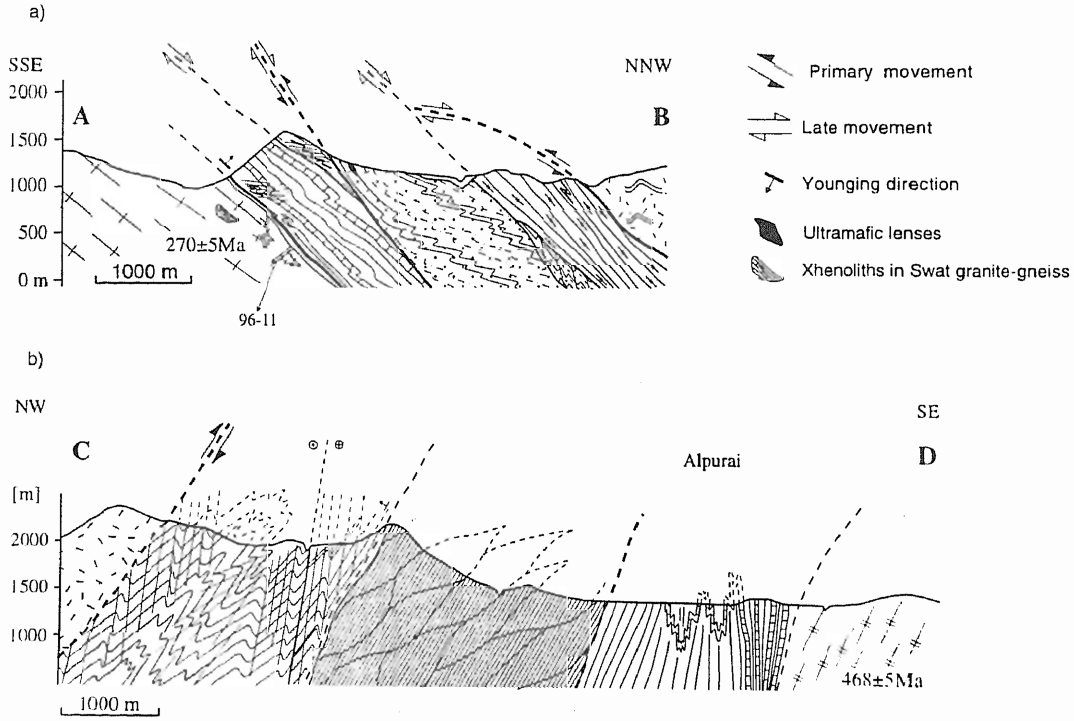

Fig. 2. Cross sections. See Figure 1 for localities.

Because our investigations have been focussed on a rather limited part of the Swat granitoids, it is still uncertain, whether the Permian age determined for their northem margin is representative for the entire upper unit or whether the Permian magmatites form smaller intrusions within Cambro/Ordovician granitoids. The results extend the spatial distribution of alkaline magmatism, previously restricted to the Peshawar Plane igneous province, to the Swat area. Furthermore, they give clear proof that this magmatism was generated in at least two cycles unrelated in age.

Le Bas, M., Mian, I. & Rex, D. C., 1987. Age and nature of carbonatite emplacement in North Pakistan. Geologische Rundschau, 76 (2), 317-323

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Rb/Sr and $^{40}Ar/^{39}Ar$ dating of blueschist facies metamorphism in Shangla region, Pakistan, NW Himalaya

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Geochronological studies of high pressure rocks in many metamorphic terrains show that Ar-Ar dating often yield ages inconsistent with other dating techniques (e.g. Li et al., 1994). Therefore an independent control by other isotopic geochronometers is needed. We present preliminary results of coupled Rb-Sr and $^{40}Ar/^{39}Ar$ dating of the Shangla blueschists.

The Shangla blueschists are squeezed within the Indus Suture Zone, on the western limb of the Besham (Indus) syntaxis (Lower Swat region of Pakistan). As such, they outcrop within the so called 'mélange zone' between the Indian plate and the Kohistan. The blueschist facies event has been previously dated at ca. 80 Ma by $^{40}Ar/^{39}Ar$ phengite dating (Maluski & Schaeffer, 1982; Maluski & Matte, 1984). Glaucophanes yielded $^{40}Ar/^{39}Ar$ data scattered between >450 and 50 Ma (Shams, 1980; Maluski & Schaeffer, 1982; Maluski & Matte, 1984).

Prior to dating, we carried out detail microprobe analyses in order to eliminate samples exhibiting retrograde features (invisible on the micro-scale) and detect possible mixing between various phases. Back-scattered electron imaging and quantitative microprobe analyses of the blue amphiboles showed no or very weak zoning. Compositions are all within the range of glaucophane - riebeckite series. Similarly, phengites do not display any significant zoning. Blue amphiboles eventually contain sub-microscopic inclusions of phengites.

Two metasedimentary and three metavolcanic types of blueschists were selected for the geochronological studies. Both show crossite/glaucophane + epidote paragenesis, which is diagnostic for the transitional blueschist - greenschist facies, typical for the Shangla region. Five glaucophanes and three phengite high-purity mineral concentrates derived from five rock samples were subjected to $^{40}Ar/^{39}Ar$ dating by stepwise heating technique. In addition, two of them were dated by the Rb-Sr method.

Rb-Sr isochrons of blue amphibole-phengite pairs allow to better ascertain the age of blueschist facies metamorphism. Low $^{87}Rb/^{86}Sr$ ratios for blue amphiboles together with high ratios for phengite (Table 1) allow precise age determination at 77.0±0.4 and 79.7±0.4 Ma (errors with 95% c.l.). The estimated thermal peak for the Shangla blueschist (300-380°C) (Jan, 1981; Guiraud, 1982) is significantly lower than the commonly accepted closure temperature for Rb-Sr system in phengite and amphibole. Therefore, we interpret our age determination as representing the time of metamorphic crystallisation under transitional blueschist - greenschist facies conditions at ca. 80 Ma.

$^{40}Ar/^{39}Ar$ dating was performed on 5 glaucophane samples. Extensive hand-picking and preliminary K concentration measurements (K<500 ppm) let us hope to have eliminated 'contamination' by phengites. However, Ca/K vs. Cl/K trajectories coupled to mass balance calculations show that true blue amphibole has K<23 ppm, and about 0.4% modal phengites intergrowths by far dominate the K-Ar budget. All ages group around 80 Ma and agree with Rb/Sr dating, Three out of 5 glaucophanes preserved preblueschist facies amphibole (?) relics, which give reproducible step ages around 400 Ma in the last 5% of the gas release. This corresponds to about 1 modal % 'relict amphibole', which appears to preserve a signature of the Ordovician volcanism.

TABLE 1. SUMMARY OF THE RB-ST DATING RESULTS

Sample	mineral	Sr (ppm)	Rb (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Age (Ma)
95-189	phengite	8	243	94.8194	0.81103	79.7±0.4
	crossite	4	0.4	0.24802	0.70400	
96-81	phengite	30	347	33.1505	0.74332	77.0±0.4
	glaucophane	21	2	0.27201	0.70736	

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Granite emplacement and subduction

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Granite emplacement is a common process in plate convergent zones and plays an important role on the architecture of island arcs and continental collision zones. This paper reports intrusion mechanism of the ≈14 Ma old, epizonal S-type Yakushima pluton emplaced at the north end of the Ryukyu arc, Japan and its relevance to the subduction of the ≈25 Ma old Philippine Sea plate. Using structural and petrological data, the author proposes that granite plutons in island arcs above subduction zones can rise diapirically and obliquely toward the adjacent trench axis from the interface between the subducting oceanic plate and overriding continental lithosphere.

The Yakushima pluton is a large pluton (≈400 km^2 in exposure) located 170 km behind the axis of the Ryukyu trench. Orthoclase megacrysts in the Yakushima pluton tend to have a rectangular platy shape with a mean aspect ratio of about 3:3:1. In the absence of either plastic or brittle deformation of the megacrysts, these rigid discrete flakes were assumed to be aligned by rotation during flow of their ductile surroundings. The results of 129 analyses of the primary flow fabric defined by preferred orientations of the megacrysts suggest a single toroidal circulation cell, that is indicated by shear along the granite contact, crestal flattening and central constriction within the exposed upper domal portion of the pluton, and interpreted as due to drag along the contact that circulate the granite interior [1]. Since the floating and rotating megacrysts in a granite melt have a short strain memory, these primary flow fabrics must have formed during emplacement of the pluton.

The symmetry axis of the circulation within the Yakushima pluton plunged down toward the northwest. This inclination of the toroidal circulation cell is attributed to the pluton having been emplaced obliquely toward the Ryukyu trench in the southeast [1]. Folds and thrusts inherited from the accretionary prism in the country rock of the Yakushima pluton were deformed toward conformity with the pluton's shape in the direction of its inferred oblique emplacement when they were thermally softened by magmatic heat now recorded by the thermal aureole [1]. Further circumstantial evidence for the oblique emplacement was obtained from patterns of late concentric sheet intrusions and veins formed during the final crystallization; these show that the buoyancy forces and/or highest magmatic pressure were centred several kilometres southeast of the geometrical centre of the pluton [1].

The S-type nature of the Yakushima pluton implies that its magma was developed by melting of crustal rocks. Petrographical and petrological studies of the Yakushima pluton show that per-aluminous cordierite granitoids in the core and periphery of the pluton are separated by the intervening main granite which is cordierite-free and contains rather primitive Nd-Sr isotopes. This doughnut-like compositional zoning shares the same inclined symmetry as the patterns of flow fabrics, and is taken as supportive evidence for the toroidal circulation [2]. Furthermore, the lithological contours of this zoned pluton locally truncate the contours of intensities of the emplacement-related solid-state deformation fabrics. Thus, the compositional zoning is likely to be inherited from the earliest stages of magmatic layering at the depth of the magma generation and relates the ascent processes. The inclination of the axes of symmetries of the emplacement - (flow fabrics etc.) and ascent-related structures (compositional zoning), therefore, indicate that the Yakushima pluton rose diapirically and obliquely toward the inner wall of the Ryukyu Trench from the depth of the magma segregation. Applying the theory of active buoyant diapirism, the source region of the Yakushima pluton could be extrapolated to the top of the subducting slab beneath the crustal accretionary wedge. The Philippine Sea plate must have been young enough to develop granite melts by slab melting in the Middle Miocene time. Sediments that sank with the subducting Philippine Sea plate may have been incorporated into the magma of Yakushima.

Had the Yakushima pluton risen by its buoyancy alone, it would have risen vertically and circulated about a vertical axis. Simplified physical models that consist of a solid plate (model subducting plate) sinking obliquely along its length from the top freesurface into a ductile medium and air bubbles rising in the ductile medium, show that the oblique rise of the Yakushima pluton can be attributed to the wedge flow induced by friction along the top of the sinking plate [3]. In the wedge near the model trench axis, bubbles rose obliquely toward the trench axis trailing inclined tails with a flat bottom and an elliptical form parallel to the trench. By contrast, where arc-nortnal horizontal extension prevailed at shallow levels remote from the trench axis, tabular bubbles were carried toward the trench along sub-horizontal paths and became elongate normal to the trench. The overall picture from the experiments accounts for, not only the oblique rise of the Yakushima pluton, but also the long axes-parallel-to-trench elliptical plan forms of the close-to-trench plutons and the long axes-normal-to-trench elliptical plan forms of the far-from-trench plutons seen in the Miocene plutons in Southwest Japan [3]. Therefore, the author consider that buoyant diapirism is the most likely mechanism for the transport of granite magmas in island arcs which are related to the subduction of the young and hot oceanic plate, to depths of less than say, 10 km.

Unlike continental collision zones where the crust is thicker and stronger than that of island arcs, and where laccolithic emplacement of leucogranites through fractures predominates [4], the crust of island arcs is thin, hot and weak [5], and thus, diapirs would have been the most important mechanism for the granite plutons [1,6]. Plutons emplaced in island arcs are expected to be distinctive in having intrusion-related deformation symmetries about axes inclined by wedge flows rather the vertical symmetry expected for a gravity driven diapir sphere. In contrast to the Yakushima pluton, flattening strains and simple zoning (normal or reverse) are predominant in the plutons that were emplaced through a conduit and/or dikes [7,8]. The case study of the Yakushima pluton raises a further possibility; thus, asymmetrically zoned plutons above subduction zones reported elsewhere [9] ascended in a manner similar to the Yakushima pluton. If so, the inclined axes of pluton's symmetries could be used to infer vergence of fossil subduction.

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Block rotations along the India - Asia collision zone - their significance on different scales detected by magnetic remanences

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The India-Eurasia collision has caused crustal deformations of enormous magnitude. Patzelt et al. (1996) presented direct palaeomagnetic evidence for a "Greater India" prior to collision (about 1500 km extent of the northern margin at 89°E, compared to the present outline). Palaeodeclinations (PD) were used to estimate the magnitude of rotational underthrusting (Klootwijk et al., 1985; Appel et al., 1991; Patzelt et al., 1996). Angles between expected and observed PDs allow the quantification of oroclinal bending. Figure 1 shows the principle of restoring the former margin of the Indian Plate by incremental rotations. The expected PD is calculated from the apparent polar wander path assuming no relative movements at the northern

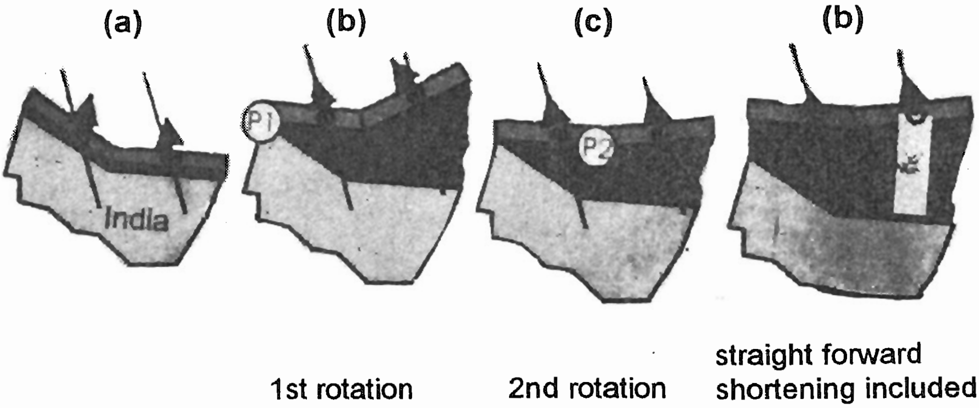

Fig. 1. Principle of restoring the former northern margin of the Indian plate from palaeomagnetic data. (a) Sketch of 'stable' India and a northern margin area subdivided into two segments. North of the thick line relative movements in respect to 'stable' India are expected. The N-lines represent the direction of expected palaeodeclinations (PDs), arrows denote observed PDs (R1, R2). (b) First rotation of both segments around a pivot P1 matching R1 with the expected PD. (c) Second rotation of the right segment around a pivot P2 matching also R2 with the expected PD. (d) Parallel displacement of both segments towards the north until palaeolatitudes match the 1500 km extension determined by Patzelt et al. (1996) for 89'E (white bar).

margin of India. Observed PDs are brought into coincidence with the expected PD by stepwise rotations starting in the western syntaxis (pivot PI) and progressing to the east. In Figure 1, this is demonstrated for the simple case of two segments. The extent of 'Greater India' is finally determined by a parallel displacement of both segments to the north until the palaeolatitude matches the result of Patzelt et al. (1996) at a longitude of 89°E.

The reconstruction is disturbed by local and mesoscale block rotations superposed on the regional movements. Data from NW Zanskar (Appel et al., 1995) demonstrate that systematic differences even occur within a few tens of kilometres. In the Pamir and along the Indus Yarlung suture zone (Otofuji et al., 1995) PDs are strongly dependent on major faults. In order to get a reliable data base for the incremental rotation model of Figure 1, systematic palaeomagnetic sampling is conducted to recognise and to isolate block rotations on different scales. In a first step, about 140 sites have been sampled from the Tethyan Himalaya (TH) of Spiti (NW India), Larkya and Shiar areas (Central Nepal). The TH rarely contains primary remanences, but is well known to record a stable secondary components carried by pyrrhotite. The remanence acquisition of pyrrhotite can be related to exhumation and cooling of the Central Crystalline and represents a thermoremanence with blocking temperatures around 300°C.

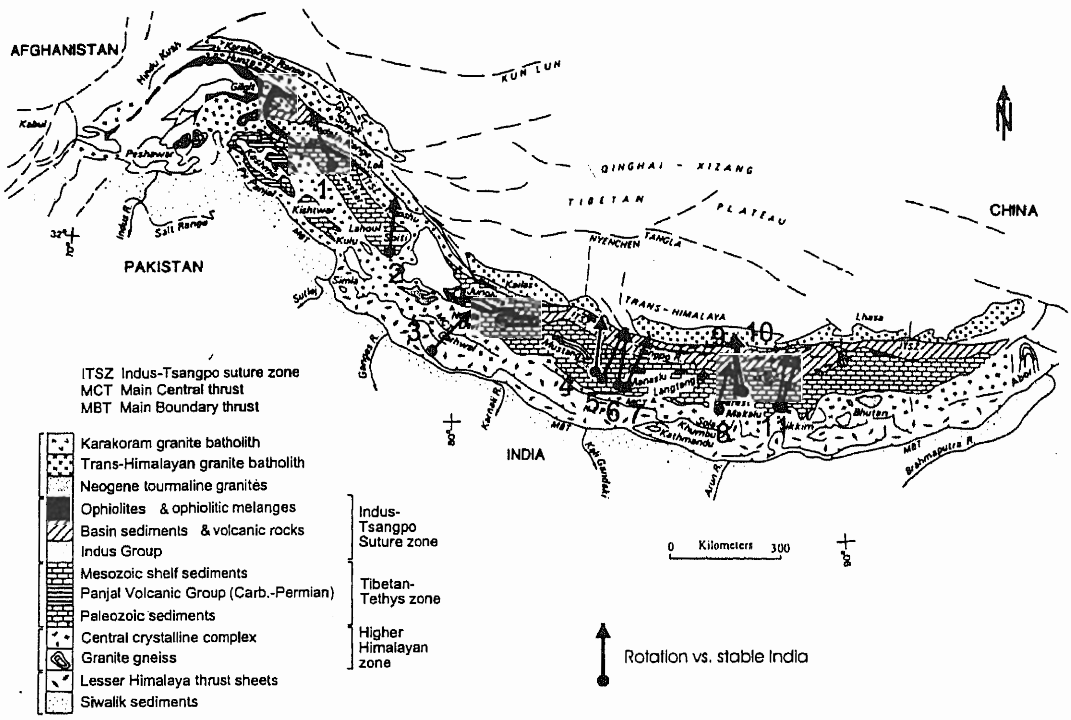

Fig. 2. Geological map of the Himalaya (after Searle et al., 1987) with rotations in respect to stable India (determined from magnetic palaedeclinations). 1) Appel et al. (1995), 2)This study (Upper Pin Valley, NW India), 3) Klootwijk et al. (1986), 4) Klootwijk & Bingham (1980), 5) Appel et al. (1991), 6) This study (Larkya, Central Nepal), 7) This study (Shiar, Central Nepal), 8) Rochette et al. (1994), 9) Appel et al. (1997), 10) Besse et al. (1984), 11) Patzelt et al. (1996).

A nearly one-component behaviour (pyrrhotite only) is observed in the Larkya area. A systematic local scatter appears with a mean in situ remanence of Larkya area, D=010, I=54 (12 sites, k=9.5, α_{95}=13.6). In the Shiar area, the pyrrhotite to magnetite ratio is decreasing towards the east. As a preliminary result from 4 sites, the pyrrhotite component yields an in situ direction of D=205, I=-12 (k=82.6, α_{95}=82.6). In Spiti, magnetite dominates the magnetic remanence. The varying content of pyrrhotite can be related to a different grade of metamorphism. The magnetite component carries a syntectonic remanence direction (k=14.4, 26 sites, Lower Pin Valley), whereas for the pyrrhotite component of the Upper Pin Valley a consistent in situ remanence direction of D=006 I=32 (12 sites, k=16.9, α_{95}=10) is obtained. In Figure 2, the rotations in respect to "stable" India are shown together with earlier results.

In our further study, several other areas will be sampled, and rotations on different scales will be analysed quantitatively to evaluate a more sophisticated model of oroclinal bending and rotational underthrusting.

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Different sets of anastomosing shear zones in the "Kamila Belt", Kohistan

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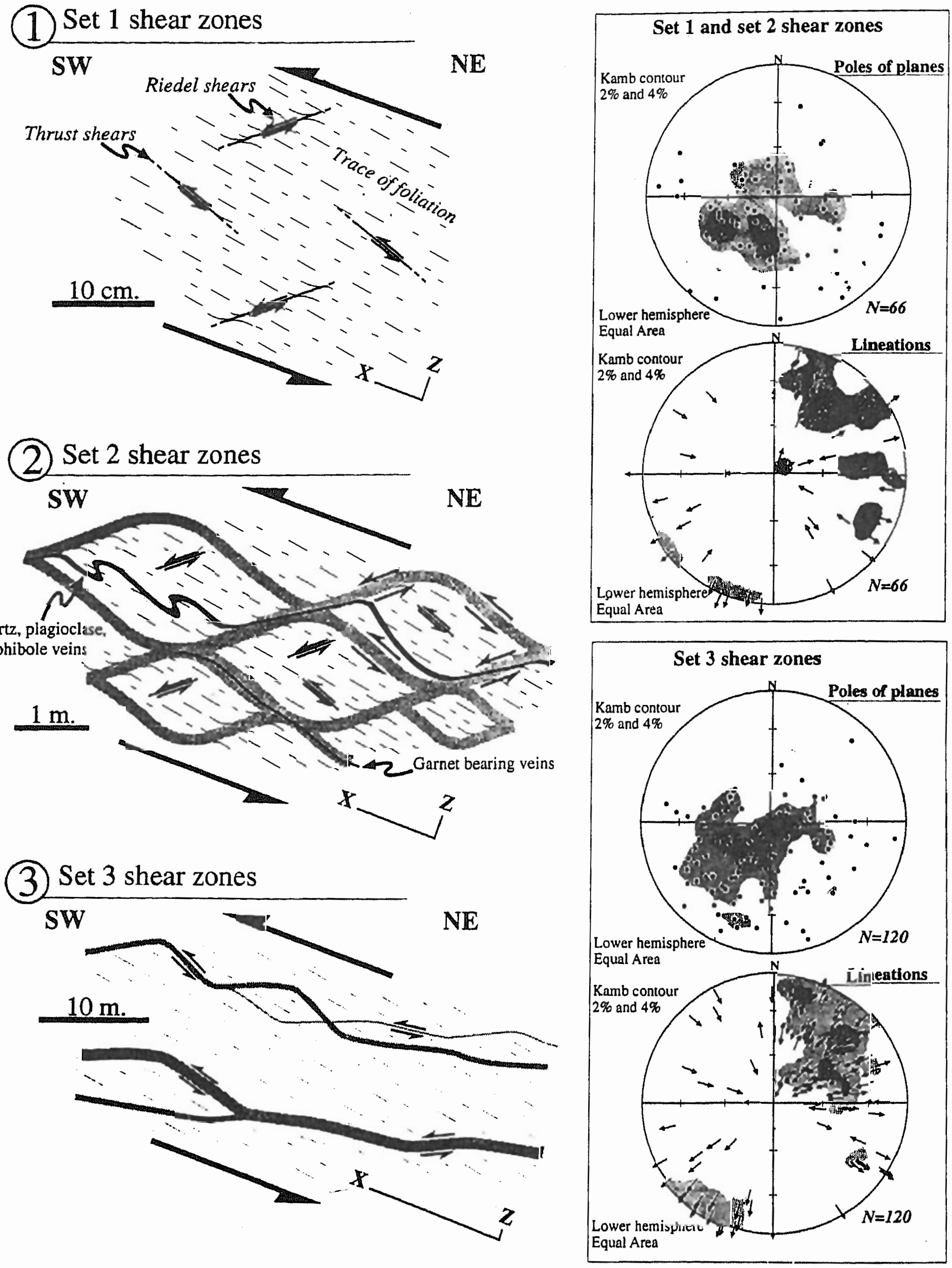
The Kohistan complex (NW Pakistan) is squeezed between the Indian and Asian continental plates [1]. Among the different units identified in the Kohistan complex, the Kamila amphibolitic belt separates the Chilas calc-alkaline gabbronoritic complex to the north from the deeper ultramafic Jijal complex to the south [2]. The southern part of the "Kamila Belt" is mainly composed of retrograde metagabbro and norite with locally preserved igneous layering intruded by hornblendite bodies and plagioclase-quartz±amphibole rich veins. The latter comprise synmagmatic differentiation veins that display the same mineralogical components as the bulk rock. The metagabbro and norite are deformed by numerous anastomosing shear zones with variable spacing and size [2]. In this poster we describe three sets recognised during field work:



Set 1 shear zones
SW
NE
Riedel shears
Thrust shears
Trace of foliation
10 cm.
X
Z
Set 2 shear zones
SW
NE
Quartz, plagioclase, amphibole veins
1 m.
Garnet bearing veins
X
Z
Set 3 shear zones
SW
NE
10 m.
X
Z
Set 1 and set 2 shear zones
N
Poles of planes
Kamb contour 2% and 4%
Lower hemisphere Equal Area
N=66
N
Lineations
Kamb contour 2% and 4%
Lower hemisphere Equal Area
N=66
Set 3 shear zones
N
Poles of planes
Kamb contour 2% and 4%
Lower hemisphere Equal Area
N=120
N
Lineations
Kamb contour 2% and 4%
Equal Area
N=120

Fig. 1

Set 1 is composed of conjugate, centimetre scale discontinuous shear zones (Fig. 1) that curve the homogeneous foliation and layering without important change in grain size. The conjugate directions are both striking 130°. One plunges $40^\circ \pm 10^\circ$ to the NE and corresponds to southwestward thrusts. Conjugate shear zones plunge $20^\circ \pm 10^\circ$ to the SW and lay along Riedel orientations consistent with a general southwestward sense of shear along a bulk plane dipping 40° to the NE. Limited grain size reduction and measurements of the curved foliations indicate shear strain $\gamma < 5$.

Set 2 is characterised by an anastomosing pattern of mylonitic shear zones (Fig. 2) with an average thickness of 10 cm and a marked grain size reduction. They result from the lengthwise connection of set 1 shear zones, the conjugate directions wrapping around lenses of less deformed gabbro. These centimetre to decametre big lenses have an average shape ratio of 2.5 with their long axis plunging to the northeast. Set 1 shear zones may occur within the lenses. The anastomosing shear zones contain leucocratic, garnet-bearing veins due to partial melting of the mylonites which, therefore, are high temperature shear zones. The anastomosing shear zones occur also in the north-eastern part of the garnet granulites of the Jijal complex (southwest of Patan). Grain size reduction points to shear strain higher than 5 within these shear zones.

Set 3 corresponds to 10 cm up to 5 m thick shear zones which are continuous and undulate with large wavelength over 50 m (Fig. 3). Shear took place along horizontal to 30° northeast dipping planes striking 130°. Strong grain size reduction and presence of centimetre size rotated porphyroclasts of plagioclase derived from stretched pegmatitic veins indicate shear strain of more than 10.

Intersections observed in the field show that these 3 sets were formed successively. Nucleation and growth of set 1 and set 2 shear zones along the same conjugate directions are interpreted as progressive localisation of shear deformation at various scales during southwestward thrusting. Relationships between veins and shear zones indicate that deformation began during the waning magmatic stage of the gabbronoritic body. Set 3 shear zones occurred later and are post-dated by east-west striking, c.45° north dipping amphibolitic sheared rocks located in the northeast part the study area [3]. They represent the ductile continuous shearing developed during the upper to lower amphibolitic facies retrogression.

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Parentage and evolution of magnesite-rich rocks from the Indus suture zone in Swat, NW Pakistan

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The Indus-Tsangbo suture between the Indo-Pakistan plate and Kohistan-Ladakh island arc assumes a broad wedge-shaped complex zone in the Lilaunai-Mingora area of Swat and contains diverse rock assemblages. This assortment of rocks, collectively known as the Indus suture mélange group, is distinguished into three principal types of mélanges: the blueschist mélange, the greenschist mélange, and the ophiolitic mélange (Kazmi et. al., 1984).

Rocks of the ophiolitic mélange occur as small to large lensoidal bodies distributed along the northern edge of the Indo-Pakistan plate. They possess well-preserved ophiolitic characteristics and consist of variably altered ultramafites, gabbros, lavas of basic to intermediate composition, and pelagic sediments including cherts as well as plagiogranites and albitites. Furthermore, carbonate-rich assemblages, which are known for producing one of the world's finest gemstone quality emeralds, form an integral part of the different occurrences of the ophiolitic rocks in the study area.

In most of the ophiolitic rock occurrences, the fine-grained, emerald-hosting carbonate-rich rocks are spatially associated with variably serpentinized ultramafic rocks. Although also present as small patches within the serpentinized rocks in some places, they mostly occur along the contact between the serpentinites and metasediments. These rocks are also traversed by abundant veins, locally producing stockworks, of quartz.

The studied rocks invariably consist of abundant magnesite and accessory to trace amounts of spinel (mostly Cr-magnetite-ferritchromite and, in some cases, Mg-poor but Cr-rich chromite) accompanied with one or more of such phases as talc, quartz and dolomite. The different relative proportion of these minerals has given rise to three major types of assemblages: (i) talc-magnesite or magnesite-talc, depending upon whether magnesite or talc is more abundant; (ii) talc-magnesite-dolomite; and (iii) quartz-magnesite. The texture of these rocks is related to the relative proportions of the different minerals, especially the absence or presence of talc in the paragenesis. That is, whereas the talc-free or talc-poor quartz-magnesite assemblages are massive, the talc-magnesite rocks are strongly foliated. In addition to the phases, mentioned above, some of the investigated magnesite-rich rocks also contain fine-grained disseminations, veins, and/ or clusters or clots of fuchsite and/ or tourmaline. The tourmaline is a Cr-rich dravite and the fuchsite shows variable but, in most analyses, anomalously high concentration of Mg amd Ni (NiO reaching up to 9 wt. %).

Most of the geochemical characteristics of the investigated lithologies are broadly similar to those of typical ultramafic rocks. More importantly, the overall ranges for most of their major, minor as well as trace elements are almost identical to those of the carbonate-free, serpentinized ultramafic rocks in the area. This is particularly true for the concentrations of Al_2O_3, MnO, TiO_2, Cr, Ni, CO, V, Zn, Sc as well as Ga. Therefore, it seems reasonable to assume that the investigated rocks could be the result of alteration (carbonation) of the previously serpentinized ultramafic rocks in the area. The close spatial association between the two categories of rocks lends further support to this interpretation. Furthermore, comparison in terms of modal mineralogy and mineral chemical data with broadly similar assemblages from other occurrences in the world suggest that this transformation probably took place at 250-550 °C and was brought about by CO_2-bearing metamorphic fluids.

Although most of the major and trace element contents of the investigated rocks fall within the corresponding limits for ultramafic rocks, the amount of SiO_2 in some of them is anomalously low. On the other hand, the SiO_2 content of a few of the samples is higher than most others. Besides, compared to typical ultramafic rocks, some of the rocks under discussion contain distinctly high amounts of some of the incompatible trace elements.

The distinctly high content of SiO_2 in some of the studied rocks could be due to the fact that precursors to these rocks, unlike the most others, were originally orthopyroxenites rather than peridotites or dunites. On the other hand, the abnormally low SiO_2 contents in the quartz-magnesite varieties of the studied rocks (less than even 10 wt. %) cannot be attributed to original compositional differences because a type of ultramafic rock having such a low amount of SiO_2 does not exist. The possibility for an alternative explanation that these lithologies were originally some sort of impure carbonate rocks of sedimentary parentage (e.g. siliceous dolomite) can easily be ruled out because their trace element contents (especially high amounts of Cr, Ni and Co) are typical of those occurring in ultramafic igneous rocks. The point to make here is that the low SiO_2 content in the studied rocks is probably a result of the process of carbonation. As their SiO_2 contents show a strong negative correlation with the LOI values variable amounts of this component were probably removed from the rocks during the process of talc-carbonate alteration (Fig. 1).

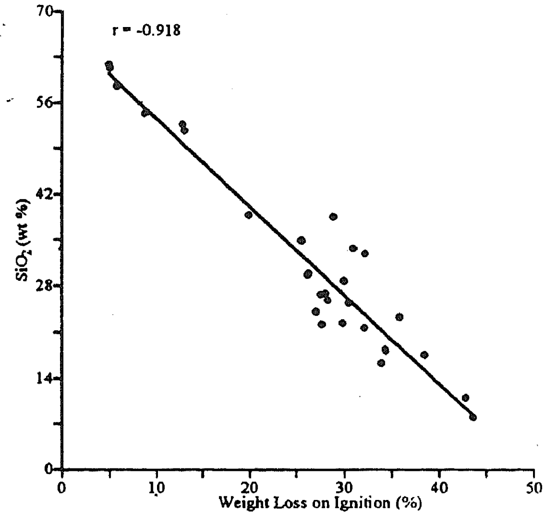

Fig. 1. Variation of whole-rock SiO_2 with the net loss of weight on ignition.

As mentioned above, some of the studied samples, especially those representing the mining sites of emerald, contain distinctly high amounts of Be, B, Li, K, As, Pb, W, Zr, Y, Ba, Rb and/ or Sr. As the average abundance of elements like these is negligibly small in typical ultramafic rocks, their notably high values in the studied may have been the result of enrichment during later processes. The lack of a meaningful correlation of any one of these elements with the values of LOI precludes the possibility for their enrichment by one of the two main processes of alteration, i.e. serpentinization and/or carbonation. Alternatively, the textural relations and mineralogical composition suggest that the mentioned incompatible elements may have been added to the studied rocks during a late-stage hydorthermal activity, most probably the one producing the quartz veins and associated phases, i.e. fuchsite, tourmaline and emerald.

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Thrust tectonics and stratigraphic correlation of the Lesser Himalaya in central Nepal

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The Himalaya, especially it's central sector including Nepal is a fold-and-thrust belt which formed in the northern margin of the Indian continent after the I-collision between India and Eurasia. It consists mainly of three thrust-bounded lithotectonic units: from south to north the

Sub-Himalaya, the Lesser Himalaya, and the Higher Himalaya with the overlying Tethys Himalaya. The thrust movement was propagated southward from the Tethys Himalaya to Sub-Himalaya with time. Among these units the Lesser Himalaya which occupies the wide area south of the Great Himalaya is bounded by the Main Central Thrust on the north and by the Main Boundary Thrust on the south, and is divided further into four subunits by thrust. These thrusts are splays off of an underlying mid-crustal subhorizontal decollement. Besides the overall Southward propagation of above thrusting, an out-of-sequence thrust also played an important role in the Himalayan thrust tectonics and the Himalayan uplift in the late Tertiary and Quaternary time (Arita et al., 1997).

The Lesser Himalaya in Nepal as well as that in other central sector of the Himalaya consist principally of the Nawakot complex (Stocklin, 1980) of late Precambrian to Early Paleozoic time and it's equivalent. In central Nepal, the Lesser Himalaya has ever widely been and is now partly covered by the metamorphic rocks of the Main Central Thrust zone of the north, and is comprised of a parautochthonous complex and three thrust sheets, i.e., from south to north (structurally from bottom upward) the parautochthon and the Lesser Himalayan thrust sheets I, II and III. The parautochthon consists of the Upper Nawakot Group and the unconformably overlying Gondowana sediments. These thrust sheets are comprised of the Nawakot complex. The thrust sheet II shows the full succession of the Nawakot complex, although the thrust sheets I and III are composed of the Middle to Upper Nawakot Group and Lower Nawakot Group, respectively. Among the parautochthon and the Lesser Himalayan thrust sheets the thrust sheet II is widely distributed in the whole Nepal, and the parautochthon occurs along the Main Boundary Thrust. On the other hand the thrust sheet I and III are observed only in central to western Nepal and central Nepal, respectively.

The Lesser Himalaya is divided into the Inner Lesser Himalaya in the north and the Outer Lesser Himalaya in the south by the Bad Gad - Kati Gandaki (central Nepal) and the Tamur Khola Thrust (eastern Nepal; Schelling & Arita, 1991) which cuts across the Main Central Thrust zone, and thus being an out of-sequence thrust. The Sun Kosi Thrust and the Bad Gad - Kali Gandaki Fault seem to be connected to each other through the Trisuli-Liku Fault which is located north of Kathmandu and cuts across the Main Central Thrust zone and separates the Kathmandu Nappe from the Higher Himalaya in the north.

Dir amphibolite as an ocean floor tholeiites underplated by Kohistan calcalkaline rocks in N. Pakistan

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Geological mapping of 673 km^2 area of Timargara - Lal Qila and Wari of District Dir N.W.F.P. was recarried out for the study of petrology, structure, geochemistry etc. (first detail work after Chaudhry et al., 1974a, b). The area constitutes the western extremity of the Kohistan island arc, where the Mesozonic amphibolatized ocean floor of Kohistan in the south is sutured to the gneisses of the Indian plate.

The amphibolites exposed in the southern and northern extreme of the mapped area were the parts of a single ocean floor under which the arc was built. These amphibolites were formed by the metamorphism of basic volcanics of tholeiitic affinity. The subordinate interlayered sediments of argillaceous, arenaceous and carbonate composition were deposited on ocean floor away or near mid-oceanic ridge (MOR). The concentration of metasediments in the southern exposure is lower than the northern part of the amphibolites where thick piles of these sediments were reported by (Chaudhry et al., 1974b). The amphibolites exposed in the Dir area are different from Kamila amphibolites which were formed by the metamorphism of basic plutonic rocks like Dassu and Kayal complexes (Ashraf, 1997; Loucks et al., 1992). The Dassu complex represents the base of the Kohistan island arc. The Dir amphibolites represent the supra crustal material of Kohistan under which the arc was built.

Geochemical discrimination diagrams show that Dir amphibolites are tholeütic as is evident from the SiO_2 and total alkalies (Cox & Pankhurst, 1979) and AFM diagram (Irvine & Baragar, 1971) plots. The K_2O - TiO_2 - P_2O_5 plots (Pearce et al., 1975) of Dir amphibolites classify them as oceanic floor volcanics. Similarly, trace elements plot also indicate the tholeütic nature of Dir Amphibolites.

The plutonics rocks exposed in the area consist of norite, gabbronorite, diorite, tonalite, trondhjemite, granite/adamellite, and quartz porphyries/aplites/pegmatites. The presence of small and large roof pendant of amphibolite in these plutonic rocks suggest that they were intruded in the Dir amphibolites and these were exposed due to uplifting and unroofing of amphibolites.

AFM plots of norites, gabbronorites, diorite, tonalite, granites, adamallites, aplites and quartz porphyries suggest a calcalkaline nature of these rocks. Al_2O_3 vs An also reveals calc-alkaline nature for the plutonic rocks in the Irvine and Baragar (1971) diagram. On the basis of TiO_2 vs. FeO/MgO (Babien 1980), these rocks classify as orogenic rocks showing emplacements of magma during collision, underplating the oceanic crust of MORB nature.

Generally three types of ultramafic rocks are exposed in the mapped area. The first type is highly altered, metamorphosed, and present as exotic blocks in amphibolites. The second types occur as roof pendents over the surface of some plutonic rocks (i.e. granite, adamellite and diorite). These ultramafics were emplaced in the oceanic crust (amphibolites) during its development at MOR. The third type of ultramafics are mostly hornblendites and scyelites exposed both in amphibolites and plutonic rocks. They were probably fractionated as hydrous magma and ascended to higher levels due to buoyancy acquired by their magmas as a result of residual liquid enrichment.

Structural studies show that the rocks of Kohistan island arc exposed in the area are folded into northward dipping southward verging tight folds in the south (near MMT) which opens up northwards. The amphibolites have undergone three phases of isoclinal folding. In the first phase of recumbent or isoclinal folding S_1 axial planner foliation was developed in these rocks. The first phase of deformation is probably related to the subduction of Kohistan under Eurasian plate. The second phase is probably related to the subduction of Indian plate under Kohistan, in which these rocks were again folded. The rocks of Kohistan mass have undergone a third phase of deformation which produced the shear zones and a retrograde metamorphism to chlorite grade.

The southern part of Dir amphibolites near MMT mostly trend EW and dips 65° to 80° northwards, which is almost parallel to the trend of MMT. In the central portion of the mapped area, the plutonic rocks trend NE to SW and their dips vary from 40° to 70° NW and SE. Most of the fold axes in plutonic sequence are parallel to each other which mostly trend NE to SW and plunge from 12° to 50°. The northern part of Dir amphibolites mostly trend NE and dips 150° to 60° SE.

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Quaternary lake deposits in the Thakkhola Graben, Mustang, Nepal

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The Kali Gandaki river drains most of the Thakkhola Graben situated in the semi arid region north of the high Himalayas or north of the MCT, respectively, to the south. Well layered yellowish fine deposits ("Marpha formation" acc. to Fort [1]) are frequently exposed in the terraces and on the valley slopes along the river between Tangbe (28° 53′ N, 83° 48′ E) in the north and Tukche (28° 43′ N, 83° 39′ E) in the south. With few exceptions, these sediments have been described as lacustrine deposits. But, the process damming the Kali Gandaki river and thus creating the "palaeolake of Marpha" [2] as well as the timing of this event has been a matter of controversy. Rapid tectonic uplift [3], a huge rock fall from the Dhaulagiri Himal [4][5] and glaciers reaching the valley bottom between the Dhaulagiri and Annapurna Himal at about 2.550 m a.s.1. [1][6][7] have been considered as being responsible for the damming of the river. Accordingly, the ideas about the age of the deposits show a considerable variability: Iwata et al. [7] assume a sedimentation prior to the last interglacial. Kuhle [6] argues that the lake developed well before the last glacial maximum and lasted until the glaciers retreated from the valley bottom. From the description given by Honnann [4] one can derive a holocene age for the rock fall deposits damming the lake.

Whatever the reason for the damming of the river was, the deposits of the "palaeolake of Marpha" represent the starting point for the latest period of incision of the Kali Gandaki river north of the High Himalayas [8]. In order to establish a chronology of the recent geomorphological evolution in this area samples of lacustrine deposits as well as samples of fluvial deposits from lower, i.e. younger terraces have been dated using optically stimulated luminescence (OSL)[9]. The location of the samples taken from the lacustrine deposits is shown in the longitudinal profile of the palaeolake of Marpha (Fig. 1).

Two samples from the bottom of sections at Marpha and Djumba (dots in Fig. 1) have been dated up to now. The sample from Marpha (28° 45′ N, 83° 41′ E, 2.702 m a. s.l.) yielded an age of 56.36 ± 6.95 ka (HDS 058) and the sample from Djumba (28° 45′ N, 83° 42′ E, 2.740 m a.s.l.) gave an age of 55.84 ± 5.9 ka (HDS 060). Although taken from the bottom of the outcrops at Marpha and Djumba, the samples are located 150 to 190 m above the recent valley bottom just north of the rock fall at Kalopani. Assuming that the recent valley bottom represents the bottom of the "palaeolake of Marpha", the younger lacustrine sedimentation in the

Thakkhola Graben started at the turn from the early to middle last glaciation. In this paper further results from the dating of the lacustrine deposits are presented and compared with results derived from a detailed analysis of the stratigraphy in the outcrop at Langlangtang, Syang Khola, SW of Jomsom. In addition, data concerning the recent incision of the Kali Gandaki will be presented. The implications of these results for the tectonic and climatological history of the area will be discussed as well.

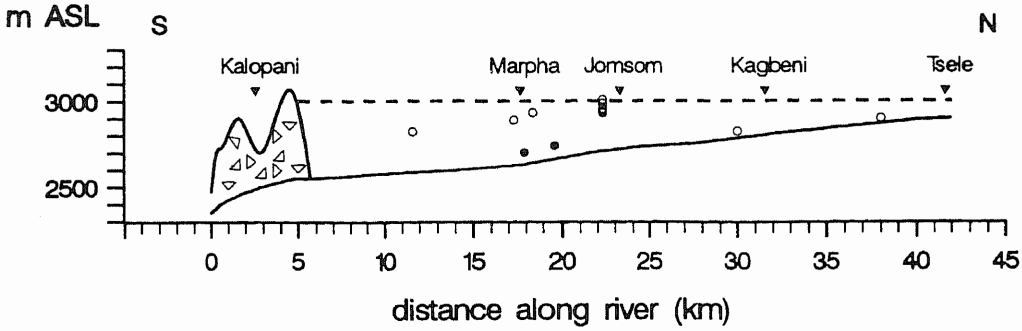

Fig. 1. Exaggerated longitudinal profile of the 'palaeolake of Marpha' showing the location of the rock fall deposit at Kalopani and the location of samples (circles and dots).

Acknowledgement: The research was funded by the German Science Foundation (Deutsche Forschungsgemeinschaft, DFG) under the grants Ma 1308/5-1 through Ma 1308/5-4.

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Paleozoic accreted terranes of Southern Mongolia

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The Southern Mongolia contains a collage of Island arc, accretionary wedge, continental margin arc, metamorphic and cratonal terranes, accreted by the Carboniferous and Triassic.

The island arc terranes include the Gobi Altai, Edren, Gurvansayhan, Baitag, Halzan, and Naran Sevestei terranes, composed mostly of Ordovician and Devonian pillow lavas, volcaniclastics, and ultrmafic rocks.

The accretionary wedge terranes are Bayanleg, Hoviyn Har, Nomgon terranes. These terranes include Ordovician to Carboniferous thick turbidite, pelite, chert, containing ulrtamafic rocks and gabbro.

The continental margin terranes include the Baaran, Atasbogd, Tost, and Tsagan Suburga terranes, which consist of Proterozoic metamorphic basement, Devonian to Permian volcanics, volcaniclastics, intruded by Paleozoic granitic rocks.

The metamorphic terranes are Tsel and Tsogt blocks, containing metapelite, amphibolite, tonalite gneiss, granite-gneiss and migmatite with lesser granulite.

The cartonal terranes include the Tsagan Uul and Hutug Uul blocks, containing Middle Upper Proterozoic gneiss, quartzite, marble and metasediment, unconformably overlying Silurian and Devonian shallow marine sediments.

The accretionary history of the south Mongolian orogenic belt is related to the progressive closure of two oceanic basins: South Mongolian on the north, and the inner Mongolian on the south. The fragments of the cratonal terranes originally were part of the Tarim craton, that was displaced northeastwards by dextral movement on the Tost fault system.

Biotic constraints on the timing of initiation of continental sedimentation in the Indus suture zone, Ladakh Himalaya

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Recognition of the earliest continental sediments in the Indus Suture Zone of Ladakh is important because of the constraints these sequences provide on the timing of India-Asia collision. In the past, varying ages (Maastrichtian through Oligo-Miocene) have been suggested for the continental sequences of Ladakh. As presently known, these sequences occur in three different tectonic settings. All along the main Indus sedimentary belt, east of the Zanskar river, enormously thick molassic sequences forming part of the Miru Unit 1[1] rest uncomformably on the Eocene flysch and thrust northwards over the Ladakh Batholith. Southwards, this molasses is overthrust by the orbitolina-bearing lower Cretaceous limestones (Khalsi Limestone). South of this main belt, in areas north of Tsokar and near Liyan Gompa in eastern Ladakh, non-marine sediments (Liyan Formation) occur in the form of outliers, overlying the typical ophiolitic rocks with an erosional contact. Fossil vertebrates from the Liyan Formation have been variously interpreted as indicating a late Eocene through Oligo - Miocene age.

Authochthonous molassic sequences also occur unconformably on the southern margin of the Ladakh Batholith which has been radiometrically dated at around 100 and 60 Ma. Originally termed Ladakh Molasses, these strata are presently known by different local names (Kargil/Wakka Chu/Karroo/Wakka River Formation) and have been generally considered to be post-Eocene in age. More recently, however, non-marine horizons of Maastrichtian - early Tertiary age (Basgo and Temesgam Formations) have been reported [2]. These formations are of considerable biogeographic significance because of their intermediate position between the Indian plate and Asian block. Freshwater biota from these horizons have a two-fold significance. First, they help to define the age of the earliest terrestrial sediments in the suture zone, which has long been a controversial issue. Secondly, these fossils provide an opportunity to investigate the recent viewpoint that the collision between India and Asia occurred as early as the latest Cretaceous (Maastrichtian) [3], much before the generally cited collision age of lower-middle Eocene. This early collision hypothesis has been proposed to explain the presence of several Laurasian taxa in Maastrichtian non-marine biota of peninsular India [4]. Recent palaeomagnetic data [5] has also been interpreted to indicate a late Cretaceous collision age.

The author's ongoing investigations of the Basgo and Temesgam formations of Ladakh, have recently led to the recovery of an interesting freshwater microfossil assemblage which includes charophytes and ostracods. Assessment of biogeographic affinities of this assemblage vis-a-vis contemporaneous assemblages from peninsular India, Chinal and Mongolia, provide new insight into the question of latest Cretaceous vs. Eocene age of the India-Asia collision.

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Evidences of hill slope instability around microhydel projects in parts of Pithoragarh district, Kumaun Himalaya

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The Eastern Kumaun Lesser Himalayan terain is marked by complex structural and geological set-up, rugged topography, high to moderate seimicity and high precipitation. The region is neotectonically active as well as geomorphologically fragile. The area of study extends from Tawaghat to Sobala and has a number of microhydel projects viz. Sobala, Kanchuti, Khet and Chhirkila along the Dhauliganga River (Fig. 1) The entire stretch is marked by prominent evidence of mass movements including rock falls, slips, creep, etc. Of these, the most prominent are the evidences of ground instability associated with the numerous *debris cones* that are typically present in the area along the Dhauliganga river.

Geologically the area forms a part of the Lesser Himalayan Sedimentary Belt with the Chhiplakot crystalline mass in the south and the Central Crystalline Zone in the north. The Chhiplakot crystalline mass is tectonically disposed as part of the large thrust sheets that once covered the entire Lesser Himalayan sedimentary sequence (Agarwal, 1994). The SSW/SW directed teconic transport of the crystalline mass in the form of thrust sheets with roots in the Central Crystalline Zone of the Higher Himalaya have caused brittle deformation in the footwall based sedimentary belt (Searle et al., 1987) as well as in the lower parts of the Chhiplakot crystalline sheet. Thus during this process of subareal transport of thrust sheets, the rock masses adjoining the thrust plane have undergone fracturing, breaking up into angualr fragments, cataclasis and subsequent pulverization thereby rendering the rock masses weak. The present day geomorphological set-up thus appears to have resulted due to the erosion of a part of the crystalline thrust sheet exposing the footwall rocks in the form of Sirdang Sedimentary Window. This process subsequently exposed the brittlely deformed rocks adjoining the tectonic planes to the active denudational processes (Fig. 2). Further, the area is seismically active and also situated in a geographic zone of high precipitation. All these factors appear to have contributed to the higher rate of erosion and subsequent transport of the heterogeneous loose and unconsolidated material whose size ranges from fine silt to angular boulders. These debris cones are geotechically very weak and as such are highly susceptible to mass movements. During the present times these morphotectonically controlled debris cones constitute the sites for slope instabilities. The microhydel projects situated around such as zones of high instability face great threat to their existence especially during the time of heavy precipitation and seismicity.

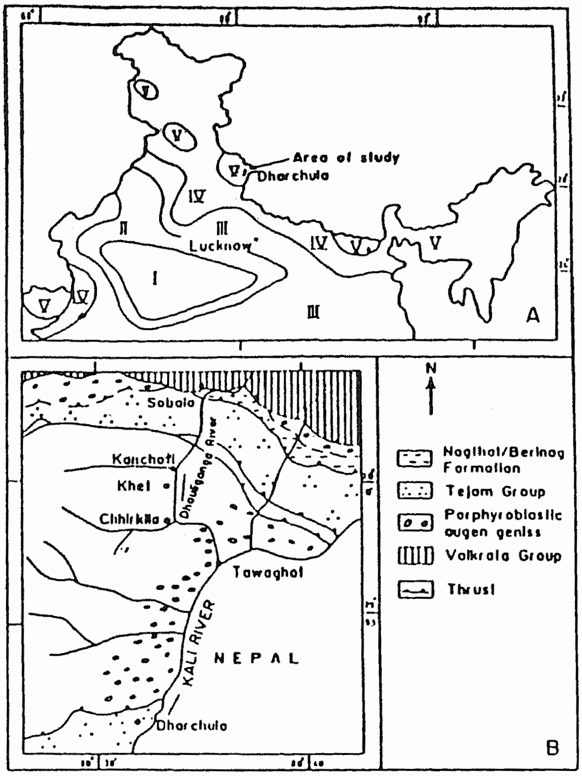

Fig. 1. A. Map giving the seismic zonation of northern India. The area of study falls in Zone V (ISI, 1893-1975).
B. Geological map of the area around Dharchula (after Validya, 1980).

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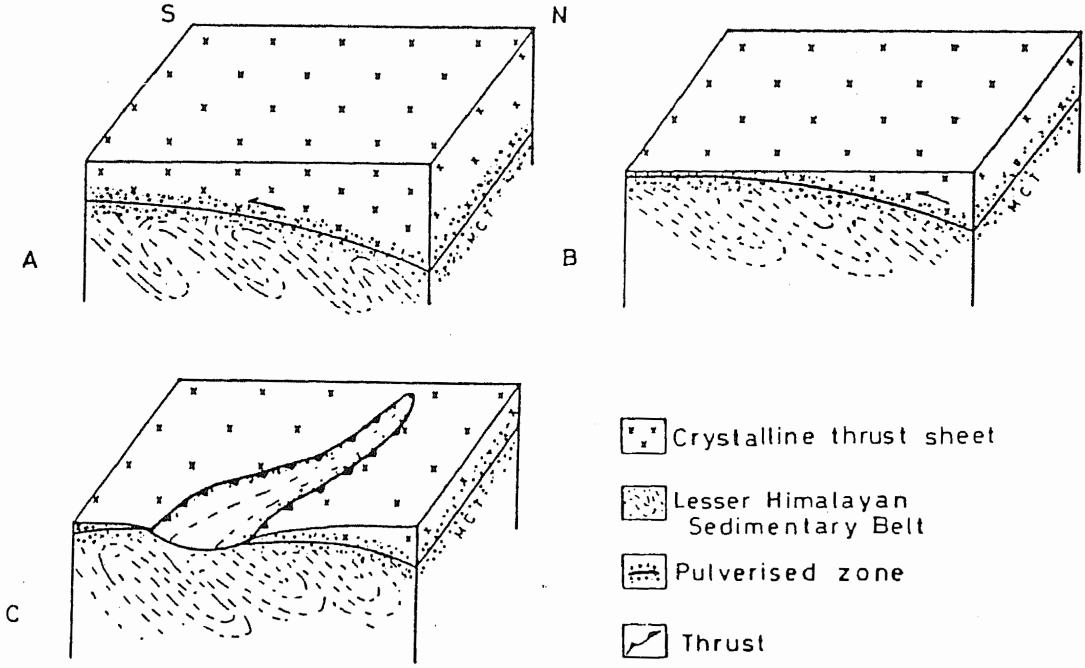

Fig. 2. Schematic diagram showing the development and location of pulverised zone due to thrust sheet movement.

a. Initial position of the thrust sheet over the Lesser Himalyan Sedimentary Belt due to south ward translation.

b. Partial erosion of the overridden crystalline sheet.

c. Present day disposition of the Sirdang sedimentary windows due to removal of the part of the overridden crystalline sheet. The erosion has led to the exposure of pulverised zone along the thrust contact.

Geotechnical aspects of hydropower projects in Indus Kohistan, Northern Pakistan

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A number of high head hydropower projects are being planned on tile tributaries of the Indus river in Indus Kohistan. These projects, with locations as shown in Figure 1, are at various levels of study and the first may come into operation around the year 2005. The estimated total installed capacity of 5,000 MW mostly in the form of peaking plants will significantly reduce the power deficit currently being faced by Pakistan.

The main characteristics of these cascade schemes include storage dams at higher elevations with regulation facilities in the middle and lower catchment sections. As is the case with most high head hydropower projects, the planned schemes are in relatively remote areas and contain long waterways (tunnels) across areas of high overburden. High erosion rate in the Himalayan region will also result in deposition of sediments in the reservoirs requiring careful sedimentation management and provision of sediment handling facilities.

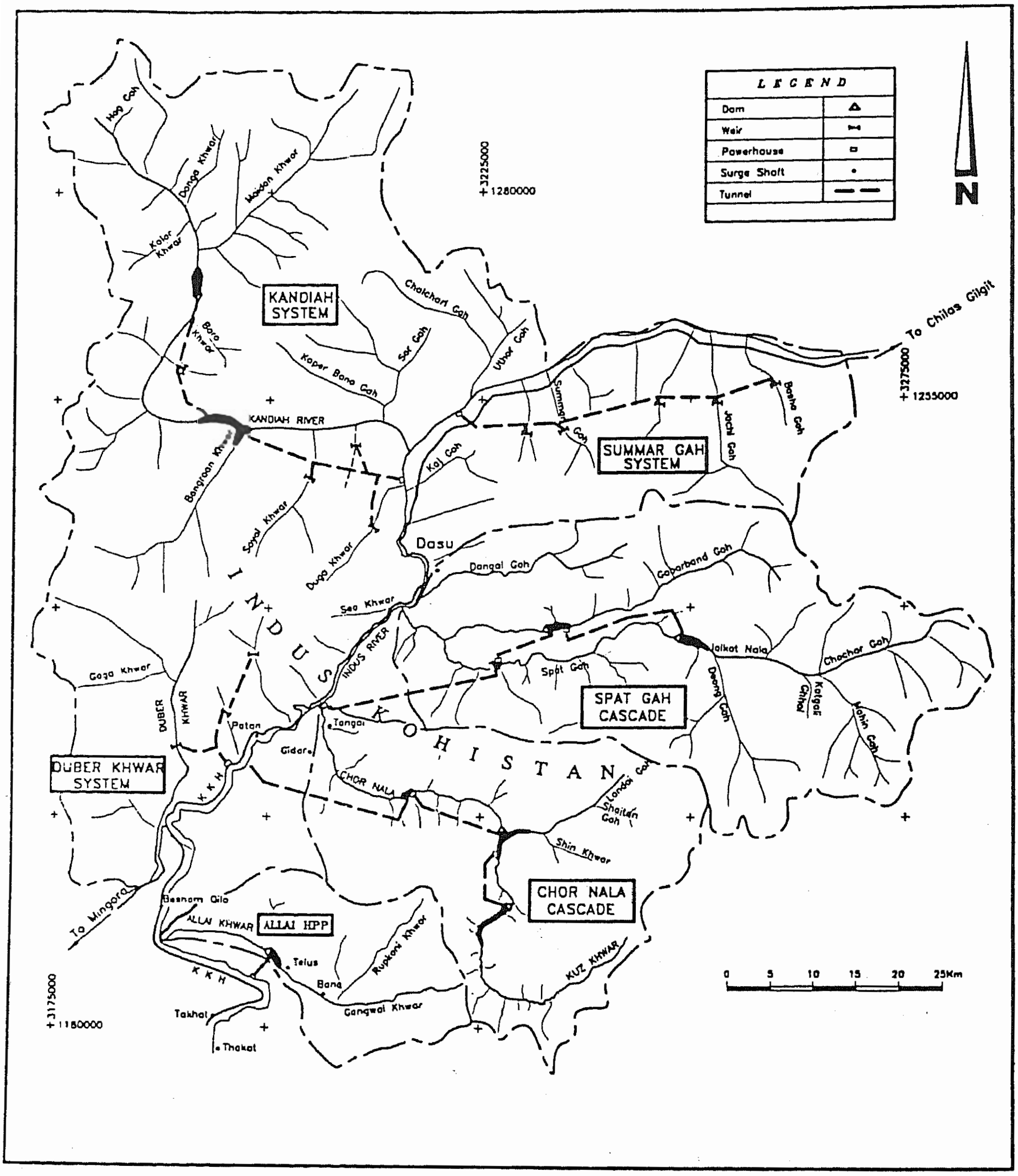

Fig. 1. General Layout of Hydropower Projects in Indus Kohistan.

Main geotechnical data available for the schemes is summarised and discussed in relevant detail. The Allai Khwar Hydropower Project is the most likely candidate for implementation ahead of others. The other cascade schemes on left bank of' the Indus river in the adjacent catchments of Chor Nala and Spat Gah have been studied to conceptual and reconnaissance level, respectively. Based on geological and tectonic setting of the area, the process of site selection and establishment of design parameters are also presented.

The continued subduction and arc-continental collision (thrusting) induced several phases of faulting and metamorphism, resulting in a wide spectrum of low to high grade metamorphic rocks. The projects areas are in close vicinity of the Main Mantle Thrust (MMT); a major orogenic feature which marks collision boundary of the Indian plate to the Eurasian plate with intervening Karakoram micro-plate and Kohistan arc. The alignment of MMT and other major tectonic features have been mapped within the projects area. Based on the regional geological conditions, the geotechnical zoning has been attempted to define expected geotechnical and geomechanical characteristics of' rock mass along the long tunnel routes. Attempt has been made to predict tunnelling conditions and rock mass behaviour together with estimated rock support requirements.

Investigation techniques including interpretation of satellite imageries and aerial photographs, engineering geological mapping, geophysical methods and core drilling is described together with their application from site selection to microlocation of the project structures.

The paper describes the successful use of various geophysical investigation techniques and results obtained at the initial stage of site selection in these relatively remote and inaccessible areas. This allowed to replace expensive and time consuming drilling and other relevant rock mechanics testing. Systematic discontinuities surveys regionally and at selected sites were carried out to define characteristics of dominant discontinuities groups. Also presented is the use of this data in stability assessment of foundations, tunnels and slopes on various project sites.

In the concluding section, recommendations are given for appropriate methodology and approach in obtaining geotechnical data and site selection for hydropower projects in northern areas of Pakistan.

Seismic risk assessment of hydropower projects with reference to the tectonic structure of northern Pakistan

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Seismic phenomenon has been responsible for the severe damage to water-retaining structures in the world. Examples from USA include Sheffield dam, Hebgen Lake dam, Upper San Fernando dam, and Lower San Fernando dam. Similarly, Koyna dam; a concrete gravity structure in India sustained severe earthquake damage in 1967. However, a complete failure of a dam due to earthquake impact is virtually unknown. The safe design of dams to withstand destructive earthquakes is, therefore, extremely important because failure of such a structure may have disastrous consequences both on life and property.

The paper briefly describes seismo-tectnoic environment in the Himalayan region and its impact on existing dams in this area such as Bakhara - Nangal dam in India, Mangla and Tarbela dams in Pakistan. In addition, earthquakes that may pose a multitude of hazards to dams either by direct loading of the structure or by initiating a sequence of events that may lead to the dam failure are discussed with a special reference to the tectonic structure of Northern Pakistan.

The geological and tectonic setting of the Northern Pakistan is an example of continental collision characterised by the occurrence of an ancient island arc. The continuing subduction and arc-continental collision induced several phases of faulting and metamorphism, resulting in a wide spectrum of low to high grade metamorphic rocks. The tectonic processes in the area have produced a mixed and very complex geological situation. The collision tectonics have resulted in formation of thrust and strike slip faults. Most of the high head hydropower projects planned in the Indus Kohistan area are located in close vicinity of the Main Mantle Thrust (MMT) and other major tectonic features. The rocks are foliated to cataclastic and mylonized with high degree of shearing and folding in the vicinity of MMT. The MMT, Indus Kohistan seismic Zone (IKZS), Thakot Shear Zone (TSZ) and the Main Boundary Thrust (MBT) in the form of a detachment fault underlying the project area are the main seismogenic features in the area. Relationship between distribution of seismic events and main seismo-tectonic features in Indus Kohistan is given in Figure 1.

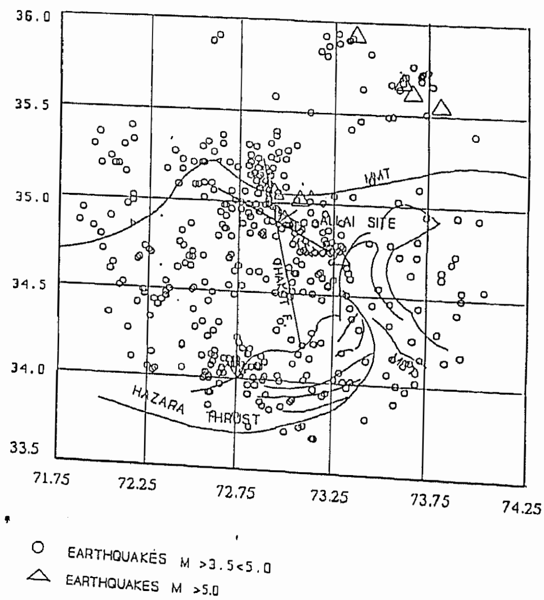

Fig. 1. Relationship between distribution of seismic events and main seismo-tectonic features in Indus Kohistan.

The northern areas of Pakistan are considered highly seismic and in spite of the fact that all the future main hydropower projects are being planned in this region, seismic data is scarcely available. Recently, M/S Allai Khwar Consultants (AKC) have managed a microseismic network study in Indus Kohistan area. The instruments installed at locations shown in Figure 2 recorded several hundred seismic events during a six months study period. The study indicated that the level of micro-seismicity in this region is fairly frequent and probably greater than in other parts of the Himalayan region. Another important aspect identified by the study is the shallow depth of seismic events. It is observed that even small magnitude events can produce high accelerations in Northern Pakistan. For example, an earthquake of' April 17, 1972 with a body wave magnitude 4.9 produced 25% g and that of February 20, 1996 with a magnitude 5.2 produced 27% g at the Tarbela site. Based on updated geological information, historical earthquake data and preliminary results of the recent microseismic network study, design parameters such as Maximum Credible Earthquake (MCE), Operational Basis Earthquake (OBE) and acceleration (g) values are proposed. Relevance of various attenuation equations for this area are also discussed.

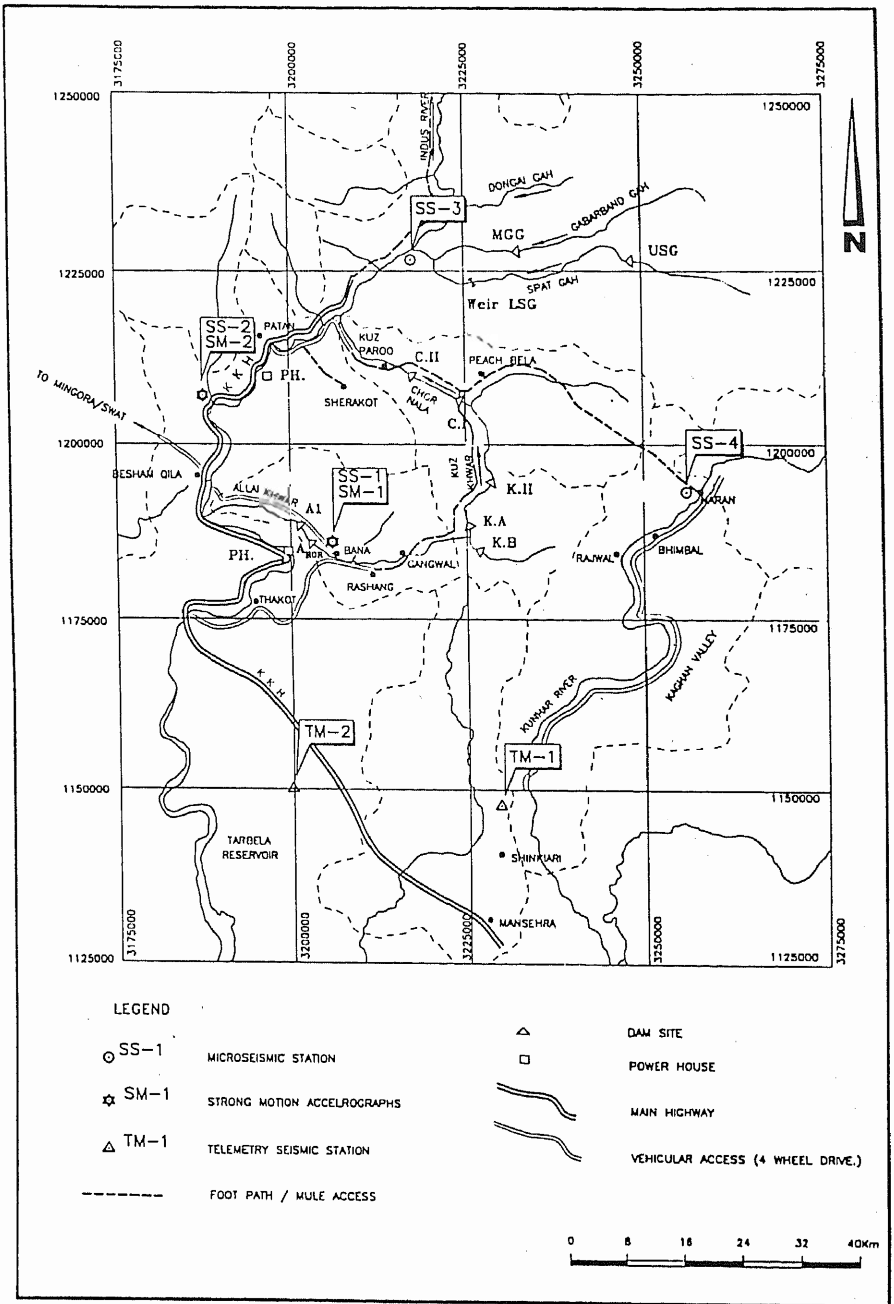

Fig. 2. Location of microseismic network in Indus Kohistan.

Satellite imagery and aerial photographs studies to determine location and lengths of lineaments provided information on the probable extent of possible movement on major fault planes. Accurate geological and tectonic mapping allowed correlation of instrumental data with the known tectonic features. Based on the recommendations of the International Committee on Large Dams (IOCLD), the investigation methods used in site selection, classification of fault systems and identification of neo-to recent-tectonic activity, are described. Relevant design features are proposed to minimise damage to dams avid appurtenant structures in case of extreme shaking during strong seismic events.

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Geodynamics and seismotectonics of the Pamirs=97 tien - shan junction zone

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In central part of the Alpine - Himalayan fold belt at the places of the maximum penetration of the Hindustan and Arabian moving plates to the Eurasian stable plate are situated the junction zones of the Pamirs with Tien - Shan and Lesser Caucasus with Great one. These exceptional structural forms study is highly important for the understanding of the geodynamic processes in the seismoactive regions. They posses wonderful resemblance by many particulars in spite of the huge removal and on different rocks formation. The shapes of the zones on plan are very similar. The northern border is characterized by latitudinal stretch, and the arc-like southern border is convex to the North. The junction zones have approximately equal areas, amplitudes of the neotectonic movements, absolute heights of the relief and other morfometric data. In the east of the arc-like Pamirs and Lesser Caucasus are situated transverse submeridional fault zones. On the flanks of junction zones the neotectonic depressions are disposed: Afghan - Tadjik and Black Sea depressions on the West, Tarim and south Caspian Sea depression on the east. Majority of the earthquakes with M > 7 took place in the narrowest parts of the zones, These and many other signs of the likeness allow to suppose that the junction zones have been formed by similar geodynamic conditions.

The Pamirs - Tien - Shan junction zone represents in geomorphologic terms a narrow dip of the terrain linking the Afghan - Tadjik and Tarim depressions. It is oriented in the sublatitudinal direction describing an arc around the Pamirs in the North and separating it from the Tien - Shen. At present the formation of the junction zone is basically considered from the standpoint of two concepts. The first of them, the mobilist concept, regards the junction zone as an arena of collision of the Hindustan and Eurasian lithospheric plates. According to the other, fixist, concept this region developed and continues to develop under the dominant influence of the vertical component of tectonic movements.

In order to determine the correlation between the horizontal and vertical movement components in the process of formation of the modern morphostructural image of the territory we have conducted a detailed analysis of the strikes of the ridges in the Pamirs - Himalayas region and the junction zone and elaborated a diagram of the "ideal" terrian and the blocks of the Earth's crust. Within the latter the strikes of morphostructures reveal a characteristic pattern typical of them alone. The analysis of the morphostructure strikes diagram has shown that the manifest arc-like shape on the diagram is characteristic only of the blocks' edges while within the blocks themselves the composition of various strikes produces a more complex pattern. The features that have been discovered in the modern image of the morphostructural plan of the Pamirs - Himalayas region and the Pamirs - Tien - Shen Junction Zone can be explained only if complex interrelation of the horizontal and vertical tectonic movements in the course of the terrain formation is recognized.

The junction zone is limited in the north by the Hissaro - Kokshaal and in the South by the Darvas - Karakul deep faults. The former is at the same time the southern surface boundary of the Tien - Shan. The analysis of the terrian and the strikes of the junction zone's morphostructures has demonstrated that the southern boundary of the Tien - Shan is even more southward: in the North of the Tarim, along the valleys of Markansu and Muksu in the northern Pamirs and further on along the ridge of Peter the Great. It is this line that represents the high seismicity zone of the region under discussion.

Traditional approaches to the problem of paleostress reconstruction from orientation of systems of joints in sedimentary rocks are based usually on the local strength criteria of the Coulomb-Navier type. We adopt the model which takes into account the typical priority of natural geomaterials - the presence of a descending branch on the stress-strain diagram. Frequently, rheological instability in such material is expressed in localized form. Note that a high degree of lithification of rocks is not a necessary condition for the realization instability. Using all these and other results we identify systems of localized layers with discontinuous shear dislocations (joints) at the time of formation of the latter. As time passes (and with an increase in the degree of lithification) in the field of operation of stresses the localized layers evolve into dislocations with a break in continuity. The folding of rocks if it takes place follows the localization instability.

We consider the reconstruction of paleostress axes as the inverse problem of localization theory. Practically, at each observation point, that is in a subregion of exposure. we measured the unit normal vectors to planes of 100 joints of tectonic origin. The maxima of density of the upper hemisphere were interpreted as the presence of corresponding joints systems. The following procedures must be performed: 1) imaginary turning of a subblock at an observation point as a rigid whole in such a way that sedimentary layers occupy their initial horizontal poistion, 2) selection of conjugated joint systems and 3) obtaining the position of stress axes by localization theory. So the axes of paleostresses operative during the sedimentation period were obtained. The method was tested for some tectonically active regions: Central Asia, the Caucasus, the Crimea, Cuba and others. For example, the Mesozoic - Cainozoic history of paleostresses in the junction zone of the Pamirs with Tien - Shen can be interpreted in the following way. The axes of maximal compression in the Early Cretaceous evidently having a sublatitudinal orientation by the Paleogene had turned in a northeasterly direction. Beginning with the late Paleogene the field of stresses in this region was determined by convergence of the Pamirs and Tien - Shan. The reconstructed Neogene - Quarternary stress field in its general plan corresponds to the present-day field established on the basis of earthquake focal mechanisms. We suppose that the most probable mechanism of their formation is a movement of the Hindustan and Arabian plates in north direction. According to the stress state data obtained for the Mesozoic - Cainozoic eras the interaction of these moving plates with stable Eurasian one began in the middle of Cretaceous and proceeds actively in the neotectonic and recent stages of the seismotectonic evolution.

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Sedimentology, mineralogy and geochemistry of fallout tephra deposits in upper Siwalik subgroup, Jammu, India

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In the northwestern Himalayan molasse basin bentonite (altered volcanic ash) and tuffaceous mudstone beds have been reported from Potwar plateau and Jhelum area (Pakistan), and Jammu and Panjab areas, India. In the project area bentonites and tuffaceous mudstones occur at several stratigraphic levels in the "Nagrota Formation". The present study reports occurrence of a persistent band of bentonite and bentonitic clay beds traceable for at least 45 km along strike in detached outcrops. The age of this altered tuffaceous band has been constrained by fission track dating method and magnetic polarity stratigraphy, and marks the Gauss-Matuyama transition at 2.47 Ma. This time coincides with the period of activity of the Pliocene-Quaternary Dasht-e-Nawar volcanic complex (Afghanistan). The strata enclosing this tuffaceous band are dominated by dark brown and light yellow mudstones. These mudstones exhibit thin (1-2mm) wavy and planar lamination, numerous vertical and horizontal burrows (25mm in diameter) and minor organic debris, and yield molluscs, ostracods, charaphytes, microvertebrates, coated grains and oncoids. Interbedded with mudstones are many thin (5-15cm) beds of massive silty and fine grained sandstones. The bentonite band exhibit a sharp basal contact with mudstone beds and varies in thickness along strike (Fig. 1) with a maximum of 3.60m at Barakhetar village.

This altered tuffaceous band exhibit a stack of 19 beds of bentonite and bentonitic clays with bed thicknesses varying from 1.0 to 5.3 cm. These beds are nodular, laminated, massive, and graded, and display oscillation ripples, current ripples, interference and tunning fork type wave ripples, worm tracks, and load and flame structures. One of the bentonite beds 11 cm thick, exhibit 15 distinct sedimentary structural divisions (Fig. 2) characteristic of fine grained turbidites (Stow & Shanmugam, 1980). The thicker beds consist of various units distinguished by subtle colour changes, texture, grading and thickness and in a few cases are bounded by clay and silt laminae. This colour and compositional zoning is caused by wind sorting and settling through the water column, and may comprise several eruptions or may be related to successive eruptions from a zoned magma column.

The bentonite beds yield platy and pumice type glass shreds, quartz and zircon phenocrysts, feldspar, biotite and sanidine. These mineral grains are generally of 4-6 Ø in size. The clay minerals identified include montmorillonite, kaolinite and paligorskite, and zeolites including phillipsite and clinoptilolite. Compositionally these altered tufts are andesitic (dark) and trachytic (light grey to olive) in nature. The bulk chemical composition of the samples taken from different layers in the individual beds is comparable with standardised chemical composition of andesites and trachytes (Maitre, 1976). However, the results are markedly high in Mg and K and depleted in Si, Ca, Na, Al and Fe. These variations may be related to the effect of secondary Mg and K gain, and Si, Fe, Ca and Na loss during the depositional phase in a water body rich in Mg and K.

The assemblages of sedimentary structures representing high energy shallow water and relatively low energy deep water conditions reported from the two sections approximately 30 km apart along strike at the same stratigraphic level reflect morphometrically eustrophic lacustrine conditions. The ostracod assemblage encountered from the underlying mudstones suggest a water depth ranging from 3-10 m. The fine grained turbidites may have been deposited probably in protected and deeper parts of the lake. The stacking pattern of lamination in the couplets of light and dark layers reflect variable suspension input into the lake, as some ash fails are composite and consist of subunits that represent pulses within a single eruption. The shallow water signatures reflect deposition along the shoreline or mudflats of the lake which is attested by the high yield of charaphytes from the mudstone beds underlying the bentonite band in this section.

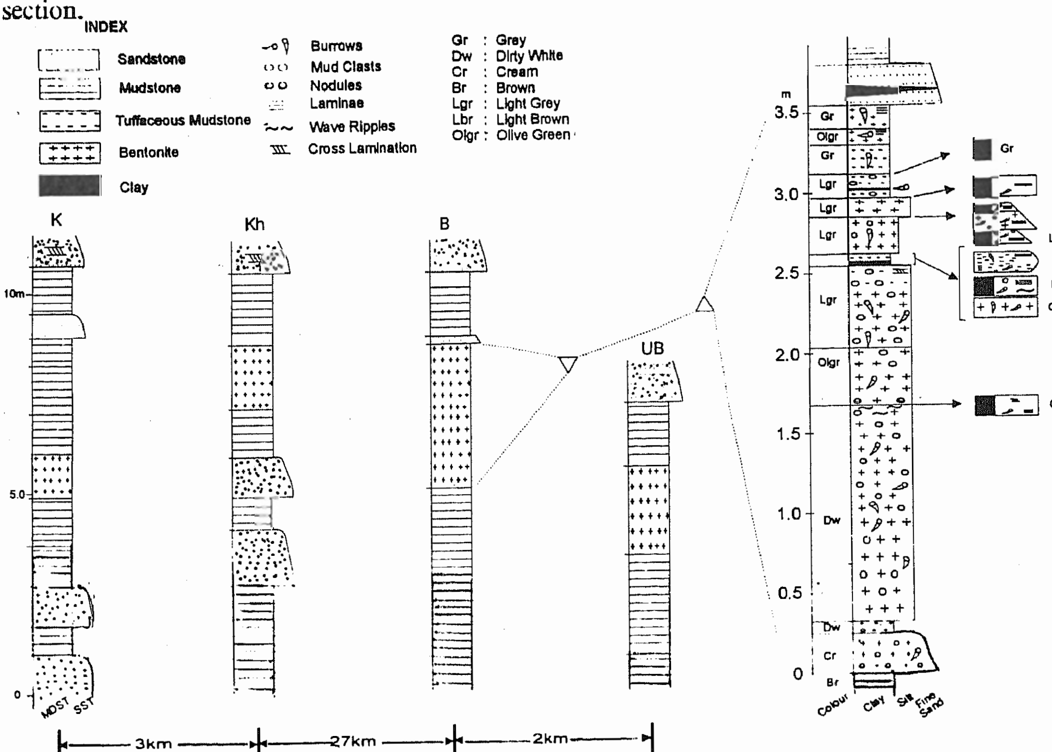

Fig. 1. Lithologs of altered tuffaceous band and the enclosing strata: K=Kammani section, Kh=Khanpur section, B=Barakhetar section, UB=Uttarbani section.

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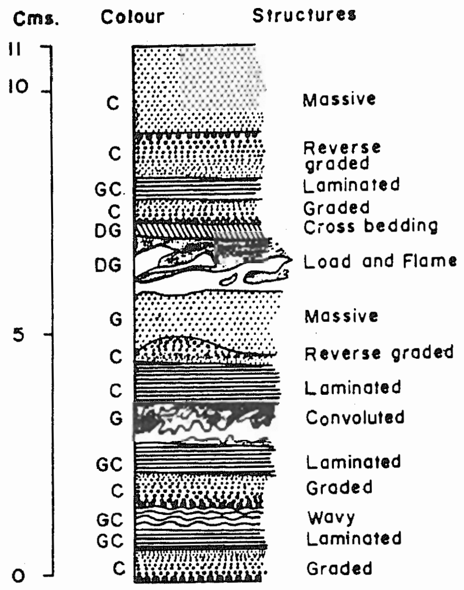

Fig. 2. The sequence of 15 distinct sedimentary structural units characteristic of fine grained turbidites. C=Cream, GC=Grey and Cream layer alternation, DG=Dark grey, G=Grey.

^{40}Ar-^{39}Ar dating of volcanic units of the Ladakh collision zone

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The geochronological framework of the three major volcanic units [1] the Dras, Shyok and the Khardung volcanics, of Ladakh collision zone is not clear, while the Drass volcanics are supposed to be the eastern continuation of tholeiitic Kohistan island arc [2] and are intruded by the granitoids of Ladakh Batholith [3]. The relationship of Shyok volcanics and acidic Khardung volcanics is not well understood.

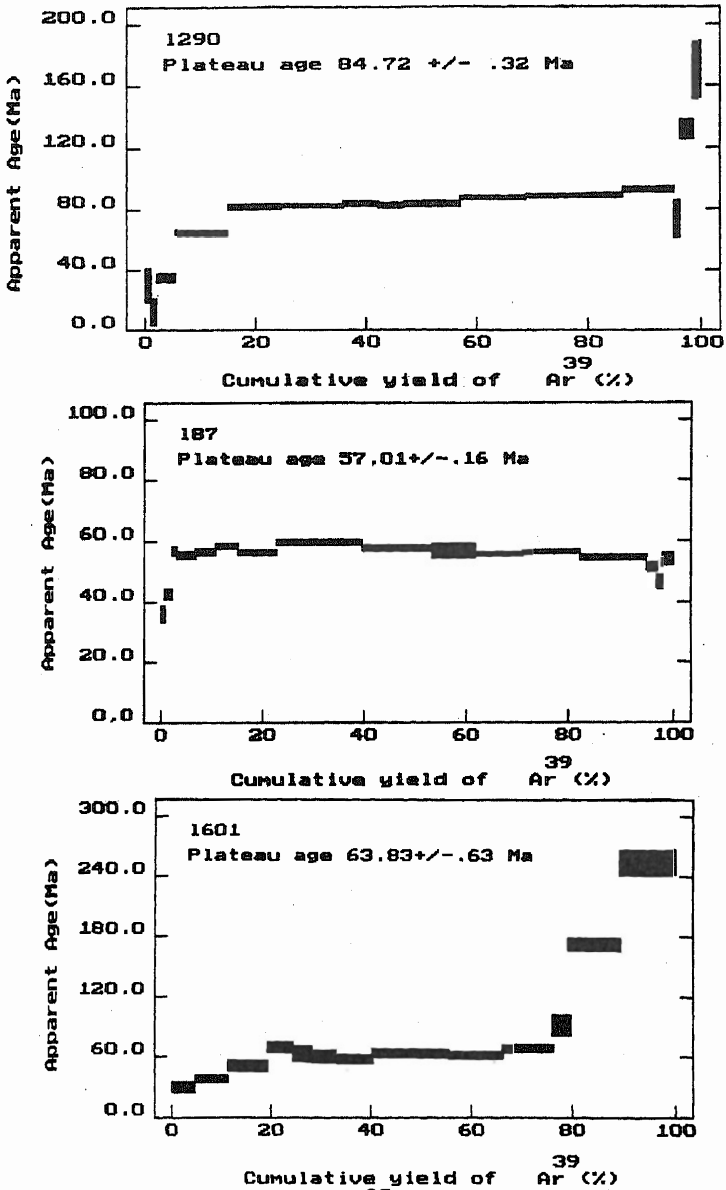
The present study is a reconnaissance one in which three samples from Dras and Khardung volcanics have been analyzed by ^{40}Ar-^{39}Ar step heating method. The age spectra are shown in Figure 1 and the results are given in Table 1. Sample No. L-290 of Dras volcanics shows a cooling pattern with plateau like age of 84.7 $\pm$ 0.32 Ma (Fig. 1). The experimental procedure is according to Venkatesan et al., [4].

Two samples of acidic volcanics of Khardung type are taken from Chushul (sample no. L-601) and Dungti (sample no. L-87) villages from the northern side of Ladakh Batholith. The age spectra for the both samples show plateau like segments and age of around 60 Ma.

These results suggest that the Dras volcanics are distinctly older (-84Ma) and the Khardungs represent a younger event at ~ 60Ma. Detailed work is in progress and the result would be presented in the conference.

TABLE 1

Sample No.	Plateau Age Ma	% ^{39}Ar in Plateau steps	Isochron Age Ma	Trapped Ratio of $^{40}Ar/^{39}Ar$
L290	84.72±0.3	71.04	84.16±1.1	309.48±10.9
L601	63.83±0.6	56.62	61.10±2.9	308.34±10.7
L87	57.01±0.2	72.36	57.52±0.8	288±7.73



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The Kohistan island arc, N. Pakistan, a geochemical perspective on arc stratigraphy

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The Kohistan terrane represents a Cretaceous arc initiated offshre of Asia as an intraoceanic arc. At ca, 100Ma it was accreted to the southern margin of Asia, and subsequently behaved as a continental margin volcanic arc until being underplated by continental India at the initiation of the India-Asia collision.

Three main volcanic sequences have now been recognised in the arc: from the south, these are the Kamila amphibolites, the Jaglot Group and the Chalt Volcanic Group. On geochemical criteria, Treloar et al. (1996) argued that the Kamila amphibolites can be divided into two suites: one which predated the arc and has a chemistry typical of ocean plateaux, and one which relates to the erection of a supra-subduction fore-arc on the ocean plateau sequence. They argued that subduction was to the north, and that the bimodal Chalt Volcanic Group, which contains deformed, pillowed lavas, some of which have basaltic komatiite - high Mg basalt to high - Mg andesite and boninite chemistry, was extruded into a back-arc basin. In contrast, (Khan et al., 1997) proposed that the direction of subduction was southwards, and that the Chalt Volcanic Group represents a fore-arc sequence, the Kamila amphibolites forming a back-arc basin.

In an attempt to resolve this difference, we present new geochemical data from both the Chalt Volcanic Group and Kamila amphibolite sequences, as well as the first full data set for the Jaglot Group. Preliminary interpretation of these data shows a clear geochemical transition from the rocks of the Kamila amphibolites to those of the Jaglot Group. This is consistent with the field evidence that the Jaglot Group rocks overlie the Kamila amphibolites with a consistent northward dip.

Although all rock units have clear subduction - related chemical signatures, those of the Chalt Volcanic Group are distinctly different from the others. The boninitic geochemistry of some of these rocks, and in particular the rare earth element pattern, bars a close similarity to the boninites from the Eocene Zambales Ophiolite in the Philippines (Yumul, 1996) and the Group III lavas from the Limassol Forest Complex, Cyprus (Rogers, et al., 1989), which are characteristic of a supra-subduction zone setting in a primitive intraoceanic arc or incipient back-arc or marginal basin.

Ongoing geochemical, isotope and modelling programmes should enable the erection of a model for the initiation of subduction, the evolution of magma source regions and the role of crustal contamination in magma evolution.

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Bending of syntaxes : consequences

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Syntaxis areas where orogenic structures seem strongly bent around a vertical axis are fundamental features of modern collisional orogens. The still active Himalayan mountain belt is one example that terminates at both ends into nearly transverse syntaxes [1]. The West and East Himalayan syntaxes (named after the Nanga Parbat and Namche Barwa, respectively) are crustal antiforms in which granitic and migmatitic rocks yield Cenozoic to very recent apparent ages [2,3].

The first part of this talk will emphasise that both syntaxes present remarkably similar thermomechanical evolution of basement rocks overprinted by Himalayan metamorphism and Pliocene - Pleistocene high-grade metamorphism and anatexis. Both straddle the same Neogene time span and have undergone rapid denudation, which links their continuing growth to the uplift that produced Tibet in the last few million years. A rise of the Moho level is recorded under Nanga Parbat [4]. No information on this topic seems available beneath the Namche Barwa. In Pakistan, the Hazara - Kashmir Syntaxis is the southern continuation of the Nanga Parbat Syntaxis [5]. In the Arunachal Himalaya, the Siang antiform [6] appears as the south-western continuation of the Namche Barwa syntaxis. All interpretations point to crustal scale folding as the driving mechanism that has produced these orogenic structures.

Folding and buckling instabilities as a response to layer parallel shortening are well investigated features in geodynamics [7]. Classical theories are restricted to the initial stages of instability development and to linear viscous, elastic and visco-elastic rheologies. Recent theoretical developments extend to waning stages of folding and to non-linear visco-plastic rheologies. However, gravity plays a fundamental role at a crustal or lithospheric scale, which means that new methods are needed to model folding of the oceanic [8] and continental [9] lithospheres.

We employ 2-Dimension FEM modelling to study shortening of the continental lithosphere driven by far field motions of relatively rigid plates over an invisid substratum (asthenosphere). Features of the model are:

1. Visco-elasto-plastic rheology. Viscous deformation is power law creep. Plastic yielding is according to Mohr-Coulomb plasticity.
2. There are three compositional layers: upper felsic crust, 25 km; lower mafic crust, 15 km; and subcrustal olivine lithosphere 70-140 km.

3. Boundary conditions are free surface, erosion and zero temperature at the top; zero differential stresses and fixed temperature at the bottom, compressional velocity and no heat flux at the lateral boundaries.
4. Erosion is modelled according to linear diffusion equation.
5. Second order implicit FEM is used to discrete the momentum and heat transfer equations. Because of the number of parameters controlling the style of folding we do not attempt any systematic study. We restrict ourselves to a particular example of continental shortening - the West and East Himalayan "syntaxes".

Modelling yields the following results:
1. Only cold (strong) lithospheres exhibit buckling with a wavelength of ca. 200 km. Significant amplification is achieved in the overall strain range of 10-25%.
2. Topography due to buckling is up to 5-10 km. Exhumation is limited by fold locking and the typical amount is ca. 20 km.
3. After locking up the first anticline, lateral fold propagation occurs.
4. The Moho is uplifted beneath crustal antiforms and one can define several Mohos at strongly deformed stages.
5. High heat fluxes are detected within the antiforms whilst tectonic overpressure as high as twice of the lithostatic value may build in limb areas.
6. There are broad small amplitude depressions around the growing anticline.

We extend point 6 to discuss the development of synformal basins on both sides of crustal antiforms. We propose that the Peshawar and Kashmir basins are such structural depressions. The synclinal Peshawar basin to the west is readily seen on any geological map as a structural analogue of the synclinal Kashmir basin to the east of the Hazara - Kashmir Syntaxis. This relationship and the possible correlation between these two synformal depressions were noted by [10]. Like the Karewas of Kashmir, the Peshawar basin has a thick Plio-Pleistocene to recent fill of alluvial sediments that began around 4 My. ago [11]. We note that both basins have the same beginning age as the syntaxis and that sedimentation developed in both basins, although their bulk history is that of surface uplift [12]. Our interpretation explains the location of both basins, which a ramping interpretation does not.

The kinematic model involving crustal folding to explain the Himalayan syntaxes is verified by our FEM dynamic modelling. In addition, first order features of the "cold model" of lithospheric folding fit well with geological observation. We conclude that buckling is a basic response of the continental lithosphere to shortening. We emphasise that dominant geological and physiographic features of Northern Pakistan formed during the last 4 Ma have been controlled by the growth of the Nanga Parbat syntaxis. This is true also for the less known eastern Himalayan Syntaxis.

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A preliminary account of sedimentology of Hazara basin from Jurassic to Eocene

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The Mesozoic to Eocene Hazara basin dominated by shelf carbonates is characterised by a distinct package of sediments punctuated by a number of diastems, hiatuses and unconformities. The environment of deposition vary from supratidal to shelf edge (250m) and from open shelf to restricted circulation anoxic conditions as a consequence of plate movement. The average lithified rates of sedimentation vary from 0.96 mm to 83.30 mm per 1000 years.

During upper Hettangian the Hazara landmass changed into a marine basin with the development of a transgressive shore line with the deposition of Datta Formation which overlies either Upper Proterozoic Hazara Formation or Cambrian Hazira Formation. It was deposited during open marine, lower to upper shoreface, lagoonal to subareal regimes (Chaudhry et al., 1995; Chaudhry et al., 1996; Chaudhry et al., 1997). It is composed of lenses, sheets and layers of poorly sorted, medium to coarse grained quartz arenites with rare grit and interlayers of carbonaceous shales, silty shales, marls and oolitic to pelletoidal limestones. The average lithified rates of sedimentation were approximately 2mm/1000 years. Provenence studies show derivation from an igneous metamorphic sialic Indian plate. source lying to the south.

The Samanasuk Formation represents an epicontinental intertidal environment with upper shelf ooidic-pelletoidal shoals deposited from Toarcian to Callovian. Cross bedding and burrows are frequent. The sediments are composed of ooidic-pelletoidal wackestones to grainstones, bioclastic limestones and dolomitic horizons. Rare calcirudites also occur. The oyster topped beds and hard grounds represent slow rates of deposition and subareal exposures. The average lithified rate of deposition was about 6 mm/1000 years.

At the close of Callovian a restricted anoxic environment prevailed and a condensed pyrite-rich and belemnite-bearing black shale- siltstone sequence represented by the Chichali Formation of Oxfordian to Kimmeridgian age was deposited. The lithified sedimentation rates were about 2.3mm/1000 years.

Strongly reducing conditions changed to mildly reducing conditions with better circulation in the Tithonian during which the Lumshiwal Formation was deposited. It is composed mainly of glauconitic quartz arenites (Chaudhry et. al., 1994, Chaudhry et. al., 1997) with submarine hard grounds. These sediments are generally cemented with quartz, clay, iron oxides or glauconite. The ubiquitous glauconite indicates slow rates of deposition in mildly reducing environments. The suite of heavy minerals once again indicates a sialic igneous metamorphic provenance. The average lithified rates of sedimentation were about 0.96mm/1000 years.

In the Cenomanian, the Hazara basin deepened (upto a maximum of 250m as shown by the presence of oligostigena (Ahsan et. al., 1993, Ahsan et. al., 1994, Chaudhry et. al., 1992) during a major global transgression with deposition of Kawagarh Formation composed of. pelagic mudstones, wackestones and packstones. The upper beds (Maastrichtian in age) of Kawagarh Formation were exposed during a wide spread regression due to initial contact of the Indian with the Kohistan arc at 67±2 Ma prior to main India-Eurasia collision (Bard et. al., 1979) at 50 - 55 Ma. The average lithified rates of sedimentation of Kawagarh Formation have been estimated as 9mm/l000 years (Chaudhry et. al., 1994).

The subareal exposure under subtropical conditions reworked the Maastrichtian sediments of the Kawagarh Formation into fire clay, pisolitic bauxite and laterite. The rate of accumulation of these residual sediments of Hangu Formation are about 1.77mm/1000 years.

The crustal bulge which developed due to initial Kohistan arc-Indian Plate contact at 67±2Ma (Bard et. al., 1979; Chaudhry et. al., 1994) subsided by Thanetian and Hazara Basin once again changed into an open shelf to deposit nodular Lockhart Limestone in shallow shelf (subtidal) ermronments. The sediments of the Lockhart Limestone rich in benthic forams are composed of mudstones, wackestones and packstones. The average lithified sedimentation rates are worked out at about 30mm/1000 years.

The carbonate shelf developed into a siliciclastic basin with increased turbidity which supressed deposition of carbonates and olive grey splintary shales of Patala Formation with occasional limestone bands were deposited. The average lithified rates of deposition of Patala Formation are about 30mm/l000years.

During Ypresian the siliciciastic basin developed into a carbonate platform and deposited the Margala Hill Limestone in upper subtidal to lower subtidal environs. It is composed of mudstones, wackestones and packstones with many intercalations. The average rates of sedimentation of the Margala Hill limestone are about 62.5mm/1000 years.

The Chorgali Formation is composed of shales, mudstones, wackestones and packstones. The same environment that deposited the Margala Hill limestone deposited the Chorgali Formation. The average lithified rates of sedimentation were about 83-3mm/1000 years.

At about 55-50 Ma, the main collision between India and Asia took place due to which during Lutetian the sea started retreating. In Hazara wfth brief episodes of transgression. The Kuldana Formation represents these changing conditions and is represented by red continental shale-siltstone beds with intercalations of fossiliferous marine limestones. The average lithified rates of sedimentation of this unit are about 71.1mm/1000 years. Thereafter the Himalayas started rising with the deposition of continental molasse represented by Murree Formation with a Himalayan rather than Indian plate provenance.

The cement stratigraphy for carbonate sediments of Hazara basin (except Samanasuk Formation) shows that non ferroan microcrystalline calcite was penecontemporaneous with deposition. The second stage involves that dolomitization of calcite and bioilasts. Replacement of dolomite and bioclasts by ferroan calcite is the third stage. The final stage is the silicification of groundmass, bioclasts and at places the dolomite rhombs. In Samanasuk Formation dolomite occurs as first stage supratidal cement and sparite as early burial cement.

In addition to submarine and very early calcite cement the follovang order in cement stratigraphy for the pre-Danian clastic units of the Hazara Basin has been worked out: i) thin rim early quartz cement, ii) kaolinite cement, iii) early calcic cement, iv) dolomitic cement, v) ferroan calcite cement, vi) deep burial quartz cement and vii) lite diagenetic kaolinite cement.

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Sedimentary response in the Yingge Sea basin to uplift of the western Yunnan plateau

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The Western Yunnan Plateau (WYP), a part of the Qinghai-Tibet Plateau (QTP), is located at the southeastern edge of the QTP. The Yingge Sea basin (YSB), coupled with the WYP, lies along the southeastern portion of the famous Red river fault zone (RRFZ) and is a pull-apart basin in age of Tertary-Quaternary. Through several investigations of sedimentology, stratigraphy and isotope geology in the YSB comprising 11,500m sediments and the Cenozoic terrestrial basin group including the Rongchuan basin, the Yingjiang basin and the Genma basin and river terraces in the WYP a complete uplift history of the WYP is obtained as follows:

1. During the 20.0-18.0Ma espisode, the WYP produced a series of small-scall strike-slip basins while the YSB received little sediments. This probably reflects that WYP just started uplift.
2. During the 16.2-11.0Ma espisode, the sedimentary rate and flux increased rapidly, the sedimentary enviorment and paleocommunity changed clearly in the YSB and the basins of the inner plateau tilted from south to north or suffered denudation in the time from 13.0Ma to 11.0Ma. These indicate that the plateau uplift very quickly at that time.
3. During the 11.0-5.3Ma espisode, the sedimentary rate and flux in the YSB decreased suddently. Equivalent to this, the basins of the inner Plateau received undercompensated and lowcompensated sediments. This reflects that the Plateau possiblely suffered denudation and deplanation at this interval and the deplanated altitude is about 800 above sea level.
4. During the 5.3-1.6Ma expisode, the sedimentary flux and rate in the YSB increased at very high point, the basins of the inner plateau suffered denudation against the 3.0-a.6Ma interval, the denudation rate arrived the maximum at 2.5Ma which caused an unconformity between Plioncene and Quaternary. Those facts show the plateau uplift rapidly at this interval. The denudated thickness of the strata put forward by paleovegetaion and vitrnite reflectance suggests that the uplift arrived 1700-1900m range and the plateau formed basically.
5. From 1.6Ma to now, the YSB deposited 2160m marine sediments in age of Quaternary and the sedimentary flux arrived the maximum. Since 0.647Ma, the plateau have uplifted 700-610m. At the 0.386-0.09Ma interval, the uplift rate also arrived the maximum which is 1.24mm/a.

The Thakkhola - Mustang graben (Nepal) and the Late Cenozoic extension of the Himalaya

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The Thakkhola - Mustang graben is a high intermontane basin, altitudes varying between 3000-4000 m at the bottom to more than 6000 m on the surrounding summits. Located at the northern foot of the Dhaulagiri and Annapurna ranges, fram by the Paleozoic and Mesozoic sediments of the Tethyan series, it was filled with a thick series of probably Plio-Pleistocene age, the Tetang and Thakkhola formations (Bassoullet et Colchen, 1974; Fort et al., 1982).

The structural pattern is characterised mainly by a series of transverse faults and cleavages, striking N.02°-04°, the Thakkhola fault system, responsible for the development of the dissymetric graben. This system corresponds to plurikilometric faults of regional W-E to WNW-ESE extension, which are well expressed on the western part of the basin.

The precise study in the substratum and in the sedimentary filling in several outcrops indicate in polyphased faulting with the relative chronology:

Before the sedimentary filling (Miocene)

1. NNW-SSE to N-S compression created conjugate fault system in the substratum with N020-040 and N 180-010 sinistral and N 130-140 dextral strike slip faults mainly in the western border and WNW-ESE extensional faulting some parts in the Tethyian series as indicative the age at 14 Myr for the N. 020-040 normal faults of the Marsyandi valley (Coleman & Hodges, 1995) ;

During the sedimentary filling(Pliocene-Pleistocene)

2. W-E to NNW-ESE extension with N 180-010 and N 020-040 normal faults and tectonic subsidence of the graben and Tetang sedimentation period (Pliocene age) ;
3. N-S minor compression created N020-040 as sinistral strike slip major fault and N 130-140 as dextral strike slip faults and E-W doming of the Tetang deposits followed by a short erosion (cf. unconformity between Tetang and Thakkhola formations) ;
4. WE to NNW-ESE major extension and tectonic subsidence of the graben and Thakkhola filling (Pliocene-Pleistocene) ;

After the sedimentary filling (Pleistocene-Holocene)

5. NE-SW compression with recurrent faulting of the N 020-040 and N 180-010 dextral strike slip faults and N 075-095 as sinistral strike slip faults.

A general extension with recurrent faulting of the N 020-040, N 180-010, N 075-095 and N 130-140 as normal fault during the recent time (cf. N-S and NE-SW normal faults in quaternary formations of the terraces).

In conclusion, we discuss the faulting geodynamic interpretation about considering:

- the geographic situation of the Thakkhola - Mustang graben between the Yarlung Tsangpo suture zone and the metamorphic basement of the High Himalaya and its individualisation in the Tethyian series above the North Himalayan Fault ;
- the geodynamic conditions of the convergence between India and Tibet (Tapponnier et. al., 1986) and the dextral East-West shearing between Himalaya and Tibet (Pecher et. al., 1991);
- the extensional faulting mainly localized from the Pliocene in the north Himalayan in particulary in the Thakkhola - Mustang graben.

Geochemistry of metabasaltic and metadoleritic garnet granulites from the NE Nanga Parbat - Haramosh Massif, Northern Pakistan: preliminary results

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In the NE Nanga Parbat - Haramosh Massif (NPHM) of the NW Himalayan syntaxis (Stak and upper Turmik valleys, Susrut Nala) metabasaltic and metadoleritic dykes of garnet granulite intrude garnet-kyanite-biotite-muscovite para- and orthogneisses of the Higher Himalayan basement complex [1, 2].

Compositionally the garnet granulites are tholeiitic to mildly alkaline basalts and (rarely) picritic basalt and picrite. In a Ti-Zr-Y diagram most of the samples plot in the field of within plate basalts as defined by [3] whereas the metapicrites and a few metabasalts lie in the compositional field of ocean floor basalts because of their higher contents of Y.

Significant variations of major and trace element contents occur between the metapicrites (mg# 0.75-0.67) and the most evolved metabasalt; an alkali metabasalt from the Subsar area of the Indus valley (mg# 0.27), which still has the pristine igneous plagioclase and titaniferous ferroaugite. Harker diagrams show a good agreement in trends of major and trace elements plotted against an index of magma evolution such as MgO and the less mobile element Zr. A positive correlation exists between Zr and P_2O_5, K_2O, TiO_2, Ba and Rb, whereas Ni and Cr are negatively correlated with Zr. SiO_2, Na_2O, Al_2O_3, Y and Sr show more scattered trends relative to Zr. Such trends, particularly the enrichment in incompatible elements, and major elements variations are explained by polybaric fractional crystallization of olivine, clinopyroxene and plagioclase [4] at low pressures and low amounts of water.

MORB-normalized spidergrams show subparallel trends of enrichment up to 100x MORB values and variable depletion of Ni and Cr from the metapicrite to the alkali metabasalt. The observed enrichment is consistent with the effects of the fractional crystallization mentioned above. A negative Sr anomaly is observed for all samples with the exception of the metapicrites. The Sr anomaly is larger for the alkaline metabasalt and it might be explained as the effect of plagioclase fractionation. REE data for one metapicrite and three metabasalts indicate a positive Eu anomaly (Eu/Eu*=1.15) and LREE enrichment for the metapicrite, whereas the metabasalts appear more REE-enriched with higher LREE/HREE ratios. The positive Eu anomaly decreases with the increase of the REE content. These features may result from fractional crystallization after removal of mafic phases in an earlier magmatic stage or by presence of inherited cumulus plagioclase previously equilibrated with a magma in conditions of very low oxygen fugacity. However, the range observed in contents of REE and other trace elements (for example Rb and Nb) cannot be completely accounted for by a simple mechanism of fractional crystallization starting from a parental magma of composition similar to the less evolved metabasalts. Open-system magmatic fractionation or element mobility during metamorphism is therefore invoked for these cases. Further isotopic studies could better identify the dominant mechanism of differentiation and the possible role of crustal contamination.

The NPHM metabasic dykes are geochemically similar to the Lower Carboniferous Baralacha La Dyke Swarm of SE Zanskar, Upper Lahul and NW Spiti [5] and to the amphibolite-facies metabasaltic dykes of the Higher Himalayan basement of the Western Syntaxis area [6]. On the other hand, different trends of Ba, Rb and Y during fractionation and the different contents of TiO_2 and P_2O_5 suggest a different magmatic evolution of the NPHM metabasic dykes relative to the Middle Permian Panjal Trap basalts of SE Zanskar, Upper Lahul and NW Spiti studied by [5].

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Photang thrust sheet - a subduction zone accretionary complex structurally below the spontang ophiolite

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Detailed structural, sedimentological, palaeontological and geochemical data are presented from the Spontang ophiolite and associated allochthonous thrust sheets in the Ladakh Himalaya, NW India. A distinct thrust sheet of subduction zone accretionary complex rocks has been identified immediately underlying the ophiolite (Photang Thrust Sheet)[1]. The acereted units consist of up to 140 m thick sequences of basaltic lavas and pillow lavas capped by sediments ranging from late Permian to late Cretaceous in age. Other thrust slices consist of tectonic melanges containing blocks of carbonates (late Permian-Late Cretaceous), chertz, serpentinites and basaltic lavas and pillow lavas. The youngest rocks dated are late Cretaceous pelagic carbonates immediately beneath the Photang Thrust.

Immobile trace element geochemistry of volcanic rocks from the crustal section of the ophiolite and the Photang Thrust sheet is used to infer their likely tectonic environments of formation. Within plate alkali basalts and highly evolved phonolites have been identified as forming the thick volcanic sequences of the Photang thrust sheet and are interpreted as remnants of former ocean islands. Isotropic gabbros, sheeted dykes and pillow lavas of the ophiolite show a consistent MORB chemistry. Samples from a volcanosedimentary sequence exposed east of the Spontang ophiolite show geochemistry consistent with formation at a destructive plate margin. Blocks from each of these groups are present within the tectonic melanges of the Photang thrust sheet.

The Spontang ophiolite was located in the hanging wall of a north dipping subduction zone until the late Cretaceous when obduction onto the outer shelf of the north Indian continental margin began. This subduction zone is entirely separate to that responsible for volcanism in the Dras arc, which lay over 1000 km to the north in the Late Cretaceous. In contrast to Reuber et al. [2] who presented Eocene dates from the mélange at the southern margin of the ophiolite, the youngest sediments we have identified immediately beneath the Spontang ophiolite are Late Cretaceous in age. The Eocene mélange has been re-interpreted as arising from later stage re-thrusting of the ophiolite onto the Tertiary sediments of the Indian margin following India-Asia collision [3].

Previous arguments opposing Late Cretaceous abduction have centred around the stratigraphy of the northern Indian continental margin sediments. Detailed structural mapping in the shelf sediments, combined with published stratigraphic data [4] has enabled us to constrain the thickness variations in the Cretaceous - Early Tertiary formations across the width of the original undeformed passive margin. Two stratigraphic columns corresponding to the outer and inner shelf have been backstripped and the tectonic subsidence calculated. We demonstrate that the subsidence history is consistent with a Late Cretaceous loading of the continental margin, prior to India-Asia collision in the Eocene.

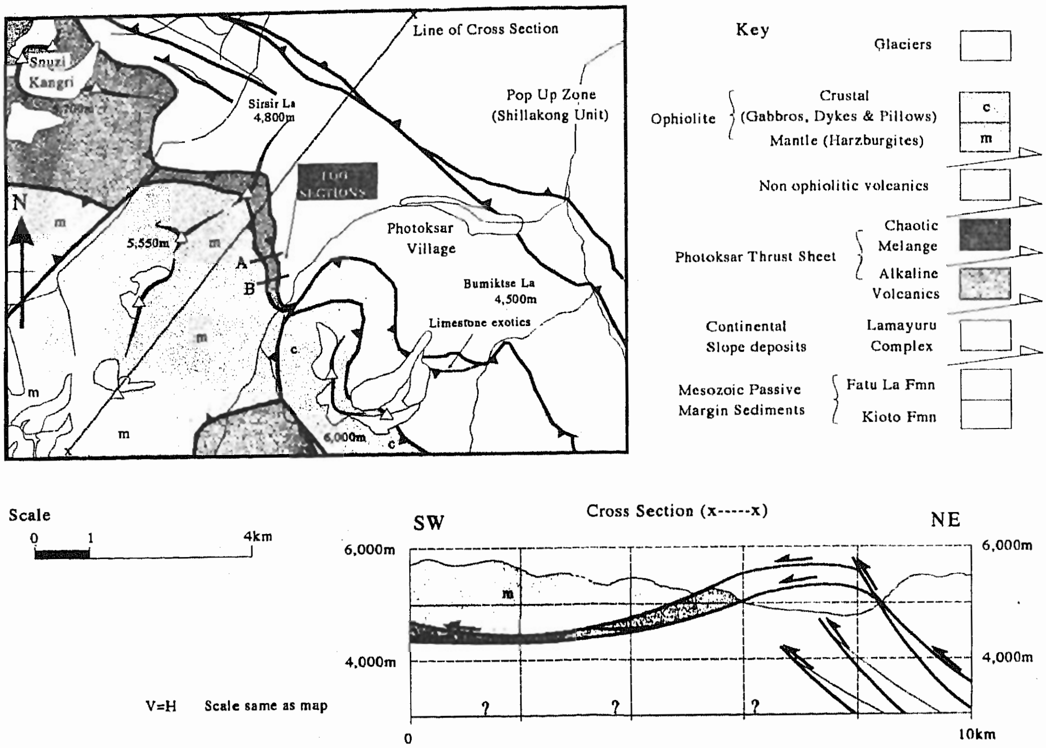

Fig. 1

1. Corfield R.I., Searle M.P. & Green O.R. in preparation Photang thrust sheet - A subduction zone accretionary complex structurally below the Spontang Ophiolite
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Late Cretaceous obduction of the Spontang ophiolite, Zanskar mountains, NW. India: The evidence and tectonic implications

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The Spontang ophiolite lies 30 km south of the Indus suture zone on top of deformed Tethyan passive margin sediments of Permian to Middle Eocene age. It is one of the few remnants of Tethyan ocean floor in the Himalaya so the abduction history is vital to our understanding of the collision zone.

Late Cretaceous versus Eocene abduction of the Spontang ophiolite has been a long running controversy in Himalayan geology and has often been the source of lively debate at previous workshops, most recently last year in Rome.

Six months detailed mapping of the ophiolite over the last three years, with the aim of resolving this problem has produced considerable new evidence (Corfield & Searle, 1996; Corfield & Searle, 1997; Searle, et. al., 1997). Here I review this evidence alongside the previous arguments (Colchen et, al., 1987; Fuchs, 1982; Gaetani & Garzanti, 1991; Reuber, et. al., 1992; Searle, 1986).

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Paleoclimatic reconstruction of the Late Pleistocene loess-paleosol deposits in the Attock basin, north western Himalayan foothills, Pakistan

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Late Pleistocene (approx. 18-130ka) loess-paleosol deposits exposed along the Haro river, Attock basin Pakistan, north western Himalayan foothills has been studied for stratigraphy, particle-size distribution, geochemistry and paleoclimatic investigation. The deposits cover approximately 30km^2 area and are up to 20 meters in thickness. The deposits are mostly composed of less-weathered loess while at least seven highly-weathered paleosol beds, PS-1-7 in descending order, are intercalated. Loess beds are generally light brown to brown in color, poorly-stratified, porous, and calcareous. Paleosols are generally dark reddish brown in color and have vertical partings and solution cavities.

Particle-size distribution analysis of the loess-paleosol deposits shows that loess beds have generally unimodel, well-sorted, leptokrutic, and negatively-skewed particle-size population whereas the paleosols have bimodel and poorly-sorted population. Loess deposits are generally composed of high percentage of silt-size particles while paleosols are rich in sand-size particles. On the basis of median particle-size (Md in ϕ scale), silt content (in weight %), and modal analysis, the loess-paleosol sequence can be divided into two part: The lower part, below the PS-4 paleosol bed show relatively coarser population with smaller Md ϕ values and larger sand-content (wt. %) attribute to an increase of local input of coarser materials and/or aggregating fine particles caused by relatively active pedogenesis during the accumulation of loess deposits. On the other hand the upper part, above the PS-4, gives relatively finer population with larger Md ϕ values and larger silt-content (wt. %) representing lower pedogenic activity during the deposition. (Nizam-Din & Yoshida, 1997).

Geochemical analysis of the loess paleosol deposits shows that the loess has high weight percent Of SiO_2 and CaO with respect to the paleosol enriched in $A1_2O_3$ and Fe_2O_3. Stratigraphic variation of chemical composition and molecular weathering ratios (Retallack, 1990) in the loess-paleosol sequence also reveals a two fold division. The lower part shows high concentration of Al, Fe and Mn and a dominant effect of hydrolysis, hydration and Ca dissolution representing a humid and warm climate. Conversely the upper part shows relatively high concentration of Na, Ca, and LOI and is more oxidized, salinized, dehydrated which is probably caused by arid and cool climatic condition during the accumulation of upper part.

Similarly the magnetic susceptibility of the loess-paleosol deposits (Akram & Yoshida, 1997) also show a systematic variation. In the upper part these show low values marking arid climate and very high values in the lower part representing a comparatively warmer conditions.

These drastic changes in particle-size distribution, geochemical characteristic and magnetic susceptibility between the upper and lower parts of the loess-paleosol sequence possibly provides a terrestrial record of continental paleoclimate in the area during late Pleistocene: i.e. it can be interpreted in terms of relative strength of paleo-monsoon winds by the model in Chinese loess plateau (Heller et. al., 1991). That is, the lower part is marked by intense summer monsoon winds whereas the upper part is dominated by stronger winter monsoon winds. This climatic deterioration in the section may correspond to the climatic change from the Last Intergalacial to the Last Glacial epoch of Himalayan glaciation.

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Deformation, high-pressure metamorphism and cooling history of the eastern Himalayan syntaxis

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Introduction: The latest known eastern Himalayan syntaxis (EHS), resulted from the collision and the following indentation of the north-eastern Indian plate, is composed of the Lhasa block and the Namjagbawa massif (NBM). The Yarlung Tsangpo flows around the NBM, resulted in the biggest U-shaped canyon in the world. The above two units are separated by the Indus-Tsangpo suture [1,2].

Deformation in Eastern Himalayas Syntaxes: The compression between the Asian plate/Lhasa block and the Indian plate in EHS had been undergoing along the Indus-Tsnagpo suture (MMT), MCT, MBT and Guyu thrusts (GYT). This resulted in the subduction of Indian plate under the Lhasa block/Gangdese arc, the stacking of Tethyan sediments in the front of the Indian plate and the outcropping of Gangdese basement in the center of the Lhasa block.

Within the Northeastward NBM, the compression mainly occurred along the Duoxong thrusts (DXT) and Nanao thrusts (NAT). The Ar/Ar age for amphibole from a diorite intruding along the thrusts is 8 Ma.

There are two direction strike-slip faults in EHS. The North is the NW direction rightlateral Zayu strike-slip fault (ZSF) and Lhari strike-slip fault (LST). The U-Pb age for Zircon and Ar-Ar age for muscovite of two leucogranites veins 250km apart from each other along the LST indicate that the large strike-slip occurred at about 16-24 Ma. In the NBM, the NE trending Medog strike-slip faults (MSF) is right-lateral offset and the Pai and Nage strikeslip faults is left-lateral offset. Their peak activating K-Ar biotites age is 20-21Ma.

High-Pressure Metamorphism: The NBM show a decrease in metamorphic grade from the granulite through to amphibolite to greenschist through the NMT zone toward south of the MSF separated by the NAT and DXT. In the Northwestern terminus of the NBM, low- to medium-pressure granulites are outcropped. Some very high-pressure granulite relics occur within these low- to medium-pressure granulites such as garnet-kyanite and garnet-clinopyroxene granulites which yield peak metamorphic pressure of 12-18kb and a temperature of 750-850°C, followed by a rapid exhumation characterized by low- to medium-pressure granulite metamorphism at P=4-8 kb and T=700-800°C[3]. The U-Pb, Ar/Ar and Rb-Sr ages of the high-pressure granulites suggest that the time of high-pressure peak metamorphism was approximately 14-17Ma ago. Geochemical features of the high-pressure granulites show that their protoliths are sedimentary rocks in origin.

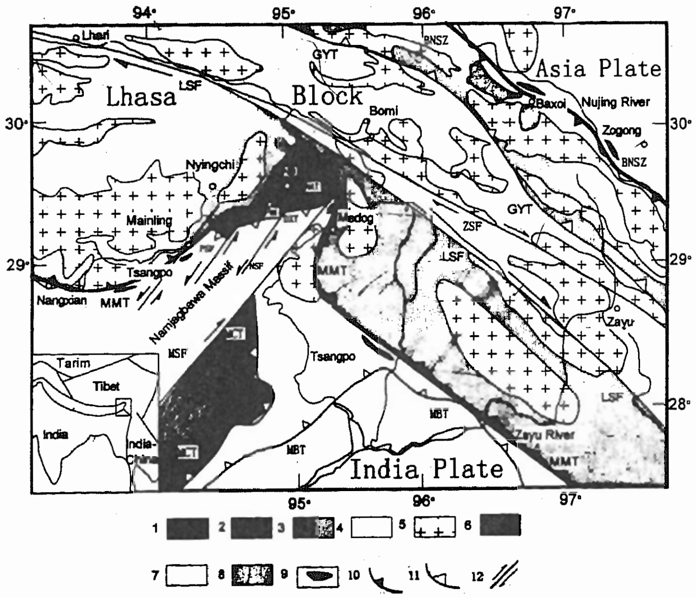

Fig. 1. Tectonic map of the eastern Himalayan syntaxis. 1. Namjagbawa complex; 2. High Himalayan crystalline; 3. Basement of Gangdese arc; 4. Paleozoic-Mesozoic sediments; 5. granitoid rocks; 6. granodiorite-diorites; 7. Cenozoic sediments; 8. calcic volcanic rocks; 9. ophiolites; 10. suture zones; 11. thrusts; 12. strike-slip faults; BNSZ = Bangong-Nujang suture zone; DXT = Duoxong thrust; GYT = Guyu thrust; LSF = Lhari strike-slip fault; MBT = Main boundary thrust; MCT = Main central thrust; MMT = Main mantle thrust; MSF = Medog strike-slip fault; NB = Namjagbawa; NAT = Nanao thrust; PSF = Pai strike-slip fault.

Cooling History of EHS: A series of samples (more than 60) for fission-track dating was collected from representative granite batholiths in Lhasa block, some granodiorite-diorites and metamorphic rocks in NBM. It is interesting that except one batholith from Lhasa block. almost all fissiontrack ages of apatite of the EHS, occupying an area of nearly ten thousand square kilometers, are of 0.16-3Ma. Furthermore, in the NBM, the apatite ages (0.16-1.5Ma) are very close to zircon fission-track ages (3Ma) with a lag of less than 2Ma and all the K-Ar ages for biotite of metamorphic rocks and granodiorite-diorites range 2-3Ma. All the petrologic, thermobarometric and geochronologic data mentioned above show that there is an accelarative uplift since 3Ma in the EHS, specially in NBM [2]. The average uplift rate is 3-4 km/Ma in the whole EHS and 5-10km/Ma in the NBM after 3Ma respectively.

Conclusions: The above mentioned structural, metamorphic and isotopic studies provide a constraint on the tectonic evolution of the EHS. The P-T history recorded by the high-pressure granulites shows that the Tethyan sediments in front of Indian plate were once subducted and equilibrated in the upper mantle conditions (70km depth) at middle Miocene (14-17Ma). The onset of largescale thrusting, strike-slipe faulting and magmatic activities must have begun before or coeval with the time of the high-pressure metamorphism. A rapid exhumation of the high pressure granulites marked by the low- to medium pressure granulite metamorphism, resulting from the granodiorite-diorites underplating, had occurred soon after the peak metamorphism. After 3Ma, the EHS began an accelerated uplift with the whole Tibetan Plateau.

Acknowledgements: This work was supported by National Natural Science Foundation of China and Chinese Academy of Sciences

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Tectonics of the Indus suture zone in Northwest Pakistan

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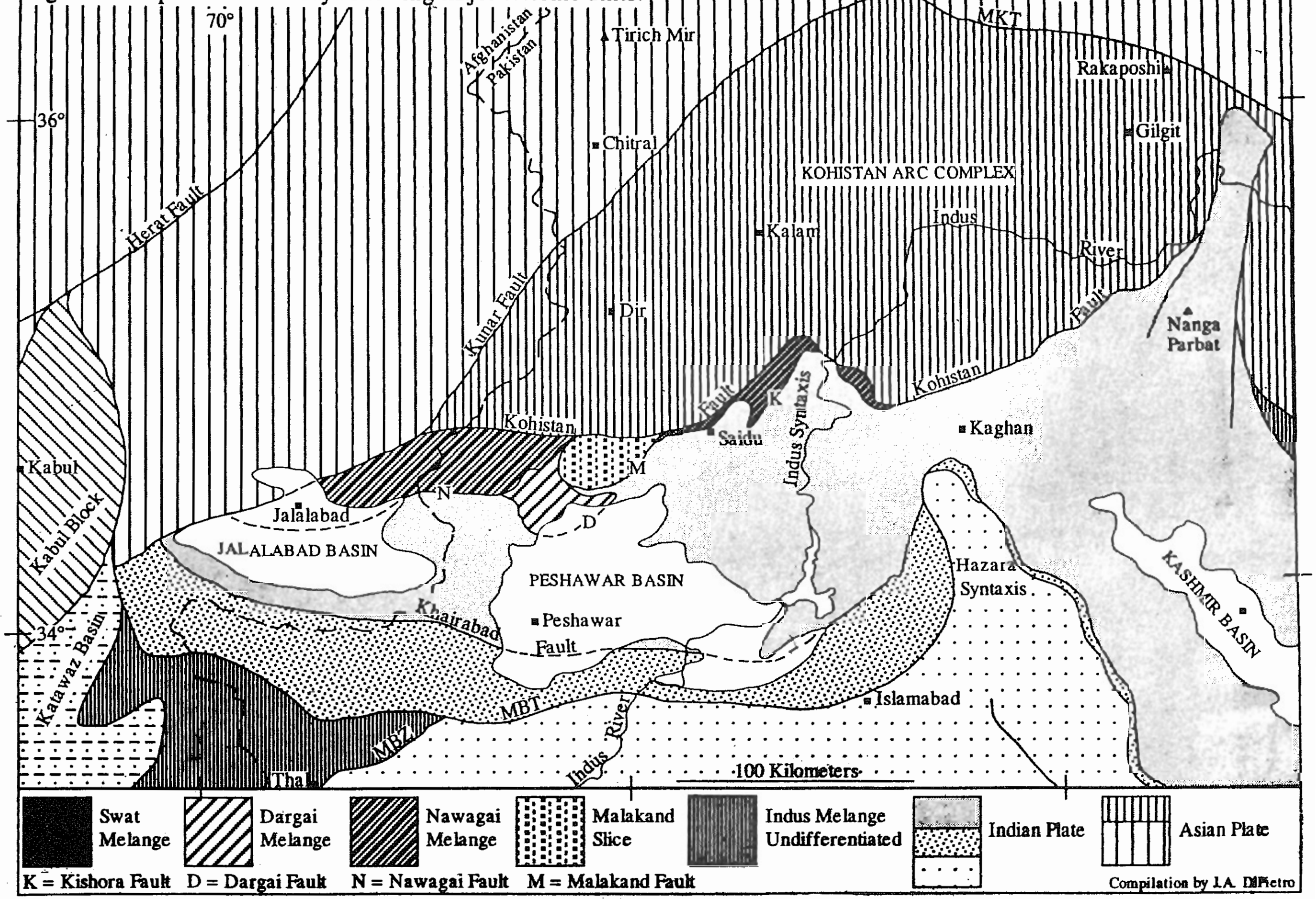
The Indus suture zone in northwest Pakistan is composed of three internally imbricated mélange slices (Fig. 1). All three slices contain greenstone, serpentinite, talc-schist, and phyllitic schist. The "Swat" mélange is characterized by blueschist; the "Dargai" mélange by ultramafic rocks, and the "Nawagai" mélange by marble. The basal fault of each slice is the Kishora, Dargai, and Nawagai fault, respectively. The Swat mélange extends from the Indus syntaxis westward to Malakand where it is truncated by the Malakand slice which is an allochthonous block of metamorphosed Indian plate rock. Farther west, the Malakand slice is truncated by the Dargai mélange which, in turn, is truncated by the Nawagai mélange. All four of these fault slices overlie a coherent stratigraphy of metamorphosed Indian plate rocks that extends southward to the Khairabad fault. The Main Mantle thrust (MMT) is the boundary between Indus mélange and the Indian plate. It is therefore equivalent to the Kishora, Dargai, and Nawagai faults where these faults overlie the Indian plate and is equivalent to the Main Boundary zone (MBZ) of Beck and others (1996). The large-scale fold sequence on the Indian plate is syn-metamorphic, west-vergent, overturned folds followed by late-metamorphic, N-S-trending, open folds. This fold sequence implies that the Indian plate was affected by E-W compression throughout metamorphism and not N-S compression as is widely assumed. The Malakand, Kishora, Dargai, and Nawagai faults are syn-metamorphic faults that pre-date the metamorphic peak in the underlying Indian plate. The Swat mélange appears to be the first of the slices to be emplaced. The existence of synmetamorphic, west-vergent folds on the Indian plate suggests that emplacement may have been from the east or northeast. Thus, the Swat mélange, and the underlying Indian plate, may have been affected by the same west-southwest-vergent deformation that is preserved cast of the Hazara syntaxis. The stacking sequence of the other

Figure 1. Map of NW Himalaya showing major tectonic units.



slices suggests that the Malakand slice, the Dargai mélange, and the Nawagai mélange were emplaced from the west or northwest following emplacement of the Swat mélange. Metamorphism on the Indian plate may have begun as early as 88 Ma based on a concordant U-Pb zircon age from Precambrian gneiss in the Indus syntaxis. This implies that metamorphism was a long-lived event that began with Late Cretaceous ophiolite abduction. Rather than initiate metamorphism, the India-Asia collision resulted in exhumation and cooling of the metamorphic pile between about 67 and 31 Ma. The Kohistan fault is a late- to postmetamorphic fault that cuts across the structural and metamorphic fabric of the mélange slices and the Indian plate. The Kohistan fault completely cuts out mélange in areas east and north of the Indus syntaxis and in the area north of the Malakand slice. Final emplacement of the Kohistan arc along the Kohistan fault probably occurred in the Oligocene. This emplacement, therefore, has no direct connection to the much older metamorphism that affected the Indian plate and gives no direct information to the timing of initial contact between India and Asia. West of Saidu, the Kohistan fault is a right-lateral strike-slip fault suggesting emplacement of the Kohistan arc from the west or northwest. Following the emplacement of Kohistan, foreland structures including the Khairabad fault and the MBT transported the metamorphosed Indian plate, the Kohistan arc, and the three mélange slices southward as a single block. In Afghanistan, the Kunar fault appears to truncate both the Kohistan arc and the Indus (Nawagai) mélange. Indus Mélange reappears south of the MBT but intervening faults suggest several 100 kilometers of displacement separating this mélange from the three mélange slices in the north (Fig. 1).

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A numerical modeling study on the porcesses of uplift and planation of Tibetan plateau and the comparison with an investigating model

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There are two absolutely opposite processes included in the altitude variation of the Tibetan plateau. One is raising process, which is controlled and dominated by tectonic activity in the interior of the earth. Another is planating process, which is caused by denudation and erosion of rain, wind and water. The planation is increasing with the uplift of the plateau. The differential equation of the plateau altitude with respect to time t can be given as

$$\frac{dh}{dt} = U - D \qquad (1)$$

where h is the mean altitude of the Plateau, U the uplift velocity and D the denuation rate. In this paper, D is defined as

$$D = \beta h \qquad (2)$$

U is set as

$$U = \alpha t \qquad (3)$$

Accoridng to statistical analysis and theoretical hypothesis: if palaeomagnetic field is normal the convective activity in earth is strong, which makes orogenic movement violent and the raising velocity of plateau high; conversely, if palaeomagnetic field is reversed the convective activity is weak, which makes orgeny slow and the raising velocity zero. During the positive geomagnetic polarity period the uplift velocity of the plateau was high. On the initial condition of $h_{t=0} = h_0$, the analytical solution of eq.(1) is obtained:

$$h = \begin{cases} \frac{\alpha}{\beta} t - \frac{\alpha}{\beta^2} + (h_0 + \frac{\alpha}{\beta^2}) e^{-\beta t} & (t \in t_p) \\ h_0 e^{-\beta t} & (t \in t_n) \end{cases} \quad (4)$$

With the Powell method for multi-dimensional function eq.(4) can be solved, and α_0, β_0, can be determined as

$$\begin{cases} \alpha_0 = 9.465x10^{-3} & (m^4 / Ma^2) \\ \beta_0 = 0.382 & (/Ma) \end{cases} \quad (5)$$

The Tibetan plateau has experienced numbers of processes of uplift and planation by turns since about 45 Ma when it begun to raise. A comparison between the results of the model and the conclusions from the field studies indicates that the former is quite similar to the later. The model results are able to basically reproduce the alternating processes of uplift and planation of the plateau in geological hisotry.

Before that, Zhong Dalai and Ding Lin were constructed a investigating model (IM) on the uplift of Tibetan plateau by using fission track ages of the eastern Himalayan syntaxis. Both of them presented a curve of uplift of Tibetan plateau, respectively. In the numeical model (NM) the curve stands for the height but in the IM the curve stands for the velocity. To compare the two curves, we interpolated the height-curve and differentiated the data then onbtained the velocity-curve of the NM. Drew the two velocity-curves in Figure 2, it appears that the tendencies of the two curves are similar. The correlation coefficient is 0.779, and it pass the confidence limit of $\alpha = 0.005$.

The major uplift periods are tabulated in Table 1 show correspondence with each other. Especially the second and the third period, they are almoslty the same.

TABLE 1. COMPARISON OF THREE MAJOR UPLIFT PERIODS OF TIBETAN PLATEAU BETWEEN TWO MODELS

	Investigating Model	Numerical Model
1	25Ma ~ 17Ma	28 Ma ~ 18 Ma
2	13Ma ~ 8Ma	12Ma ~ 8 Ma
3	3Ma ~ present	3Ma~ present

In the two models, it is regarded that after 3Ma.B.P. the plateau ascended at relatively high speed till it formed the present condition. By calculating, the mean ascending velocity (NM) of this period is 1.33 mm. a^{-1}, and according to the reference, the mean velocity is 1.5mm a^{-1}, it is very close to the results of the NM.

In both these data there is a common idea that the ascending process is multi-stage, repreated and inhomogenerous. It can be concluded that the NM is simple, however, because of the explicit physical processes, the appropriate control factors and the reasonable initial and boundary conditions, the results are satisfactory.

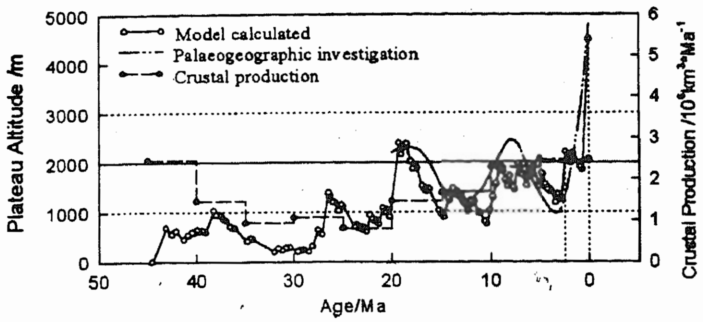

Fig. 1. Model-calculated integrated palaeogeogrphic research of the Tibetan Plateau's altitude with the plateau uplift(10) and the crustal production.(15)

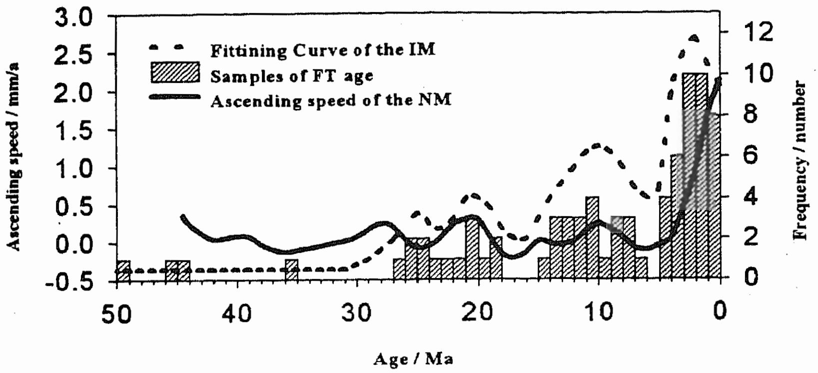

Fig. 2. Comparison of two ascending-speed curves of two models.

Jurassic brachiopod succession and palaeogeography of the Qinghai - Xizang plateau

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As is known, the Qinghai-Xizang plateau was formed by the convergence of the Gondwanan and Eurasian continental margins during the Cenozoic era after a long period of geological evolution in the Mesozoic. Recent studies indicate that the plateau is composed of several terranes from north to south including the North Kunlun Terrane, the Middle Kunlun Terrane, the Taxkorgan-Tiansuihai-Kokxili-Bayan Hor Terrane, the Karakorum Terrane, the Qiangtan Terrane, the Gangdise-Lhasa Terrane and the Himalaya Terrane. These terranes are mutually separated by approximately east-west stretching deep faults regarded as the sutures in different times. This paper deals with the stratigraphical sequences of Jurassic brachiopods from the Qinghai-Xizang plateau and the brachiopod geographic distribution in relation to plate movement and palaeoceanographic development based on previous work and the new extensive work by the present author in the Karakorum Terrane, The Qiangtang Terrane and the Himalaya Terrane.

According to the described 65 genera and 193 species of Jurassic brachiopods from the Qinghai-Xizang plateau, 28 assemblages for the Karakorum, Qiangtang, Gangdise-Lhasa and Himalaya terranes are established. The analysis of the affinity index of the faunas shows the close relation among the brachopods from the former three terranes and the faunas are also very similar to those of Pamir, Caucasus, Europe, West Yunna, Burman and Thailand. Therefore, they as some parts of Eurasian continental margin, should be attributed to the palaeobio-geographical realm of the northern margin of the Tethys. On the contrary, the Jurassic brachiopod fauna of the Himalaya terrane appears to have a close relationship with that of so called "Ethriopian province" of south shore of the Tethys (e.g. north and east Africa, Saudi Arabia and India). Based on faunas and strata, an aspect of palacogeographical evolution of the plate movemont and the palaeoceanographic development has been traced out. It indicates that along the Waser-RushanPshart-Bangongcuo-Nujiang-Mandeley suture, there might only have existed a narrow breakup-type short-lived pullapart basin developed from the interior of the Cimmerian continent during Jurassic time after the closure of the palaeotethys. This basin, mainly expanded in Middle Jurassic, did not form a true wide ocean to constitute a sufficient barrier preventing the migration of brachiopods. Otherwise, the Indus-Yarlung suture represents the principal part of the new Tethys, which developed for a long time (splitting in Late Permian, expanding from Middle-Late Triassic to Cretaceous and closed in Paleocene-Eocene). Therefore, the suture zone is the recognizable boundary separating the two Jurassic brachiopod biogeographic realms and consequently must be regarded as the major suture dividing the Gondwana from the Eurasia continent during the Mesozoic.

The sedimentary protoliths of the HHC in the Chamba-Lahaul area NW-Himalayas, India

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In the Higher Himalaya the relationship between Paleozoic and Mesozoic sediments of the Tethyan Zone and their Precambrian "basement", the so-called Higher Himalayan Crystalline (HHC), is still poorly understood. In literature the HHC is usually thought to build a crystalline basement for the Tethyan sediments, ignoring the fact of almost continuous sedimentation from the Precambrian to the Phanerozoic, e.g. Parahio valley (Spiti), Kurgiakh valley (Zanskar). The reasons are the obscuring of the sedimentary features of the HHC by deformation, metamorphism and granitic intrusions as well as the deposition of the Phanerozoic sediments on different erosion levels due to a structured topography of an Ordovician event.

The Pir Panjal range with a combination of a relatively good outcrop-situation and moderate metamorphic overprint represents good possibilities for studying the sedimentary structures of the HHC. Sediments of the Tethyan Zone are limited to the tightly folded, NW-SE trending Eastern Kashmir, Chamba and Tandi Synclines.

The most important feature for the understanding of this area is the gradual, continuous relationship of amphibolite facies metasediments near Kishtwar and northern Kullu Valley with the vast low grade areas in the central Pir Panjal with well preserved sedimentary structures. Taking the clear continuation of these sediments to the Haimanta Group in Spiti into account we suggest the name Haimanta Group (modified Haimanta system of Griesbach, C.L. 1891: Geology of the central Himalayas.- Mem. Geol. Surv. Ind., 23, 232p) for all sediments and metasediments of the HHC with maximum greenschist overprint, above the MCT and below the Early-Mid Cambrian Parahio Formation On the base of significant lithological and sedimentological differences in the area of investigation, the Haimanta Group is divided in three Formations. The age of these sediments devoid of any body fossils is not well constrained; due to regional comparison a Late Proterozoic age is probable, the more carbonaceous Parahio Formation yielded Early to Middle Cambrian trace fossils and brachiopods.

Haimanta Group: Phe Formation
Manjir Formation
Chamba Formation

The Chamba Formation comprises the lowest part of the sequence above the MCT up to the first diamictites of the Manjir Formation The Chamba Formation consists mainly of metapelites, metasiltstones and metagreywackes, subordinately interbedded with carbonaceous layers. The Formation shows an overall coarsening-upward trend, sedimentary structures like graded bedding, load casts and flute casts pointing to a turbitite type depositional environment.

The Manjir Formation consists of thick massive rarely stratified pebbly mud- and sandstones and metagreywackes, sometimes intercalated with thin metapelites. The matrix-supported, polymodal, poorly sorted clasts with sizes up to 1 m are dispersed in a chaotic manner. These diamictites contain subangular to rounded clasts mainly consisting of quartzites, greywackes, slates and subordinate granies and gneisses. Rarely striated clasts can be found. The depositional environment of these sediments is probably glaciomarine. Directly or some tens of meters above the diamictites follows a dolomitic layer of variable thickness, which is comparable with several Proterozoic carbonates in the world, succeeding glaciogenic sequences.

The Phe Formation encompasses alternating metagreywackes, metasiltstones and metapelites. The calcareous influence becomes more and more important towards the top of the formation. Commen sedimentary structures like graded bedding, load casts, flute casts, chevron marks and groove marks indicate a turbitite type depositional environment. There are several dark carbonaceous layers within the Phe Formation, most of them are occur locally. One of these layers turned out to be of regional importance and can be traced from Sach Pass in the west to Spiti in the east. We suggest the name Rothang Member for this special horizon within the Phe Formation It includes black siliceous slates, black carbonaceous carbonates and black cherts intercalated with yellowish, pyritous slates. The thickness varies between 10-50 m.

Implications: The Higher Himalayan Crystalline in vast low grade areas is not a crystalline basement *senso stricto* of the Tethyan Zone, but represent the Proterozoic to Cambrian sediments (Haimanta Group) below the Tethyan Zone with continuous sedimentation in some areas. The basement of the Haimanta Group itself is still a matter of discussion.

The Haimanta Group shows a development of turbitite sedimentation in its lower part, a glaciomarine deposit in the middle part and again turbitite sedimentation in the upper part with a shallowing-upward trend to the top.

Correlation of the glaciomarine Manjir Formationwith the Neo-Proterozoic glaciogenic Blaini Formation in the Lesser Himalaya is probable. Comparable lithological successions imply the deposition of the Proterozoic sediments of Higher and Lesser Himalaya in the same basin.

Palaeocurrent directions of the Chamba and Phe Formation defined by flute casts, chevron marks and foreset-dip show a dominant sediment transport direction to the SW-SE, whereas the Simla Slates of the Lesser Himalaya have a dominant sediment transport direction to the NW-NE. As a consequence the model of a Proterozoic sedimentation of the Higher and Lesser Himalaya both on the northern shelf of India turns out to be oversimplified. The source area for the clastic sediments in the Simla Slate can probably be identified in the Aravalli-Delhi Mountains, while the source area for the Haimanta Group is probably a yet unlocated Gondwana fragment in the North of the basin. The pre-thrusting, paleogeographic relationship between the Higher Himalayan and Lesser Himalayan sequences remains poorly understood.

The Alpine zonal metamorphism in the central Pamir: an age, main features, relationship with the deformation and the igneous activity

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The central Pamir is a northern outlying part of the Cimmerian-Alpine Pamir-Himalayan belt. It forms an arc stretching in near-latitudinal direction and includes deposits of all stratigraphic systems from Vendian till Neogene with the total thickness of about 10 km. This area was subjected to the rifting during Early Paleozoic when contrast volcanics and porphyritic granites were formed, Later on descending movements prevailed in the region; Variscan and Cimmerian folding poorly displaced, In Oligocene-Miocene the Central Pamir was drawn in the Alpine orogeny with the folding, thrusting, metamorphism and magmatic wedging.

The Alpine metamorphic belt traces in accordance with the stretching of rocks. It consists of the series of thermal anticlines and granitegneissous domes connected with them. There is an intermediate high-pressure type metamorphic zonation, the metamorphic grade being increased from the greenschist to the amphibolite facies towards the cores of the thermal anticlines. The chlorite-sericite, chloritoid, staurolite zones and the high temperature zone without staurolite are in pelitic rocks. Migmatites appear in the high temperature zone. Remobilized bodies of Early Paleozoic granite gneisses occur in cores of the Shatput and Jalan domes at the eastern part of the Central Pamir. There are gabbroids and pyroxenites which have experienced the metamorphism together with host rocks. Metamorhic rocks were subjected by the Na metasomatism (mainly albitization and scapolitization). The early development of kyanite in the chloritoid zone and association of this mineral with Mg cordierite and K-feldspar in the high temperature zone suggest high pressure metamorphic conditions. Paleothermometric and paleobarometric study shows the maximum temperature of 700-750°C and the pressure of 8-9 kb. Paleothermal gradient in the metamorphic domain was of 50°C/km.

Syenite and leucogranite bodies, pegmatite and aplite veins cut across metamorphic rocks. The anatexis was caused by the decompression which has also resulted in appearance of the late andalusite-bearing assemblage in metamorphic rocks. The metamorphism was accompanied by deformations. Lying folds and overthrusts formed during the maximum metamorphism stage, Later on they were refolded by large straight or overturned folds.

K-Ar dates of metamorphic and accompanying plutonic activity are in the range of 10-50 Ma. Granite gneiss from the core of the Shatput dome contains two types of zircons with U-Pb ages of 527 $\pm$ 2 Ma and 20 $\pm$ 7 Ma accordingly. The early Paleozoic age of the granite crystallization is born out by the Rb-Sr whole-rock dates of 523 $\pm$ 21 Ma, with initial $^{87}Sr/^{86}Sr$

of 0.7059 ± 0.0025 for the Shatput dome and of the 515 ± 9 Ma with initial $^{87}Sr/^{86}Sr$ of 0.7070 ± 0.0003 for the Jalan dome. The Rb-Sr whole-rock dates for high-grade metasedimentary rocks of the eastern part of the Central Pamir are about of 20 Ma. Recent emplacement of the leucogranite is suggested by the Rb-Sr data.

Structural geology around southern Nanga Parbat; Synkinematic granite and truncation of MMT footwall in the SW, deformation styles in Rupal, and the Shonthar Thrust traced to the SE

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The Main Mantle Thrust (MMT) is the regional contact between collider India and the overthrust Kohistan-Ladakh fossil island arc in the Pakistan Himalaya[2]. The Nanga Parbat-Haramosh Massif (NPHM). Pakistan [NW Himalaya syntaxial region] is a tectonic half window of partly re-worked, largely Proterozoic, Indian plate rocks that have been exhumed from beneath Kohistan-Ladakh[3]. Early Himalayan age, general MMT thrust displacement is modified by very young (e.g. 1.4 Ma leucogranite Th-Pb ages[4]) tectonism at Nanga Parbat Haramosh Massif (NPHM). Our investigations in SW NPHM reveal a complex interplay of features related to (1) MMT-convergence, and (2) subsequent NPFW general uplift and tectonism.

In the area that is encompassed by the N-S trending Bunar valley, and NW trending Diamir valley, the main fabrics trend mostly N to NNE. In this area, the Indian "cover" passive margin rocks that form the original MMT footwall include sequences of carbonates and amphibolites (probably the Permian "Panjal Traps") interlayered with metapelites. In Diamir valley, these are not more than a few 100's metres thick. Here, the regionally NW-dipping cover sequences and MMT hanging wall (Kamila amphibolite) are overturned to become SE-dipping. These overturned layers are traceable to a recumbent open fold (the Gashit fold) in Airl Gah near the village of Gashit, where they form the upper (overturned) limb. The hinge line and axial plane of the fold plunge gently NS of this fold, the lower limb is exposed, thus sequences are not overturned and are observed to dip moderately to steeply west. The thickness of the cover sequence increases markedly to the south; carbonates, amphibolites and metapelites of several kilometersm of structural thickness are present in the W-E Airl-Nashkin section, 10 km to the south of Diamir valley.

Structurally lower in the MMT footwall, and to the east, the cover sequence passes into a dominantly plutonic, ~5 km thick crystalline sequence that forms a continuous, ~30 km long, ~N-S belt with vertical to steeply E-dipping fabrics. The Diamir and Airl Gah (both ~W-E) valleys offer almost continuous outcrop sections through the belt. From these valleys, it is clear that a coarse-, to medium-grained biotite granite (the Jalhari granite) grades into granitic and porphyroclastic gneiss due to syn- to post-plutonism deformation. Jalhari leucogranite lenses (10's - 100's m thick) showing little to no sub-solidus deformation are separated by 10's - 100's m thick layers of gneiss where deformation of the granite has been localised. These higher strain layers anastamose around the granite lenses, and mark reverse faults that "climb" to the west. The granitic gneiss shows significant sub-solidus strain, including S-C porphyroclastic fabric whose sense of shear consistently indicates east side (NPHM) up and over west. Well-developed ductile/brittle shear bands and local fault gouge horizons, both of the same range of orientations as the ductile fabric, are also common. Late strain is often indicated by narrow (metres) zones where hydrothermal flux has developed thick biotite accumulations. Spectacular asymmetric folding (cm-wavelength) of the biotite layers indicates east side up and over west. In the eastern portions of the Diamir valley section through the granite, a series of highly stretched, constant width (10-30 cm) amphibolite sheets can be followed for >100's m in continuous outcrop. These are parallel to sub-parallel to the deformed Jalhari granite. If these amphibolite sheets pre-date the granite, they imply a very large contrast in mechanical competence both during and after intrusion of the Jalhari granite. Th-Pb microprobe *[UCLA's Cameca IMS1270]* analyses of monazites separated from deformed and undeformed portions of the granite give ages ranging from 3-12 Ma[5].

Overall, the granite gneiss belt defines a N-S trending, W-vergent reverse sense shear zone ~5 km in width. We term this the Jalhari shear zone. The E over W displacement sense of the Jalhari shear zone is consistent with the development of the Gashit fold, and with the upper limb that includes the overturned cover/MMT layers. This shear zone forms the mechanical continuation of the main Raikhot Fault (a NW-vergent reverse fault with NPHM in the hanging wall[6]). The Raikhot Fault is much narrower (<<5 km) however, and represents more focused strain.

The geology between the Jalhari shear zone and the central portions of massif is well exposed in the Diamir and Airl Gah valleys. The zone boundary is marked by brittle deformation within layers/lenses of retrograde (highly chloritised) metapelite. These then pass to more typical basement gneisses (e.g. showing metric banding due to differing Fe-weathering & biotite content). From here to Rupal valley, structures are more complex. Across Mazeno Pass, the 1.4 Ma[4] pluton shows evidence of some normal motion associated with it's emplacement. (top to NW on steep, NW-dipping fabric). Principal gneissic fabric is N-NE trending. In places this is cut by quartz-pegmatites, and by leucogranite dykes that stem from the Mazeno Pass pluton. Some of the leucogranite dykes cross-cut the quartz-pegmatites, and in both cases, wall rock margins show normal sense of opening, but this may not be significant if (e.g.) the granite remained super-solidus during much of the strain.

Normal structures (top-to-NNW) are seen throughout Rupal valley. All, however, are brittle, probablv very late, and of minor displacement. Most are developed on older thrust planes that are ~W-E trending., the western portion of the Rupal Chichi Shear Zone (RCSZ[7]). There are vast thickness of orthogneiss in Rupal showing top to SSE thrusting. The NW-dipping fabric is continuous throughout the Rupal Face., biotite gneiss dips ~43°NW at the summit of Nanga Parbat. The Rupal Face is very steep. Locally, a ~2 km thick leucogranite with irregular margins intrudes western Rupal Face, above Shaigiri village (between -5000 & ~6800 m). This may be emplaced in the axial zone of a tight antiform with NW-dipping axial surface, and whose axial trace passes to the south side of the summit ridge. This antiform is seen on Chongra ridge (again NW-dipping) and can be traced to the "western antiform" (Edwards & Kidd, 1997) described from the Astor Gorge. In both of the valley walls, amphibolite, coloured marbles and metapelites are found as fairly homogeneously deformed metre-scale layers/lenses within the extensive orthogneisses. At lowest elevations in the valleys walls of central Rupal, numerous thick fault gouge zones are seen, possibly indicating that at least part of Rupal valley has provided a (topographic) local crustal weakness to focus late brittle deformation. In the southern portions of western Rupal (in Shaggin Glacier valley, and all along the south side of Rupal &

Toshain Glaciers) gnessic fabric dips SW to S and shows excellent SW stretching lineation, typically with a clear top-to-SSW sense of shear. Intrusive, now-L-tectonised granite pods[7] pre-date this fabric, which may be very young.

Part of our continuing work in Chichi Nullah (SE NPHM) has included mapping of the southern portion of the RCSZ whose margin is well exposed here. It is sub-parallel to the Chichi Nullah and marked by a contact between the non-coaxially sheared granitic orthogneiss (continuous north to central Rupal) and the extensive marbles, amphibolites and metapelites of local Indian plate cover sequences. The foliation of the cover rocks and the gneisses are largely parallel, and orientation switches from NW dipping (overturned) in northern Chichi, through vertical, to SE-dipping in southern Chichi. This is another example of southern NPHM "bulging out" in cross sectional view (c.f.[7]) In southern most Chichi, within the locally SE-dipping marbles and amphibolites, several reverse faults define a >200m wide, NW-vergent thrust zone. This is most spectacularly expressed by a clear box fold (box = 10's m^2 area of section) within the zone. The thrust is observed to continue SW over the southern wall of Chichi Nullah. It's surface trace can be drawn from here and confidently joined with the Shonthar (Gali) thrust that has been mapped in Azad Kashmir near the Pak-Indo Line of Control[8,9]. Also noteworthy is that in southern Chichi, the sheared orthogneiss of the RCSZ dies out. This is replaced (further south) by a largely undeformed, fine-grained leucogranite of several 100's km^2 area. The (apparently intrusive) margin of the granite does not visibly cut the foliation of the country rock (i.e. marbles). Close to the margin, the granite shows minor sub-solidus deformation, however, we found no part of the granite that can be termed a gneiss. The granite forms dull brown craggy towers along the tops of the valley walls, exactly like the sheared orthogneiss to the NE. We are investigating whether the granite and the orthogneiss may be originally related in some manner.

Discussion: The abrupt northward thinning of cover sequences in SW NPHM is orders of magnitude too large to be original depositional variation and there must be some type of tectonic excision. Large amounts of STDS-type normal motion have not been reported from the MMT - only collapse folding[10], or diffuse shear type deformation[11] both occurring structurally deeper within the MMT footwall. Similarly, we have found no compelling evidence around NPHM for substantial normal motion on the MMT Consequently, we suggest that a large-scale frontal ramp in the original MMT gave rise to a local duplex structure that imbricated thin slices of cover, and possibly basement. This model is consistent with our mapping in Niat Gah, the next main valley to the west of NPHM, where a basement slice occurring close to the MMT implies large-scale imbrication of the cover sequences.

We interpret the emplacement of the Jalhari granite to be at least partly syn-kinematic with exhumation of NPHM, intruded in discrete episodes between 3 and 12 Ma. Together with other granites that we have mapped around NPHM[7]. we find a lack of consistency amongst igneous cross-cutting relationships. It seems that there is no succession of compositionally disctinct melt products, and that a given type of melt is not restricted to a given time. This is consistent with our geochronologic studies[5]. Accordingly, we suggest that discrete episodes of anatexis have continued since ~12 (?) Ma (c.f.[5]).

The brittle normal fauting seen throughout the massif indicates that southern NPHM is in a state of collapse. It seems that there is a small value for normal stress on existing fractures of many orientation, and that only a small rotation of the stress field is required to switch from reverse to normal motion on preexisting fault surfaces. Focal mechanisms for resolvable seismic moments within southern NPHM are consistent, showing extensional first motion to ~6 km depth. With the exception of possible post-Himalayan (i.e. non-rotated) SSW-directed fabric in SW Rupal, however, there is no evidence for large-scale tectonic exhumation at NPHM.

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The prograde thermal history of the Nanga Parbat Haramosh-Massif, Pakistan

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The Nanga Parbat-Haramosh Massif, in Pakistan, is unique in the Himalaya in that it has experienced recent and rapid exhumation (approaching 4 mm/yr.; Whittington, 1996) with associated decompressive melting and leucogranite intrusion (Zeitler et al., 1994). Zircon rims and monazites recovered from high-grade basement gneisses have eilded young ages which have been interpreted by some workers (e.g. Smith et al., 1992) to indicate that a Neogene partial melting event was also related to this rapid upift. However, it remains to be established whether the entire massif underwent this event, and whether there is any part that preserves the earlier metamorphic history of this polymetamorphic terrane. The discovery of relatively low- grade metasediments along the margins, in particular in the south-eatstern corner of the massif, allows an investigation of this problem. The best exposure of these rocks occurs in the lower Rupal valley where they form a sequence of kyanite + staurolite + garnet mica schists with associated garnet amphibolites and calcsilicates. Nd model ages and E(Nd) values of these and other such metasediments cluster around 1.8 Ga and -14 respectively, allowing them to be correlated with the High Himalayan crystalline unit exposed elsewhere in the central Himalaya rather than with the basement gneisses of the massif, which are more readily correlated with the Lesser Himalayan Unit (Whittington et al., this volume). Here we present new garnet - whole rock Sm - Nd ages for these rocks and show that they experienced garnet - grade metamorphism at about 20-50 Ma. These data, together with P - T - t path significantly predating the recent exhumation - related event. This study illustrates the power of garnet Sm - Nd chronometry to see through late stage overprinting events, and the importance of a systematic approach to the study of polymetamorphic terranes.

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Structural and metamorphic evolution of the deep crust in the Hunza Karakorum, Pakistan

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The Karakorum metamorphic complex forms the southern most margin of the Asian plate with the northern limit of the complex in Hunza being marked by a tectonic contact with the Hunza plutonic unit. (Desio, 1964; Crawford & Searle, 1993). This granodiorite is a pre-collisional batholith that exhibits a strong foliation at its southern contact with the underlying metamorphic rocks. The southern margin of the complex is marked by the Shyok suture zone as described by Pudsey (1986).

A detailed map of the middle Hunza valley has been produced that illustrates the principal lithologies, structural features and locations where detailed petrology and thermobarometry has been carried out. Rocks ranging from staurolite through kyanite to sillimanite grade occur in the middle Hunza valley and exhibit an inverted metamorphic sequence with structurally higher units exhibiting the highest metamorphic grade. This is reflected not only in the mineral assemblages present, as previously noted by Broughton et al., (1985), but also in pressure and temperature estimates throughout the slab, extending previous work carried out by Okrusch et. al., (1976). This inversion appears to be a consequence of south directed ductile and semi-ductile shear and later brittle thrusting which emplaced higher grade units over those of lower grade in agreement with earlier work of Crawford and Searle (1993). P-T work shows a small variation in values for staurolite grade rocks, but those of sillimanite grade rocks show a greater variation in pressure estimates. Retrograde reaction textures have been observed in those sillimanite grade samples that have yielded lower pressures of 5.8 ± 1.2 and 4.4 ± 1 kb. Temperatures are typically 628 ± 41 to 674 ± 49 °C. These P-T patterns may reflect those seen in the Baltoro (Searle & Tirrul, 1991; Allen & Chamberlain, 1991; Lemennicier et. al., 1996).

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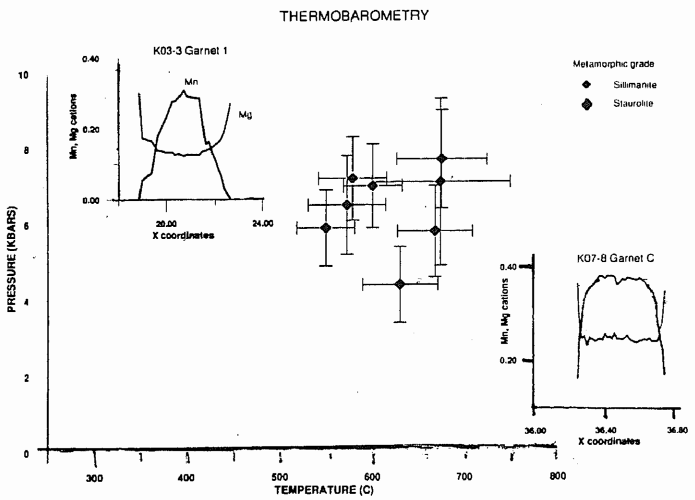

Fig. 1. Garnets from sample KO3-3 exhibit prograde growth zoning. This sample is from staurolite bearing schists. Garnets from a sillimanite grade sample, KO7-8, exhibit retrograde zoning patterns. Other sillimanite grade samples studied exhibit growth zoning profiles.

U-Pb geochronology on the timing of metamorphism and magmatism in the Hunza Karakoram

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U-Pb dating has been carried out on samples from the regional metamorphic rocks and leucogranites of the Hunza Karakoram with the aim of deciphering the thermal and magmatic evolution of the thickened Asian plate crust. The pre-collisional origin of the Hunza plutonic unit granodiorites forming the main component of the Karakoram batholith in this part of the range has been confirmed by three concordant zircon analyses yielding a U-Pb crystallisation age of 105.7±0.5 Ma (sample K94-24). The Hunza dykes consist of a co-genetic suite of granodiorites, monzogranites and leucogranites, which intrude the early phase of the batholith, as well as the sillimanite grade rocks to the south. One sample (K 94-23) of a garnet + biotite leucogranite dyke emanating from the southern part of the granite batholith and cross-cutting sillimanite gneisses and phlogopite ± ruby corundum marbles, has been dated using zircon, monazite and uraninite at 35.3±0.4 Ma, similar to the age of the Mango Gusar pluton south of the Baltoro plutonic unit to the east (37.0+-0.8 Ma, U-Pb on zircon; R.Parrish data in [1]. These two ages put an upper time constraint on sillimanite grade peak metamorphism and deformation in the Karakoram metamorphic complex south of the Karakoram batholith.

The Sumayar leucogranite is a small isolated tourmaline leucogranite with minor biotite and garnet intruding staurolite grade schists south of the Karakoram batholith in the Nagar region east of Hunza. It is a water-saturated, minimum-melt leucogranite similar to many High Himalayan granites, probably derived from melting of a pelitic lower crustal source [2]. U-Pb dating of zircon and uraninite yields an age of 9.2±0.1 Ma, whereas xenotime intergrown with zircon yields 8.55±0.15 Ma. The apparently distinct ages of intergrown zircon and xenotime could be explained by two periods of mineral growth (and partial resorption?) or by Pb loss in xenotime. This shows that this is the youngest crustal melting event in the Karakoram, and it cannot therefore be linked temporally to the Mango Gusar or Chingkiang-la plutons, south of the Baltoro granite, as previously thought. Several phases of granitic dyke intrusion are present in the Hunza section and dykes emmanating from the Sumayar pluton must be a younger phase than the Hunza dykes.

Metamorphic monazites were extracted from a staurolite + garnet mica schist (K94-20) from Nasirabad in the Hunza valley. The $^{206}Pb/^{238}U$ age of monazite is 15.5-16.5 Ma and due to probable excess ^{206}Pb, we interpret the crystallization age as 14-16 Ma. This must date the timing of monazite growth during staurolite-grade metamorphism, and is considerably younger than the previous estimates of a pre-37 Ma age for metamorphism of all the southern Karakoram metamorphic complex [3]. All presently available U-Pb geochronology from the Hunza and Baltoro Karakoram suggest that two metamorphic episodes are present: (1) a pre-37 Ma late Eocene - Oligocene sillimanite grade event south of the batholith in Hunza and the Baltoro region, and (2) a mid- to late Miocene ~16 Ma staurolite - kyanite grade event along the southern part of the metamorphic complex.

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The Zhob-Waziristan-Khost ophiolite

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Detailed field mapping, intensive biostratigraphic sampling, Landsat Thematic Mapper (TM) data and radiometric dating have revealed the existence of three regionally extensive and biostratigraphically distinct allochthons of Mesozoic sedimentary and ophiolitic lithologies that cover more than 20,000 km^2 of NW Pakistan/E Afghanistan.

The tectonostratigraphic units are from structurally lowest to highest: 1) Mesozoic to lower Paleocene parautochthonous Indo-Pakistani shelf strata of limited areal extent. 2) A lower ophiolitic nappe of pillow basalts hosting Cyprus-type massive sulphide deposits, Aptian-Albian to Senonian radiolarian chert and overlying olistostroms of shallow marine upper Jurassic limestone. 3) An upper ophiolitic nappe of serpentinized harzburgite, gabbroic/dioritic rocks and sheeted dyke complex. 4) A nappe of deep and open marine Triassic to Turonian-Maastrichtian shale, limestone, and sandstone. The three nappes were intensly folded before deposition of Paleocene siliciclastic and shallow marine carbonate strata and are separated by an angular unconformity from upper Paleocene and younger strata. Final emplacement of the Zhob-Waziristan-Khost ophiolite onto the Indian margin occurred after the Gallic and was followed by post-early Maastrichtian (probably Early Paleocene) collision of India with a continental block (Kabul or Eurasia), and thrusting of the Triassic to Turonian-Maastrichtian deep marine sediments onto the ophiolite nappes and all together E to SE onto the Indo-Pakistani shelf.

The sedimentary rocks associated with the Zhob-Waziristan-Khost ophiolite, the style of deformation, the presence of blueschists, and preliminary ^{40}Ar-^{39}Ar results of ~90 Ma show clearly that this ophiolite belt is older and not in continuation with the ~70 Ma old Bela-Muslim Bagh ophiolite belt of Balochistan.

The tectonic evolution of the Zhob-Waziristan-Khost area is an important key to understanding the pre-Himalayan evolution of the Indian margin. It is expected that ophiolites with similar emplacement age remain unidentified along the Himalayan suture zones.

Timing of thermal events in the Upper Kali Gandaki valley of central Nepal Himalaya

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The Annapurna detachment (AD), a segment of the South Tibetan detachment system, is exposed just north of Kalopani, in the Kali Gandaki valley of central Nepal. It juxtaposes greenschist facies biotite-muscovite psammites of the Annapurna-Yellow Formation of the Tethyan sedimentary sequence in its hanging wall with amphibolite facies biotite-garnet-sillimanite schist, garnet-diopside calc-silicate and leucogranitic gneiss of the Greater Himalayan metamorphic sequence (GHMS) in its footwall. We present new U-Pb and $^{40}Ar/^{39}Ar$ muscovite cooling ages from footwall and hanging wall rocks of the AD. These data bring additional constraints on the timing of metamorphism, melt production, and normal faulting in this area.

A 300 m thick leucogranitic orthogneiss from Formation III, which contains a variably developed foliation attributed to movement on the AD, was sampled for dating. This unit has been interpreted to be ca. 500 Ma based on Rb/Sr [1]. U-Pb data will be presented at the workshop.

In the AD zone, just north of Kalopani, an high angle, cross-cutting, 3 metre-thick tourmaline-muscovite leucogranite dyke intrudes both the calc-silicate gneisses of the uppermost GHMS and the Ms-Bt psammites of the Annapurna-Yellow Formation of the Tethyan sedimentary sequence. The dyke contains a magmatic layering, and a very weak foliation, both parallel to the AD fabric. It is interpreted to have been injected in the late stages of ductile normal shearing associated with the AD.

The uppermost part of the GHMS contains up to 15% leucosome material. Near Taglung, kyanite-bearing and sillimanite-bearing leucosomes are observed within sillimanite-bearing pelitic schists. Sillimanite has not been previously observed in the Kall Gandaki., and most importantly, this is the first known occurence of kyanite this high in the GHMS.

U-Pb geochronology is being carried out on these rocks and should provide answers to several questions: 1) Do U-Pb data confirm the Rb/Sr age obtained for the Formation III gneisses of the Kalopani area ? 2) Is the kyanite-grade metamorphism and leucosome production in the Kall Gandaki Eohimalayan is Eocene-Oligocene in age, as described further east in the Modi Khola [2] ? 3) Are the leucogranitic dykes, sillimanitc-bearing leucosomes, and the sillimanite-bearing pelites part of the Neohimalayan Miocene thermal event? U-Pb analytical results will be presented at the meeting.

Our $^{40}Ar/^{39}Ar$ work, combined with that of Vannay and Hodges [3] reveals that muscovite cooling ages from the lowest to the highest structural level in the GHMS are between 15.5 $\pm$ 0.3 Ma to 13.0 $\pm$ 0.3 Ma (Fig. 1). This confirms the interpretation of Vannay and Hodges [3] that the entire GHMS in the Kali Gandaki valley cooled through the muscovite Ar closing temperature (330-430°C) between 15 and 13 Ma, following Neohimalayan metamorphism. This is compatible with rapid tectonic exhumation resulting from extensional faulting.

Muscovites from the immediate hanging wall rocks of the AD yielded slightly younger ages, between 13.1 $\pm$ 0.5 Ma and 11.8 $\pm$ 0.4 Ma, testifying to late hydrothermal activity in the AD zone. This is compatible with observed annealed textures in the Annapurna-Yellow Formation, comprising coarsening of micas and quartz and the presence of polygonal strain-free quartz grains overgrowing part of the high strain zone fabric [4]. Muscovites extracted from cleavages within north-verging folds of the upper Ordovician strata of the Tethyan sedimentary sequence yielded an older cooling age of 18.1 $\pm$ 0.7 Ma. This indicates that rocks above the high strain zone of the AD were not reset by the late thermal overprinting which affected the AD zone.

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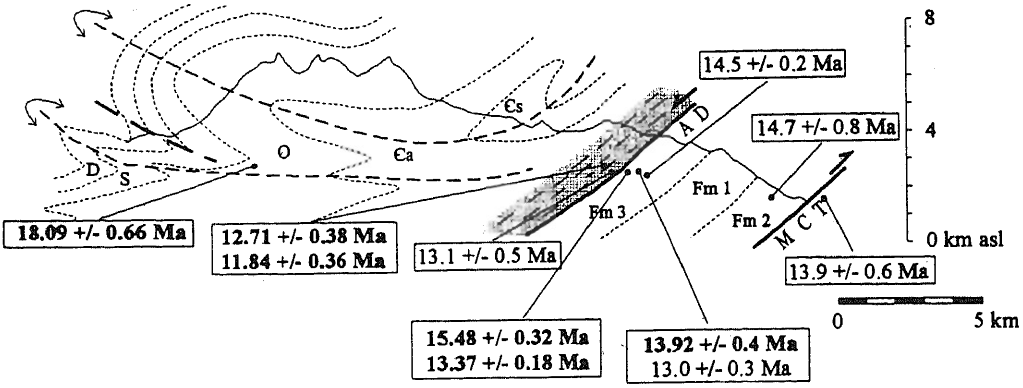

Fig. 1. $^{40}Ar/^{39}Ar$ muscovite isochron ages; bold ages are from this study, other ages are from Vannay.

Kinematics model of the Main Central Thrust zone, Luhri (NW-Himalaya, India): implication for an inverted temperature gradient

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In the Sutlej valley, above the low-grade metamorphic rocks of the Shali Window (Lesser Himalaya), mylonitic orthogneisses mark the position of the Main Central Thrust zone (MCTZ). The mylonites have a thickness of about 600m and consist mainly of quartz, K-feldspar, plagioclase, biotite and muscovite. The strong mylonitic foliation has pronounced stretching lineation consistently dipping towards NE. The whole zone was ductily deformed under greenschist facies conditions. Feldspar reveals only limited ductile deformation and has been mainly fractured whereas quartz has undergone extensive dynamic recrystallization. The transition zone to the footwall shows a strong cataclastic overprint. Abundant shear sense indicators with monoclinic symmetry reveal a non-coaxial progressive deformation history of this shear zone with a SE directed sense of thrusting.

Throughout this zone quartz filled tension gashes, which have been rotated at variable angles with respect to the mylonitic foliation documenting non-coaxial flow, can be observed. These gashes always cross cut the foliation and follow the inflexion surface of a fold with a synformantiform pair resembling structures described by Passchier (1997, EUG Abstract) as "vein margin folds". The opening angle of the folds is clearly a function of the rotation component during deformation: Gashes that underwent only limited rotation have open folds whereas larger rotation may lead to nearly isoclinal folds. This observation probably suggests that the angle between the fracture and the foliation abutting it approximates to the initial angle of fracture. Several vein-systems reveal different generations of tension gash formation: Older central parts of the veins have rotated in the bulk flow, while younger outer parts still propagate outward probably along the instantaneous shortening axis. The youngest generation of veins which shows no evidence of rotation and folding of the foliation, indicate an angle of about 20° between the instantaneous stretching axis and the mylonitic foliation. Within the limits of a number of assumptions these rotated vein systems can be used as quantitative kinematic indicators and by means of off-axis Mohr circle construction the Lagrangian position gradient tensor can be derived. For the geometry of the vein system investigated in that part of the MCTZ a flow regime deviating significantly from simple shear is suggested. Note that the position gradient tensor reconstructed in this way describes only a part of the total deformation, from the point in time when the veins begin to form.

From the same outcrops samples from highly deformed quartz ribbons were analyzed using a XRay texture goniometer. Quartz has undergone extensive dynamic recrystallization associated with well-developed lattice preferred orientation pattern. Systematic variations of c-axes and <a>-axes pattern include: (1) In all cases <a>-axes are distributed along the periphery of the stereonet. Accepting models that predict <a>-axes to represent direction of flow, deformation close to plane strain is suggested. (2) Lattice preferred orientation pattern suggests systematic change of glide systems from prism<a> glide (upper structural levels of the MCTZ) over rhomb <a> glide towards basal <a> glide in MCTZ footwall units. This is interpreted to correspond with a systematic temperature variation (inverted temperature gradient) within the MCTZ. Higher syndeformative temperatures occurred within upper structural levels and lower temperatures within lower structural levels. (3) Modeling of Lister and Hobbs (1980) suggests that central girdle of quartz c-axes pattern develop orthogonal zones of zero angular velocity which is parallel to shear plane in simple shear deformation. Within sub-simple shear deformation the two planes of zero angular velocity are the flow apophyses. Hence, the angle between the perpendicular to the central girdle and the foliation is equal to the angle between the flow plane and the flattening plane of strain. For steady state constant volume deformation this angle is function of the vorticity and the finite strain only. Finite strains are not known from this part of the MCTZ known but trajectories for centers of off-axis Mohr circles at given values of finite strain may be drawn for various vorticities (Passchier 1989). Observed small angles between flow apophyses and foliation suggest a significant pure shear component during deformation. (4) The asymmetry of textures confirms the overall observed top to the SW sense of shear. Simple mathematical deformation models demonstrate that inverted temperature gradients in a shear zone can be easily explained by progressive deformation. The type of flow pattern responsible for the deformation, the angle η between the isotherms and the shear zone boundary during deformation and the total offset of the shear zone mainly control if the shear zone records an inverted temperature gradient. Surprisingly there is a significant difference in η needed for the temperature inversion between simple shear and general shear deformation. Whereas η rapidly approaches few degrees with increasing offset in ideal simple shear zones, a flow pattern between pure shear and simple shear requires η values above 60°, even if the offset is large. Consequently, if the rotated quartz veins in the investigated part of the MCTZ indicate a flow regime, which significantly deviates from simple shear, two progressive defonnation histories are possible: (i) The MCTZ thrusting was characterized by a general flow in which case the angle between the isotherms and the shear zone boundary during deformation was large. (ii) Only the late stage of the deformation within MCTZ was characterized by general flow and the inversion of the metamorphic gradient is due to an earlier simple shear deformation. In that case the angle between the isotherms and the shear zone boundary during this earlier deformation was probably just a few degree.

Origin of the serpentinites in the indus suture zone (eastern Ladakh): its role in the exhumation of the Tso Morari eclogites

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Serpentinites are recognised in various tectonic setting, such as slow-spreading ridges, transform faults and divergent margins [1], but appear also as serpentine seamounts associated with HP/LT rocks in a subduction zone such as the Mariana forearc [2]. Deformation experiments demonstrate that serpentine minerals, are weaker than other common rock-forming minerals and their ductility increases with the increase in the confining pressure greater than 400 MPa [3]. The occurrence of serpentine minerals would reduce the strength of the rocks by up to 30% and the presence in an active tectonic domain would strongly influence the rheology of the domain.

Here we report the geochemical and petrological characteristics of 7 samples of serpentinites collected in the eastern part of the Indus suture zone of Ladakh and discuss their origin and the role of these rocks in the exhumation process of the Tso Morari eclogites. In eastern Ladakh, serpentinites occur in different tectonic units. In the Nidar ophiolitic complex, they form a kilometer-thick homogeneous sequence above a gabbroic series (samples TS 18c and CH35a), in the Drakkarpo unit, they are associated with the igneous rocks with chemical affinity of OIB and MORB [4] and marine sedimentary rocks (sample CH52c). Finally, serpentinites outcrop within the Zildat Normal fault zone, the northern tectonic contact of the HP Tso Morari unit (CH98a, CH98b, CH146, CH187). All serpentinites show similar mineralogy, consisting predominantly of antigorite and minor anthophyllite and spinel with or without brucite. One sample (CH98b) contains very high-Mg rich olivine (FO_{96}), suggesting the reaction:

$$\text{antigorite} + \text{brucite} = \text{forsterite}$$

This suggests the temperature between 400 and 500°C [1], which is compatible with the occurrence of greenschist facies minerals in the surrounding rocks. These rocks are highly altered and deformed. In addition, ultramafic rocks are generally low in lithophile incompatible elements, which add further difficulties in evaluating the geological setting of these rocks. Some chromite grains retain original compositions and chromite in the Zildat fault samples shows high Cr#, low Al# and high Mg#, which is compatible with the derivation from depleted mantle.

Five serpentinite samples have low TiO_2, Al_2O_3, MnO, and CaO but have high Mg# (0.80 to 0.85), NiO and Cr_2O_3. Their bulk compositions suggest that their original rocks are likely to be either dunite or harzburgite. Two samples (CH52a and TS 18c) show relatively high Al_2O_3 (9.4-19 wt.% on dry basis) and CaO (3.6-5.1 wt.% on dry basis), suggesting that the original rocks may have contained plagioclase. Moreover, CH52e from the Drakkarpo unit is far more evolved compared to the rest of samples with low Cr and Ni. Together with its high Al and Ca, it is likely of crustal origin. High Y and Zr may suggest its formation in an oceanic plateau or a continental rifting environment.

The concentrations of platinum-group mineral confirms the hypothesis. TS 18C and CH52C contain low Os, Ir and Ru and the ratios of Pd/Ir and Pt/Ir are high, indicating that the original rocks are basal cumulates formed at a lower crust. Five other sample have high concentration of Os and Ir and low ratios of Pd/Ir and Pt/Ir, indicatint that they were derived from a depleted mantle.

Discussion: Our results are compatible with the Tethyan origin of the Nidar ophiolite as first suggested by [5]. In contrast, in the Drakkarpo unit, the occurrence of predominantly alkaline basalts and minor sub-alkaline basaltic rocks and associated with enriched-type serpentinite seem compatible with a Permian continental rifting environment as described in western Ladakh [6] rather than a mélange zone above a subduction zone [4].

Concerning the Zildat normal fault zone, the depleted mantle character of the serpentinites is very similar to the diapiric serpentinite seamounts drilled in the Mariana forearc [2] and are more depleted than the abyssal peridotites from the mid-oceanic ridge. In convergent-margin environment, this type of rocks is interpreted as residues of extensive partial melting (between 20 and 30%) in the mantle wedge above the subduction zone.

The Tso Morari eclogite records the P-T condition (20 kb, 580°C) equivalent to the mantle in a subduction zone [7] and serpentinite minerals are stable at pressure greater than 20 kb [1]. Considering the above, we propose that the Tso Morari eclogites encountered with hydrated mantle wedge during the subduction and the buoyancy of serpentinites brought the two to the surface. The serpentinites likely played a major role in the exhumation of the Tso Morari eclogites. In fact, the low density of the serpentinitite (2600 kg/m3) compared to the dry peridotites (> 3200 kg/m3) assisted its upward movement by buoyancy. This vertical motion is probably facilitated by the reduction in the strengh and the localization of the strain in very ductile and very weak zone with a strongly reduced coefficient of friction when the mantle wedge is serpentinized.

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Space-time pattern of ophiolites in Tibetan plateau and the evolution of the Tethys

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The Tibetan Plateau (Qinghai-Xizang Plateau) infers to a vast area that is bordered by the Qilian range, the Kunlun Range, the Ailaoshan Range and the Longmenshan Range in SW China. Tectonically, it consists of several ophiolite belts formed in different geological time, with many blocks and orogenic belts in between. The space-time pattern of the ophiolites in the Tibetan plateau shows the characteristics as follows:

1. The ages of formation of ophiolites successively became younger both southwards and westwards. To the north, the Qilian ophiolite, Altum ophiolite, and the Kunlun ophiolite were the Caledonides, formed in the Cambrian- Ordovician. To the south, Animaqin ophiolite, Litang-Garze-Xijinwulanhu ophiolite, Ailaoshan-Jinshajiang ophiolite, and Changning-Menglian-Lancangjiang ophiolite formed in the Variscian-Indosinian period, i.e., in the late Permian-middle Triassic, the Carboniferous-Permian, the Carboniferous-early Permian and the Carboniferous-Permian, respectively. Further to the south, Bangongco-Nujiang ophiolite and Yarlung Zangbo ophiolite formed in the late Indosinian-Yenshanian period, i.e., the late Triassic-early Cretaceous. It is noticed that, however, there may be relics of the early Carboniferous ophiolite in the eastern portion of the Yarlung Zangbo ophiolite belt (Luobusha), according to $^{40}Ar/^{39}Ar$ dating of Plagioclase and clinopyroxene from accumulative gabbros.
2. The age of formation of an ophiolite belt varies along its strike. For instance, time of formation of the Bangongco-Nujiang ophiolite belt varies in different segments, that is, the late Triassic-very early Jurassic at Dingqing, early middle Jurassic at Dongqiao, and the late Jurassic-early Cretaceous on the south bank of the Bangong Lake. The Litang-Garze-Xijinwulanhu ophiolite is another example. The times of formation of the ophiolite belt westwards are subsequently the late Permian, the late Triassic, the early Carboniferous-early Permian, and the late Triassic. Furthermore, the sequence of ophiolite also varies in different segments of the same belt, implying that they formed in various tectonic environments.

The space-time pattern mentioned above gives us a hint to understand the formation and evolution of the Tethys. The Qinghai-Xizang (Tibet) Tethys originated from the early Paleozoic within the North China-Tarim continent. The oceanic basin formed on the south margin of the Yangtze Platform in the late Paleozoic-Triassic. Then the Tethyan oceanic basin shifted to southern Tibet in the late Triassic-early Cretaceous. In addition, the Precambrian crystalline basement deformed in multi-stages in Tibetan Plateau eventually consolidated in the Qomulangma Movement (the equivalence of the Assynthian Movement) in Sinian Period, and thus joined in Huabei (North China), Yangtze and Indian Pre-Sinian platforms to become a composite continent. The Paleozoic Gondwana cool-cooling warm type of fauna crossed the Kunlun Mountain. The Carboniferous-Permian impure conglomerates, representing the ice water facies, occur at the Guliya Cross on the main ridge of the Kunlun Range. On the other hand, the Carboniferous-Permian warm water type of fauna from the Yangtze Platform reached the Himalayas. The two faunas mentioned above alternatively occurred with time and spatially mixed. All the facts mentioned above suggest that the Tibetan Plateau had close relationship with the adjacent platform. The Qinghai-Xizang Tethys formed and evolved on basis of the Pangaea. The processes of continental rifting, opening and closing of oceanic basins, and combination of continents took place in various locations for different stages.

Studies on pollen vegetation relationship in western Himalaya

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This paper presents synoptic analysis of palynological researches carried out on pollen vegetation relationship from (Garhwal and Kumaon Himalayas. Though only limited attempts have been made in this direction but have covered different plant communities distributed from Himalayan foot hills to subalpine. Pollen analysis of moss cushions, soil samples/air catches show that modern pollen deposition differently reflect vegetation of area and do not fully match with actual floristics. Certain taxa *(Shorea robusta, Acacia catechu, Rhododendron* spp., etc.) fail to express their actual representation in vegetation and remain under-represented completely or unrepresented even if dominate in the vegetation due to their entomophilaus nature, poor pollen production, high pH of soil, differential preservation, absence/poor occurence of sporopollenin, physico-chemical/biological degradation, etc. On the contrary, certain others (particularly *Pinus)* exhibit false presence and often acquire prominent position even in their complete absence in the vegetation due to long distance transportation of pollen from source area. Such studies provide basic criterion for the pollen analytical investigations of the Quaternary sediments to reconstruct palaeovegetation and decipher palaeoclimate.

Comparison of the heavy metals pollution in the eastern and western parts of Peshawar metropolis, NWFP, Pakistan

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Heavy metals pollution is a serious environmental threat to air, soils, and waters of the industrialized communities in third world. Peshawar, the capital and the only metropolis of NWFP and a major city of the lesser Himalayas is filled to the brim with metals-based small and large businesses, workshops, industries and transport media. Two recent studies, one in the eastern part (Peshawar city; Hamidullah et. al., 1997a) and other the western part (University Town - Cantonment area; Hamidullah et. al., 1997b) of Peshawar metropolis, have shown that the air, surface-soil and sewerage of both eastern and western parts are loaded with heavy metals including Cr, Co, Na, Zn, Cu, Fe and Pb. Soils at 2 feet depth are however, still safe and therefore also, not a source of this pollution. This paper compares these studies carried out in the western and eastern parts of Peshawar metropolis. The data shows that compared to the western part, the eastern part is under a considerably high threat from heavy metals pollution

due to the high number of sources (workshops businesses; vehicles, rusted bridges etc.) and dispersing agents (moving vehicle) in the east compared to the west. In addition, sewerage system originates in the western part and carries the garbage to the east, thus enhancing the calamities of the city area. The study has also shown the impacts of heavy metals pollution on the Budni canal and Kabul river.

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Platinum group element signatures of ultramafic-mafic rocks of the Kohistan block: evidence for crustal cumulate origin

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The Kohistan block in northern Pakistan near the India-China border is bounded by the Main Karakoram Thrust to the Eurasian continent and by the Main Mantle Thrust to the Indian continent, The east-trending, crescent-shaped block is interpreted to be a 100 Ma island arc within the Tethys ocean, which was accreted and uplifted during the Himalayan arogeny. The block consists of four units; ultramafic Jijal complex, Kamila amphibolite, gabbroic Chilas complex and volcanic rocks of Chalt complex in ascending order to the north. The Chalt complex is predominantly basaltic-andesitic volcanic rocks with intercalated sedimentary rocks. The Chilas complex consists of gabbro, gabbronorite, norite and minor troctoilte and dunite. The igneous rocks in the complexes show low concentrations of high field strength elements (HFSE) compared to large ion lithophile elements (LILE) indicating arc origin [1]. High εNd (100 Ma; +5 to +6) and mildly low initial $^{87}Sr/^{86}Sr$ ($\approx$ 0.70400 at 100 Ma; [2]) suggest derivation from a depleted mantle wedge.

The Jijal complex consists of dunite, pyroxenite and websterite. The lithology and the relationship with other units have suggested an origin as cumulates of arc magmas. However, there has been no geochemical evidence to ,support this interpretation because the incompatible elements that might have been useful for petrogenic study, have low contents in the ultramafic rocks. Also, alteration-metamorphism may have modified their trace element compositions. Thus the usual geochemical tools are not likely to be useful for identifying the origin of the ultrarmafic rocks. Ultramafic rocks, however, contain significant concentrations of platinum group elements (PGE; ruthenium, palladium, osmium, iridium, platinum, rhodium), which are diagnostic for the origins of the rocks.

Here, we report the concentrations of Re and PGE for the ultramafic and mafic rocks from the Kohistan block.

The concentration of PGE in Kohistan rocks are highly fractionated with low Os, Ru and lr and high Pt, Pd and Re. Gabbroic rocks contain very low lr-type PGE (Ir, Ru, and Os): less than 10 ppt Os and 50 ppt lr. Even ultramafic rocks of the Jijal complex with high MgO (<30 wt.%) and Ni (<800 ppm) contain low Os (<0. 13 ppb), lr (<0. 79 ppb) and Ru (<0. 9 ppb).

They are much lower than mantle rocks, which contain ~ 4 ppb Os, ~ 3 ppb Ir, and ~ 5 ppb Ru. The patterns of PGE, which are normalized to primitive mantle composition, show a deep concave shape: moderately high Ni, deep lows at Os, Ir and Ru and steep positive slope towards Pt (<0.5 times PM), Pd (<3 times PM) and Re. The total PGE contents show a broad correlation with the concentrations of Sr. Because Sr is an incompatible lithophile element, the correlation with siderophile and chalcophile PGE indicates a low sulphur concentration in the parental magmas. The results indicate that the ultramafic rocks in the Kohistan block are indeed cumulates of arc magmas, which formed by partial melting of a depleted mantle, under sulphur-unsaturated condition, The parental magmas did not reach sulphur saturation during cumulate crystallization- The PGE concentrations and patterns from the Kohistan ultramafic rocks are identical to websterite and dunite from the cumulates of the Jurassic Talkeetna arc in Southern Alaska [3]. Similar patterns of PGE and covariation with other lithophile elements from the two arcs appear to suggest that arc magmas are generally sulphur unsaturated during the partial melting in the mantle source and during crystallization in the lower crust.

To evaluate the Os isotope ratios of the arc magma, $^{187}Os/^{186}Os$ ratios were determined. They range from 1.19 to 1.55 ($^{187}Os/^{186}Os$ =0.143-0.187). The values are low, although higher than the depleted mantle value, $^{187}Os/^{186}Os$ = ~1 ($^{187}Os/^{186}Os$ = ~ 0.120). Although the precise initial ratios are difficult to determine due to probable mobility of Re, the date suggest that the subduction-related mantle metasomatism was accompanied by little enrichement of radiogenic Os.

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The tectonic significance of 24 Ma crustal melting in the eastern Hindu Kush, Pakistan

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Northward directed subduction has taken place beneath the Hindu Kush from when it formed part of the southern margin of Asia in the Mesozoic, and still continues today. Accretion of the

Kohistan arc took place at about 100-85 Ma [1,2], followed by the Indian plate at 55-50 Ma [3,4]. After the India-Asia collision, a regional crustal melting event occurred around 25-21 Ma to the east of the Hindu Kush in the Karakoram range, producing the Baltoro pluton [5,6]. In the eastern Hindu Kush range, most of the granitoids appear to be pre-India-Asia collision, subduction related plutons. However, the Gharam Chasma pluton is a two mica garnet ± tourmaline) leucogranite that has intruded into staurolite grade schists and sillimanite K-feldspar grade migmatites.

U-Pb ages on monazite, xenotime and uraninite from undeformed samples of the Gharam Chasma pluton and a leucogranite dyke that cross cuts the migmatites indicate that crustal melting took place in the eastern Hindu Kush at around 24 Ma. This is contemporaneous with the event that produced the Baltoro pluton in the Karakoram, 400 km to the east. This extends the range and confirms the importance of widespread crustal melting in the southern margin of the Asian plate around the earliest Miocene.

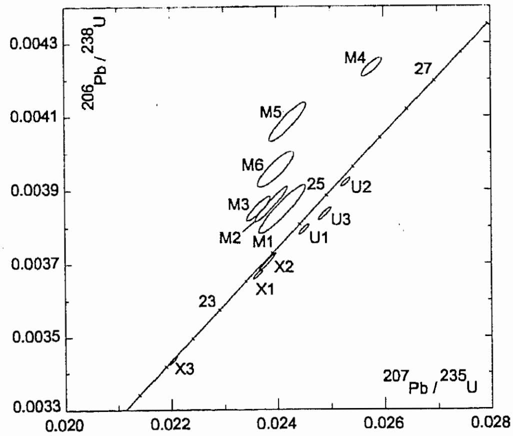

Fig. 1. U-Pb concordia diagram for the leucogranites from the Gharam Chasma area of the eastern Hindu Kush.

The presence of lamprophyres with the same early Miocene age as the Baltoro pluton support the possibility of a mantle heat input to promote the crustal melting in the Karakoram [8]. In the eastern Hindu Kush, there is no indication of any lamprophyres or other potentially mantle derived melt that could potentially have a similar 24 Ma age, so alternative heat sources are required. The leucogranites in the Gharam Chasma area are spatially associated with sillimanite grade metamorphism and migmatites. Consequently, a more likely model for the generation of these leucogranites would appeal to peak metamorphism and decompression provide the heat and conditions necessary for melting. Such a model would be similar to models proposed for the generation of the High Himalayan leucogranites [e.g. 9].

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Crustal structure of western Tibetan plateau from geophysical survey

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In the western region of Tibet plateau the trend of geological and geophysical structures are obvious and prominent in the plateau, which have a close relationship to the tectonic pattern and geodynamic system of the whole Tibet plateau. In 1994, a multi-discipline geophysical survey was carried out for crust-mantle structure in westem region of Tibetan plateau. Wide-angle seismic reflection, magnetotelluric deep sounding etc. surveys are integrated to study the crust-mantle structure.

Wide-angle seismic reflection survey: A wide-angle seismic reflection profile was designed to detect crustal structures, the profile extends northward from the Coqen county to Sangehu and runs through the Bangongco-Nujiang suture zone (BNSZ), about 400km long. Three shotpoints are fired at Dawco, Dongco and Lugu respectively. The wave signal from the explosive sources is received by sixty seismic recorders along the profile with 6-km interval. Six groups of dominant wave phases can be traced from seismic time sections. One is Pg refraction wave. The Pg traveltime of each recorder reveals shallow velocity crustal structure. The others are reflection waves generated by interfaces within the crust.

A ray-tracing method is applied routinely to map crustal structures. In uppermost part of crust, the velocity contour beneath *Dongco to Gerze* varies obviously. This zone is the suture belt of Gandise and Qiangtang. From surface geology, some ultrabasic rocks outcrops on *Gerze* and Mesozoic sedimentary is widespread on Dongco.

The interpretation of results also show that the crustal velocity of Gandise is slightly lower (6.23km/s) than that of Qiangtang block (6.48km/s), the average velocity of crust is about 6.35 km/s. At about 20-km depth in upper crust, there exists a 8-km-thick low velocity layer (LVL), widespread in the Tibet plateau. Like the MHT, a famous LVL in upper crust, they may be a shearing detachment belts. Within middle crust at depth of about 40km, other low velocity body exists only beneath Dongco basin south of BNSZ, roughly coinciding with high conductivity zone and high Bouguer anomaly. This low velocity body is probably representing a partial melting medium composed of basic-ultrabasic rock from the mantle along the tectonic fracture of lower crust.

The reflection interfaces of crust have an obvious undulation, on two sides of BNSZ. They are deeper in south than in north. The Moho is about 75-78km deep in Gandise, but it becomes shallower in Qiangtang block (65-68km deep) with a displacement of about 10km. According to the variation of velocity contour and crustal thickness of model, authors infer that the Bangongco-Nujiang fault dip slightly to north. A seismic depth section drawn by means of fan profile show the upper mantle of Gandise thrust down into Qiangtang block.

Magnetotelluric Deep Sounding(MT): In this research activity, besides wide-angle seismic reflection, Magnetotelluric Deep Sounding (MT) is other main method to decipher the structure of the lithosphere. MT profile is about 590km, running from Gyirong on north of the Himalayan MTS., passing through Saga, Coqen and Gerze to Sangehu. Along this profile there are 16 survey sites. After processing those data, a model for the electrical structure of lithosphere can be mapped.

The electrical structure with strong inhomogeneity implied a complicate structure of lithosphere in this region. From geological view, in study region, the Himalayan, Gandise and Qiangtang block are main tectonic units and Yarlung Zangbo river and Bangongco-Nujiang belt are their suture zone. The MT results roughly show that the high conductivity layers beneath suture zone change steeply. The buried depth of the layers beneath the two sides of Yarlung Zangbo suture and BNSZ have more than 10km displacement, and the sutures run deep to asthenosphere.

Besides, from the model of electrical structure, a deep fault may be existing near Lugu and Dawaco, respectively. Accordingly, each of Gandise and Qiangtang blocks can be subdivided into two parts. The distribution and shape of high conductivity layers show an obvious difference in each block, such as the southern part of Gandise and Qiangtang block have two high conductivity layers, but the other parts have only one. This is an evidence for two phases of tectonic activity responsible for the formation of Yarlun Zangbo, suture zone and BNSZ. To sum up, the buried depth of crustal, high conductivity layers in south of Yarlun Zangbo suture zone is thick and shallow, and then gradually increases from the south to the north and the layers looks like piling of tiles, especially beneath the two sides of BNSZ. The results of MT also show that asthenosphere is about 100 km deep in Gandise block and in Qiangtang block deepens to 230 km. The Qiangtang with high resistivity and thicker lithosphere defended naturally the moving of deep material from south to north.

Tectonic implication: The comprehensive geophysical survey reveals a lithosphere that is both vertically and horizontally heterogeneous. The western Tibetan plateau can be divided into diverse tectonic units and the lithosphere is characterized by a layered structure. The layers beneath the two flanks of suture belt have obvious displacement. Such complex structures should be the result of tectonic activities in the history of formation and evaluation of Tibetan plateau. For example, it is conceived that BNSZ was produced by the evaluation of a small ocean basin on north of Tethys. However, by the closure of the ocean basin at the end of Jurassic, the direction of unstalsubduction needs further consideration. Many evidences from the crustal structure show the upper mantle of Gandise suducting downward. That is, at the end Mesozoic the Indian subcontinent collided with Eurasia, and Tethys was closed completely. The Indian plate still moves to north, while Tibetan plateau is blocked by Tarim terrane. Finally, the force of compression made Gandise subuction to north and Qiangtang block upthrust to the south.

Discontinuity system in central Nepal and neotectonic stress field

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Disconitnuity systems in Central Nepal have non-random orientation indicating their genesis from endogenic forces identified as the tectonic stress field. Orientation of the principal neotectonic stress in the region can also be inferred from statistical analysis of the orientation of the discontinuity systems. Present research inferred the nature and orientation of the principal neotectonic stress direction from the back analysis of the Himalayan discontinuity system. Inferred principal neotectonic stress field will be very important for the major engineering structures in the area.

The study area is subdivided into six units on the basis of the tectonic facies as well as structural pattern. The major faults and thrusts are the tectonic boundaries of these tectonic units. The axis of the majority of the folds strikes WNW and ESE. Strike direction of the axis of most of the folds deviates from the general strike of the Himalaya. This is due to local rotiational and overthrusting tectonic events and it also depends on the respective deformation behavior of the rock mass.

All types of discontinuous deformation structures like joints, fissures, extension fractures (veins), shear fractures and faults, large scale thrust and low angle faults, shear zones of the area are named as discontinuities for the respective analysis. Discontinuity systems of the area are further catagorized into seven order.

In Mohr-type fractures, the bisectrix of the small angle between joint sets at an outcrop should mark the greatest compression (Scheidegger, 1980). The largest at $\sigma 1$ and smallest $\sigma 3$ principle stress direction are the bisectrix of the joint sets. Excluding the stress release joints resulting from successive upliftment and erosion, the stereoaraphic analysis of the fracture shows the tentative principle stress direction in the area northwards of the Kathmandu valley: ($\sigma 1$ in N20°W - N40°W/S20°E - 540°E, $\sigma 2$ in N50°W - N70°W/550°E - 570°E and $\sigma 3$ almost vertical due to the overburden. On the account of the folding axis of the anticline and their successive syncline the tentative principle stress direction $\sigma 1$ in NE/SW, $\sigma 2$ almost vertical (due to overburden) and $\sigma 3$ in WNW/ESE. Similarly in the area south of the Kathmandu valley $\sigma 1$ in N20°E - N40°E/S20°W - S40°W ($\sigma 2$ in N50°W - N70°W/S50°W - S70°W and $\sigma 3$ in almost vertical. On the account of the folding axis in NW / SE, in almost vertical due to the vertical load and in NE/SW. Taking only the compressive major stress and all the other circumstances constant.

The discontinuity orientation pattern is genetically syntectonic with the foldina process. Fracture concentration is greater towards the foldiner axis and towards the higher order of discontinuities (major faults). The axial zone of the syncline indicates the compressive stress and the axial zone of the anticline indiactes mainly the extensional stress in their discontinuity surfaces. Similarly the higher order of discontinuities (major faults/thrusts) and the lower order i.e. 4th and 5th order discontinuities (joints and shear fractures) have also the syngenctic relation. The axis of the Sindhu Khola anticline is faulted. Analysis of the 4th and 5th order discontinuities joints) shows the faulting successive to the folding.

Inferred neotectonic stress field of the area coincided with the orientaion of the Himalayan ncotectonic stress in regional scale but it deviates in local scale.

Stratigraphic and structural framework of the Himalayan foothills between Panjal-Khairabad thrust and MMT, Peshawar basin, Northern, Pakistan.

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The Panjal-Khairabad Thrust form the boundary between the Lesser Himalayan and Tethyan section, a function performed by the Main Central Thrust (MCT) in the Central Himalaya of India and Nepal. All pre-Cenozoic rocks north of the Panjal-Khairabad Thrust have been metamorphosed. The metamorphism increases from south to north from greenschist to kayanite grade. An almost complete sequence of rocks ranging from Precambrian to Jurassic age has been established for the first time in the area. The proterozoic rocks represented by Gandaf Formation and Manki Formation with associated carbonate form the base of the stratigraphic section. These rocks are overlain by Precambrian and Cambrian Tanawal Formation; Cambrian(?) Ambar; Orodovician Misri Banda; Llandoverian to Pridolian Panjpir Formation, Lochkovian to Frasnian Nowshera Formation and Kinderhookian to Westphalian Jafar Kandao Formation. The Karapa Greenschist, consisting of metamorphosed lava flows separate the Jafar Kandao from Upper Triassic (Carnian) marble of Kashala Formation. The upper Triassic and Jurassic (?) Nikanani Ghar Formation forms the top of the section.

Correlatives to the stratigraphic setup of the Peshawar Basin are present in the Khyber-Mohmand to the west and Hazara to the east. The sequence contrasts markedly with the Paleozoic and Mesozoic sequence exposed to the south of Panjal-Khairabad Thrust. The newly - dated Carboniferous to Triassic rocks provide age constrains on the high grade metasediments of Swat exposed to the south of MMT. The dating has also provided age constrains on pre-Himalayan tectonism and intrusions. The stratigraphic information combined with geochemical analyses and radiometric dates on the igneous rocks of the area permits the recognition of a major phase of Paleozoic rifting in the Peshawar Basin.

Segmentation of the Siwalik thrust belt of western Nepal and localisation of piggy-back basins

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The outer thrust belt of westem Nepal is affected by major transverse zones that delineate several segments and give a general festooned pattem to the structures of the outer belt. The western most transverse zone is located west of the Dadheldura road and mainly affects the extension of the Upper Siwaliks and of the structures at the hanging-wall of the Main Dun Thrust (MDT). It is outlined by an unconformity that locally exceeds 70°. The second transverse zone is located west of Shurket. It forms the western boundary of the Main Frontal Thrust (MFT), and is outlined by the nearly N-S very steep beds that are easily observed at the outlet of the Babai river in the Terai plain. It also affects the trends of the MDT and of the Main Boundary Thrust (MBT) and induces bending of the beds at the hanging-wall of the MFT. N 170° trending lineaments are furthermore observed in this area on aerial photos.

The West Dang Transfert Zone (WDTZ) is a major transfer zone that bounds toward the west the extension of the duns of mid-western Nepal. The width of the outer belt varies from 25 km west of WDTZ to 40 km east of WDTZ. It is formed by a superposition of sigmoïd folds and sigmoïd reverse faults. The MFT1 and MFT2 laterally die out in the WDTZ whereas MDT2 shows a dextral torsion. The MBT trajectory is not affected by the VXTZ. We nonetheless believe that the WDTZ is going farther to the north as its continuation forms a major limit of the seismicity distribution in Lesser Himalayas. It is expected that it is the recent tectonic activity of the MBT that generates its rather straight pattem. Strike-slip faults also cross through the sigmoïd structures. As they are difficult to map, we have used morphologic analysis of the drainage pattem to detect them. Two distinct populations of lineaments appear prominent: A first set shows a N170° trend nearly parallel to the mean trend of the WDTZ; a second set shows a N75° trend. This set could be a secondary set of strike-slip faults developed during the dextral torsion of the whole structures of the WDTZ. A dextral component is observed along this set West of the Dang valley, and a senestral component in the very southem part of WDTZ.

Comparison of cross-sections between the western eastern compartments WDTZ shows: 1) a change of the stratigraphic thickness of the Siwalik members involved in the thin-skinned thrust tectonics, and particularly of the Middle Siwalik member; 2) an increase of the depth of the dècollement level from West to East. Furthermore, a lateral ramp cuts upsection toward the West at the base of the stratigraphic pile (i.e. through the Bankas beds). The WDTZ appears as a complex structural zone: the superposition of strike-slip faults, sigmoïd folds and sigmoïd reverse faults that are observed show analogies with the results of physical models that involve a step in the basal dècollement. Therefore WDTZ is probably related to a substratum fault that predated the thin-skinned tectonics.

The WDTZ bound the large piggy-back basins (or Duns) of mid-western Nepal. The valley of Dang is one of the largest dun and forms a nearly 1000 km^2 and the Deukhury valley forms a nearly 600 km^2 plain that collects a drainage basin of 6100 km^2. Unconformities have been observed as well above WDTZ and MFTI. They suggest that the Himalayan front was located south of the dun basins since 2.3 Ma, and that WDTZ favoured this southward shift of the tectonic front.

The influence of meteorological factors on the initiation of the Darbang landslide, Dhaulagiri Himal, Nepal

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A variety of different phenomena, as geological, lithological, tectonical and morphological, play a dominant role as preexisting factors for massmovements. Widespread environmental degradation in the Himalayas, such as deforestation or overgrazing, assists the preexisting factors and intensifies the dangerous situation of a potential landslide area. Many landslides were triggered only by earthquakes, but most of them by outstanding meteorological events. These specific weather conditions, such as periods of heavy rainfall or intense snowmelt and/or unusual fluctuations of the air temperature are the main sources for triggering landslides. For a bigger, comprehensive landslide investigation it is absolutly necessary to study the weather conditions around the hazardous event like it is done at the following example of the Darbang landslide.

The small village of Darbang (1130m) is located in the Western Development Region of Nepal, about 40 km NW of the county capital Baglung, on the foothills of the Dhaulagiri massif. The houses of the village were spread on both sides of the Myaghdi Khola, a tributary river of the Kali Gandaki. On the 20th of September 1988 a catastrophic landslide happened, which destroyed all houses on the right bank of the river and killed more than 100 people of Darbang.

The landslide occured on an oversteepend, north facing flank, of a size of 800m in height. This mountain flank is well known for its instability for a long-term period, which emphasizes the report of the horrendous landslide catastrophy of 1926. One reason for the instability lies in the regional geology. Lithological investigations show metasediments, especially schists and phyllites in nearly horizontal bedding. But also the tectonic location of Darbang, near the Main Central Thrust (MCT), supports the rock instability in this area. The volume of the collapsed mountain flank can be estimated with 5 Mio. m^3. The debris dammed the Myaghdi Khola for 6 hours. But abruptly the debris dam broke, which caused an extreme flood-wave downstream to the valley.

How important has been the influence of the weather conditions on the initiation of the Darbang landslide. All available meteorological data (precipitation, air temperature) was analysed, which originates from the nearest climatological station at Bag-lung (Fig. 1). The precipitation, which was measured at Baglung station, shows a typical amplitude of the monsoonal circulation. The precipitation data of the decade from 1981 to 1990 show the highest average amounts during the summer monsoon months July (588mm) and August (439mm). Comparing these data with the monthly amounts of precipitation for "the year of the catastrophy, 1988", it is to noticed that the premonsoon months May and June reach rainfall quantities, which lie 37% and 24% below the average. In July 1988, with the onset of the monsoon, the precipitation amount increased rapidly to the level of the decade-average (587mm). But most important, especially for the landslide event, is the extremly high August precipitation amount, which lie 17% above the decade-average. In this month the 3rd highest amount of precipitation in August, concerning the whole decade, was detectable (513mm). The September 1988 shows a general decrease in precipitation, which was very similar to the decade-average. In contrast to ordinary September months, the precipitation 1988 shows a secondary peak in the first half of the month, and decreases not continously as regular (not in Fig. 1).

Air temperature data, especially air minimum and air maximum data are also necessary for reconstructing the weather situation, which leads to the catastrophy. A special-analysis of air minimum and air maximum temperatures of 1988 shows interesting results: Both extrem-temperature curves lie above the average-decade amplitude. This means that the year 1988 was warmer than the average of the years between 1981 and 1990. Especially the premonsoon months April, May and June show remarkable features. The measured maximum temperatures of April and May 1988 were recorded with more than 2°C, of June 1°C above the average of the decade. The premonsoon maximum temperatures for the months April to June lie between 30°C and 33°C, which are mostly higher or same as the temperatures in the monsoon months July to September.

The results of the analysis of the meteorological factors concerning the Darbang landslide are interesting and promising. The premonsoon months April, May and June 1988 showed air maximum temperatures above the average, and precipitation amounts below the average of the decade 1981 to 1990. These weather conditions led to an extreme dryness before the summer monsoon 1988 started. The poor soils of this area, which are under intense agricultural cultivation dried up, with a dominant appearence of deep cracks and fissures. With the begining of the monsoonal activity in July, the water seepeded into the soil through this countless drying cracks. Continuing monsoonal activity activated all cracks, till the water reached the bedrock. Through fractures and joints, which are common for a tectonically stressed area, the horizontally bedded rocks became oversaturated, and collapsed under gravitational forces.

Preparatory causal factors and environmental degradation are the common reasons, but the specific weather situation of the year 1988 was the actual decisive cause of the terrible hazardous event, the Darbang landslide. It is obvious that under similar weather conditions, new spontaneous massmovements can happen.

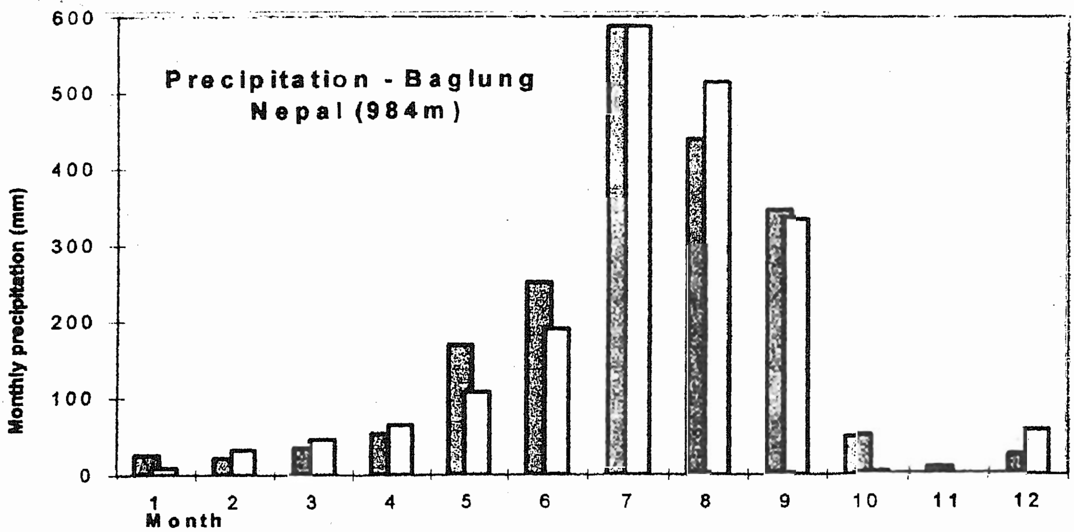

Fig. 1. Precipitation Baglung (984m), pillar 1: average prec. amount from 1981-90; pillar 2: prec. amount 1988.

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Urban geology and evironmental issues of Jhelum city, Punjab, Pakistan

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Jhelum city is located between Potwar plateau and Chuj Doab plains. The area of Jhelum city comprises fluvial sediments of Siwalik Group and Quaternary deposits are of the Pleistocene to Recent in age. These rocks are classified into the Dhok Pathen and Soan Formations while quaternary deposits are further subdivided into (i) mixed alluvium deposits (ii) terrace gravel deposits, (iii) alluvial fan deposits, (iv) sub-alluvial fan deposits, (v). Potwar Leossic clay deposits, (vi) older flood plain deposits., (vii) younger flood plain deposits, (viii) dune sand deposits and (ix) stream channel deposits. Urban geology has become vital in land-use planning and development of urban area, mitigation of geohazards and solving environmental issues now-a-days.

Due to increase of population, the urban areas have developed rapidly without much consideration for the geology and environment. The style of landform has drastically changed due to this haphazard construction of more houses, roads and industrialized zones in the area which demands more resources for water and food stuff. These factors cause many natural and man induced hazards and environmental problems. Most of low lying parts of city have been levelled without considering geological and geomorphological factors which are of vital significance in urban planning. This has resulted in many problems including urban flooding, rapid erosion, more dust, noise and smoke in the city. The most densely populated areas are located in high risk zones where urban flooding and water contamination are major environmental issues. Proper urban and land-use planning, geological data and integrated informations from other agencies can redress the natural hazards and environmental problems. Total mitigation of environmental problems is impossible but risks of life and property can be minimized by application of geological data and land-use planning.

This study has been summarized in a set of six maps on 1: 250,000 scale. These maps are (i) geological map, (ii) landform map, (iii) construction material map, (iv) water resources and quality map, (v) land-use planning map and eventually (vi) an environmental geological map. These data would be synthesized and its application would be helpful in land-use planning, conservation of construction and water resources, and minimizing the risk of hazards and quality controll of air, water and noise in the city. This approach is an example of how geological factors can be arranged in a better way to help urban planners, engineers and public for reduced cost of engineering infrastructure with minimum degradation of environment and risk of hazards.

High-pressure rocks from the Naga Hills ophiolite, NE India

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The eastern margin of the Indo-Burman Range (IBR) is characterized by a series of tectonic slices consisting of ultramafic-mafic igneous and closely associated pelagic sediments. Such typical ophiolitic assemblages in the north-eastern part of the Naga Hills occur in a relatively narrow belt extending for about 200 km. These rocks, referred to as the Naga Hills ophiolites (NHO), constitute the northern part of the IBR. The rocks of the NHO are believed to be pre-Upper Cretaceous in age and emplaced tectonically during the post-Maastrichtian and pre-Eocene (Acharyya et al., 1984). Geochemical investigation suggests that the volcanic rocks of the NHO include both tholeiitic and alkaline types. These two groups are not cogenetic and reflect different source region compositions for the lavas and their generation at different tecotnic settings. The geochemical characteristics of the alkalic lavas are similar to seamount/ ocean island basalts. Most of the tholeiitic lavas, on the other hand, resemble MORB or back-arc basin basalts in their geochemistry and thus were probably generated in a marginal basin set-up (Sengupta et al., 1989; Acharyya et al., 1991).

Locally, the tectonic slices of the NHO contain high-pressure mineral assemblages (Ghose and Singh, 1980). Marked differences in the texture and mineralogical compositions of these rocks suggest that they were derived from mafic igneous (including both putonic and volcanic) as well as sedimentary (greywackes) precursors. Whole-rock major and trace element geochemical data on six (representing the mafic, ?volcanic, varieties) of the samples, collected during the present study, is inconclusive as far as their original tectonic setting goes. These samples may represent mélange blocks derived from different tectonic settings or they may have undergone substantial alteration.

The high-pressure rocks consist of blue to yellowish green amphibole + phengite + quartz + epidote clinopyroxene ± garnet ± rutile ± albite ± chlorite ± carbonate ± tourmaline ± sphene. The amphibole grains in most of the studied samples are optically inhomogeneous and display concentric zoning with cores of blue amphibole surrounded by margins of the blue-green/ yellowish green type and vice versa. The blue amphibole also occurs around clinopyroxene. The grains of garnet contain inclusions of quartz, clinopyroxene and blue amphibole.

Whereas the blue amphibole is mostly crossite in chemistry, the bue-green amphibole is sodic-calcic (winchite-barroisite) and the composition of the yellowish green variety is calcic (tremolite-actinolite) (Fig. 1). The clinopyroxene is omphacitic and the garnet is almandine-rich containing a substantial amount of the grossular and notable admixture of the pyrope components. Except for a localized chloritization of garnet and sphenization of rutile, textural relations among the major phases in most of the studied samples are suggestive of equilibrium mineral assemblages.

The distribution of Al^{IV} and NaB in blue amphibole indicates pressure in excess of 7 kb. The Si content of the amphibole also suggests a pressure of ~6.5 to 7 kb. The distribution of Mg and Fe^{2+} between coexisting garnet and phengite grains at 7 kb pressure yields a temperature estimate of 435 to 535°C. The Mg-Fe^{2+} distribution between garnet and clinopyroxene gives a temperature range of 720-790°C. These P, T estimates, mineral parageneses and textural details are suggestive of metamorphic conditions ranging from those of greenschist-epidote amphibolite to eclogite-blueschist facies. Zoning in amphibole reveals a growth history from initial burial during subduction (greenish, calcic cores) to maximum burial (blue amphibole, omphacite, garnet) to obduction (calcic amphibole margins).

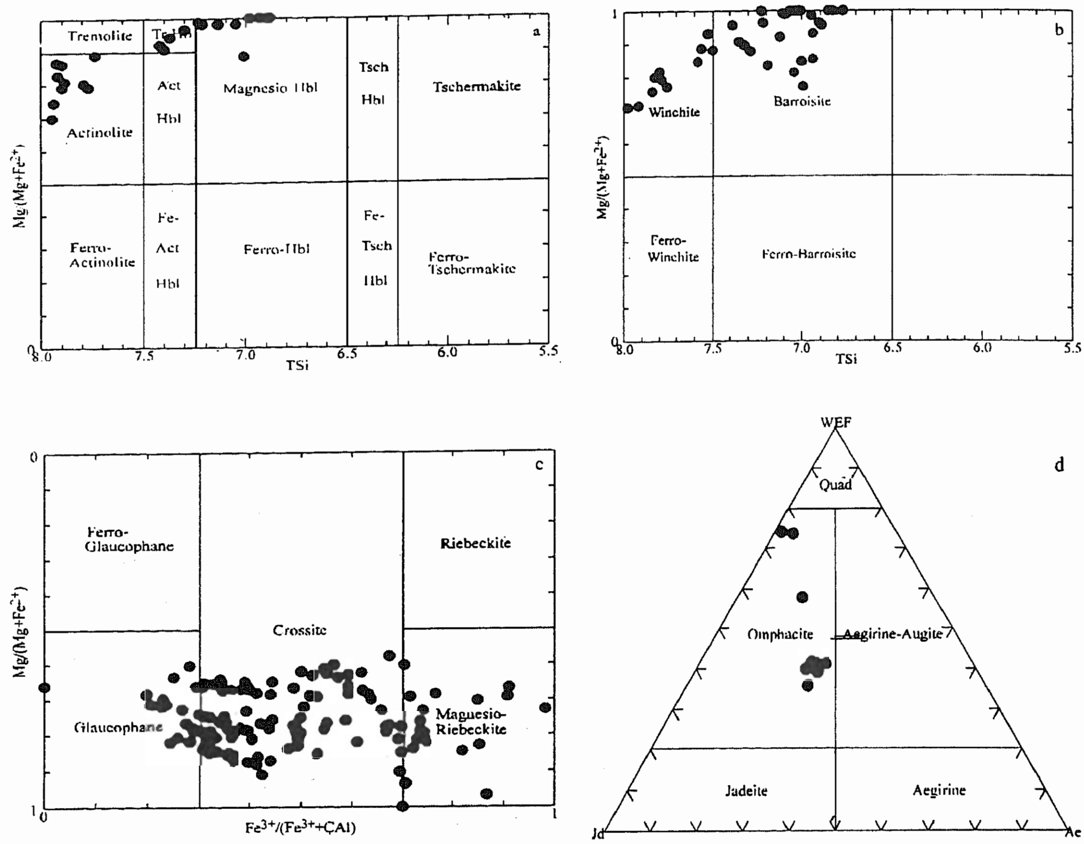

Fig. 1. Chemical composition of amphiboles (a-c) and pyroxene (d) from the high-pressure rocks of the Naga Hills ophiolite, NE India.

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Acharyya, S.K., Ray, K. K. & Sengupta, S., 1991. Physics and Chemistry of the Earth, 18 (I-II), 293-315.

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Preliminary results of GPS measurements across western Nepal

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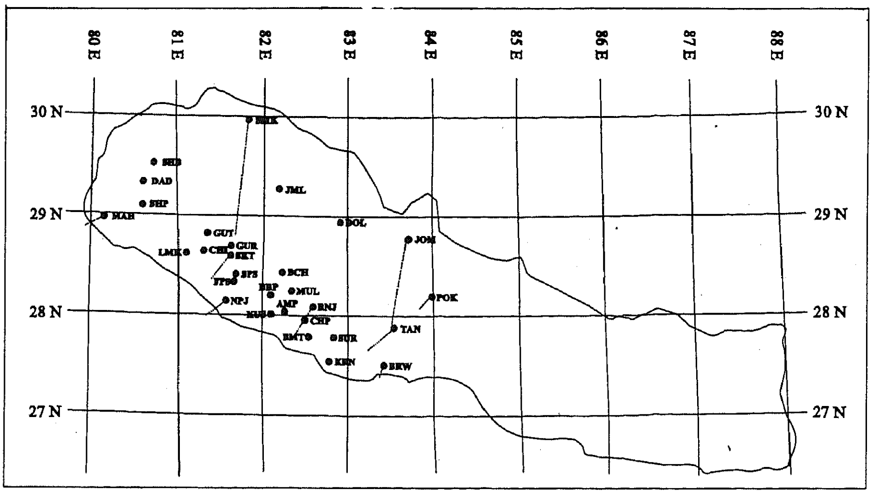
The Himalaya absorbs about one-third of the present convergence between India and Eurasia (58 $\pm$ 4 mm/a). The present-day deformation of the Himalaya is characterized by big earthquakes (nearly half of the chain has ruptured over the last century), and by a significant uplift reaching 7 $\pm$ mm/a. The historical seismicity of Nepal indicates the occurrence of big earthquakes in the eastern and central Nepal, the western Nepal being characterized by a lack of recent big earthquake. To study the present-day deformation of the western Nepal a GPS network of 29 benchmarks has been measured in November 1995 (IDYLHIM project) with 9 points of the 1991 CIRES network [1]. This network has been designed to test the existence of spatial strain variations between the central and the western Nepal especially in the historical seismic gap. The dense network installed in the Siwaliks could bring into evidence an aseismic creep already evidenced by leveling comparison in central Nepal [2] and will allow to precise the strain location between the different thrusts and lateral ramps structuring the lesser and outer Himalayas (Fig. 2). The thrust belt is segmented in at least 3 compartments by 2 major transfer zones (WDTZ and WSTZ on Fig. 2). The northward prolongation of WDTZ is the West boundary of the gap of micro-seismic activity beneath high Himalayas.



• Points measured in 1995 • Points measured in 1995 and 1997

Fig. 1. Location of the IDYL GPS points and displacements obtained from the comparison CIRES1991/IDYL GPS measurements (Bilham et al., 1997).

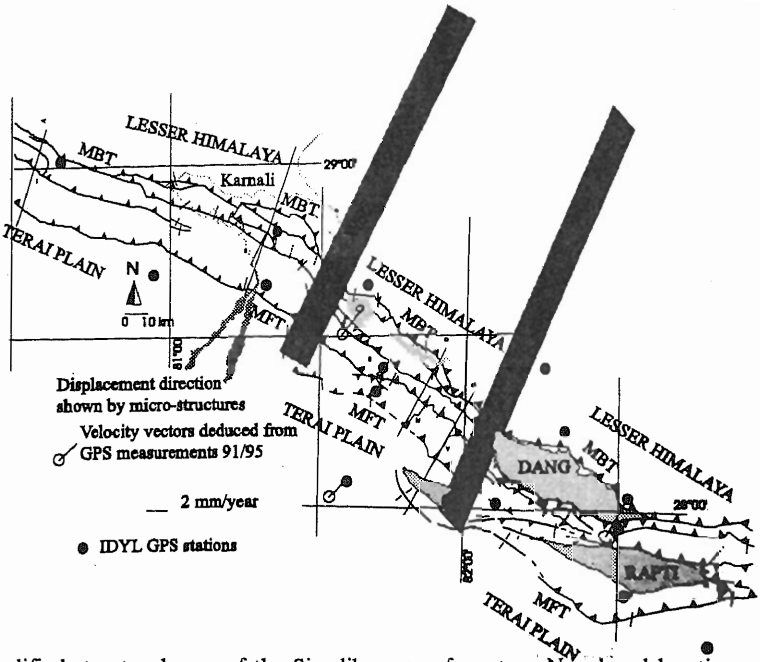


Fig. 2. Simplified structural map of the Siwaliks area of western Nepal and location of the IDYL GPS sites.

A comparison of the 1995 and the 1991 data has already been performed [1] (Fig. 1 & 2). This GPS displacement field and the leveling data indicate that the slip of India beneath Himalaya and Tibet can be approximated by a single dislocation with a ramp located in the central Himalaya [1] where an important microsismicity is recorded.

A part of the network has been measured again in November 1997; we will present here the first results of the 1995/1997 comparison.

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[2] Jackson & Bilham, 1994. Geophys. Res. Lett., 21, 1169-1172.

Regional geology and structural framework of farwestern Nepal, lesser Himalaya

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About 6000 km^2 area in the Lesser Himalaya of farwestern Nepal was investigated. The area is demarcated by Main Boundary Thrust (MBT) in the south and by Main Central Thrust (MCT) in the north. In this part of the Lesser Himalaya three distinct allochthonous crystalline sheets namely Dadeldhura Crystalline Nappe, Parchani Crystalline Klippe and Khandeshwori - Bajhang Crystalline Klippe and three authochthonous metasedimentary complexes such as Bunder metasedimentary complex, Baitadi metasedimentay complex and Ghusa metasedimentary complex were identified. Main Boundary Thrust, Dadeldhura Thrust, Parchuni Thrust, Darchula- Paribagar Thrust, Bajhang Thrust and Main Central Thrust (MCT) are the prominent linear structures which separates various crystalline complexes from the metasedimentary complexes. A number of linear features, transverse faults and folds were developed during tectono-metamorphic events in the geological past.

In this area each crystalline sheet forms the asymmetrical fold structure. Among them Dadeldhura syncline, Khaptad Daha syncline, Budhiganga anticline and Malika syncline are the major ones. They are distinct in their lithological characters, structures and grade of metamorphism. Baitadi metasedimentary complex is exposed as tectonic window of Inner Lesser Himalaya and mainly represented by Precambrian stromatolitic dolomite, limestone and carbonaceous shale/slate, graphitic phyllite and quartzite. Bundar metasedimentary complex is the southern most unit which comprises quartzite and phyllite with few minor metavolcanic (basic rocks/ amphibolites) rocks. These metasedimentary complexes of early Paleozoic to Precambrian (?) age appear to be equivalent rocks of Nawakot complex in Central Nepal and Ramgarh (Chail) Group and Tejam Group in Kumaon Himalaya, India. One of the interesting thing in this area is the occurrence of a continuous band of none fossiliferous purple shale and quartizitic sandstone, which can be traced from Mahakali in the west to Bajura in the east. A similar rock but slightly effected by metamorphism is also traced towards southeastern part of the investigated area in Achham.

Among the three crystalline sheets, the Dadeldhura crystalline complex is the eastward extension of Almora Nappe. Similarly Parchuni and Khandeshwori - Bajhang crystalline sheets are the klippen as Askot and Chiplakot klippen of Kumaon Himalaya in India. They are represented by low to high grade metamorphic rocks of green schist to garnet amphibolite facies and kyanite sillimanite garnet mica schist, porphyroblastic augen gneiss. Lesser Himalayan Dadeldhura granite of 470 $\pm$ 5.6 million years age is emplaced in Dadeldhura crystalline complex, Khaptad granite and granitic gneiss in Khaptad complex and Malika granite gneiss in Bajura crystalline complex. However, granite gneiss in the peripheral part of the Dadeldhura granite is massive and other crystalline rock of Dadeldhura complex are similar to the granite gneiss and other crystalline rocks in Khaptad and Bajura crystalline complex.

Almost all the rock types when correlated however, indicate a general increase in the grade of metamorphism towards east.

Evidence for High-Temperature-Pressure crystallization during early magmatism of the Kohistan arc, Northern Pakistan

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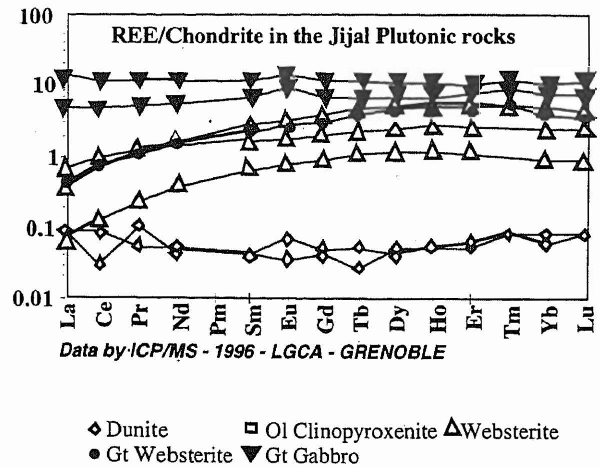
In the southern Kohistan arc, the Jijal ultramafic complex is commonly interpreted as an assemblage of alpine-type ultramafic rocks intruding garnet granulites (Jan & Howie, 1981) or as the remains of a magma chamber (Coward et al., 1987; Miller, 1991) that formed at the base of an immature intra-oceanic island arc in response to northward-directed subduction of neo-Tethys ocean lithosphere during Late Jurassic and Cretaceous. Located just north of the MMT, it was tectonically emplaced over the gneissic basement of the Indian plate at 50 to 45 Ma.

Jijal complex contains two distinct sections. The basal section is composed of ultramafic rocks consisting basically of layered dunites and pyroxenites. Pyroxenites display large variations in mineralogy and are subdivided into four mappable macro-rhythmic units: olivine clinopyroxenite, websterite which evolves to garnet websterite and garnet clinopyroxenite to the top. The upper section is mainly composed of banded garnet gabbro with small amounts of garnet hornblendites.

All the ultramafic rocks present cumulative textures. The LREE depleted chondrite normalized patterns of pyroxenites ($0.07<(La/Yb)_n<1.09$) are consistent with pyroxene accumulation. In the garnet gabbros chondrite-normalized patterns are more REE enriched and are slightly depleted to flat ($0.64<(La/Yb)_n<1.26$). Crystallization of olivine and pyroxene minerals in ultramafic section can account at least partially for the LREE enrichment in garnet gabbro as these rocks are resulting from crystallization of residual liquids (Mg# = 0.79 to 0.71). MORB normalized trace element pattern for garnet gabbro shows negative Ta and Nb anomaly, similar to modern arc related basaltic to andesitic rocks. This consistent REE behaviour supports the operation of magmatic crystallization processes and lends confidence to the application of mineral/melt fractionations to the interpretation of the course of plutonic crystallization differentiation.



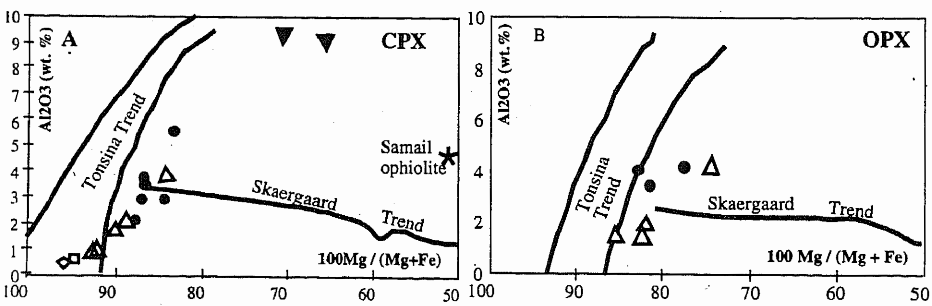


Fig. 1. Plots of Al_2O_3 vs. 100Mg/(Mg+Fe) ratio showing trend in Al content of the Jijal clinopyroxene and orthopyroxene with fractional crystallization. Note opposite trend from low pressure Skaergaard intrusion but approximately parallel to high-pressure Tonsina assemblages.

The mineral chemistry also indicates that the Jijal complex represents a magmatic sequence formed by successive fractional crystallization. The ferromagnesian minerals show large chemical variations in accordance with the lithological change in the series from dunite - olivine clinopyroxenite - websterite - garnet websterite - garnet clinopyroxenite to garnet gabbro. Mg content of olivine regularly decreases from Fo_{94} to Fo_{78}. Clinopyroxene is also characterized by continuous compositional variation from $Ca_{48}Mg_{49}Fe_3$ in dunite to $Ca_{49}Mg_{33}Fe_{18}$ in garnet gabbro. Al and Ti contents of clinopyroxene increase with decrease of Mg numbers (Mg/(Mg+Fe). Orthopyroxene probably crystallized late with Mg number 85 in the earlier stage to 76 in the later. The slight variation in garnet composition is characterized by $Al_{37}PY_{30}Gr_{29}SP_2Ad_2$ in garnet websterite to $A1_{43}PY_{33}Gr_{21}Sp_1Ad_2$ in garnet gabbro.

The presence of abundant olivine clinopyroxenite and websterite, mineral chemistry of these ultramafic-mafic cumulates, as well as the petrological and field data are not consistent with crystal-liquid fractionation of a primitive basaltic magma at low pressures. It is proposed on the basis of mineral chemistry, crystallization sequences, garnet-clinopyroxene thermometry that the basal sequence of the Jijal complex was crystallized from a melt at pressures >10 kb and equilibrated at temperatures of 1050 to 1100°C which is consistent with data of Irvine (1974) indicating conditions around 14 kb and 1180°C.

Garnet websterite indicates excellent evidence for the exsolution of garnet and orthopyroxene from original aluminous clinopyroxene. This formation of garnet is consistent with the relatively low HREE contents of the garnet pyroxenites. The appearance of clinopyroxene and orthopyroxene having very high Mg number (92 to 85) and the absence of plagioclase as early fractionating phases coprecipitating with forsteritic olivine (Fo_{94-85}) point to a crystallization history at high-pressure.

Al-poor phases such as olivine and pyroxene at moderately high temperatures and pressures, has increased the Al contents in the residual basaltic magma. The onset of the crystallization of plagioclase as a separate cumulate phase is reflected in increased Al_2O_3 and CaO and concomitant fall in MgO in garnet gabbro. This represents the product of evolved magma at relatively shallow level. Such processes are common mechanism for island arc magma evolution at depth (e.g., Aleutian arc, Alaska).

Himalayan emeralds: Geology and genesis

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The known Himalayan emerald-deposits and showing are confined to the NW Himalayas and occur within a narrow, 450 km long belt that largely comprises the Indus suture rock-sequence. Emeralds occur at Gandao, Nawe Kili, Bucha, Pranghar and Kot (Mohmand Agency); Maimola and Mor Darra (Bajaur Agency); Shamozai, Mingora, Char bagh, Makhad and Gujar Kili (Swat District); Allai Kohistan (?); and Khaltaro (Gilgit District). Some of these deposits have been studied by a number of authors, mainly by Jan 1968, Jan et al., 1981, Kazmi et al., 1986, Kazmi and Snee 1989, and Laurs et al., 1996.

The emeralds occur in a region characterised by three major tectonostratiraphic subdivisions. North to South these are (1) the Kohistan magmatic arc sequence which has been faulted against (2) the Indus suture mélange group and the latter had been abducted previously onto (3) the Indo-Pakistan plate sequence. The Kohistan rocks have no bearing on the genesis of emeralds. The Indus suture mélange and the Indo-Pakistan hand, directly involved in the formation of the emerald deposits.

The Indus suture mélange group comprises tectonic blocks of ophiolites, blueshists, greenschists, metavolcanics and metasediments in a matrix of sheared and variously metamorphosed fine-grained sediments and/or serpentinite. These rocks occupy the MMT zone between the Kohistan andesitic arc and the northern margin of the Indo-Pakistan plate. The latter contains Paleozoic and Mesozoic shelf sediments, unconformably underlain by Precambrian crystalline schists and Paleozoic granitic intrusions. This sequence is intruded by Tertiary granites. The emeralds occur in two distinct geological environments. Except the Khaltaro deposit, all others are suture associated and occur as disseminations or pockets in talc-carbonate-schists. The mineralisation is confined to faults or shear zones. Emeralds formed late in the history of the suture associated rocks after major deformation had been completed as they are nowhere crushed, stretched or otherwise deformed. Emerald mineralisation apparently relates to the final stages of the metasomatic alteration of the ophiolite mélange to talc-dolomite mélange. The absence of granitic or pegmatitic veins in the mélange, presence of beryl pegmatites and tourmaline in the granitic rock near Kot and Pacha Fort and the occurrence of young (tertiary) leucogranits near Karora, Iram and Saidu (close to the suture zone) suggest that the mineralising fluids came from these youngest granitic rocks. Emeralds developed only in the Mingora mélange which provided the chromium.

The Swat emeralds are among the most Cr-rich known (up to 2 wt.% Cr_2O_3). They have higher Mg and transition metals and lower Al per 18 O atoms that the pegmatite Khaltaro emeralds. They contain inclusions of actinolite, chromite, dolomite, enstatite, feldspar, gersdorffite, magnesite, mica and pyrhotite. Fluid inclusions are generally two-phase (brine + CO_2 - vapour). Homogenisation temperatures range from 305° to 349°C and salinity ranges from nil to 20 eq.wt.% Nacl. The host rocks (talc-carbonate schists) have ultramafic geochemical signatures (930-2520 ppm Cr; 980-2540 ppm Ni). Altered rocks near emerald deposits are locally enriched in Al, Si, Be, and REE reflecting the hydrothermal addition of a continental crust-derived component. Collision of the Indian and Asian plates along the Indus suture zone was an important factor in the genesis of the deposits because it juxtaposed sources of Cr (ophiolitic mélange) with sources of Be (continental crust).

South of the Indus suture zone, the Indo-Pakistan plate sequence in the Haramosh Range,. comprising Proterozoic schists and layered gneisses, hosts the Khaltaro emeralds. emeralds occur in thin (0.1-1.0m) hydrothermal veins and granitic pegmatites occuring as sill-like body within garnet-mica schist. The pegmatites give $^{40}Ar/^{39}Ar$ muscovite date of 9.13 $\pm$ 0.04 Ma. Emeralds are found mainly within thin (< 30cm) veins of quartz and tourmaline-albite and more rarely in pegmatites, near the contacts with altered amphibolite. The pegmatites are zoned, having ;an inner zone of biotite, tourmaline and fluorite with local albite, muscovite, quartz, and rare beryl, an intermediate zone containing biotite and fluorite with local plagioclase and quartz and an outer zone of amphibolite containing sparse biotite and local quartz. According to Laurs et al. (1996), the inner and intermediate zones experienced gains of K, H, F, B, Li, Rb, Cs, Be, Ta, Nb, As, Y and Sr, and losses of Si, Mg, Ca, Fe, Cr, V and Se. The outer alteration zone has gained F, Li, Rb, Cs, and As. Oxygen isotope analyses of igneous and hydrothermal minerals indicate that a single fluid of magmatic origin produced the pegmatite-vein system and hydrothermal alteration at temperatures between 550° and 400°C. The emeralds formed due to introduction of HF-rich magmatic-hydrothermal fluids into the amphibolite, which caused hydrogen ion metasomatism and released Cr and Fe into the pegmatite-vein system.

Gold potential of northern Pakistan, an assessment based on the results of geochemical exploration survey for gold in northern Pakistan

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Northern Pakistan, comprised of three geological units; the Asian plate, the Kohistan arc and the Indian plate which are separated by major suture zones, offers a high potential for a variety of mineral deposits occurring in similar geological enviromnents elsewhere in the world. Due to its geotectonic history and associated igneous and metamorphic processes the area seems to be very promising for mineral prospecting. The region is a challenging ground for the mineral prospector because of its complex geological enviromnents and geomorphic features.

Orientation studies based on regional panned-concentrates and geochemical exploration surveys were conducted for gold and precious metals in two geologically different terranes of northern Pakistan. The Chitral area forms part of the Asian plate and the Gilgit region is part of Kohistan arc sequence. These two are separated from each other by northern Suture and from Indian plate by Main Mantle Thrust (MMT).

Our regional survey in Chitral reveals that the area has a high potential for gold mineralization associated with Ag, As and Sb. Gold anomalies of moderate to high nature were detected in various valleys of the area. The mentioned anomalies contain gold ranging from (10-5000) ppb with an average of 380 ppb. Ag, As, and Sb range between 1-21 ppm, 2-1500 ppm and 1-16 ppm, respectively. As far as zonation of anomalies is concerned the area north of Shoghor limestone and the Reshun Formation is better prospects than that to the south of it. Strong anomalies were located in Tirich, Barum and Past valleys while moderate anomalies were found in Kafiristan valley.

The regional panned- concentrates survey of Gilgit area (Kohistan arc) demonstrates that many of the valleys contain anomalies of precious metals along with Ag and As. In these anomalies gold ranges from 10-7800 ppb with an average of 700 ppb and the concentrations of Ag and As are in the range of 10-25000 ppb and 2-1400 ppm respectively. In Bagrot valley, however, the concentration of gold ranges from 2-14 ppm which is associated with very high concentration (up to 6000 ppm) of As. Highly anomalous valleys, for precious metals along with silver, arsenic and antimony, are Bagrot, Dainyor, Pisan and Minapin in the area of Gilgit town.

Intra and extrabasinal controls on sedimentation of Neogene fluvial sequence in Himalayan foreland basin

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Molassic, fluvial rocks of the Siwalik Group record changing depositional environments in the Himalayan foreland basin. In the Potwar plateau, Chinji, Nagri, Dhok Pathan and Soan formations of this Group comprise relatively thick (tens of meters) sandstone bodies and mudstones that contain thinner sandstone bodies (meters thick) and palaeosols. Thick sandstone bodies extend for kilometers normal to paleoflow, and are composed of sandstone storeys stacked laterally and vertically adjacent to each other. Sandstone bodies represent single or superimposed braided-channel belts, and storeys represent channel bars and fills. Channel belts had widths of km, bankfull discharges on the order of 10^3 cusecs and braiding parameter up to about 3. Individual channel segments had bankfull widths, maximum depths, and slopes on the order of 10^2 m, 10^1 m and 10^{-4} respectively, and sinuosities around 1.1. These rivers are comparable to many of those flowing over the megafans of the modern Indo-Gangetic basin, and a similar depositional setting is likely. Thin sandstone bodies within mudstones extend laterally for on the order of 10^2 m and have lobe, wedge, sheet and channel-form geometries. They represent crevasse splays, levees and floodplain channels. Mudstones are relatively bioturbated/disrupted and represent mainly floodbasin and lacustrine deposition. Mudstones and sandstones are extremely disrupted at places, showing evidence of prolonged pedogenesis. These "mature" palaeosols are meter-scale thick and extend laterally for kilometers. Lateral and vertical variations in the nature of their horizons apparently depend mainly on deposition rate.

The kilometer scale thick Siwalik Group is comprised of two major 100 m scale coarsening upward megasequences. The lower sequence (Chinji and Nagri Formations, ca. 14-9 Ma) records coarsening upwards from fine to medium sandstones, followed by basin-wide abrupt fining at the base of the upper sequence (Dhok Pathan and Soan Formations, ca. 9-2 Ma). The highest proportion of major channel sandstone bodies (upper Nagri Formation) is associated with laterally extensive and interconnected channel-sandstone bodies, which have relatively thicker and vertically superimposed sandstone storeys. Compacted deposition rates decrease with sandstone proportion (0.53 mm/year for Nagri, 0.24 mm/year for Dhok Pathan and 0.21 mm/year for Soan), and palaeosols are not as well developed where deposition rates are high. Within the Siwalik formations there are 100 m-scale variations (representing on the order of 10^5 years) in the proportion and thickness of thick sandstone bodies, and tens-of-m-scale alternations of thick sandstone bodies and mudstone-sandstone strata that represent on the order of 10^4 years. Formation-scale stratal variations extend across the Potwar plateau for at least 100 km, although they may be diachronous: however, 100m and smaller scale variations can only be traced laterally for up to tens of milometers.

Alluvial architecture models indicate that increases in the proportion and thickness of thick sandstone bodies can be explained by increasing channel-belt sizes (mainly), average deposition rate and avulsion frequency on a megafan comparable in size to modern examples. 100-m-scale variations in thick sandstone-body proportion and thickness could result from regional shifts in the position of major channels, possibly associated with fan-lobes on a single megafan or with separate megafans. However, such variations could also be related to local changes in subsidence rate or changes in sediment supply to the megafan system.

Formation-scale and 100-m-scale stratal variations are probably associated with interelated changes in tectonic uplift, sediment supply and basin subsidence. Increased rates of hinterland uplift, sediment supply and basin subsidence, recorded by the Nagri Formation, may have resulted in diversion of a relatively large river to the area. Alternatively, changing river sizes and sediment supply rates may be related to climate changes affecting the hinterland (possibly related to tectonic uplift). Climate during deposition of the Siwalik Group was monsoonal. Although the Siwalik sequence contains no direct evidence for climate change, independent evidence indicates global cooling throughout the Miocene, and the possibility of glacial periods (e.g. 10.8 Ma, corresponding to the base of the Nagri Formation). If the Himalayas were periodically glaciated, a mechanism would exist for varying sediment supply to megafans on time scales of 10^4 10^5 years. Although eustatic sea-level variations are related to global climatic changes, they are not directly related to Siwalik stratigraphic changes, because the shoreline was around 1000 kilometers away during Miocene.

Trondhjemites in the southeastern part of the Kohistan island-arc terrane, Pakistan: A product of partial melting

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The Kohistan terrane in N. Pakistan is sandwiched by two major thrusts, the Main Karakorum Thrust (MKT) in the north and Indus Suture or Main Mantle Thrust (MMT) in the south. Recent geological mapping in southeastern part of the terrane, along a N-S transect, provides new and important information about the geology of the area. Hence, the base of the terrane is occupied by a stratiform mafic-ultramafic complex (the Sapat complex), which overrides the crust of the Indian plate along. The complex was intruded into the base of a thick pile of metavolcanics of different environments (the Kamila belt). The Kamila belt is intruded by a suite of granitoid rocks divisible into three groups. gabbroic association, gabbro-diorite/tonalite-granodiorite-granite association and trondhjemite association.

The trondhiemites occur as thin veins and dykes in the northern part of the Kamila amphibolite belt. Here, the belt is in contact with the Chilas complex along a strong shear zone known as Jal shear zone. Under the microscope the trondhjemites contain feldspar, quartz and amphibole with minor epidote, muscovite, biotite, sphene, garnet and ore, and show parallel alignment of mineral grains in one major direction. They show a very spiked pattern and are depleted in all HFSE, particularly strongly in Ti, P and Nb relative to the other granitoids of the area. The trondhjemites formed by the partial melting are depleted in these elements due to occurrence of amphibole and garnet as the residual phases in the arc basement

Partial melting of a basaltic source material is considered to be the most viable mechanism for the generation of high-AI trondhjemites similar to those of the area studied by Drummond and Defant (1990). Basalts converted to amphibolites and eclogites when involved in subduction-zone setting are partially fused to generate trondhjemites (De Vore, 1983a, b., Windley, 1984; Martin, 1986, 1987). The geochemical modeling and experimental studies (Drummund and Defant, 1990) favour a hot oceanic crust (20-30 Ma old) subducting and melting to produce trondhjemites. The trondhjemites of the present study are probably a product of partial melting of Kamila amphibolites but a direct role of subduction is not observed.

Treloar et al. (1990) considered that the amphibolite-facies metamorphism and deformation in the Kamila belt is related to the Kamila shear zone of 80 Ma, suggesting a similar age for the trondhjemites. The emplacement of Chilas complex (90-80 Ma) might have played an important role in the genesis of the trondhjemites as a heat source. Field evidence, distinctive geochemical signatures and restricted distribution of trondhjemites close to the Jal shear zone and the lower contact of the Chilas complex support the idea but the exact petrogenesis of the trondhiemites cannot be properly evaluated without data on rare-earth elements.

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Geothermobarometery in Landakai and Chakdara areas, Swat and Dir districts, NWFP, Pakistan

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The Landakai and Chakdara areas, occupy the northern part of the Indian plate south of the Main Mantle Thrust. The oldest rock unit in the area is the metamorphosed Swat granite gneiss of Cambrian age. The schists, marble and amphibolite exposed in the region are believed to be continental shelf sediments of Silurian-Devonian age which have a tectonic contact with gneisses. The rocks of the MMT/Mingora ophiolitic mélange were tectonically emplaced upon the metasediments of the Indian plate during late Cretaceous to early Tertiary time.

Metamorphism in the area ranges from low to medium grade at relatively high pressure. The rocks exposed north of the Swat river belong to the greenschist facies, whereas rocks exposed south of the river fall in the kyanite zone of the amphibolite facies. Retrograde metamorphism has affected the area throughout but is more intense north of the river.

Geothermobarometery was carried out in pelites and amphibolites south of the Swat river. Applications of the garnet-biotite geothermometer and garnet-aluminum silicate-plagioclase geobarometer in metapelites gave a T and P range from 535° C, 8.3 kb to 662°C, 11kb. In amphibolites, the garnet-hornblende geothemometer and garnet hornblende-plagioclase geobarometer gave a T and P range from 588°C, 10.8 kb to 705°C, 11.9kb.

Trondhjemites from the Waziristan ophiolitic mélange, NW, Pakistan

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Small amounts of leucocratic intrusions composed of quartz, feldspar, and accessory ferromagnesian minerals are associated with most ophiolites, These, commonly called trondhjemite or plagiogranite, are soda-rich and potash-deficient as compared with normal granite. These rocks are generally found in the upper part of mafic cumulates of the ophiolite sequences, but the trondhjemites in the Waziristan ophiolitic mélange are associated mostly with ultramafic cumulates and only locally with mafic cumulates. In both the cases they have sharp intrusive contacts with the host rocks. They occur in the form of veins, pods and plugs, ranging from a few centimetres to four metres in width and six to ten metres in length. The rocks are light-grey to milky-white, medium-to coarse-grained, equigranular, non-foliated, and composed of quartz, albite (An_{8-10}) and minor biotite and hornblende. The constituent minerals, especially plagioclase, show alteration to chlorite, calcite, sericite, epidote and muscovite.

The rocks are characterized by relatively high SiO_2 (60.47 - 79.70 wt.%), Na_2O (3.04 - 6.06 wt.%), CaO (0.52 - 6.95 wt.%), and low K_2O (< 1 wt.%), TiO_2 (< 1 wt.%), P_2O_5 (< 1 wt.%) and MgO (0.23 - 2.82 wt.%). They are sub-alkaline in composition and classify as trondhjemite on the basis of normarive albite, orthoclase and anorthite contents [1]. The Rock/Primordial Mantle spider diagram pattern (Fig. 1) shows enrichment in LIL elements (K, Rb, Ba, Sr) relative to HFS (Ti, Y, Nb) elements [2]. The geochemical pattern for the trondhjemites is transitional between those of island arc and mid-oceanic ridge granites.

K/Ar whole rock ages of trondhjemites (77 $\pm$ 2 - 70 $\pm$ 1 Ma) are much younger than the overlying radiolaria (Late Jurassic to Early Cretaceous) found in the pelagic sediments lying on top of the ophiolite [3]. From these dates we conclude that the ophiolite was generated by the Late Jurassic and emplaced during the Latest Cretaceous-Paleocene.

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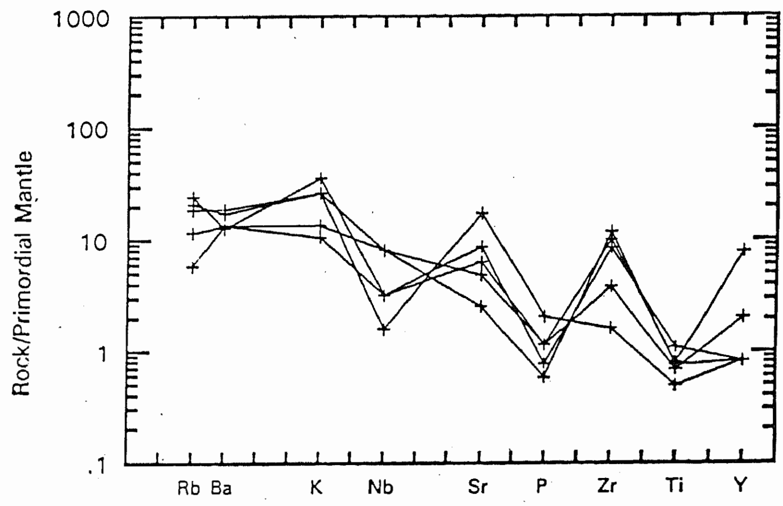

Fig. 1. Rock/Primordial Mantle spider diagram for trondhjemites from Wazlristan ophiolitic mélange (normalizing values after Wood et al., 1979).

Tectonic implications of major and trace elements geochemistry of volcanic rocks from the Waziristan ophiolitic mélange, NW. Pakistan

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Volcanic rocks are the most voluminous component of the ophiolite segments in the Waziristan ophiolitic mélange (WOM). They are divided into two-groups, (i) Vizhda Sar Complex volcanics (VSCV), and (ii) Waziristan ophiolitic mélange volcanics (WOMV). The VSCV are erupted along the western periphery of the Mesozoic shelf sediments of the Indian plate, in Waziristan, Pakistan. Their most excellent outcrops are found between Vizhda Sar to the south and Baba Shaga to the north. The name Vizhda Sar Complex is proposed after Vizhda Sar, the second highest peak in the area and is composed entirely of pillow basalts. The VSCV contain exotic blocks of limestone and shale ranging in age from Lower-Middle Triassic to Late Cretaceous. They are basaltic in composition, and are not associated with dykes. To the west they are obducted by the WOM. The WONV form the uppermost segment of the ophiolite sequence overlying the mafic cumulate and underlying the pelagic sediments, respectively. In the normal ophiolite sequence they found as pillow lavas, while in the ophiolitic mélange part, they are sporadically distributed over a considerable area and found as pillow lavas, sheet flows, agglomerates and breccias. Contrary to the VSCV, the WOMV are intruded by dolerite dykes, showing chilled margins. The WOMV have a wide range in composition varying from basalt to rhyolite. Geochemically, the VSCV are more primitve as evidenced by their higher content of MgO, Cr, and Ni than the WOMV, which are more fertile in LIL (K, Rb, Ba, Sr) elements. Both types are soda-rich, potash deficient, sub-alkaline and tholeiitic in composition. The VSCV are mid-ocean ridge basalt, whereas the WOMV are transitional between mid-oceanic ridge basalt and island arc tholeiite. Field and geochemical data suggest back-arc basin affinity for the formation of WOMV.

The radiolaria found in the cherts lying on top of the ophiolite sequence are of Late Jurassic to Early Cretaceous age, suggesting a Late Jurassic age for the generation of WOM [1]. The presence of tectonic blocks of Globotruncana-bearing limestone of Late Cretaceous age in the WOM, the K/Ar radiometric dates of gabbroic rocks (77 $\pm$ 2 - 75 $\pm$ 1 Ma) and trondhjemites (77 $\pm$ 2 - 70 $\pm$ 1 Ma) and Early-Middle Eocene strata unconformably overlying the ophiolite sequence, suggest Latest Cretaceous-Paleocene as the time of emplacement of the WOM. This is consistent with the emplacement of Khost ophiolite to the north in Afghanistan [2] and Muslim Bagh ophiolite to the southwest in Pakistan [3]. The high scale deformation of the Tertiary (Early to Middle Eocene) sequence unconformably overlying the ophiolite sequence [1] and the serpentinite splinters cross-cutting the Oligocene-Miocene flysch sediments of the Katawaz basin west of Muslim Bagh propose Pliocene age as the time of India-Afghanistan collision.

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Crustal study in lesser and sub-Himalayas of northern Pakistan based on gravity modelling

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In Lesser and Sub-Himalaya in Northern Pakistan the deformations have been observed in crystalline crust and sedimentary and metasedimentary wedge using gravity technique. The crystalline crust of 38 km thickness extended all the way in the study area and faulted into blocks under the western limb of Hazara-Kashmir Syntaxis. These faults are Hazara Lower Seismic Zone (HLSZ) and Bagh Basement Fault (BBF). These predeveloped faults have been reactivated after collision of Indian and Eurasian plate. The HLSZ has been associated with the basement fault under northern Potwar trending NW-SE. Along this fault 6 km relative movement of the blocks have been observed. In the gravity modelling best fit of the observed and calculated curves in the northeast of Abbottabad also suggested 4 km relative movement of the blocks. This fault has been named as the Bagh Basement Fault which is existing between HLSZ and Indus Kohistan Seismic Zone (IKSZ).

In the sedimentary and metasedimentary wedge the deformations have been developed by the southward migration of this wedge. The thrust faults have brought in contrast the different stratigraphic units in sedimentary and metasedimentary wedge of the Hazara-Kashmlr Syntaxis. From north to south in Lesser Himalaya Nathiagali Thrust (NT) brings the Hazara Slates of Precambrian age over the Eocene to Cretaceous marine rocks. The Main Boundary Thrust (MBT) is the major southern most lineament along which the pre-collisional marine sediments are thrusted over post-collisional molasse in the Sub-Himalaya. The fault plane of MBT is steeper near surface and becomes gentle in depth, and joins the low angle detachment. The fault plane of the NT does not join the MBT, which indicates that NT is not a part of MBT Zone. The MBT at present is active in the north of Kohat and in the eastern limb of Hazara-Kashmir Syntaxis. The present gravity investigations suggested the presence of the Panjal thrust between Panjal volcanics and Tanol Formation in the eastern limb and do not pick the Main Central Thrust up-to the Kundul Shahi. This may exist in the upper Neelum valley. The thrust system of eastern and western limbs were converging near the apex of Hazara-Kashmir Syntaxis. The Jehlum Fault cuts Panjal Thrust (PT), MBT and the Kashmir Boundary Thrust in the Kashmir side and the Hazara Thrust System in the western side in northern Pakistan. The dips of the Hazara Thrust system increase towards northeast. The differential movement exists in the Hazara-Kashmir Syntaxis due to the presence and absence of decollement (salt). In the western limb thrust nappes are thrusting southward over the decollement, whereas, in the eastern limb the thrust nappes are uplifted in the absence of decollement. These differential movements developed the Jehlum Fault. The sedimentary and metasedimentary wedge of the western limb of Hazara-Kashmir Syntaxis moves southward along the Jehlum Fault. The Kuldana shales are acting as a secondary decollement, in the sedimentary wedge. The average crustal thickness or Moho depth in the area seems to vary from 46 km (southwest) in Fatehjang to 59 km in Kundul Shahi (northeast). It seems that the total crustal thickness from Potwar plain (Fatehjang) to the Neelum Valley (Kundul Shahi) Azad Kashmir increases by 13 km.

Geology of the Kohistan batholith in Kar Gah and Gor sectors, Kohistan arc terrane, Gilgit, North Pakistan

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Kohistan arc terrane lies between the Asian and Indian continental plates (Fig.1). Both the northern and southern contacts of the arc are marked by suture zones commonly known as Main Karakoram Thrust (MKT) and Main Mantle Thrust (MMT). The Kohistan bathohth which is one of the major rock components of the arc and the Trans-Himalyan batholith extends for more than 2700 km along the length of Himalaya and Karakoram. The Kohistan batholith in Kohistan arc extends for 300x50 km between the Afghan border on the west and the western flank of the Nanga Parbat massif on the east (Fig. 1). The batholith is an ENE-SSW elongated body consisting of many plutons which intrude the Jaglot Group and Chilas complex of the Kohistan arc. The Kohistan batholith, south of Gjlgit, in Kar Gah and Gor sectors comprises multiphase plutons forming Shinghai and Gor plutonic belts. The Shinghai plutonic belt is basic to intermediate in composition comprising gabbro, gabbroic-diorite and diorite along with younger intrusions of granodiorite and granite (minor). The belt also contains serpentinite, pyroxenite? and paragneiss as xenoliths. The Gor plutonic belt is the principal occurrence of the Kohistan batholith along the drainage divide between the Indus and Gilgit rivers. It is a coherent body of mainly quartz diorite composition but also contains intrusions of tonalite, granodiorite, adamellite and granite along with ample aplite and subordinate pegmatite. The main pluton contains abundant xenoliths

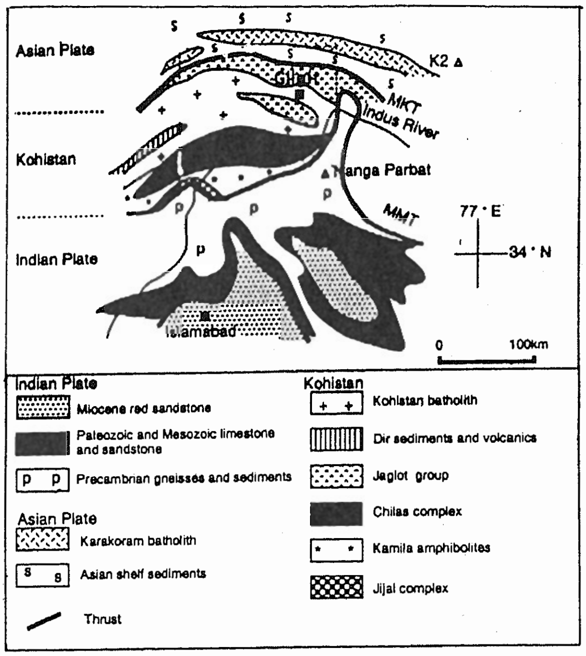

Fig. 1. Generalized geological map of the Kohistan arc terrance, North Pakistan.

and/or autoiths of basic composition. Both the northern and southern contacts of the Gor pluton are intrusive into the metasedimentary succession of the Jaglot Group and the Chilas complex, respectively.

Major and trace element geochemical patterns and petrological characteristics of the Kohistan batholith in the study area reveal that (i) chemical variation seen in the batholith is not due to high level differentiation but can be better explained by partial melting, (ii) much of the Kohistan batholith appears to be the product of mantle wedge above the subduction zone, (iii) some of the leucogranite and aplite seem to be derived by partial melting of the crust of the Kohistan arc, and (iv) there are certain plutons which are alkaline in nature and contain a higher amount of K_2O over Na_2O which may be derived from crustal material such as Gilgit paragneisses and/or from a possible basement of the Indian plate crust underplating the arc. The frequency of C twins in the Kohistan batholith is mostly 10 to 20% showing igneous features and shallow depth of emplacement for the batholith.

Nature of Indus suture (MMT) and Astak fault east of Nanga Parbat-Haramosh Massif

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Recent studies have shown that in much of the Himalaya the Indus suture (IS) demarcates the boundary between the Indian plate and the "Asiatic" mass with local occurrences of ultramafic rocks and ophiolitic melanges. In the northwestern Himalaya, however, a more complicated scenario has been documented due to the presence of an extensive zone, the Kohistan-Ladakh island arc (KLIA), between the Indian plate and Asia. The contact between the Indian plate and the KLIA is an extension of the IS and locally (i.e. within Pakistan) named as the Main Mantle Thrust (MMT).

The MMT is quite variable in nature. It is razor sharp in some places (e.g. Sapat; Jijal; Timargara), consists of ophiolitic melanges (e.g. Shangla; Alai; N of Peshawar), or of melanges containing elements of the Kohistan arc and Indian plate with or without components of the neo-Tethyan crust-mantle (e.g. Babusar; E of NPHM). In some places high-P rocks have been reported in the MMT zone (Patan; Kaghan; N of Astak; Le Fort et al., 1997).

The IS on the eastern margin of the NP is a good example of a melange zone containing all three components. The Indian plate is represented by metasediments and gneisses, the KLIA by amphibolites, and the neo-Tethyan oceanic crust by mafic-ultramafic assemblages. Individual blocks range from a few to hundreds of meters in dimension and show varying degree of deformation and alteration.

West of the Astak river confluece with the Indus river (~3 km W of Astak police station), a series of pelitic and possibly some psammitic rocks, variably deformed and boudinaged, contain lenses of amphibolite (meta-gabbros), semi-pelites, calc-silicate and ultramafic rocks. The mafic-ultramafic assemblages include meta-gabbros (now garnet amphibolite), altered chromite-bearing dunite, peridotite and pyroxenite, and are enclosed in biotite-rich matrix. This biotite-rich matrix probably formed from a mud-rock. The pelites are garnetiferous and have streaky bands and veins of quartz and feldspathic material. Some muscovite pegmatite are highly boudinaged (upto 15 cm thick). Some amphibolite occurs in cm-scale bands. Amphibolite lens may contain 1/2 mm garnet porphyroblasts. The mafic-ultramafic lithologies are highly altered and mostly consist of ?tremolitic green amphibole with or without talc, boudinaged within biotite-rich band. The biotite-rich 'beds' are also boudinaged and in rare cases, reach ~1.4 m in width. These 'beds' consist of abundant biotite and subordinate green amphibole, with possibly a small amount of quartz. These green amphibole-bearing pockets in biotite-rich matrices, normally not more than a few meters across probably represent olistostromes formed at the surface of the neotethyan oceanic crust. The mafic-ultramafic lenses are upto a third of a meter in length and some 10-13 cm thick. One ultramafic lens (1/2 m x 20 cm) contains poorly defined layers as well as disseminated grains of chromite in an altered green ultramafic matrix. The outermost 1-2 cm crust of the 'nodule' is very dark, rich in amphibole, possibly some olivine and some orthopyroxene.

Also contained in the zone are lenses of a dense rock consisting of garnet, ?opx, ?cpx, and qtz. One disc shaped, 2 x 3/4 m in size, ultramafic lens contains, from core outward, talc, talc+tremolitic amphibole, and ~1 cm rim of tremolitic green amphibole, enclosed in biotite-rich band. The largest ultramafic lens (~20 m broad), consists of grey/brown material in a greenish to yellowish serpentinitic matrix. In the interior of this lens, there is a biotite-rich zone ~½ m across which contains altered nodules of the ultramafic. These nodules may have talcose interiors surrounded by colorless and/or green fibrous amphibole. Adjacent to the ~20 m ultramafic lens, the biotite band passes into grey to white fibrous amphibole ± talc-bearing band with a green inner and a grey outer zone. Locally this ultramafic lens is grey serpentinitic. Alteration zones in the ultramafic main lens contain upto ~3 cm long green mica, prisms of upto ~2 cm long green amphibole, and ?magnetite.

The ultramafic lithologies are hosted by metasedimentary rock which gets more and more gritty to conglomeratic westwards. Well-bedded siltstone and sandstone lithologies are exposed ~250-300 meters west of the eastern-most ultramafic lens. Some of these gritty rocks contain over 1 cm rotated garnet porphyroblasts. Local biotite-rich bands with greenish material continue westwards for at least several 100s of meters. This melange zone extends over ~2 km to the west from the Astak River confluence with the Indus river.

Further west, associated with these rocks are greyish orthogneisses, garnet-kyanite gneisses and banded amphibolites and granitic sheets, all intruded by deformed quartzo-feldspathic material (aplites and pegmatite dikes). Similar melange zone has been found some 25-30 km to the south along Astore river east of Harchu, although the scale of the mafic-ultramafic 'pockets' here is several orders of magnitude smaller.

Geochemistry is in progress to sort out details and tectonic locale of the various mafic-ultramafic lithologies.

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Recent seismic activity in the Sulaiman fold-and-thrust belt, Pakistan

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A 150 km long and about 50 km wide area of the Sulaiman Fold-and-Thrust Belt has been affected by earthquake activity since 2.08 a.m. of 27th February 1997. Even today shocks are being recorded from the area. The first event of Mb = 6.3 resulting in the death of 57 people was followed by 206 events of Mb ranging from 6.0 to 3.3 till 30th April, 1997.

Focal mechanism solutions of the main event and subsequent 5 events for which relevant data is available show strike-slip faulting with a right-lateral sense of slip in all cases. A number of faults notably Khalifat, Harnai and Khattan faults are believed to have been activated during this seismic activity.

The P and T-axes orientations indicate NE-SW and NW-SE directions respectively. In this area along the western plate boundary mixed thrust and strike-slip solutions were obtained by Verma and Chandra - Sekhar for events recorded during 1965-1978 whereas in our case all solutions are of strike-slip faulting. A kinematic change from thrusting to transpression as a result of oblique collision is believed to be the present stage of evolution.

Total intensity magnetic survey of a part of Peshawar basin, Pakistan

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Total Intensity ground magnetic measurements at 0.5 km interval were made in the eastern parts of Peshawar basin. A total of 515 observation stations were observed on about 280 km long profiles along the existing roads. The diurnal and normal corrected data indicate that the basement is not smooth and dips generally towards north. The depth estimation of various residual anomalies using different empirical relations show that deeper basement depths occur near Shahbazgarhi, Charbagh, Gohat-i and Adina in the northern side of the area whereas shallow depths have been estimated at Menai and Risalpur in the southern half of the area . The presence of dykes has been verified by fitting dyke model of Ram Babu. These dykes are becoming nearly vertical northwards and are buried at deeper depths indicating the northern edge of the graben structure.

Multidisciplinary investigations in the Quaternary-Holocene Lamayuru basin, Ladakh Himalaya

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Multidisciplinary investigations, by using geology, palaeomagnetism, neotectonics and palaeontological remains, were carried out in a 150m thick Late Pleistocene-Holocene terrestrial sequence in the Lamayuru basin, Ladakh Himalaya. About 35-40 ka BP, an episode of neotectonic activity along the Indus Suture Zone in the western Ladakh caused instability and dammed the River Lamayuru, as a result of which a lake was formed at Lamayuru (3600m altitude), This event is synchronous with a major regional tectonic episode throughout the Himalaya. Palaeomagnetic studies reveal a reversal of polarity at about 35 ka BP, correlatable with the Indian Ocean event. So far, this is the oldest reversal recorded in the Qaternary-Holocene terrestrial sequences in the Indian subcontinent.

Sedimentation took place in the palaeolake until it was drained due to revival of neotectonic movements around 1000-500 yr BP, This phase of tectonic instability resulted in the deposition of mega-colluvial debris from the adjacent mountain slopes and subsequently, the entrenchment of the Lamayuru drainage into its own deposit.

The 150m thick palaeolake profile is represented by four episodes of deposition resulting from fluctuating water level and sediment supply, Nine fossiliferous horizons (stratigraphically 30cm, 1.5m, 6.4m, 1.7m, 24.8m, 27.8m, 31.7m, 37m and 38.9m above the base) have yielded ostracods and gastropods, Out of several taxa of micro-invertebrates recovered, three *(Succinea, Gyraulus convexisculus* and *Ilyocypris gibba)* are reported for the first time from the Ladakh region, The presence of micro-invertebrates indicate shallow freshwater conditions throughout the existence of the palaeolake.

Palaeoclimatic conditions in Late Pleistocene lacustrine profiles of central Himalaya, India

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For the first time in the Central Himalaya in India, multidisciplinary data on the Late Quaternary climatic changes have been achieved. The data provide the first chronometric evidence of a regional tectonism throughout the Himalaya around 40 ka BP, an event which resulted in formation of lakes on the strike faults in the zones of major and active intracrustal thrusts in the region. The revival of neotectonic movements on the major and/or subsidiary thrusts around 9 ka BP terminated the lacustrine sedimentation, Thus, the palaeolake profiles are dated between about 40 and 9 ka BP. Two minor magnetic reversals, at 28-26 ka BP (= Mono Lake Excursion) and ca. 7.7 ka BP, are reported for the first time in the subcontinent. Three seismic events (at ca. 33, 30.8-30.7, 30.7-33.0 and 28.8 ka BP) and a micromammalian assemblage (ca. 35 ka BP). reported for the first time in the Central Himalaya, enhance the importance of this work.

Three prominent humid phases (ca. 31-27. 25.9-24 and 18.5-13.0 ka BP) show expansion of moisture loving arboreals, marshy/shrubby taxa, aquatics and ferns. The arid periods (ca, 40, 27-25.9, 24-18.5 ka BP) are characterised by enormous rise in Cheno/Ams, substantial increase in *Pinus*, considerable reduction in marshy taxa, decline in shrubs and aquatics, abrupt decline in ferns. almost disappearance of humid arboreals and predominance of C4 vegetation, More interesting is a period from 18.5 ka BP onwards which shows expansion of marshy elements, increase in shrubs, fern spores, *Lycopodium* and aquatics, re-appearance of wetland arboreals, substantial decline in steppe elements and in *Pinus*, indicating a prominent climatic amelioration. This proves that the LGM (Last Glacial Maximum) was >18,000 yr BP in Central Himalaya, The anti-correlation between Himalaya and peninsular India may be explained either by early deglaciation in some parts of the world or by strengthening of northeastern monsoon and heavier winter precipitation during this period of weak southwestern monsoon.

Origin of ultramafic-felsic association in the Chilas igneous complex, Kohistan arc, north Pakistan - Exotic block derived from oceanic crust

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The Chilas igneous complex is one of the major geologic units in the Kohistan arc region, located in the western Himalaya of northern Pakistan. It is a huge gabbroic body, 300 km long, intruding the Kamila amphibolites which occur widely in the southern half of the Kohistan arc region. The Chilas igneous complex is composed mainly of gabbronorite with minor two-pyroxene quartz diorite and two pyroxene granodiorite. The complex contains several small xenolithic bodies of ultramafic-felsic association (UFA), layered two pyroxene gabbro and amphibolites. The layered two pyroxene gabbro is the cumulus facies of the gabbronorite (Kubo et al., 1997).

Within the Chilas igneous complex, several bodies of UFA exist. Of these, the body cropping out along the Karakoram Highway (KKH) to the east of Chilas village (named as Thak body) is described in detail. The Thak body extends 2.8 km along the KKH, enclosed and intruded by gabbronorite of Chilas igneous complex. The Thak body consists of cyclic units of layered cumulate rocks. The layered rock units are younging from west to east throughout the body. The cumulates are classified into olivine cumulate and pyroxene-dominant cumulate. Olivine-dominant cumulate consists mainly of olivine cumulate (dunite), associated with minor amount of olivine-clinopyroxene cumulate (wehrlite). It occurs as 10 to 400 m thick layers, alternating with thin layers of plagioclase dominant cumulate. Plagioclase-dominant cumulate occurs as layers several meters to several tens of meters thick. It consists of plagioclase olivine-clinopyroxene cumulate, though the modal ratio of each mineral changes greatly within a layer. The amount of clinopyroxene occurring as primocryst is very low. At the basal part of plagioclase dominant cumulate,, a trough structure develops. It crosscuts the underlying olivine dominant cumulate. The boundary between the top of the plagioclase-dominant cumulate layer and the overlying olivine-dominant cumulate slayer is generally straight, and is parallel to the rhythmic layering or lamina in the upper part of plagioclase-dominant cumulate. This suggests that the plagioclase-dominant cumulate was covered conformably by the olivine-dominant cumulate and the boundary plane represents a horizontal plane during the crystal accumulation.

Under the microscope, the plagioclase-dominant cumulate shows adcumulus texture. Plagioclase, olivine and clinopyroxene occur as granular primocrysts. Olivine is sometimes partly rimmed by clinopyroxene, orthopyroxene and/or hornblende embedded by vermicular spinel. A similar texture is also recognized rarely in the olivine-dominant cumulate. The characteristics are as follows, i) frequently, olivine is in direct contact with plagioclase without the interception of other crystals, and ii) the rock has an igneous texture and keeps the normal compositional zoning of primocrysts though very weak. Effects of regional metamorphism are not recognized. These characteristics and mineral chemistry data indicate that the vermicular spinel within clinopyroxene, orthopyroxene or hornblende was formed by the reaction between olivine and plagioclase, under the condition of the inconstant existence of a liquid phase among the primocrysts, i.e., the reaction between plagiociase and olivine proceeded during the magmatic stage, instead of during the metamorphic stage.

Pyroxene-dominant cumulate occurs as a layer 18 m in thickness. The upper boundary of the layer is straight and covered concordantly by olivine-dominant cumulate, and the lower boundary is cut by gabbronorite. It consists of orthopyroxene-clinopyroxene cumulate (websterite) and clinopyroxene cumulate (clinopyroxenite). Pyroxene-dominant cumulate occurs also near the eastern margin of the Thak body as platey blocks, 20 m in thickness, intruded by gabbronorite. EPMA data show that the compositional variation of each mineral is very small within and among the layers, and systematic changes through the Thak body are not recognized, i.e., cryptic layering does not exist. The Thak body and gabbronorite of the Chilas igneous complex are very different in petrologic and mineralogical characteristics, indicating that these rocks have different origin. The crystallization process of UFA is summarized into, i) olivine and small amounts of clinopyroxene crystallized continuously near the central part of a magma reservoir and settled on the bottom. The settled crystals made up the homogeneous accumulate (olivine-dominant cumulate). During this process, the chemical composition of crystallizing minerals and the magma (liquid) above the cumulate was kept constant, ii) at the same time, crystallization of pyroxenes and plagioclase occurred at other portions of the same magma reservoir. Some accumulated plagioclase and pyroxenes flowed down along the bottom of the magma chamber (like a mudflow in water) toward the place where olivine was accumulating. Thus the plagioclase-dominant and pyroxene-channeled or eroded olivine-dominant cumulate, iii) plagioclase, olivine and interstitial liquid could not coexist stablely, and a reaction rim was formed between plagioclase and olivine, and iv) as the downward flow of plagioclase and pyroxene occurred intermittently, plagioclase dominant and pyroxene-dominant cumulates were covered by olivine-dominant cumulates conformably until the next flow arrived. This magma reservoir is characterized by open system crystallization. That is, primitive magma is continuously supplied into the magma reservoir and differentiation proceeds from the center to margin of the reservoir. Such a magma reservoir is not known except for that supposed for the generation of oceanic crust. Therefore, the ultramafic-felsic association is considered to be derived from the oceanic crust.

Geological map of western central Karakorum, North Pakistan Hindu Raj, Ghamubar, and Darkot areas at 1:250,000 scale

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We have produced a new geological map at 1:250,000 scale of the mountainous region of NW Pakistan comprising the Hindu Raj and Ghamubar ranges, and the Darkot area in between. The map includes the Karakorum central granitoid belt, in the region where it is divided into two branches, and the slightly metamorphic Darkot sedimentary group.

The region covered by the present map covers three main units: two crystalline masses separated by a sedimentary unit:

- the northern crystalline masses, the Hindu Raj' unit, is mainly made up of plutonic rocks varying from diorite to granite in composition, the granite being in the center, flanked to the north and south by the mafic plutonic rocks. In general, the Chikar meta-sedimentary formations and migmatitic gneisses occur in the northern part; intruded by the Ishkarwaz pre-Ordovician granitoid, they represent the basement of Karakorum;

- the middle sedimentary unit, the Darkot unit, is composed of low-grade meta-sedimentary formations, including arenites, slates, and limestones in which Upper Paleozoic bryozoans and brachiopods have been found [1]. We have also found Triassic megalodonts, and possible Cretaceous rudists;
- the southern crystalline mass, the Ghamubar unit, is composed of plutonic rocks also varying from diorite to granite in composition, and intruding into a large northern stripe of Aghost gneisses and migmatites.

To the north and north-east, the area is separated by a series of folds, thrusts, and lineaments from the East Hindu Kush, in which a large Jurassic porphyritic granite outcrops.

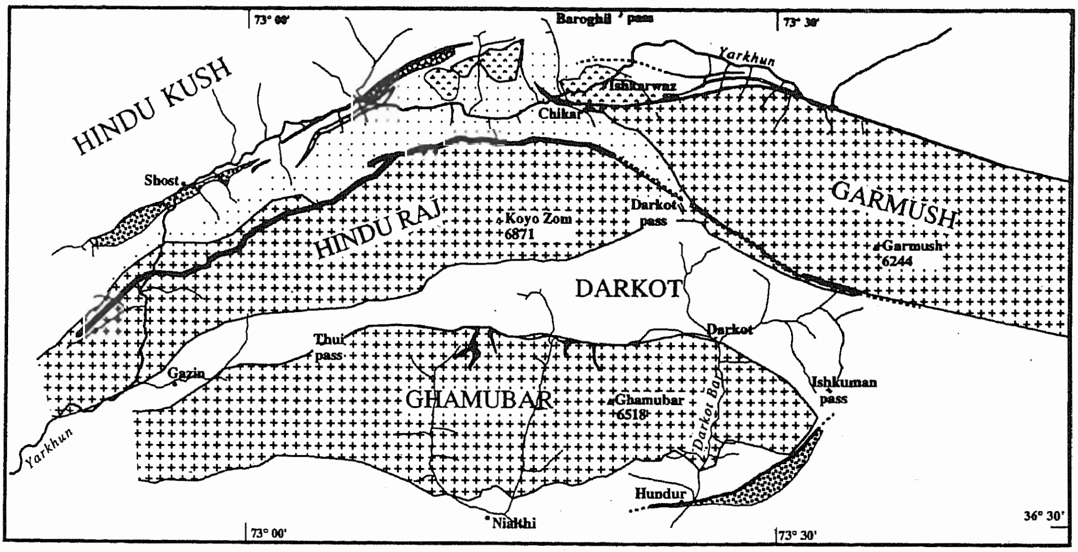
To the south, the Nialthi meta-sedimentary formation, at least Permian in age, is overlain by the Lower Cretaceous detritic and partly volcanic formations of the Yasin group. Within the Nialthi formation we have discovered a separate strip of conglomerate: the Hundur formation.

One of the salient feature is the presence throughout the map of extended pinched strips of sedimentary rocks (Reshun and Hundur conglomerates, Dobargar sedimentary horizons) that underline the lenticular shape of the crystalline masses.

The large scale tectonics can be divided into three main phases:

1. a longitudinal stretching with boudinage of the batholith,
2. a left-lateral strike-slip that has doubled the batholith and is probably responsible for the pinched structure of sedimentary formations,
3. and a north-south extension fast enough to produce a layer of pseudotachylite (see Le Fort & Villa, this volume) on the southern side of the 5 to 10 km wide Darkot graben.

[1] Hayden, 1915. Rec. geol. surv. India, 45(4), 271-335. Ivanac et al., 1956, Rec. geol. surv. Pakistan, 7, 3-27.



Geological framework of NW Karakorum

Dobargar pinched sedimentary structure pseudotachylite band

crystalline massifs Chikar quartzite and gneiss Reshun and Hundur conglomerate

Fig. 1

Preliminary results of Himlung expedition to northern Manaslu massif, central Nepal

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The Scientific committee of the Club alpin français and the C.N.R.S. have organised a joint scientific and climbing expedition to the leucogranitic Himlung peak (7139 m) during spring 1997. It enabled to survey the northern part of the Manaslu pluton as well as the geology of the western and north-western surrounding sedimentaries of the High-Himalaya. Previous knowledge was limited to the results of the 1969 and 1971 expeditions [1] and [2].

We will mainly restrict ourself to the field results as the petrologic and geochemical investigations are under way. The field discoveries that we synthesize in a map (see Fig. 1) concern: i) the nature and continuity of the sedimentary series, and ii) the tectonic evolution of this part of the High Himalaya.

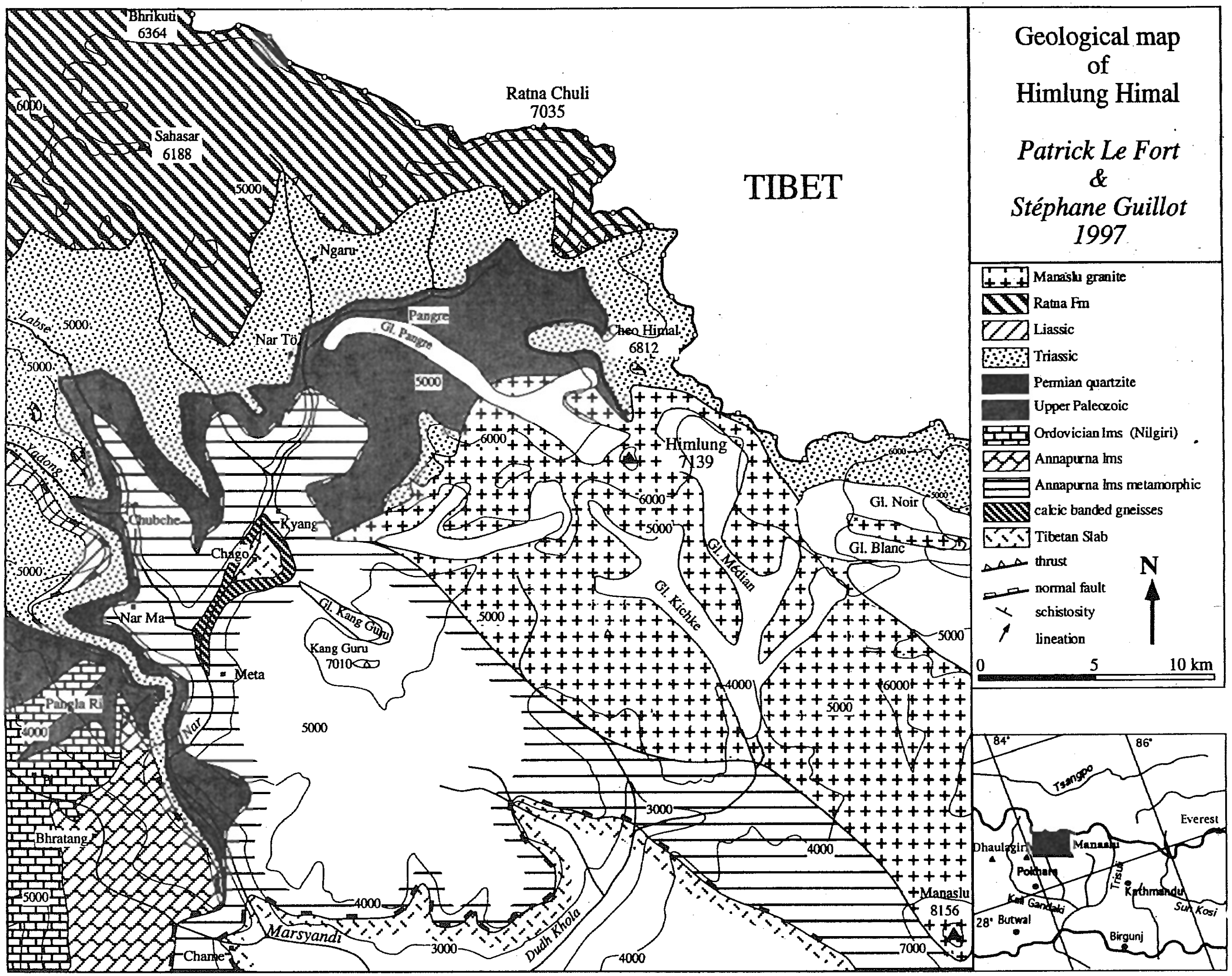
Geology:

1) Permian white quartzites: we have followed this excellent stratlgraphic marker for some 70 km, from the southern end of the Nar valley to when they intersect the intrusive contact of the Manaslu granite. In the Nar Ma region, as already shown by Bordet et al. (1975), they occur twice in the same section; but the upper sequence that belongs to the inverted limb of the Annapurna huge fold, are associated with the spilitic episode of [3];
2) Ordovician Annapurna Formation: we have discovered that this thick formation is repeated twice with a lower occurence metamorphosed in the amphlbolite facies, and an upper one in the greenschist facies. The contact is a flat normal fault that constitutes the base of the Annapuma fold;
3) Mesozoic Ratna Formation: this is a new formation that we have discovered in the northernmost part of the valleys. It is made up of massive alternations of marly and arenitic beds, and exceeds 1000 m in thickness. Towards its base, fossiliferous remains and sedimentological characteristics have enabled J. P. Bassoullet from Poitiers to ascertain a probable Upper Liassic to Lower Dogger age to these levels.

Tectonics: The region is a typical example of interference between the north- and south-vergent tectonics

- to the south, the Annapuma fold, the Nar Ma normal fault at its base, and the Kyang normal decollement below it, are all north-vergent;
- to the north, the folds of the region of Nar Tö and Pangre, and the thrust at the base of the Ratna formation are south-vergent;
- in between, south of Nar Tö, the south-vergent tectonic event is clearly reworked by the north-vergent one.

According to our mapping, the Kyang normal decollement is compatible with its prolongation into the floor of the Manaslu pluton.


Geological map
of
Himlung Himal
Patrick Le Fort
&
Stéphane Guillot
1997
Manaslu granite
Ratna Fm
Liassic
Triassic
Permian quartzite
Upper Paleozoic
Ordovician lms (Nilgiri)
Annapurna lms
Annapurna lms metamorphic
calcic banded gneisses
Tibetan Slab
thrust
normal fault
schistosity
lineation
N
0
5
10 km
TIBET
Bhrikuti
6364
Sahasar
6188
Ratna Chuli
7035
Ngaru
Nar Tö
Pangre
Gl. Pangre
Cheo Himal
6812
Himlung
7139
Gl. Noir
Gl. Blanc
Gl. Médian
Gl. Kichke
Gl. Kang Guru
Kang Guru
7010
Kyang
Chago
Chubche
Nar Ma
Meta
Nar
Pangla Ri
Bhratang
Chame
Marsyandi
Dudh Khola
Manaslu
8156
Labse
Yadong
84°
86°
Tsangpo
Everest
Dhaulagiri
Manaslu
Pokhara
Kali Gandaki
Trisuli
Kathmandu
Sun Kosi
28°
Butwal
Birgunj
Fig. 1

[1] Bordet, P., Colchen, M. & Le Fort, P., 1975. Carte géologique au 1/75.000 ème du NyiShang, éd. CNRS, Paris.
[21 Colchen, M., Le Fort, P. & Pêcher, A., 1980. Carte géologique au 1/200.000 ème du Dhaulagiri - Annapurna - Ganesh Himal, éd. CNRS, Paris.
[3] Le Fort, P., 1975. A spilitic episode in the Tibetan Upper Paleozoic series of central Nepal, Bull. Indian Geol. Assoc., 8, 100-105.

A new map of Hunza to Baltistan at 1:150,000 scale, northern Pakistan

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We are finalizing a new geological map at 1: 150,000 scale of the mountainous region joining Hunza and Baltistan (Fig. 1). The map includes the central granitoid belt and the southern metasedimentary complex of the Karakorum range, volcano-sedimentary and igneous formations of the Kohistan and Ladakh island-arc units, and the northern tip of the gneissic Himalayan spur.

Some of the salient features evidenced during mapping include:

1. Lithology:

- The very continuous marble horizons of the Karakorum metamorphic complex (KMC), some of them of Permian age (see Rolland et al., this volume).
- The existence of long stripes of orthogneissified granitoid in Karakorum.
- The reconnaissance of terrigeneous formations in south-western KMC.
- The continuity of the Kohistan to Ladakh formations, limestone horizons in particular. Some of them dated as Cretaceous.
- The existence of ultramafic lineament that separate the island-arc in two domains.

2. Tectonics:

- The large isoclinal folding of the Karakorum metamorphic complex (KMC), underlined by very continuous marble horizons.
- The folding of the Karakorum granites in the isoclinal folds.
- The presence of a mélange zone along the MKT, north of it (Karakorum side) to the west. south of it (Ladakh side) to the east.
- Folding of the boundaries between the three units, MKT and MMT. Likeliness that some traditionally described formations may actually belong to the neighbouring unit (e.g. amphibolites in the Himalayan unit).
- The pervasive doming stucture in a band, east of the Raikot fault, cutting across Himalaya-Ladakh and South-Karakorum.
- The northern tip of the Raikot fault, presently the most active fault, corresponding to the north-western edge of the NPHM dome.

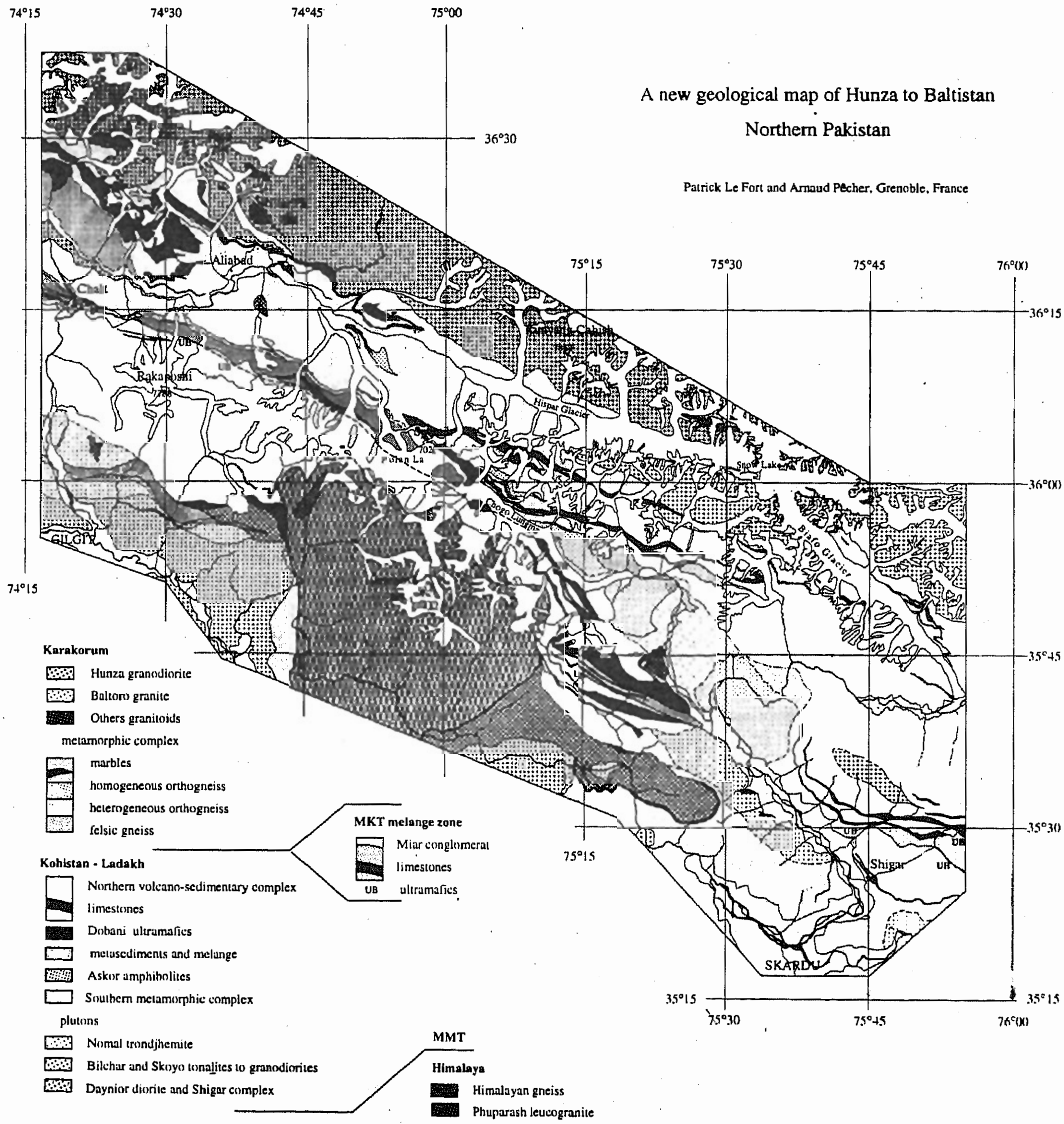
A new geological map of Hunza to Baltistan
Northern Pakistan
Patrick Le Fort and Arnaud Pêcher, Grenoble, France
74°15
74°30
74°45
75°00
36°30
75°15
75°30
75°45
36°15
36°00
35°45
35°30
35°15
Aliabad
Chalt
Bakaposhi
Hispar Glacier
Snow Lake
Biafo Glacier
Shigar
SKARDU
GILGIT
Karakorum
Hunza granodiorite
Baltoro granite
Others granitoids
metamorphic complex
marbles
homogeneous orthogneiss
heterogeneous orthogneiss
felsic gneiss
Kohistan - Ladakh
Northern volcano-sedimentary complex
limestones
Dobani ultramafics
metasediments and melange
Askor amphibolites
Southern metamorphic complex
plutons
Nomal trondjhemite
Bilchar and Skoyo tonalites to granodiorites
Daynior diorite and Shigar complex
MKT melange zone
Miar conglomerat
limestones
UB ultramafics
MMT
Himalaya
Himalayan gneiss
Phuparash leucogranite

Fig. 1

Pseudotachylites at crustal scale in Karakorum: the Thui pseudotachylite, northern Pakistan

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The Karakorum mountain belt is typically divided into three main units: a northern sedimentary belt (NSB) and a southern metamorphic complex (KMC) separated by a central granitoid batholith (CGB) often referred to as the Axial batholith. In the western part of the Karakorum mountain. two crystalline belts occur: a northern Hindu Raj belt, that includes Darkot pass and Garmush crystalline masses, and a southern Gamubar belt, that are separated by the Darkot unit of mildly metamorphosed sedimentary series (see Le Fort & Villa, this volume; Fig. 1).

In 1996, during the course of our regional reconnaissance and mapping of north-western Karakorum, with Maurizio Gaetani, we have discovered that the northern side of the Ghamubar belt is profusely invaded by a band of pseudotachylite. From north to south, the generally north-dipping section comprises:

1. the 4 to 7 km wide Darkot unit that had yielded Permian fossils [1] and where we have retrieved Triassic megalodonts, and possible Cretaceous rudists (Gaetani, pers. comm., 1996);
2. a tightly folded and metamorphosed contact zone, about a 100 m thick, mainly made up of black silicic schists at the top and quartzites at the base;
3. the km-thick zone of Aghost banded gneisses, mostly granitic, but also containing very dark blotite and/or amphibole gneisses, as well as several group of layers of marble, presenting tight isoclinal folds usually north-verging. The **Thui pseudotachylite** fringes the northern boundary of this Aghost Formation;
4. a several km thick and massive zone mainly composed of biotite-garnet-sillimanite gneisses interlayered with granitic gneisses and partly migmatised. To the south, this zone is intruded by the Ramach granodiorite and the Ghamubar porphyritic granite (Ghamubar plutonic unit [2]).

We have followed the Thui pseudotachylite for more than 40 km East-West, between Gazin glacier (Yarkhun valley), and summer settlement of Ghamubar (Darkot valley) at the eastern foot of the Ghamubar pass. More to the east, the pseudotachylite seems to pass to ultramylonitic bands within the Aghost gneiss. Vertically, it extends for nearly 3 km. The best set of outcrops is located in the upper Kerun Bar valley where the pseudotachylite forms most of the southern slope, and has a total thickness probably exceeding 10 m.

In the field, the rock appears as centimeter- to millimeter-thick black streaks anastomoziner within the Aghost gneiss, disregarding the orientation of the metamorphic foliation. The disposition of the veinlets reminds of the hydraulic fracturation. The intruding dark veins have a glassy appearance, a conchoidal fracturation, and contain many cataclastic disrupted remains of the enclosing rock. Under the microscope, the veins have an isotropic texture.

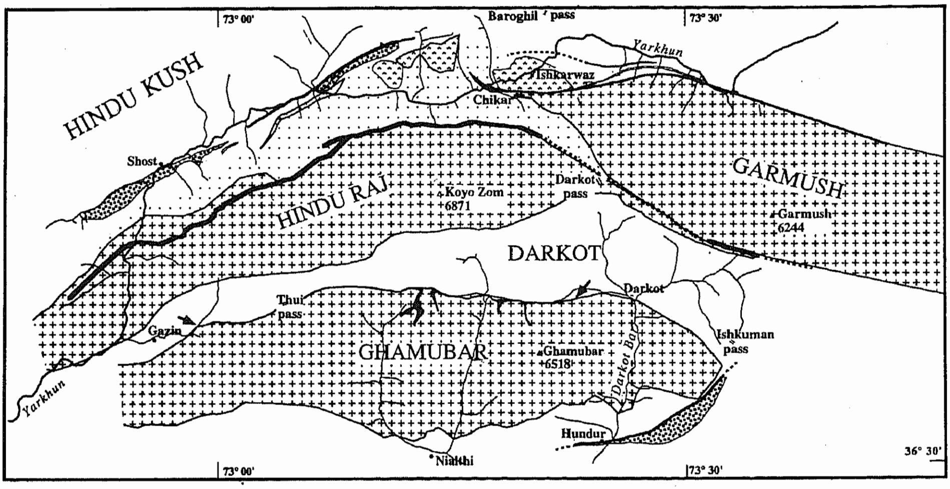
In the "basal shales" of the overlying Darkot group, the pseudotachylite develops a few meters thick "contact metamorphism" with micas and, occasionally, garnet. It is very little deformed: on a unique outcrop, we found it to be folded at 50 cm-scale. For the moment,

$^{40}Ar/^{39}Ar$ dating by stepwise heating shows the predominance of inherited clasts from an older protolith.

This apparently largest so far discovered pseudotachylite, is related to the fast collapse of the sedimentary cover along the top of the southern crystalline mass. One of the latest tectonic movement of the region, it has produced the Darkot graben.

[1] Hayden, 1915. Rec. geol. surv. India, 45(4), 271-335. Ivanac et al., 1956, Rec. geol. surv. Pakistan, 7, 3-27.

[2] Debon, F., Le Fort, P., Dautel, D., Sonet, J. & Zimmermann, J. L., 1987, Granites of western Karakorum and northern Kohistan., Lithos, 20, 19-40.



Localisation of the Thui pseudotachylite in the geological framework of NW Karakorum

beginning and end of the pseudotachylite band — Dobargar pinched sedimentary structure

crystalline massifs — Chikar quartzite and gneiss — Reshun and Hundur conglomerate

Fig. 1. Location of the Thui pseudotachylite in the geological framework of NW Karakorum.

Magnetotelluric study in the area along the profile Yadong-Bam Co

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[3]Geological Survey of Canada, Canada

In coordination with the INDEPTH seismic studies of the collision zone, magnetotelluric (MT) experiments took place along three main profiles from April 25 to August 5, 1995. The united group (CUG, UW and GSC) recorded long period (20s~20000s) MT data at thirty three locations and wideband (320Hz~2000s) MT data at fifty locations using twenty one LIMS systems and one VS system. The profiles are: (1) Yadong ~ Xuegula; (2) Yangbajin ~ Damxung; (3) Dazhi ~ Bam Co.

Through processing the data and analysing the inversion models, the following conclusions can be drawn out:

1. Both upper and lower groups of low-angle north-dipping electrical gradient and distorted zones, more or less discontinuous, are developed in the Central and Southern Tibet at different depdis along the INDEPTH survey. The gradient zone lying at about 25-60 km depth is in good coincidence with MHT discovered during INDEPTH-I in the Southern Tibet. It is extending from south to north up to Damxung, where it is getting steeper and then dies out. The upper electrically distorted gradient zone is widely developed between 15-30 km depths. They might be electrical expressions of a series of thrusts and decollements.
2. The intracrustal low-resistivity and high-conductivity bodies are generally developed in the Central and Southern Tibet. The high-conductivity bodies, however, do not connect one with another, generally at shallow depths with large extension, and they seem to be located at localities of concrescence between tectonic belts. The high-conductivity body revealed within Gangdise Tectonic Belt in the Central Tibet has a wide distribute, with its top surface lying at about 20 km depth, and its base at 40-65 km depth, suggestive, plausibly, of mid-crust partially molten layer.
3. No electrical expression of deep fault was noted in the area of Yarlung-Zangbo river. A large-scale north-dipping low-resistivity and high-conductivity body, however, is observed between Gyangze and Rinbung, with its base lying at 55 km depth. The origin of this high-conductivity body is probably related to the collision between Indian plate and Eurasian plate, hence it is suggested that the Yarlung-Zangbo river Suture should be in the vicinity of Gyangzc.
4. The high-resistivity bodies distributed in the upper crust in the area along Yadong-Bam Co mostly correspond to rock-bodies. Thus it can be seen that the hidden rock-body Pagri, YZR rock-body and Nam Co rock-body are all large by scale, with their bases lying at 30-50 km depths. While the granites in the vicinity of Lhunzhub occur in horizontal beds, with their bases lying at about 15-20 km depth. The ophiolite belt exposed in the area Rinbung is about 4 km thick, rootless. The Kangmar rock-body probably is a displaced body, with its root located on the southern side of Kangmar.
5. The media north of Damxung beneath 50 km depth have more or less homogeneous conductivity, with apparent resistivity less than 80 Ω m, exhibiting a regional conductive background. This probably shows that a distinct crust-mantle structure occurs in the Central Tibet.

Glaucophane and barroisite eclogites from the High Himalayan Crystallines of the Kaghan valley, Pakistan Himalaya

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This report presents preliminary results of a petrographical and mineral chemical study of the eclogite samples from the High Himalayan Crystallines (HHC) of the upper Kaghan valley in which Pognante [1] discovered the presence of glaucophane.

The eclogites described here were collected by U. Pognante in 1991 just south of Babusar Pass, close to the summer settlement of Gittidas. They belong to the same suite as the garnet - omphacite - phengite quartz - Futile eclogites [2] dated as Eocene [3]. The Gittidas eclogites show differences in mineralogy which reflect compositional differences in the protolith and were apparently equilibrated in different stages of the metamorphic history. In addition to omphacite, garnet and accessory rutile, most samples contain a significant amount of quartz (up to 15% vol.). The peak assemblage may also include kyanite, zoisite and ankerite or phengite. Poikioblasts of blue-green or blue amphibole are conspicuous in thin section. In Fe-rich eclogite the amphibole is glaucophane, with high Al^{iv} (up to 0.2 atoms p.f.u.) and Ca in M4 (up to 0.4 atoms p.f.u.), whereas in more magnesian varieties it is barroisite with high Na in M4 (up to 0.7 atoms p.f.u.). Paragonite may be present either as part of the peak assemblage or as a retrogression phase after kyanite. A reddish epidote of allanite composition was found in the glaucophane eclogite.

Garnet is only slightly zoned in the glaucophane eclogite but displays strong prograde zoning in more magnesian varieties, with Fe decreasing and Mg increasing from core to rim. The iron-rich core is usually crowded with minerals of the peak assemblage, but locally inclusions of green and blue-green amphibole were also found. In foliated eclogites the garnet inclusions often define an internal foliation, commonly discordant to the main external foliation. In some garnet crystals, retrograde biotite appears to develop from the Mg-rich rim inwards, producing an atoll-like structure.

Omphacite is frequently crowded with very small rutile needles, suggesting replacement of a former Ti-bearing igneous (?) pyroxene.

During retrogression garnet develops a thin corona of green amphibole, omphacite is replaced by a symplectite of albite + amphibole, and phengite by a symplectite of biotite + feldspar.

The Gittidas eclogites are associated with a metasedimentary sequence of paragneiss with the high pressure assemblage garnet - K-white mica - plagioclase - kyanite - staurolite - zoisite and accessory rutile, with retrograde margarite and biotite. Garnet is zoned, with Fe-rich cores and Mg-rich rims, its chemical composition and zoning being comparable with those found in the barroisite eclogites. This suggests that the quartzofeldspathic country rocks probably suffered the same high pressure metamorphism as the eclogites did.

Equilibration conditions in the Gittidas barroisite eclogites have been estimated at $T = 600 \pm 30\ ^{o}C$ and $P > 13$ kb from Fe/Mg partition in garnet-omphacite and garnet amphibole pairs, and from the jadeite content of omphacite (X_{Jd} up to 0.42). This estimate is close to temperature conditions estimated [4, 5] for the eclogites and high pressure metapelites of the North Himalayan Tso-Morari Dome ($580 \pm 60\ ^{o}C$ and $550 \pm 50\ ^{o}C$, respectively). However, the Tso Morari metapelites have jadeitic pyroxene, and hence this unit is believed to have equilibrated at metamorphic pressures significantly higher than the Kaghan HHC.

At the regional scale, metamorphic peak temperature recorded by both the Kaghan and Tso Morari eclogites during the Eocene high pressure event appear to be significantly different from those recorded by metabasaltic and metadoleritic garnet granulites in the HHC of the northeastern Nanga Parbat-Haramosh Massif, where geothermobarometry of the peak assemblage clinopyroxene - plagioclase garnet - quartz - rutile suggests temperatures around 700^{o}-$800\ ^{o}C$ and pressures around 12-14 kb [6,7] for a younger (Miocene?) high pressure metamorphism affecting the High Himalayan Crystallines of the North Western Syntaxis.

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Metamorphism in the Tibetan slab of the Arun valley and Everest massif, Nepal and southern Tibet

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Combining literature data with new observations, this contribution describes the thermal evolution in and below the Tibetan Slab in the Arun valley and Everest Massif such as it can be inferred from geothermobarometry of metamorphic mineral assemblages.

New data from the thrust sheets of the Main Central Thrust zone, which in the western limb of the Arun mega-antiform divide the garnet-kyanite-muscovite augen gneisses of the Lesser Himalayan Crystallines (LHC) from the high-gade Barun gneiss of the Tibetan Slab, show that in some of the thrust sheets the assemblage garnet-kyanite-staurolite-muscovite-biotite, characteristic of metasedimentary intercalations at the top of the LHC, is replaced by the texturally later assemblage garnet-sillimanite-muscovite-biotite. This change in phase compatibilities suggests an increase in metamorphic temperature (T) coupled with a decrease in metamorphic pressure (P).

Geothermobarometry of garnet amphibolites and kyanite-anthopyllite amphibolites from the same thrust sheets points to a similar P-T evolution, as garnet in the former is replaced by plagioclase + amphibole, and the kyanite- anthophyllite pair is replaced in the latter by garnet-cordierite, suggesting a change from moderately high P (7-9 kbars) and medium T (600^{o}-630 ^{o}C) to lower P and higher T.

The metamorphic evolution of the Barun gneiss is at first sight quite different from that recorded in the thrust sheets, as neither muscovite and staurolite nor kyanite (replaced by sillimanite) appear to be stable in this unit. However, all these mineral phases were found in the

Barun gneiss of the Kharta region, as relict porphyroclasts (kyanite) or as inclusions defining a relict foliation in garnet porphyroblasts (staurolite and rare muscovite). P-T values estimated for the first metamorphic event in the Barun gneiss (M1) are constrained by the kyanite and staurolite stability curves and by the reaction Alm + Rt = Sil + Qtz + Ilm at T of 550 - 570 ^{0}C for P= 6-7 kb. Ml was followed by decompression under increasing T (M2a) producing the dominant mineral assemblage (garnet-sillimanite-biotite), and then by strong decompression under high T (M2b).

Muscovite-absent, biotite - sillimanite - cordierite ± garnet assemblages with late andalusite characterize the Namche migmatite orthogneiss and the so called Black gneiss, i.e. the middle and upper part of the Tibetan Slab on the southern (Nepal) side of the Everest Massif. On the Tibetan side, the top of the HHC is formed by biotite-muscovite gneiss (Rongbuk Formation) which in places has cordierite, andalusite and fibrolite as characteristic minerals.

Rongbuk Formation is actually the site of the ductile shear zone which is the lower part of the South Tibetan Detachment System in the Everest region. As a more complete section of the ductile shear zone is visible in the southern face of Lhotse, we will call Lhotse-Rongbuk Shear Zone (LRSZ) this major synorogenic extensional structure which in the Lhotse face appears to be 1.5 km thick.

A telescoped Barrovian zonation ranging from the sillimanite to the staurolite and biotite zones is characteristic of the LRSZ. Evidence for re-equilibration of mineral assemblages under increasing T and decreasing P was found throughout the whole LRSZ, but is most compelling in metapelites of the staurolite zone, where relics of staurolite and garnet are preserved in biotite - muscovite - sillimanite - cordierite assemblages.

Summing up, salient features in the metamorphic history of the Tibetan Slab and MCT zone in the Arun valley are:

1. the identity between mineral assemblages in the LHC and a first (relict) assemblage both in the MCT zone and in the Tibetan Slab
2. evidence for decompression at high T both in the MCT zone and in the Tibetan Slab. In the latter decompressional recrystallization is conspicuous especially at the base, in the Barun gneiss, and at the top, below and in the LRSZ.
3. Strong telescoping of metamorphic isograds in the LRSZ between the upper amphibolite facies Black gneiss and the low-grade North Col Formation.

Such features suggest that:

1. the inverted metamorphism of Barrovian type affecting the Lower Himalayan units (M1) is older than the main recrystallization in the Tibetan Slab (M2a) and predates the emplacement of this unit,
2. the Tibetan Slab was emplaced onto the LHC during decompression under high T conditions (M2b). Overthrusting along "cold" (greenschist facies) mylonite zones is not the major mechanism for emplacement but just a late phase,
3. decompression in the MCT zone, throughout the Tibetan Slab and the STDS may have been synchronous.

A tectonic scenario satisfying such constraints may be formation of a nappe pile with inverted metamorphism in which continuing compression and self-heating cause extrusion of deep-seated parts of the nappe pile. More complex models are required if decompression in the MCT zone and at the base of the Tibetan Slab was not synchronous with decompression at the top of the Slab during exhumation through the STDS.

A cross section of juvenile continental crust exposed in the Hidaka mountains, Hokkaido, Japan

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Our understanding of the nature and origin of continental crust has progressed through the studies of exposed crustal cross sections such as those in the Kohistan zone (Pakistan) and the Ivrea zone (Italy) [1]. In this paper, we present an overview of a very good example of exposed cross section of juvenile continental crust, the Hidaka Magmatic Belt (HMB), in Hokkaido, northern Japan, which may shed light on the understanding of magmatic evolution of the Kohistan paleo-island arc.

The 300-km-long HMB crops out in central Hokkaido [2] (Fig. 1). Upthrusting of the southern half of the HMB along the western foothills of the Hidaka mountains since the Late Miocene [3] has exposed a crustal section which becomes shallower toward the east [4,5]. The Hidaka crust consists of Paleogene mafic- to intermediate-plutonic rocks, high T/low P metamorphic rocks, and felsic anatexites as well as terrigenous sedimentary rocks of the late Cretaceous to early Paleogene accretionary prism (Fig.1). Maximum P-T conditions obtained for the deepest level of the Hidaka crust is 870 °C and 7.2 kb (Fig. 2) [7], indicating that the crustal thickness is over 20 km. Although upper-mantle peridotites overlain by crustal lithologies are also exposed in the Hidaka mountains, it has not been yet established if they represent an exposed mantle-crust transition zone.

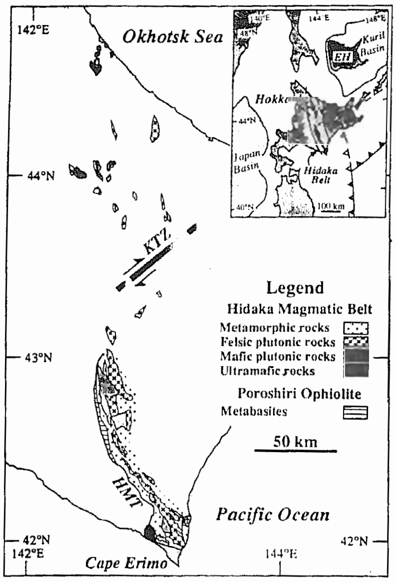

Fig. 1. Distribution of plutonic rocks, metamorphic rocks, and peridotites in the Hidaka Magmatic Belt (HMB). The alignment of the HMB was dextrally displaced by about 50 km along the Kamishiyubetsu Tectonic Zone (KTZ). The Hidaka crust, crustal cross section of HMB, is exposed on the south of KTZ. The sole of the Hidaka crust is marked by the Hidaka Main Thrust (HMT). Inset map shows the location of the Hidaka Belt. Before opening of the Kuril backarc basin in Miocene time, the East Hokkaido block was located north of its present position (EH), and the HMB faced the Pacific Ocean on the east. Dashed lines with open triangles are trenches at that time.

In the northern Hidaka mountains, thick sections of plutonic rocks are exposed. From the base, these are the Pankenushi layered gabbroic intrusion, the Memurodake gabbroic-dioritic complex, and the Nissho Toge granite complex. Metamorphic and anatectic rocks derived from the Late Cretaceous to Early Paleogene accretionary prism are exposed between and around these plutons (Fig. 2). The Pankenushi layered gabbroic intrusion (4x30 km) consists of olivine-rich troctolite, olivine gabbro, and ferrogabbro, with intercalations of anorthosite. Lack of hiatus in olivine crystallization suggests that the Pankenushi gabbro crystallized under relatively high pressures compatible with those of the underlying granulites. Although troctolite is present in the lower part and ferrogabbro in the uppermost part, cryptic mineral compositional variations through the sequence are consistent with periodic replenishment of primitive magma. The Memurodake pluton (8x16 km) consists of hornblende-bearing gabbro and hornblende- and biotite-bearing diorite. In outcrop, the Memurodake suite is a heterogeneous assemblage of fine-grained mafic and coarse-grained felsic rocks. The Nissho Toge complex (5x35 km) is mainly composed of I-type, ilmenite-series granitoids. This plutonic section is gravitationally stable, that is more mafic, denser gabbroic rocks are present in the lower part and more felsic, lighter granitic rocks in the upper part. Upper-mantle peridotite bodies, such as the Magarisawa body (0.6x2 km), composed mainly of plagioclase lherzolite are underlying the Pankenushi intrusion. These upper-mantle peridotites are in a tectonic contact with the crustal lithologies, and relations between them are poorly understood.

We have found two distinctive mantle-derived primitive magmas as dike rocks, normal mid-ocean ridge basalt (N-MORB) and high-Mg andesite (HMA) affinities from the lower crustal levels [8,9]. Intrusion of the mantle-derived magmas into the base of the accretionary prism resulted in high-temperature metamorphism up to granulite facies and anatexis to form felsic metamorphic rocks and calc-alkaline anatectic melts. Intracrustal evolution of the mantle-derived magmas was accompanied by assimilation of the accretionary prism. Mixing and/or hybridization of the mantle-derived magmas and crustal anatectic melts also formed calc-alkaline rocks. Thus, a juvenile continental crust is formed through the interaction of asthenospheric mantle and supracrustal rocks (Fig. 3). Deeper parts of continental crust may be "migmatite", on a macro-scale, which is composed of mantle-derived igneous rocks and supracrustal metamorphic rocks.

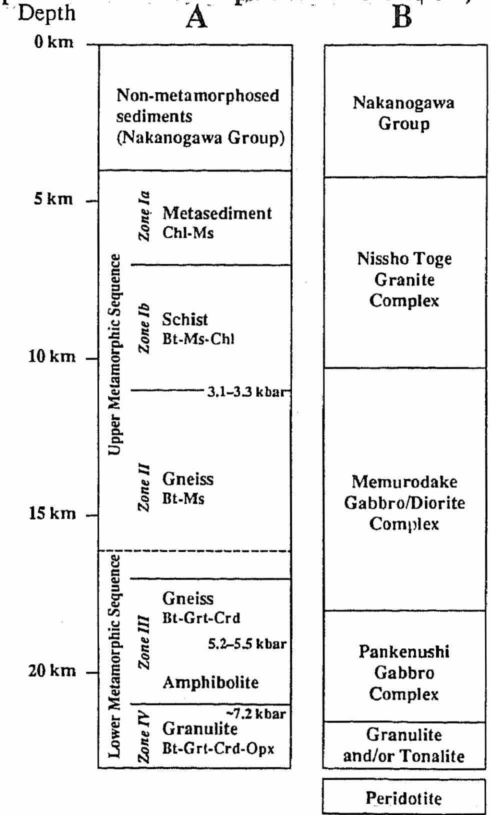

Fig. 2. A. Crustal depth columns of rocks of the HMB (based on [5,6]). Chl: chlorite; Ms: muscovite; Bt: biotite; Grt: garnet; Crd: cordierite; Opx: orthopyroxene. B. Simplified columnar section of the Pankenushi-Memurodake area, northern Hidaka Mountains.

The association of N-MORB and HMA can be explained by a ridge-trench collision model [8,9]; N-MORB originated from an upwelling asthenospheric mantle (lherzolitic, εSr = -27.79, εNd = +10.71) along the Kula-Pacific spreading ridge, and HMA from the mantle wedge (harzburgitic, εSr = +2.17, εNd = +2.84) of the overriding plate due to thermal anomalies induced by the ridge subduction. Apparently when a spreading ridge interacts with an accretionary prism, magmatic and metamorphic processes become extremely different from those of the mid-ocean ridges, where oceanic crust of basaltic composition is formed. Comparison between these two settings suggests that thick sedimentary sequences contribute significantly to the generation of continental crust. The Hidaka crustal cross section provides crucial clues to deciphering the role that mantle-derived primitive mafic magmas play in the generation of continental crust.

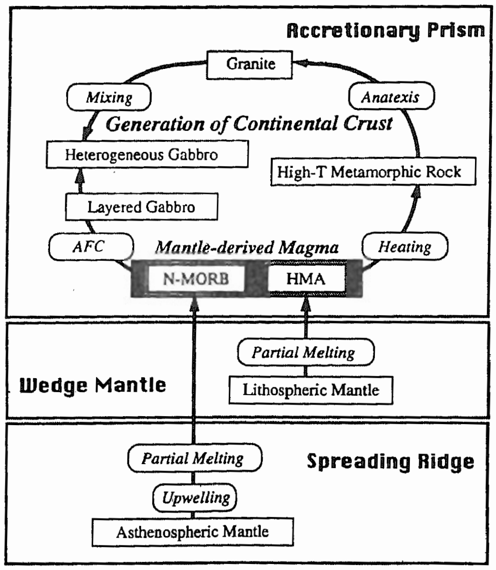

Fig. 3. Magmatic and metamorphic processes in the HMB, and scheme for generation of continental crust in forearc settings by ridge subduction.

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Evidences for the turning of Yalusumpu river as a "hot spot" on the earth

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The definition of "hot spot" was put forward at first from the applied view-point. Furthermore, based on solid geophysics the turning of the Yalusumpu river is a region with high temperature, low density, low geomagnetism, negative gravity, active earthquakes and strong tectonic movement.

The center of the "hot spot" was approximately positioned according to the available data. The temperature difference (ΔT) between the earth and the atmosphere at meteorological stations in January is an inverse dependence upon the distance away, from the "hot spot". The geothermal flux under the "hot spot" center is as large as 25W/m^2 calculated from the earth surface energy balance equation. Moreover, this "hot spot" is in the region with maximum precipitation and highest latitude of the tropical forest in the world. It also acts as an "triggering region" of climate change.

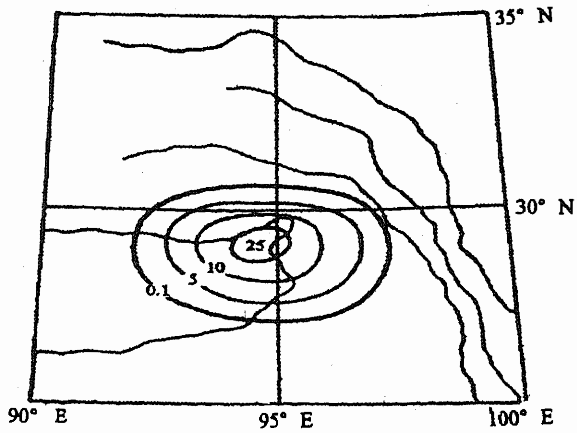

Fig. 1. Distribution of geothermal flux around the "hot spot" in the Tibetan Plateau. (Unit:W/m^{-2}).

Keywords: Hot spot, Geothermal flux, Triggering region of climate change, The turning of Yalusump River.

The hypothesis of atmospheric Heat Engine Efficiency Variation on the causes of the Great Ice Age

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Why had the Great Ice Ages (hereafter referred to as GIA) always connected with violent orogenesis in the earth evolutionary history. Some explanations had been given by geologists but not exact enough. And those proposed by astronomers are poor in integrating the cause of the GIA with the orogenesis. An explanation was put forward in this paper from the meteorological view point, which regards both of them as an orogenic whole.

Huge relief (like Tibetan plateau) began to ascend following the coming into being of mountain-making movement. It could only generate "mountain-valley wind" with very low atmospheric engine efficiency at its initial stage. Shallow plateau monsoon began to form after the horizontal scale of huge relief reached the critical scale of geostrophic adjustment of baroclinic atmosphere ($L_o = \sqrt{\alpha RT} / f$); deep plateau monsoon appeared when the height of huge relief increased as high as condensation and dynamic critical levels, which caused an evident increase in heat engine efficiency (hereafter referred to as HEE). Taking Tibetan plateau as an example, the HEE of modern plateau monsoon is greater than that of mountain-valley- wind by 6-7 times.

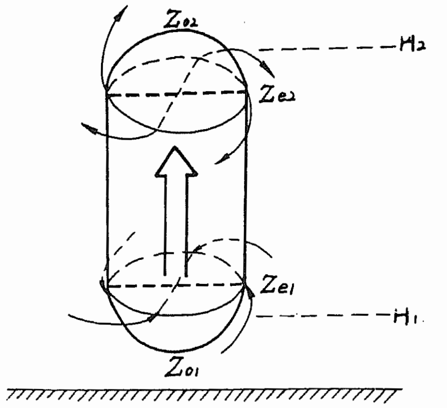

Fig. 1.Illustration of the positive atmospheric heat engine (H_1 ~average height of lower convergence region; H_2 ~average height of upper divergence region; Z_{01} ~ isobaric layer at the center; Z_{e1} ~ isobaric layer at the edge; Z_{02}, Z_{e2} ~ same as Z_{01} & Z_{e1} but for divergence region).

The evident increase in HEE may cause the GIA under the precondition that the direction of huge relief is basically from east to the west (like Tibetan plateau at the present). The causality chain is as following:

Strong orogenesis → steep fluctuation on the earth surface → the huge relief reaching a certain critical scale and generating efficient circulation system (plateau monsoon) → increase in global HEE increase → atmospheric kinetic energy → strengthening of planetary westerly (providing that the huge relief is from the east to the west) → increase in temperature difference between the equator and the polar regions (restrained by thermal wind principle) → sharp cooling in high latitudes and the polars (supposing the solar radiation was approximately constant) → forming GIA.

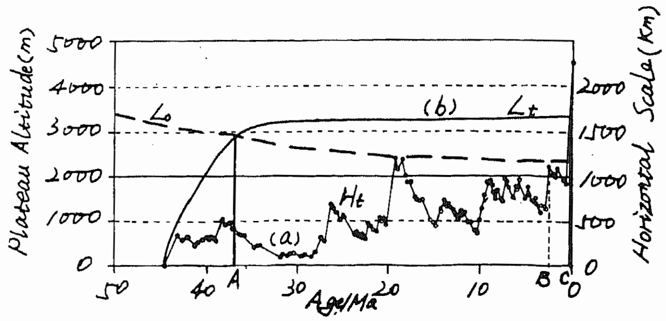

Fig. 2. The theoretical curves of the uplift (a) and expansion (b) process of the Tibetan plateau (H_t ~ altitude of the plateau; L_t ~ horizontal scale of the plateau; L_o~ critical scale of the geostrophic adjustment of the barolinic atmosphere; A, B ~ two critical time).

Key Words: Strong orogenesis, plateau monsoon, atmospheric heat engine efficiency, Great Ice Age.

Polyphase deformation in the sedimentary sequences of the Spiti (Tethys) Himalaya

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The thick marine sedimentary sequences exposed in the Spiti basin, form one of the best developed sections in the northern most Tethys Himalayan tectonic belt. If the stratigraphy and the sedimentology of the Spiti series have been studied since a lonor time (Hayden, 1904; see Bagati, 1991 for a synthesis) descriptions of their structural pattems are scarce.

During summer 1997 a field work was devoted to decipher the complex array of fold systems and faults in the western part of Spiti valley between Kunzum La and Pin Valley.

Four major deformation stages have been recognized. The oldest one is characterized by south-vergent recumbent folds associated with a flat-lying, or gently northward-dipping, cleavage and low metamorphism grade. Large scale folds are rare except in the Lower Paleozoic west of Losar. Large decollement is frequent in the stratigraphic pile particularly where exists a strong rheologic contrast. This is the case at the boundary between Permian and Triassic characterised by a major decollement on top of the Kuling shales, well observed at Losar, Lingti, and in Pin valley. A second major decollement occurs on top of Lower Triassic (Otoceras-Ophiceras beds), well exposed in the same places. Other important decollements exist at the base of Kioto limestones and in the Spiti shales. Axial directions vary from N 120 to N 130: transport directions are near N 40.

The second deformation episode is characterised by large, open north-vergent folds, which are the main characteristics of the landscape. They are often associated with a steeply south-dipping cleavage and northward directed thrust planes. The axial direction are still between N 120 and N 130 giving way to type 3 interference patterns.

The more recent deformations are brittle. Two successive extensional fields are characterised and very often superposed on the same fault surfaces. The oldest one is characterised by a NNE/SSW to NE/SW extension. The major structure is the WNW/ESE oriented Spiti fault (Mazari & Bagati, 1991), but minor faults pertaining to that deformation are observed everywhere. Two type of faults are present: tensional faults are oriented WNW/ESE and sometimes rework previous thrust surfaces, specially when the thrust planes of first generation have been tilted by the second generation open folds; strike slip faults with a minor tensional component are frequent and oriented NNE/SSW to E/W.

The second tensional field is characterised by E/W extension; the previous faults are reworked: strike slip in tensional faults and tensional, like the Spiti fault, in dextral strike slip faults. These tensional fields correspond well with those observed in the Tso Morari area, 70 km North of Spiti (Colchen et al., 1994).

A model of evolution is proposed. The first south-vergent deformations correspond to a period of shortening and thickening (or re-thickening) of the Tethyan margin. In the Spiti area the stuctures (folds, cleavage, decollement) underwent moderate conditions (epimetamorphism), clearly above the MCT. The more recent deformations are related to the thining of an

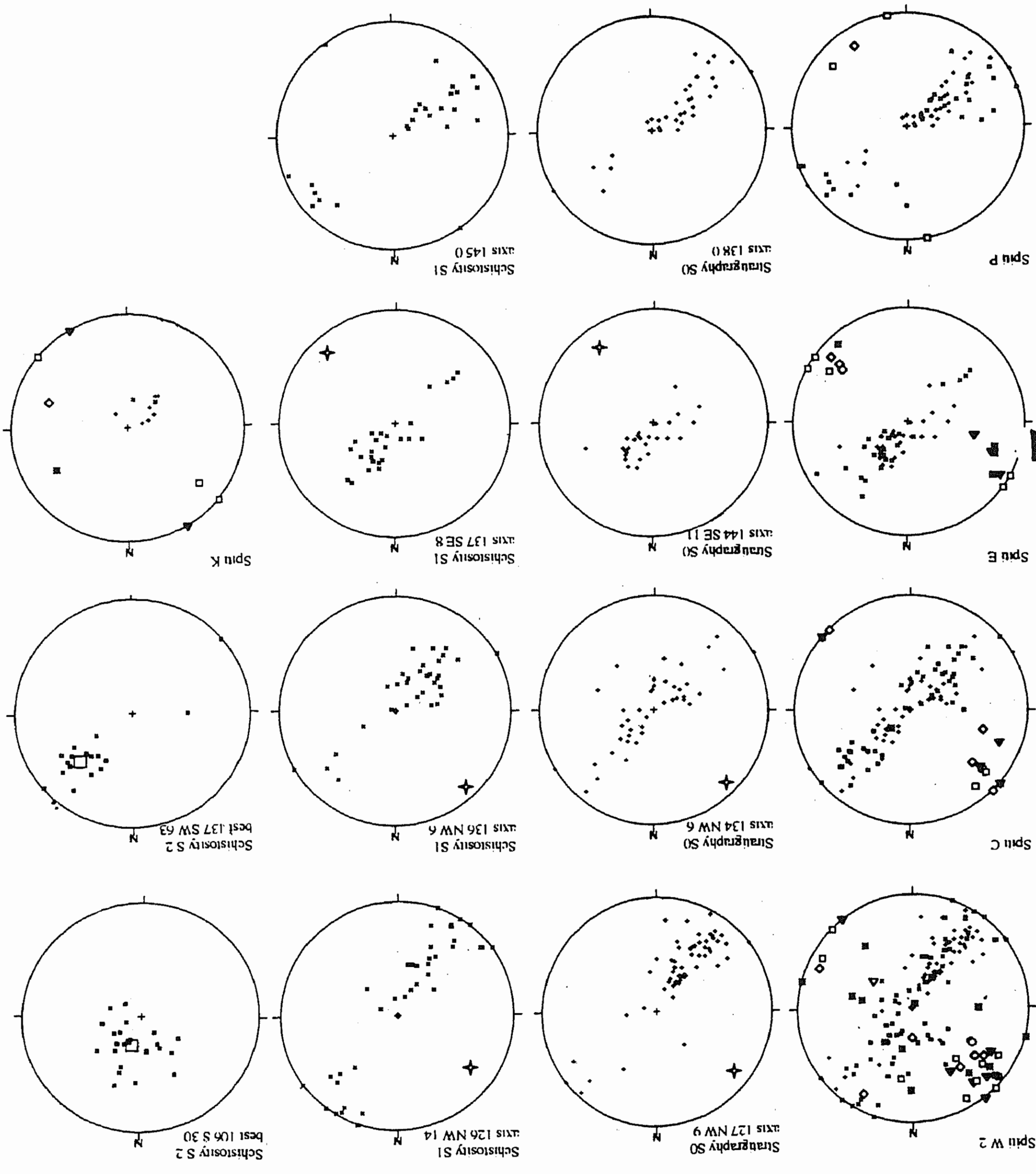

Fig. 1. Examples of structural data: W2 area of Losar, C area of Kaza/Kibber, E area of Lingti, K area of Kioto, P northern part of Pin valley. Wulf net on lower hemisphere.

overthickened sedimentary cover. The first stage corresponds to a general collapse of the sedimentary cover resulting in the northvergent folds and thrusts and related to the strong step in metamorphism occurring south of the Spiti valley between High Himalayan Crystalline and sedimentary cover. The last stage is represented by brittle deformation of the sedimentary cover in extensional regime beginning with a NNE/SSW extension then followed by a EW extension.

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Economic importance of Himalayan molasse to provide nuclear fuel

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The collision of Kohistan island arc with Eurasia plate occurred at about 90-100 Ma, resulting in an Andean type of margin. At 40 to 65 Ma, the Indian plate collided with the Eurasian Plate sandwitching the island arc. As a result of this collision the Himalayan molassic sediment were

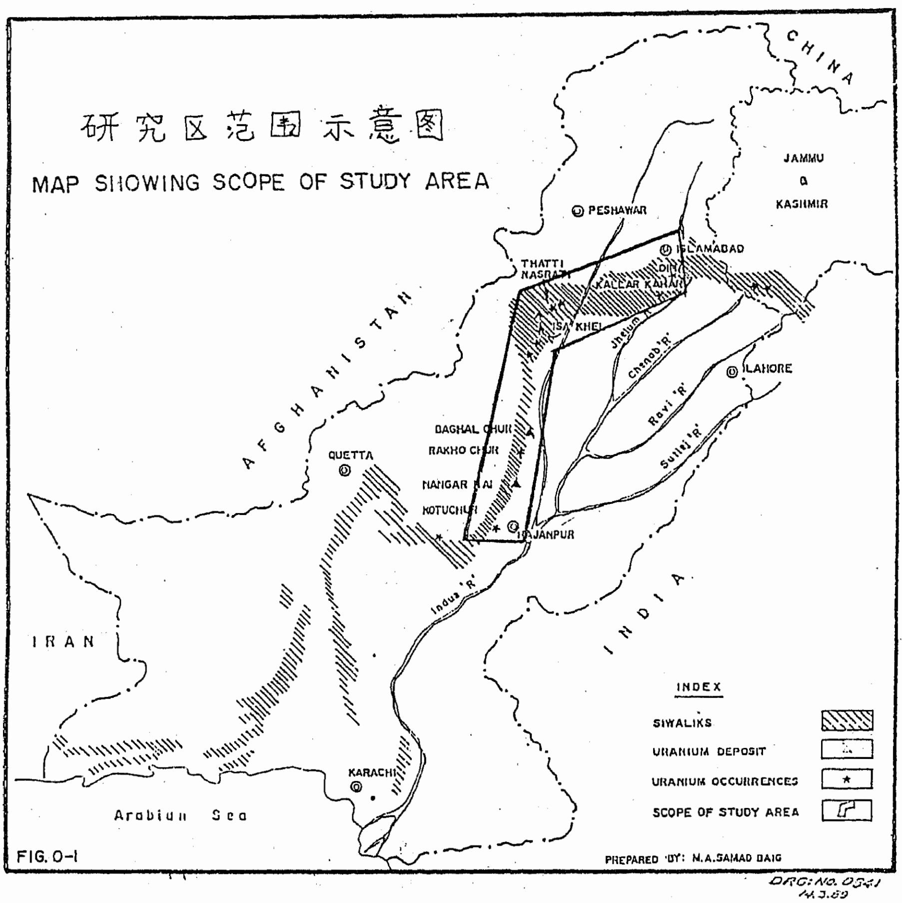

Fig. 1

started to deposit in S-shaped foredeep. Depositional pattern was changed from marine to continental. Except for an arid red-bed paleoclimate represented by the Chinji Formation, the semi-arid and sub-tropical environment, however, dominated during this period. Under these tectonic and paleoclimatic conditions in the foredeep basin a paleo Siwalik drainage was developed and a thick fluvial sequence of molassic character was deposited. Within this sequence the Dhok Pathan Formation controls the general distribution of the sandstone type uranium mineralization in Pakistan.

The sandstone type uranium mineralization discovered till today are mainly distributed in the east-west trend in the Dina Kallar Kahar - Chakrala (Potwar Plateau) and north-south trend in Thatti Nasrati, Shanawah, Isakhel and Simu Killi (Bannu Basin) and also similar trend in Bahgal Chur, Rakhu Chur, Nangar Nai and Rajanpur areas (The eastern flank of Sulaiman Range). To assess the potential of these rocks it is essential to understand the parameter controlling the uranium ore accumulation so that a proper exploration and prospection strategy could be developed to enhance the nuclear fuel supply of the country.

Seismicity and crustal structure at Nanga Parbat, Pakistan Himalaya

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Nanga Parbat lies on the western end of the Himalayan Mountain chain in NE Pakistan. This >8 km high peak, sculpted from Indian crust, is the site of rapid uplift, denudation, and young (<1 Ma) igneous and metamorphic activity. Substantial reworking of the crust occurs today, although the initial collision between India and Asia occurred ~55 my ago. While the Indian basement gneisses that make up the Nanga Parbat massif were clearly involved in a major collisional event, they exhibit virtually no evidence for early Himalayan metamorphism. As part of a multidisciplinary study to understand the active tectonic processes at Nanga Parbat we deployed a dense seismic array to characterize active seismicity at the massif (fault geometry and kinematics) and determine crustal structure beneath the mountain. Extremely rapid exhumation, the presence of hot springs, young intrusive rocks, and young metamorphism all suggest an anomalous thermal structure lies beneath Nanga Parbat.

Our 60 station array consists of 10 broadband and 50 short period three component stations deployed in a 60 x 60 km area surrounding the massif. Station spacing varies from 1 to 6 km, and station elevations range from 1.0 to 4.3 km. The array recorded local and regional seismicity for a 4 month period (May-September, 1996). Primary source regions are the Hindu Kush, the Karakoram, the Himalayan and Hazara arcs, and local seismicity beneath the massif itself. The Hindu Kush events which originate 200-300 km northwest of Nanga Parbat and at 200-300 km depth serve as a beam source to illuminate the structure beneath the massif.

In a four month time window we recorded over 1500 associated events, a combination of teleseismic, regional, and local earthquakes. Our initial focus has been on locating events and analyzing wavefoms. Ultimately, we'll use the Hindu-kush events and additional regional events from a range of azimuths combined with local events to produce a tomographic image of velocity and attenuation structure beneath the massif.

Our array recorded a high level of microseismicity at Nanga Parbat, between 3 and 8 small magnitude events per day. Seismicity is somewhat distributed along strike beneath the massif but exhibits a sharp drop off in intensity both west and east of the main summit. The sharp cut off in seismicity to the west corresponds to the mapped trace of the Raikot fault. This young active structure juxtaposes Indian Pre-Cambrian gneisses against mafic rocks of the Kohistan island arc captured during the collision of Indian and Asia and provides a mechanism to expose Indian plate rocks from beneath Asia. The adjacent Kohistan terrane is virtually aseismic. The sharp cut off in seismicity to the east is bound by the region of highest topography. In fact, the highest intensity of distributed seismicity is associated with the region of highest topography. Local seismicity beneath Nanga Parbat is restricted to very shallow depths (< 8 km bsl) providing constraints on the transition from brittle to ductile deformation. Hypocenters projected to a NW-SE cross section outline a prominent bow or antiformal shape. The cutoff of seismicity with depth is shallowest beneath the summit (5 km bsl) and deepens to 8 km to the NW and SE. This observation is consistent with petrologic and thermochronologic data indicating very high geothermal gradients ($\sim$60-100°/km) at Nanga Parbat. At these rates, rocks pass through the 450° isotherm by $\sim$7 km depth which approaches the ductile regime for quartzofeldspathic rocks, especially in the presence of fluids and high strain rates.

Most of the local events have clean impulsive signals allowing high quality focal mechanisms to be determined. While we recorded some thrust and some right-lateral strike- slip focal mechanisms, much of the observed seismicity is from a set of shallow normal faults striking roughly parallel to the main massif and dipping south to southeast, back toward the summit.

While many of the igneous, metamorphic, and petrologic observations at Nanga Parbat could be explained by a young intrusive body at depth, complicated but prominent S wave arrivals at stations throughout the array rule out the possibility of a substantial magma body beneath Nanga Parbat. This observation holds for both Hindu-kush events with a relatively vertical ray path beneath the massif sampling the entire crust and local events which travel through the shallow crust. However, we do see local travel time delays and anomalous waveforms suggesting small scale heterogeneity possibly related to small partial melt zones. We also see a large variation in waveform coda associated with propagation path (not site affects). While we see many clean impulsive arrivals, others appear more harmonic, not unlike signatures associated with geothermal systems and volcanoes, suggestive of magmatic or fluid injection at shallow depths. These events are intriguing given the evidence for recent igneous activity focused at the core of the massif and evidence from fluid inclusions indicating a dry steam phase associated a hydrothermal system below 3 km depth. Finally, on many of the local events we see evidence of shear wave splitting presumably due to anisotropy associated with the metamorphic or strain fabric of the rocks.

Petrochemical characteristics of the eastern part of the Chilas igneous complex, Kohistan, northern Pakistan

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The Kohistan terrane of the western Himalaya, northern Pakistan, is regarded as an island-arc sequence sandwiched between the Asian and Indian continental crusts [1]. Deep crustal members are now widely exposed in Kohistan, which make it an ideal area to study the genesis and evolution of subduction-related crustal structures and rocks.

The Chilas igneous complex is one of the major geological units in the Kohistan terrane, and it is exposed in a large area of 300 km long and 40 km wide [2]. Most of the complex consists of generally homogeneous gabbronorite, pyroxene diorite and pyroxene quartz diorite. They can be called as the Main Facies, which was termed the gabbro-norite association by Khan et al. [2]. Rocks with layered structure are also found within the Chilas complex, which often occur in km-scale masses. One gabbronorite mass is characterized by well-developed rhythmic layering. Some of the masses are abundant in peridotites associated with layered gabbroic rocks (UMA, ultramafic-mafic association), which are deduced to be crystal accumulates. These layered rocks are considered to be intruded by the Main Facies rocks.

The rocks of the Chilas complex (the Main Facies) have a calc-alkaline nature [2]. The UMA rocks have chemical compositions reflecting their cumulate characteristics [3]. Here we present detailed geochemical data of the constituent rocks in the eastern part of the complex, to discuss the evolution and crystallization processes in the Chilas complex.

The Main Facies rocks have continuous variation of chemical compositions. Their SiO_2 content ranges from 49 to 60 wt.% in almost all samples. The concentrations of K_2O, Y, Zr, Th and rare earth elements (REE) are positively correlative with the SiO_2 content, while the concentrations of Ga, Sr, Cr and Ni do not vary with SiO2 content. The chondrite-normalized REE patterns of many of the rocks with SiO_2 content less than 52 wt.% have a positive Eu anomaly, while those of some rocks with SiO_2 content more than 56 wt.% have a negative Eu anomaly. The light REE are enriched relative to the heavy REE, and the enrichment is clearer in the rocks with higher SiO_2 content.

Samples from the layered gabbronorite mass have chemical compositions resembling with the Main Facies, although their compositions are scattered reflecting their modal variation. In the case of the UMA, major chemical compositions of ultramafic rocks support the petrographic observation implying that they consist mainly of olivine-clinopyroxene cumulates. Some of layered gabbroic rocks in a UMA indicate accumulation of plagioclase, having low REE contents with a clear positive Eu anomaly. Ultramafic rocks and layered gabbroic rocks from the UMA have low incompatible element concentrations.

The chemical composition of the Main Facies rocks support the idea that they solidified from a single evolving magma or from magmas having similar origin. Chemical compositions of a large part of the Main Facies may be similar to those of the magma(s), rather than the crystal cumulates, and they have characteristics of magmas relating to a subduction zone. A part of the Main Facies, rocks with low SiO_2 content may have lost the residual liquid at the late stage of solidification, or may have been enriched in the early-formed crystals. Therefore, it is possible to explain the chemical variation in the Main Facies by a weak segregation of melt and early-formed crystals composed of plagioclase, orthopyroxene and clinopyroxene. The relatively low concentrations of Cr and Ni in the mafic rocks suggest the magma had more evolved characteristics than the primary magmas from mantle.

The rocks of the layered gabbronorite mass have petrographical and chemical characteristics which resemble those of the Main Facies, suggesting a common origin. In the case of the UMA, chemical composition of the layered gabbroic rocks and ultramafic rocks clearly have characteristics of cumulates, implying the separation of the melt and crystals were effective. Their chemical and petrographical characteristics suggest that they were crystallized from more primitive magma, probably at the earlier stage than the crystallization of the Main Facies rocks.

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Quaternary geology in Zanskar/Ladakh, NW Indian Himalaya

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Research into the Quaternary geology of the NW Himlaya has concentrated on the elucidation of the glacial sequence. However, whilst the main ranges of the Himalaya have been subjected to numerous glaciations and are now an obvious alpine glaciated terrain, much of the landscape in Zanskar and Ladakh is more equivocal and does not appear to have been glaciated during this time. The landscape may therefore have a much older origin and relate to preglacial events.

In Zanskar, evidence of early glaciation has been found on isolated valley remanents>200m above the present rivers. Reconstruction of these preglacial valley cross profiles show them to be generally broad and shallow, with gentle slopes. This is a distinct comparison to the present major valley systems which can usually be divided into two parts - a lower unglaciated fluvially eroded section, such as the Zanskar Gorge and an upper broad glacial section.

Mapping of the glacial moraine systems in many of the major valleys indicates that the areal extent of glaciation has been reduced with time. The overall extent of the first glaciation is still not established since it occurred within a valley system which is now extremely fragmented and gnerally inaccessible. Subsequent glaciers have increasingly eroded their valleys such that they balanced their budgets over shorter horizontal distances. This reduction was compounded as the monsoon bearing winds became increasingly remote from this region due to tectonic uplift of the southern ranges.

To understand the Quaternary evolution of this area, attention has to focus on the nature of preglacial landscape and the identification of palaeosurfaces which may give important information about the uplift history of the area.

The Shan-Thal nappe stack, western Myanmar synform and correlation with the Himalayas

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Our interpretation of geological maps and Landsat imagery indicates that Myanmar, west of the Salween River consists largely of folded stack of east-vergent nappes (Fig. 1). In the Eastern Highlands, part of the Shan-Thal "Block", Upper Palaeozoic to Mid-Triassic flysch-carbonate

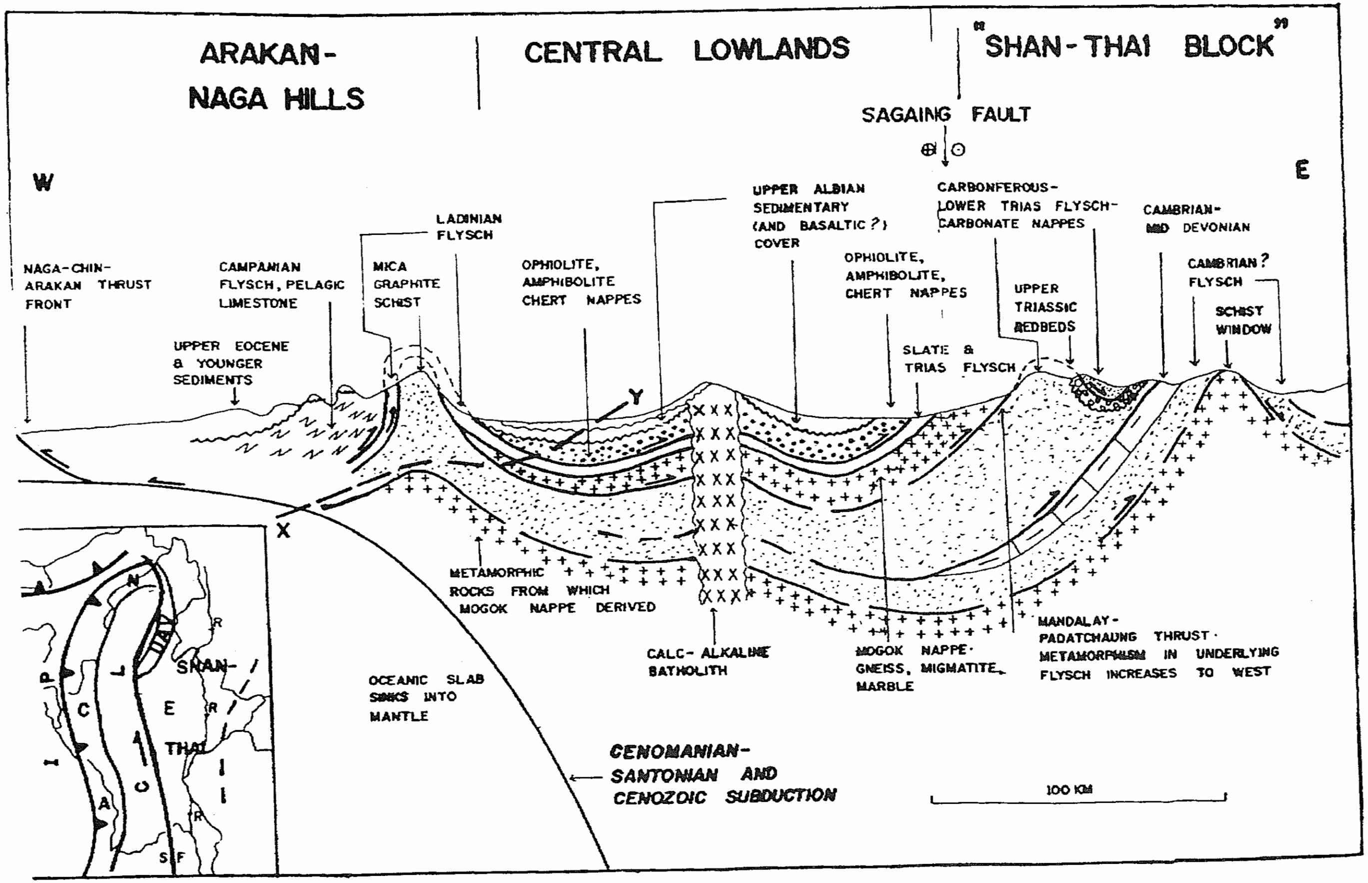
ARAKAN-
NAGA HILLS
CENTRAL LOWLANDS
"SHAN-THAI BLOCK"
SAGAING FAULT
W
E
NAGA-CHIN-ARAKAN THRUST FRONT
UPPER EOCENE & YOUNGER SEDIMENTS
CAMPANIAN FLYSCH, PELAGIC LIMESTONE
MICA GRAPHITE SCHIST
LADINIAN FLYSCH
OPHIOLITE, AMPHIBOLITE CHERT NAPPES
UPPER ALBIAN SEDIMENTARY (AND BASALTIC ?) COVER
OPHIOLITE, AMPHIBOLITE, CHERT NAPPES
SLATE & TRIAS FLYSCH
CARBONFEROUS-LOWER TRIAS FLYSCH-CARBONATE NAPPES
UPPER TRIASSIC REDBEDS
CAMBRIAN-MID DEVONIAN
CAMBRIAN ? FLYSCH
SCHIST WINDOW
Y
X
METAMORPHIC ROCKS FROM WHICH MOGOK NAPPE DERIVED
CALC-ALKALINE BATHOLITH
MOGOK NAPPE· GNEISS, MIGMATITE, MARBLE
MANDALAY-PADATCHAUNG THRUST· METAMORPHISM IN UNDERLYING FLYSCH INCREASES TO WEST
OCEANIC SLAB SINKS INTO MANTLE
CENOMANIAN-SANTONIAN AND CENOZOIC SUBDUCTION
100 KM
SHAN-
THAI

Fig. 1

(Mergui, Maubin) nappes and other nappes of Cambrian to Devonian shelf sediments and flysch lie east of, and structurally beneath, the Mogok Metamorphic nappe of possible Proterozoic age, Metamorphic grade in the flysch-carbonate rocks increases westwards towards the overlying Mogok nappe, The west-dipping Mogok nappe is overlain to the west, in the Upper Ayerwaddy valley, by slates and then by successive nappes of Triassic flysch, chert, greenstone and ophiolitic ultramafic and basaltic rocks which occupy a regional synform. Further west, structurally lower mica, talc and graphite schists, minor marble and quartzites form the Katha-Gangaw Range antiform. We interpret the flysch nappes as deposits of the Asian margin thrust east in the Late Triassic. They were rethrust east in the Early Cretaceous during eastward emplacement of both the Mogok nappe on the intracontinental Mandalay-Padatgyaung thrust, and the overlying ophiolitic nappes. The Late Cenozoic Sagaing Fault, on which dextral movement of over 400 km has been demonstrated, separates the Eastern Highlands and Upper Ayerwaddy valley from the Central Lowlands and Naga-Arakan Ranges of western Myanmar. The Central Lowlands, interpreted as the offset southwestward continuation of the Upper Ayerwaddy synform, consist of ophiolite and meta-ophiolite nappes overlain by basalts beneath Albian sedimentary cover, all intruded by a medial belt of early Upper Cretaceous calc-alkaline batholiths. The batholiths imply eastward subduction beneath Myanmar, on the Naga Thrust and its southward continuation as the Sunda Trench. The subduction succeeded the eastwards emplacement of ophiolite, west-directed back-thrusting and consequent arc reversal. Along the eastern side of the Naga-Arakan Ranges, Triassic flysch nappes over mica schist domes resemble the Katha-Gangaw Range antiform east of the Sagaing Fault, and are probable equivalents of the Palaeozoic to Middle Triassic Eastern Highlands nappes. West of the Naga-Arakan schist, late Upper Cretaceous flysch may have been thrust eastwards onto Asia in an end-Cretaceous event, probably involving emplacement from the west of an ophiolite nappe, an interruption in eastward subduction, and thrusting further east. We correlate the Upper Ayerwaddy - Central Lowlands synformal ophiolitic nappes with the ophiolitic rocks of the Yarlung-Indus zone; nappes of the Katha-Gangaw Range antiform and equivalent eastern zone of the Naga-Arakan Ranges with the lower Himalayas: and the Upper Cretaceous batholiths with the Gandise arc. Consequently we equate the Mandalay-Padatgyaung thrust with the Main Central Thrust, beneath the rootless Mogok Metamorphics-Tibetan Slab (Higher Himalayan Crystallines) nappe, and the Naga Thrust with the Main Boundary Thrust (MBT) This requires that the Himalayas are part of Asia, and that India collided with Asia on or beneath the MBT, after the Mid-Eocene.

Magmatism and thermal history of Tibetan plateau

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As one of the most important ways to mass/energy exchanging between the crust and the mantle, magmatism has made great contribution to the evolution of the plateau lithosphere. One can not fully understand the dynamic evolution of the Tibetan plateau without knowledge of magmatism and thermal history of the plateau.

During the subduction of the Neo-Tethys and syn- and post-collision between Indian and Eurasian continents, huge scale of magmatism took place and quantity of igneous rocks formed in Tibet and adjacent regions. By estimation, volcanic and plutonic rocks occupy an area of 300,000 km^2, equaling to 10% of total area of the Tibetan plateau. It clearly indicates the importance of magmatism for the geodynamic evolution of the Tibetan plateau.

Temporally, there were three pulses of volcanism and plutonism in the plateau after the closure of the Eastern Paleo-Tethys as follows: 120 to 85 Ma, 70 to 45 Ma and later than 20 Ma, respectively. The first pulse of magmatism (120 to 85 Ma) was presumably related to mainly the subduction of the Bangong-Nujiang, the north branch of the Neo-Tethys, and predominately formed I-type granitoids and calc-alkaline volcanic rocks, which occurred in 23% of the total area of igneous rocks in the plateau. The second pulse of magmatism took place during 65 to 45 Ma. It was probably related mainly to the subduction of the Indus-Zangbo, the main branch of the Neo-Tethys, and the collision of the India with the Eurasia (50 Ma or so). It developed predominant I-type and subordinate S-type granitoids and calc-alkaline basalt-andesite-dacite-rhyolite assemblage. Subordinate high-K calc-alkaline and shoshonitic volcanic rocks formed at the end. Igneous rocks formed in this stage concentrated in the Gangdise-Nyainqentanglha region and occurred in 60% of total area of igneous rocks in the plateau. The last pulse of magmatism happened in the period from Miocene to Quaternary (later than 20 Ma) was likely an intra-continental event. It formed mainly S-type muscovite- and tourmaline-bearing granites and high-K volcanic rocks, which took 15% (in area) of the total igneous rocks in the plateau.

Spatially, six tectonomagmatic belts were distinguished as follows: the Kunlun-Kokoxil belt, within which igneous rocks took 14,300 km^2 of area; the North Tibetan belt, within which igneous rocks took 12,000 km^2 of area; the Karakunlun-Qiangtang belt, within which igneous rocks took 14,000 km^2 of area; the Gangdise-Nyainqentanglha belt, within which granitiods and volcanic rocks took 80% of the total area of igneous rocks in the plateau, i.e. 240,000 km^2 or so; Trans-Himalayas belt, in which non of igneous rocks were well developed; the High-Himalayas, within which only muscovite+tourmaline-bearing granites occur.

As mentioned above, the temporal and spatial distribution of igneous rocks in the Tibetan plateau is very inhomogeneous. Most of plutonic and volcanic rocks concentrated temporally in the period of 70-45 Ma and spatially in the Gangdise-Nyainqentanglha belt, formed a huge complex granite-volcanic belt. The Gangdise-Nyainqentanglha belt, and its southern and northern adjacent regions show very different features of igneous rocks, especially those produced by post-collision events. While the region to the south of Gangdise-Nyainqentanglha (especially High-Himalayas) was characterized by well development of muscovite-bearing granites with no high-potassic volcanic rocks, the one to the north of Gangdise-Nyainqentanglha was by highly potassic volcanic rock series without muscovite-bearing granites. However, both of these two types of rocks developed in the central portion of Gangdise-Nyainqentanglha region.

In addition, geographical shift of magmatism with time is another character in Tibetan plateau. In the plateau, intermediate-acidic plutonic rocks successively became younger southwards, whereas volcanic rocks became younger northwards. Both granitic plutonism and volcanism shifted inwards with time within a belt, e.g., the Gangdise-Nyainqentanglha. Furthermore, the types and characteristics of igneous rocks, even the magma source changed with time within the same belt. For instance, in northern Tibet granitoid rocks derived from the crust source well developed in the period of late Triassic - early Cretaceous, whereas no granitoid rocks but only highly potassic volcanic rocks occurred in the Cenozoic, implying either the change in tectonic regime or in thermal condition beneath the plateau with time.

The Gangdise-Nyainqentanglha belt has been the most thermally active area in the plateau since 200 Ma, especially since 120 Ma. As mentioned above, the first and the second tectonomagmatic events which took place mainly in this area, resulted into the development of a volcanic rocks-granitic belt complex of 240,000 km^2 showing a geothermal structure with both warm mantle and warm crust (Wyllie, 1979). Isotopic data such as 143Nd/144Nd, $^{87}Sr/^{86}Sr$, Pb isotopes and =A6=C418O (SMOW) for volcanic rocks, granitoid rocks and mafic enclaves suggest that these rocks contain a large amount of mantle components, implying that a great quantity of mantle materials had transferred into the crust through magmatism. By calculation, the crustal thickness in the Gangdise-Nyainqentanglha, and the other portion of the plateau as well, was still normal until 50 Ma or so (about 37 km thick at 50 Ma). The crust had been considerably thickened since 40 Ma or so (about 52 km at 40 Ma), just following the second pulse of magmatism, the largest scale of magmatic event in the plateau. It suggests that transfer of huge amount of mantle materials to the crust in terms of magmatism was presumably one of the main mechanisms for crustal thickening of the plateau, at least of the Gangdise-Nyainqentanglha.

As mentioned above, the third magmatic pulse, a post-collision event, was characterized by development of muscovite-bearing granites and highly potassic volcanic rocks. Muscovite-bearing granites seemed to be a result of intra-continental subduction (Deng et al., 1993) and linked to the low velocity zones within the mid-crust mainly in south portion of the plateau. Highly potassic volcanic rocks such as shoshonites are rich-in incompatible elements and in radiogenic isotope of Sr and Pb. Accordingly, they inferred a lithospheric source of magma rather than adiabatically decompressed asthenosphere, as Molnar et al. (1996) argued. Therefore, these highly potassic basalts presumably represent, as Arnand et al. (1992) suggested, either a southward subduction beneath northern Tibet, or melting of lower lithosphere beneath northern Tibet (and central Gangdise- Nyainqentanglha) in response to small-scale convection there. We prefer the latter and believe that convective removal of the lower lithosphere, plus huge storage of heat energy within the crust transported from the mantle by the above-mentioned second and third pulses of magmatism, could be a very important cause for the Pleistocene-Quaternary fast uplift of the Tibetan plateau.

Stress-state evolution and seismicity of the Pamirs lithosphere

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On the base of our paleogeomorphological reconstruction the schemes of amplitudes of vertical crustal movements during Neogene (N), Quaternary (Q), and each epoch of Q (Q1, Q2, Q3, Q4) separately were compiled for the Pamirs territory. Using the theory of bending of thin plates we have determined the evolution of stresses of the Pamirs lithosphere and visco-elastic properties of the lithosphere. On the base of analysis both the spatial distribution of vertical movements and stress state evolution it was established that the transverse Pamirs-Himalayan deep fault was superposed on the ancient sublatitudinal structural plan of the Pamirs in Late Neogene. As well as schemes of Neogene and Quaternary movements the schemes of spatial distribution of seismic activity (i.e. the density of epicenters of crustal earthquakes) were drawn up for the Pamirs region. The analysis of energy classes K=10, 11, 12 testifies to similarity of these distributions which confirms the usual magnitude-frequency relationships. The comparison between the spatial distributions of seismic activity and the amplitudes of vertical tectonic movements during Q4, Q3, Q2, Q1 and N shows that their profiles are also similar. Moreover the highest degree of similarity is typical to the profile of Holocene (Q4) movements and gradually lessens with removal from Q4 to Q3, Q2, Q1 and N. Assuming the dependence of the present seismic activity on the whole history of tectonic deformation of the lithosphere it may be seen that seismicity has functional dependence with fading memory on prior vertical movements. Within the framework of linear heredity the values of the exponentially fading memory were obtained. It was assumed that the movements of the lithosphere as a rigid body causes no seismicity. The stability of results to changes of seismicity distributions, dimensions of area under study and to errors of discretization of hereditary law were analysed. It was obtained that the time T of relaxation of seismic activity in regions which contain the active transverse Pamirs-Himalayan deep fault is about: T = (10-250) x 10000 years (for K = 10), T = (5-150) x 10000 years (for K= 11), T = (0.5-5) x 10000 years (for K = 12). These are the characteristic times of decay of seismicity in hypothetical case of stopping of deformation process of the Pamirs lithosphere. They are of the same order as the relaxation times obtained for visco-elastic Pamirs lithosphere in framework of the model of plate bending. In the regions out of the zone of deep fault influence T is less than 10000 years for K=10,11,12. So the seismicity in this region is conditioned by recent movements.

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Tourmaline as an indicator of granite petrogenesis

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Introduction: In granites either formed in a subduction zone (ex. Japan) or in a collision zone (ex. Himalayas), the difference in magma genesis is whether or not the recycling of subducted oceanic sediments and/or altered oceanic crust at convergent margins occured or not. Boron isotopes are excellent tracers for revealing this recycling because of their high mobility during magmatic and fluid-related processes. If boron isotopes of bulk rocks are measured, the petrogenetical discussion becomes too vague as in the past. Boron isotope mapping in a single mineral is needed.

What minerals should be studied?: Ubiquitous rock forming minerals which contain boron are biotite and muscovite. The contents of boron in biotite and muscovite are about 25 ppm and 100 ppm, respectively. Low concentration of boron in these minerals is not suitable for boron isotopes mapping using SIMS. Tourmaline is also a silicate mineral which contains boron. This is a ubiquitous accessory mineral in igneous, metamorphic and sedimentary rocks. However, tourmalines in granitic rocks are considered to have some origins. Tourmaline veins and tourmaline 'flowers' on joint planes are considered to be of secondary origin. Some tourmaline grains, considered to be primary, are observed under microscope. We must identify magmatic tourmaline to analyze boron isotopes which show magma genesis.

Magmatic tourmaline: Tourmalines found in vein or amygdaloidal cavity were excluded. Chemical compositions of tourmalines was analyzed using EPAU. The Mg value of tourmalines has positive relation to one of the coexisting biotites in the same thin section. Moreover, tourmalines from peraluminous S-type granitic rocks have a high content of Al and low content of Ca (schorl-dravite substitution), and those from metaluminous I-type granitic rocks have low content of Al and high content of Ca (schorluvite substitution). Therefore, we conclude that tourmalines are magmatic minerals.

Isotopes mapping: No SIMS analysis has theoretical matrix correction method. We succeeded in the development of an analytical method without matrix effect. The method is as follows. Cleaned tourmaline which had been analyzed using EPMA was cut off the thin section, and attached to the Al plate. No coating such as Au is needed. Broad ion beams (400 gm x 120 gm) were irradiated at tourmaline crystal and Al plate at the same time, and secondary ions were counted.

Do boron isotopes preserve their original characteristics? Boron isotopes of tourmaline in quartz-tourmaline micro vein (3 mm in width) in a thin section were measured. As quartz-tourmaline micro vein implies an open system, isotopes should not be constant. The difference of boron isotopes from core to rim in a tourmaline crystal was 15 per mil. This value is higher than the repeatability value, 4 per mil. We conclude that boron isotopes in tourmaline preserved their original characteristics.

Boron mapping in a tourmaline crystal: Tourmalines from Miocene Ohmine S-type granitic rocks, Southwest Outer Zone of Japan, were analyzed using EPMA and SIMS. The Mg value in a tourmaline crystal varies from 0.7 to 0.4. Boron isotopes are, however, constant. The result suggests that there is no assimilation or interaction between igneous magma and crustal materials.

Keywords *:* tourmaline; boron isotopes; isotopes mapping; SIMS; S-type

Evolution of the Ceno-Tethys branch in the Muslim Bagh continent-continent collision zone, Pakistan

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The wedge-shaped Tethys ocean between the Gondwanan and Asian continents has been recently divided into three ocean systems : the Paleo-, Meso-, and Ceno-Tethys [1]. Getting the timing of opening and closing of each Tethys ocean, especially the closing time of the Ceno-Tethys, is critically important in understanding tectonic evolution of the South Asia [2].

The Muslim Bagh area, northwest Pakistan, is located in the suture between the Indian sub-continent and Asian continent. The area is one of the best in Pakistan for understanding the timing of opening and closing of the Ceno-Tethys, because the shallow to deep marine sediments deposited on the Indian passive margin to ocean floor, igneous rocks including oceanic crust, and ophiolite are well exposed.

The Muslim Bagh area is underlain by Tertiary shallow marine sediments (Katawaz basin), Late Cretaceous ophiolite (Muslim Bagh Ophiolite), Mesozoic sedimentary-igneous rock complex (Bagh Complex), and Mesozoic to Tertiary shelf sediments (Calcareous Zone), from north to south. They form a north-dipping nappe pile. The Bagh Complex is litho- and bio-stratigraphically divided into the Lower and Upper sedimentary rock units (Bls and Bus), Hyaloclastite-mudstone unit (Bhm), Basalt-hert unit (Bbc), Serpentinite-matrix and Mudstone-matrix mélange units (Bsm and Bmm), Ultramafic-mafic rock unit (Bum), and an undivided unit (Bs). The rocks of the Calcareous Zone accumulated on the Indian sub-continental shelf, while the Bagh Complex was deposited on the Indian continental slope to ocean floor of the Ceno-Tethys branch. Formation of the Bsm and Bmm was related to the obduction of the Muslim Bagh Ophiolite.

Our biostratigraphic, structural, and geochemical studies [3,4,5] reveal the following evolutionary history of the CenoTethys (Figs. 1 & 2).

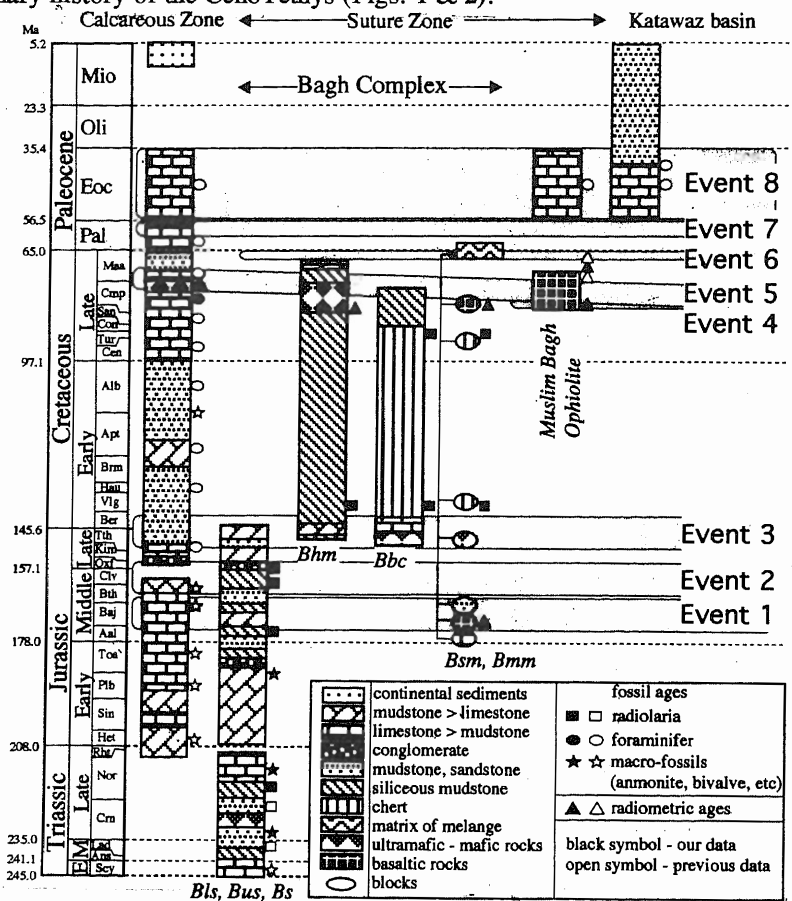

Fig. 1. Schematic diagram showing the major geologic events 1 to 8 and generalized stratigraphic columns of each rock unit in the Muslim Bagh area. Modified from [5].

A 171 Ma hornblendite block probably derived from Bmm or Bsm (Event 1), Late Jurassic disconformity in the Calcareous Zone, and sedimentation of conglomerate in the Bus (Event 2) suggest that the rifting following volcanism took place in the western Indian shelf and shelf edge in the Late Jurassic. The formation of MORB pillow lava conformably covered by Early Cretaceous radiolarian chert in the Bbc (Event 3) indicate that the opening of the new oceanic crust, the Ceno-Tethys branch, occurred during the Latest Jurassic to Early Cretaceous, giving rise to a wide ocean floor where pelagic sediments such as radiolarian chert could accumulate.

The 81 and 71 Ma alkaline basaltic rocks in the Bhm and Calcareous Zone (Event 4) represent an episode when the western Indian passive margin passed over the Reunion hotspot. The Muslim Bagh Ophiolite is considered to have been formed in a back-arc basin around 82 to 81 Ma (Event 5). This timing indicates that the formation of the arc at the southern margin of Asian active margin was related to the subduction of the Ceno-Tethys oceanic crust toward north.

The youngest deep marine sediments and mélange blocks in the Bagh Complex (Event 6) suggest that the ophiolite obducted over the Bagh Complex after Maastrichtian time, and the closure of the Ceno-Tethys branch occurred during the Maastrichtian to Early Paleocene. The nappe structures, consisting of the ophiolite and Bagh Complex over the Calcareous Zone, occurred during the Paleocene, because Early Eocene limestones accumulated on the nappes (Event 7). The formation of a nappe pile resulted from the collision between the Indian and Asian continents, followed by deposition of the rocks in the Katawaz basin (Event 8).

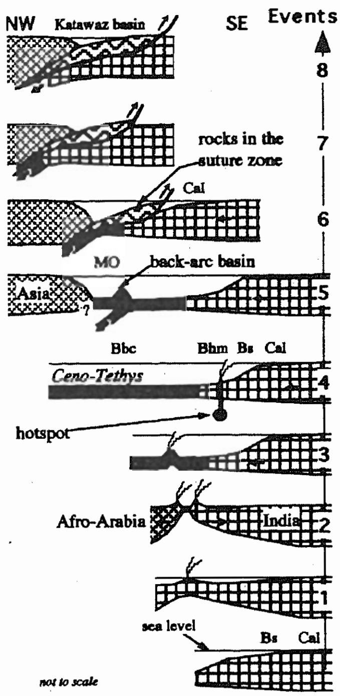

Fig. 2. Schematic cross sections of each event showing tectonic evolution of the Ceno-Tethys in the Muslim Bagh area.

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Pinjor fauna of the upper Siwalik subgroup of India

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Pinjor Fauna is well known from Chandigarh and Jammu regions of India. Chandigarh region has the type area of the Pinjor Formation which has been dated by magnetostratigraphy and ranges f'rom 2.48 Ma to 0.63 Ma. In Jammu region the Nagrota Formation of the Upper Siwalik is having both the Tatrot and Pinjor faunas. Recent advances during the last three decades based on in situ fossils are discussed here. Now from the type area of the Pinjor Formation, the pre-Pinjor beds (Tatrot beds of several workers) are well demarcated and Tatrot Fauna is represented by *Stegodon bombifrons, Hi ppohyus tatrot Proamphibos, hipparionines,* etc. The Pinjor Fauna marks the end of Siwalik vertebrate faunal succession which was established in early Miocene. The overlying Boulder Conglomerate Formation, the youngest formation of the Siwalik Group, is found barren of fossils. On the basis of the work carried out in last three decades by various workers about 30 taxa are found restricted to the Pinjor Formation and a few of these include *Homo erectus, Elephas hysudricus, E.Platycephalus, Equus sivalensis, E.namadicus, Coelodonta platyrhinus, Rhinoceros sivalensis, R. palaeindicus, Potamochoerus theobaldi, Bubalus palaeindicus, B.platyceros and Bos acutifrons*. The process of extinction or migration of' the Pinjor Fauna started near Olduvai subchron, but in two sections, Parmandal - Utterbeni of Jammu and Patiali Rao of Chandigarh, it survived well above the Olduvai subchron and extinction in various sections ranges from 1.72 Ma to 0.6 Ma. Near Oldutvai subchron, the last phase of Himalayan orogeny, was marked by initiation of the deposition of the Boulder Conglomerate and this was probably one of the reasons for the gradual extinction of the Pinjor Fauna. On the basis of megnetostratigraphy two biostratigraphic interval - zones, *Elephas planifrons* interval zone (3.6 Ma to 2.7 Ma B.P.) and *E. hysudri cus* interval - zone (2.7 Ma to 0.6 Ma B.P.) are also recognized. 10 taxa are found restricted to older zone whereas 24 taxa are found restricted to the Younger zone.

Origin of chromitites from the Jijal complex, Kohistan arc, north Pakistan

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The Jijal complex is a tectonic wedge of layered ultramafic cumulates and garnet granulites exposed at the base of the Cretaceous Kohistan arc [1,2]. The lower half of the complex is composed of layered peridotitic and pyroxenitic rocks, which are strongly mylonitized and amphibolitized, especially along the Main Mantle Thrust. Towards the central part of the complex the rocks are fresh and the primary minerals, magmatic textures and structures are well preserved.

On the basis of chemical composition of constituent minerals, the ultramafic rocks are classified into two series. The orthopyroxene-free dunite-chromitite series is composed of dunite, wehrlite and chromitite having high-Mg#, high-Cr# and low-Ti. The second series is pyroxenite series, comprising dominantly of clinopyroxenite, websterite and small amounts of dunite, wehrlite, chromitite, with relatively low-Mg#, low-Cr# and high-Ti. Rocks of both the series occur irregularly and are mixed, suggesting magmatic interaction of crystal mushes during the process of crystallization. At places a number of clinopyroxenite dykes and veins cross-cut the dunite-chromitite series rocks.

The chromitite occurs as disseminated and massive bodies in close association with dunite and clinopyroxenite of both the series. Clinopyroxene-chromitites are rarely observed in the pyroxenite series. The mode of occurrence of the Jijal chromitites is similar to the stratiform-type chromitites [1] and some times similar to podiform-type chromitites in ophiolitic sequences. Rhythmic layering, modal gradation of chromite and cross-bedded structure in disseminated chromitites, suggest gravitational control during the deposition of chromitite.

Olivine ranges from $Fo_{(95.4-90.8)}$ in chromitites to $Fo_{(91.5-89.4)}$ in dunites for the dunite-chromitite series, and from $Fo_{(93.0-87.4)}$ in dunite, $Fo_{(90.6-89.2)}$ in wehrlite, $Fo_{(89.2-86.1)}$ in clinopyroxenite, to $Fo_{(84.1-80.6)}$ in websterite for the pyroxenite series. The variation in NiO wt.% of olivine with decreasing Fo content in the dunite-chromitite series shows a fractionation trend clearly distinctive from that in the pyroxenite series. The systematic Mg# change of spinel and clinopyroxene cores with the lithological change from chromitite through dunite to pyroxenite also suggests a fractional crystallization in separate magmatic processes. The range of Cr# of spinel cores from the dunite-chromitite series (Cr# = 86.1-66.3) is higher than that of the pyroxenite series spinel cores (Cr# = 73.5-42.6). The Cr# and Mg# variations also display separate fractionation trends from chromitite, through dunite and wehrlite, to pyroxenites. The TiO_2 contents in spinel cores are 0.62-0.10 wt.% for the dunite-chromitite series, and 2.08-0.20 wt.% for the pyroxenite series. Clinopyroxene mineralogy also supports the above explanation.

The chemistry of the constituent minerals suggests that the magmas for the formation of Jijal ultramafic cumulates can be explained as boninitic for the dunite-chromitite series and island-arc basaltic for the pyroxenite series. The very high Cr# range of the dunite-chromitite series spinels is consistent with that of spinels in boninites [2], whereas the pyroxenite series spinels also have high Cr# range which is consistent with that of island-arc basalt magma derived from highly depleted mantle peridotites [3]. Extremely high Fo content in the dunite-chromitite series olivines and a moderately high Fo content in the pyroxenite series are suitable to the parentage described above. The extremely low content of TiO_2 in spinels (< 0.5 wt.%) and in clinopyroxenes (< 0.03 wt.%) from the dunite-chromitite series rocks characterizes the magma type as boninitic one. It can be assumed that an interaction process between two different magma types "boninitic and island-arc basalt" has taken place within a single, large-scale magma chamber.

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Permian granitoids of the High Himalayan slab, Zanskar Himalaya

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The High Himalayan Slab (HHS) in the western Himalaya of Zanskar is host to several episodes of granite magmatism, which collectively have resulted in one of the greatest volumes of granitoids exposed in the Himalaya. Previous studies established that two main groups of granites are present. Circa 500 Ma granites, intruding the metapelitic rocks and part of a widespread magmatic event identified throughout the High Himalayan Slab, are preserved in the cores of some gneiss domes that form circular culminations in the core of the High Himalayan range, and are often mantled by younger migmatites and granitoids of indeterminate age [1,2]. Widespread partial melting of musc-kspar-sill bearing metapelites at temperatures and pressures up to 700°-750° C and ~10 kbar produced leucogranitic melts that formed melt pods, dikes, and discrete intrusions [3]. Monazite and zircon U-Pb isotope data show that the melt pods and related intrusions were crystallized between 21 Ma and 19.5 Ma, akin to ca. 20 Ma intrusive activity elsewhere in the Himalaya [4].

During the course of our U-Pb geochronology studies of Zanskar granitoids we have recognised two occurrences of ca. 280-290 Ma foliated granitic sills that, in the field, are not particularly distinguishable from the ca. 20 Ma suite. The granites, from Sankoo and Parcatchic, intrude into the central high-grade core of the HHS. Garnet and allanite are common accessories, both of which show corroded surfaces, with allanite being replaced by epidote. Zircons are particularly abundant in both granites and have a simple morphology dominated by (100) and (101) faces, typical of zircons observed in alkaline/high temperature granitoids. The zircons commonly contain tubular melt inclusions generally oriented oblique to the host grain's c-axes. Xenocrystic cores are not generally visible.

Initial results show that the zircons form a discordant group of points around 280-300 Ma in age. Some of the data form a collinear array with an upper intercept of ~ 285 Ma. We interpret this array of data to indicate the granite emplacement at ca. 285 Ma with a minor proportion of an older inherited component in some of the zircons. These results compare favourably with the 284 ± 1 Ma data for the alkaline Yunam granite dikes [5]. The Yunam dikes discordantly intrude the Ordovician Thaple.

Formation in SE Zanskar, are attributed to anorogenic magmatism, perhaps related to lithospheric thinning associated with transtensional to extensional rifting tectonics occurring during Neo-Tethyan rifting [5]. Such magmatism is unlikely to be restricted to a single occurrence and it is possible that the Sankoo and Parcatchic sills are related to the Yunan suite. We suspect that early Permian granitoids within the HSS are more widespread than previously thought, given that the Yunam, Sankoo and Parcatchic intrusions have Himalayan Ar-Ar ages, which would have conspired to hinder detection in the absence of U-Pb data.

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Interpretation of JERS- 1 remote sensing data on Karakoram, northern Pakistan

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Remote sensing data obtained by JERS-1 (Japanese Earth Resources Satellite) have been evaluated for lithological and structural interpretations in areas from the Karakoram, northern Pakistan. A comparison has also been made with similar images from Landsat TM. JERS-1 carries an optical sensor (OPS) which records seven spectral bands. Three bands around 2.2 micron wavelength have been designed to provide valuable information for lithological discrimination. The spatial resolution of JERS-1 (18m) is better than that of the Landsat TM (30m), and provide very detailed topographical and geological information [1]. One scene of JERS - 1 covers an area of about 75 x 75 km, and for the purposes of this study, twenty scenes of JERS-1 data were examined. Excellent data have been obtained along two strips of JERS-1, i.e. paths 183 and 188 (Fig. 1).

Among the factors limiting the use of remote sensing data in the high mountain terranes are the snow cover and the cloudy weather. For instance, the Karakoram Range is largely covered by snow in the winter, but the highest mountains are also covered in the summer. An image of northern Karakoram, north of Gilgit, taken in middle of November, shows that more than 90 % of the area is covered by snow. The images of the similar area in the northern Karakoram taken at the end of June still indicates that it is covered by snow. Thus, in order to have a minimum snow cover, it is necessary to select appropriate remote sensing data, for instance, those obtained at the end of summer (e.g., from the end of August to early September). In addition to problem by the snow cover, cloud cover also provides limitations on the image selection.

Despite the problem of the snow covers, the Karakoram range is an ideal area for interpreting the remote sensing data, since it is characterized by a scarsity of vegetation mainly due to the relatively dry weather conditions. The different rock types are easily distinguished using JERS- 1 data.

Four scenes of JERS-1 Path 183, covering the area from Nanga Parbat to Khunjerab pass, were collected at the end of September, and they contain excellent geological information. The Karakoram Highway runs in the middle of the images. These show very detailed topographic features and fine geological structures. The high spatial resolution of JERS-1 data is very useful especially in areas where there are no good topographic maps or air-photos. The JERS-1 images can be enlarged into 1/100,000 scale without the loss of image quality.

Distribution of carbonate rocks and acidic granitic rocks [2] in the area is clearly shown in the images. The carbonate horizons which are several tens of meters thick, can be easily detected. These horizons are important key beds for the structural interpretation of the area. The black slate formations, e.g., Misgar slate, can also easily traced because they are appeared with a distinct black tone on the false color image.

In conclusion, the satellite images with the high spatial and spectral resolutions are useful for making geological survey in the area with difficult access. Geological information of several limited traverses can be correlated on a regional scale by using remote sensing data. Although Landsat TM data provide useful geological information, remote sensing data with even higher spatial resolution, JERS-1 or possibly SPOT, can be utilized in the area like the Karakoram.

This study was supported by joint research program between Geological Survey of Japan and Earth Resources Satellite Data Analysis Center.

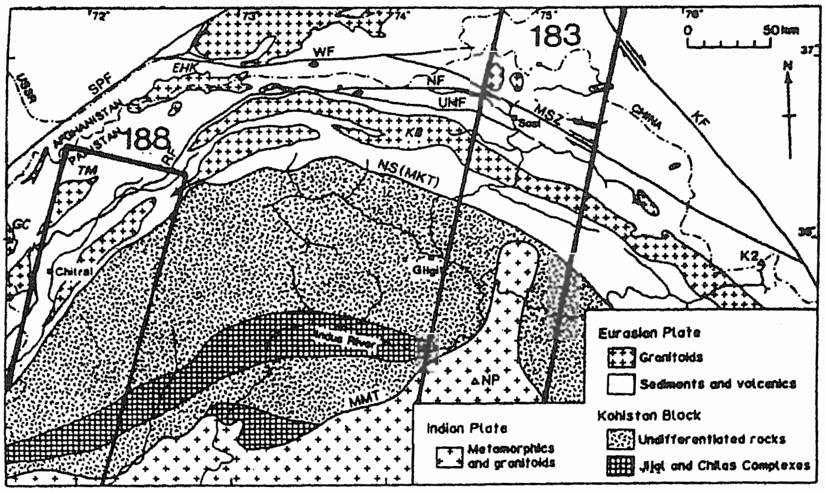

Fig. 1. Generalized geological map of northern Pakistan and areas examined with JERS-1 images.

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New muscovite Rb-Sr ages of mylonite from the Misgar shear zone, in northern Karakoram: implications for Late Cretaceous tectonism in the Eurasian plate

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The mylonite was found near Misgar in the northern Karakoram which consists largely of Permian to Jurassic sediments [1]. The mylonite is well exposed on the road cut of the

Karakorarm Highway at a distance of about 5 km upstream of the Khunjerab River from the Khunjerab-Kilik rivers junction with a width of 900m. It continues 7km northwest to north of Misgar with a N70° W trend. The mylonite separates the Misgar slate to the north from the Kilik Formation to the south. The occurence of such a wide zone of the mylonite could indicate the presence of a major shear zone. Ogasawara et al., [1] proposed to use the term Misgar Shear Zone (MSZ) to described it. The MSZ consists of mylonitic rocks, gneiss and schist originated from granodiorite, granite, limestone, sandstone and mudstone. Cataclasites after the mylonite are also present. Pseudotachylite veins are found in the cataclastic rocks. Mylonite of plutonic origin is dominant in the northern portion of the MSZ, and augen texture is commonly observed in it. Calcareous and pelitic schists are present in the southern portion. A narrow calcareous mylonite with a width of 15m bounds the southern margin of the MSZ. The mylonitic foliation mostly dips 70-80° to the south. Horizontal to southeast shallow plunging lineation is commonly observed on the foliation plane.

Several types of asymmetric microstructures, e.g. asymmetric pressure shadows, are observable in the mylonite and pelitic schist in the MSZ. All the asymmetric microstructures demonstrate a dextral strikeslip shear [1].

K-Ar ages of the muscovite and biotite of the mylonite are 66.5 ± 3.3 and 63.4 ± 3.4 Ma, respectively [1]. New muscovite Rb-Sr ages of mylonite are 69.9 ± 1.7 and 66.6 ± 1.5 Ma. Though, these are slightly older than the K-Ar ages, all the ages obtained are clearly indicating that the mylonite was formed by a Late Cretaceous tectonic event in the Eurasian plate.

The Kohistan-Ladakh arc collided with the Eurasian plate before the collision of India to Eurasia, and the northern suture is thought to have closed during Late Cretaceous time between 95 and 75 Ma [2]. Therefore, the Late Cretaceous age of the MSZ suggests that the dextral strike-slip displacement of MSZ in the Karakoram terrane may be related to final movement of the collision of the Kohistan-Ladakh arc to the Eurasia. On the other hand, Klootwijk et al., [3] suggested an early India-Asia contact before 55Ma (as early as 70Ma) from paleomagnetic constraints. Such an early India-Asia contact may have led to deformation of the Eurasian continent even in the Late Cretaceous. Late Cretaceous radiometric ages of the mylonite from MSZ could support this model.

The presence of cataclasite and pseudotachylite with dextral strike-slip sense of shear indicates that the dextral strike-slip displacement continued after several Kilometers uplift of Karakoram terrane from the depth of mylonite formation. The dextral strike-slip Misgar fault which occurs at a distance of about 5 km south of the MSZ at Khunjerab river and merges into MSZ near Misgar, also records the same strike-slip displacement [4]. Therefore, the continued convergence of the Indian and Eurasian plates led to the strike-slip displacement of the crust within the Eurasian plate and it started from the Late Cretaceous.

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Lack of crustal fluids beneath Nanga Parbat, northern Pakistan: results from magnetotelluric soundings

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The Nanga Parbat-Haramosh Massif (NPHM) in the Himalaya of northern Pakistan is a finger of Indian crust extending northward into the Kohistan-Ladakh island arc. Collision between Kohistan and the Indian plate about 55 Ma along the Main Mantle Thrust (MMT) placed plutonic and high grade metamorphic rocks of Kohistan above the Indian plate. In the past 10 M.y., differential erosion of NPHM has exposed the underlying Indian crust. Recent and rapid denudation has provided a unique glimpse into modern reworking of old continental lithosphere by metamorphic processes and partial melting. As part of a multidisciplinary study of NPHM, a magnetotelluric (MT) study was conducted to determine the distribution of fluids and partial melt in the crust. Mafic partial melts, water-saturated silicic melts, brines and metamorphic or igneous waters, metallic solid phases, and graphite are all capable of increasing the conductivity of the crust and upper mantle.

This MT study was interpreted with both 2-D and 3-D models to account for the complex geology and physiography. North of Nanga Parbat in Kohistan, the upper crust (0-8 km) is generally resistive (> 500 ohm-m), the middle to lower crust (8-40 km) is generally conductive (30-50 ohm-m), and the upper mantle is again resistive (> 300 ohm-m). This structure is reminiscent of the typical continental crust in which the generally conductive middle layer reflects fluids trapped in the ductile region of the crust and is similar to the structure seen on the INDEPTH profile of Tibet. Immediately north of Nanga Parbat, the Raikot fault is imaged to a depths of 8-10 km as a vertical, tabular conductive body. The high conductivity of the fault is attributed to fluids migrating along the fault zone and to hydrothermal alteration. South of Nanga Parbat, the MT data show a moderately conductive region at midcrustal levels which appears to match a shear zone mapped by geologists. The shear zone is likely conductive because it offers a more porous conduit for fluid migration; hydrothermal alteration is seen in the zone in the eastern end of Rupal valley.

There is no evidence of conductive bodies beneath the Nanga Parbat peak between Fairy Meadows and Rupal valley to depths of at least 50 km. The data are matched instead by very high resistivities (>5000 ohm-m) indicative of igneous and/or high grade metamorphic rocks. If magma is present beneath Nanga Parbat, then it must be the result of water-unsaturated partial melting of continental crust (which would result in high resistivities). The simpler interpretation is that magma is not present, however.

Affinities of Siwalik Murid rodents: An appraisal

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In a recent publication, Jacobs and Downs (1994) have illustrated that the murids (in the form of Antemus chinjiensis) evolved from cricetids (Potwarmus primitivus) in the Siwaliks some 14 m.y. ago. Antemus gave rise to Progonomys species, a population of which produced Karnimata species. Around 8.35 m.y. ago Karnimata species diverged into Karnimata darwini (later to give rise to Karnimata huxleyi) and Karnimata species (later evolves to Parapelomys robertsi) on one hand and on the other Progonomys debruijni transformed into Mus auctor around 5.7 m.y. ago. According to the author Progonomys chopraii (Vasishat, 1985) from Haritalyangar, India, fits best for an ancestor to Mus. This is based on the similarities observed between cranial morphology of Progonomys chopraii and Mus linnaeusi (known from 2 m.y. old Siwalik deposits exposed near Chandigarh, Patnaik et al., 1996). By 4 m.y. other modern murid taxa including Golunda, Cremnomys and cf. Millardia appeared in Tatrot Formation of Siwaliks (Patnaik, in press). Indeterminate species. A and Parapelomys of Jacobs (1978) are considered here to be the descendant of Cremnomys/ cf. Millardia group and Golunda, respectively. Molar of Dilatomys moginandensis (around 4 m.y.) though similar to Parapelomys (brachydont) in cusp patttern is very hypsodont. Similarly, other hypsodont forms, Bandicota sivalensis (around 2.5 m.y.) and Hadromys loujacobsi (around 1.5 m.y.), do not show affinity towards any of the fossils recovered so far from the Siwaliks. The extant forms of Mus budooga/dunni resemble closely Mus flynni and house mouse Mus musculus seems to have originated from Mus linnaeusi; the common ancestry of Cremnomys cutchicus, Cremnomys blanfordi can be traced back to the Early Pliocene. Dental elements of Golunda species (2 m.y.old) are strikingly similar to the extant Golunda ellioti. Based on the closeness of fossil murids from Siwaliks, Karewas of Kashmir (around 2.4 m.y), Narmada valley of Central India (around 35,000 years), Karnool Cave deposits of southern India (around 40, 000 years) and Bhimtal lake sediments (around 30,000 years) to their extant counterparts, it can be safely concluded that the Pliocene and Pleistocene murids recovered so far from the Siwaliks were endemic to the Indian subcontinent.

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Is the Dobani-Dasu ultramafic lineament an internal suture for Ladakh and Kohistan?

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In Ladakh, the contact between the Greenstone complex and the Askor amphibolite (Fig. 1) is underlined by a series of isolated pods and masses of serpentinised ultramafics, one of the major ones cutting the Turmik valley at Dasu [1]. The Dasu lineament has been followed eastward into the Komara valley where a kilometer-thick body of metaperidotite is wrapped in a shell of foliated serpentinite, interlayered with chlorite-talc-magnesite schist and albite epidote-tremolite-chlorite rodingite [2]. Westward we have encountered blocks of serpentine in the valley north of Skoyo. Further to the north-west, besides ultrabasic rocks and calc-silicate fels that occur in lower Remendok valley, in a similar structural position, boulders of serpentinized material occur now and then.

In Kohistan, almost exactly symmetrical to the Dasu lenticular stripe across the Himalayan spur, squeezed against the northern end of the Raikot fault, we have discovered a similar stripe of serpentinised ultramafics: the Dobani lineament (Fig. 1). Twenty-five kilometers long, it rises from the village of Khaltaro, follows the right (west) bank of the Darchan river, crosses to the north of the Dobani peak (or Bilchar Dobani, 6134 m) in the upper part of the Gutumi glacier, forms a large kilometric band on the northern side of the Bilchar valley, and finally thins out on the right bank of the Bagrot river between the villages of Datucho and Sinakkar. Further to the west, it does not cross as such the Dyor and Hunza valleys, but leads into the tectonic lineament, that follows the edge of the Bilchar meta- volcano-sedimentary formation. There the two intricated formations could form a tectonic mélange.

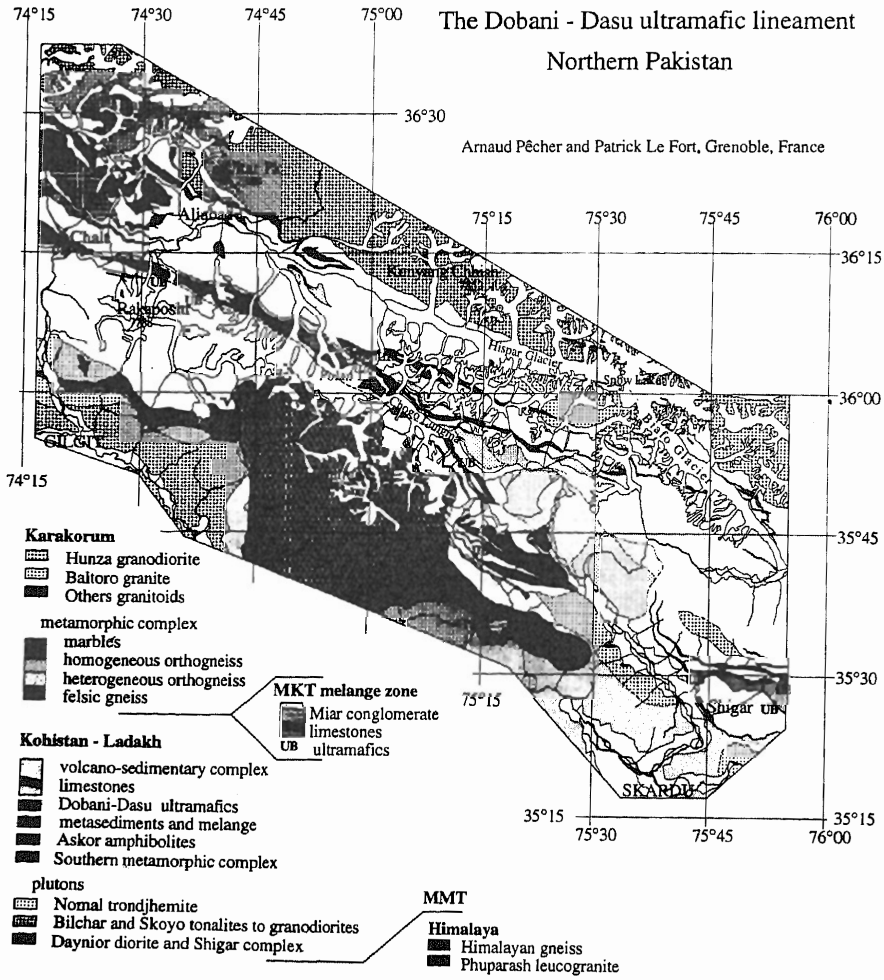

Fig. 1

In Ladakh [2] the metaperidotites are usually antigoritic serpentinites with cumulitic textures, and two generations of olivine (magmatic and metamorphic). In Kohistan the serpentinised peridotites are accompanied by pyroxenites.

The Dobani-Dasu ultrabasic lineament separates the island-arc into two units. It is possible to consider these serpentinites as a part of the ophiolitic sole of the island arc as described near Dras (Ladakh, NW India) [3]. Thus, the Chalt-Turmik volcanics, with the MKT lineament to the north and the Dasu-Dobani ultramafics to the south, compare well with the Dras volcanics that have tectonic melanges on their northern and southern sides. In our view, it could mark the limit between the volcano-sedimentary back-arc basin and the island-arc itself that includes peraluminous crustal material of Katchura Gilgit type.

The ultramafics that divide Kohistan and Ladakh in two sub-units are a good marker of the global deformation of the arc. Parallel to the general structural trend, away from the NPHM, they are bent when getting closer to the contact with the Himalayan gneisses. To the east, the bending of the lineament marks and supports the right-lateral movement also evidenced in the Greenstone complex. To the west, the curvature of the Bilchar-Dobani ultramafics would also indicate a right-lateral movement, whereas the movement observed in the mylonitic Himalayan gneiss of the upper Darchan valley, is left-lateral and obviously not of the same age. The two dextral shear zones could represent a meridian vertical slicing of the Himalayan crust that has driven the NPHM doming and the Raikot fault.

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[2] Rolfo et al., 1996. Geodinamica acta,
[3] Reuber, 1989. Eclogae Geol. Helv., 2, 699-715.

The Kohistan arc, northern Pakistan : An example of PGE and PGM distribution in convergence zones

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Latest studies on the distribution of PGE indicate that the highest absolute abundances of PGE concentrations are generally associated with chromitite and nickel sulphide occurrences in large ultramafic-mafic layered intrusions (Stillwater and Bushveld) or in greenstone belts of komatiitic affinity. Most of them are related to distensive tectonic regime or mantle plume activity. The Kohistan arc, northern Pakistan has several discontinuous and elongated ultramafic and mafic bodies that formed at the base of an immature intra-oceanic island arc in response to northward-directed subduction of neo-Tethys ocean lithosphere during Late Jurassic and Cretaceous. Each-either contain or have the potential for PGE mineralization.

Massive chromitite occurs in lenses and pods in dunite of Jijal complex and reach 2 to 3 meters thickness and 50 meters strike length. No chromite assemblages of large concentrations (1-2 vol. %) are known in ultramafic-mafic rocks from Thak Gah and Sapat areas. In the last two complexes, chromitite and Cr-rich spinel is the most common accessory phase which occur as low-grade disseminations (dunite and pyroxenite) as well as in layers (mm scale) in dunite. Jijal complex has also primary pyrrhotite, chalcopyrite, pentlandite, bornite and pyrite and they are sparsely distributed in the different cyclic units of this complex. Surprisingly, no megascopically visible sulphide phase has been found in Thak Gah and Sapat complexes.

The whole-rock abundance PGE + Au data from Cr-rich, Cr-poor, sulphide-rich and silicate rocks of Thak Gah ultramafic-mafic complex, Chilas; Sapat ultramafic-mafic complex, Kaghan valley; and Jijal ultramafic-mafic complex were determined to know the primary distribution of PGE in these arc-related rocks and their behaviour during normal igneous processes.

Thak Gah complex mostly composed of layered dunite, pyroxenite, anorthosite, troctolite and gabbro covers an area as large as 5 sq. km, east of Chilas. The complex, interpreted as intruded in the Chilas gabbro-dioritic complex (Khan et al., 1989), displays restricted range of total PGE contents (7.71 to 33.54 ppb) and exhibits positive slope (Pd/Ir=3.95 to 50.33). The abundances of total PGE range from 13.13 to 33.54 ppb in dunites; 7.71 to 13.10 ppb in pyroxenites; 6.44 to 15.74 ppb in layered gabbro and 9.04 to 20.45 ppb in gabbro norite. No PGE enrichment zone has been found in this complex.

The Sapat complex along with Jijal complex form a closely spaced group to the south of Kohistan arc and extends NE-SW immediately to the north of MMT. The complex occupies over 13 km^2 and has ultramafic sequence at the base and gabbro sequence at the top. Dunite (total PGE= 13.72 to 31.02 ppb) shows a strong Ir (1.93 to 4.06 ppb), Ru (4.12 to 8.29 ppb) enrichment and slight impoverishment in Rh, Pd and Pd resulting flat to slightly negative Pd/Ir ratio (1.31 to 0.36). Clinopyroxenite shows abundant concentration of PGE, ranging from 48.95 to 57.87 ppb, and exhibits extremely steep positive patterns (Pd/Ir = 1 12.46 to 146.76). Layered gabbro has low total PGE concentration of 12.66 ppb and less steep positive pattern (Pd/Ir=10.13) as compared to clinopyroxenite. These data suggest that silicate melt feeding Thak Gah and Sapat complexes were carrying appreciable levels of PGE and Au.

The Jijal complex, northern Pakistan, is a 150 km^2 body of dunites, olivine clinopyroxenites, websterites, garnet websterites and garnet gabbro, resting tectonically over the gneissic basement of the Indian plate. Both the ultramafic and mafic phases contain minor amounts of base metal sulphides and chromites with which the platinum group elements (PGE) are associated. The abundances of PGE range from 9 to 86 ppb in olivine clinopyroxenites; 13 to 54 ppb in websterites; 17 to 54 ppb in dunites; 9 to 41 ppb in garnet clinopyroxenites and 9 to 27 ppb in garnet gabbro. Several PGE enriched horizons occurred through the serie: 1) chromite- rich levels (la to ld) moderately enriched in Ir+Ru+Rh in lower dunites; 2) two disseminated sulphide bearing pyroxenites levels (2a and 2b) with strong concentrations of Ir-Rh-Ru-Pd-Pt, Cu and Ni (∑Y.PGE = 345 and 1417 ppb); and 3) one disseminated sulphide bearing garnet gabbro horizon (3) with moderate Pt-Pd concentrations (∑PGE 196 ppb) in upper part of the complex. The mineralogy of Pd- and Pt-bearing platinum erroup minerals (PGM) appears to be commonly associated with sulphide-bearing as intercumulus sulphides. The PGM's include merenskyite, temagamite and melonite. In addition, Miller et al. (1991) have reported atheneite, tetraauricupride, electrum and hessite from the same complex. No PGE bearing phase was recognized in the chromite bearing levels.

Mantle normalyzed PGE profiles from the chromite-rich dunite present a sawtooth appearance with low Pt - Pd and high Ir, Ru, Rh which may be related to early ferrochromite crystallization correlative with high oxygen fugacity (Amossê & Allibert, 1993). However, most of the ultramafic and mafic samples show fractionated mantle normalized PGE patterns with relatively high (Pd/Ir)n. These ratios mainly result from melt and fractionation processes. Pt and Pd were extracted during partial melting, and concentrated in the silicate melt whereas Ir and Ru were remained in the residual mantle. Crystallization of chromite and, to a lesser extent, olivine will further deplete the Ir and Ru in melt and any rock that subsequently forms from this fractionated magma will have more steeper positive slopes than the original liquids (i.e. higher Pd/Ir ratio).

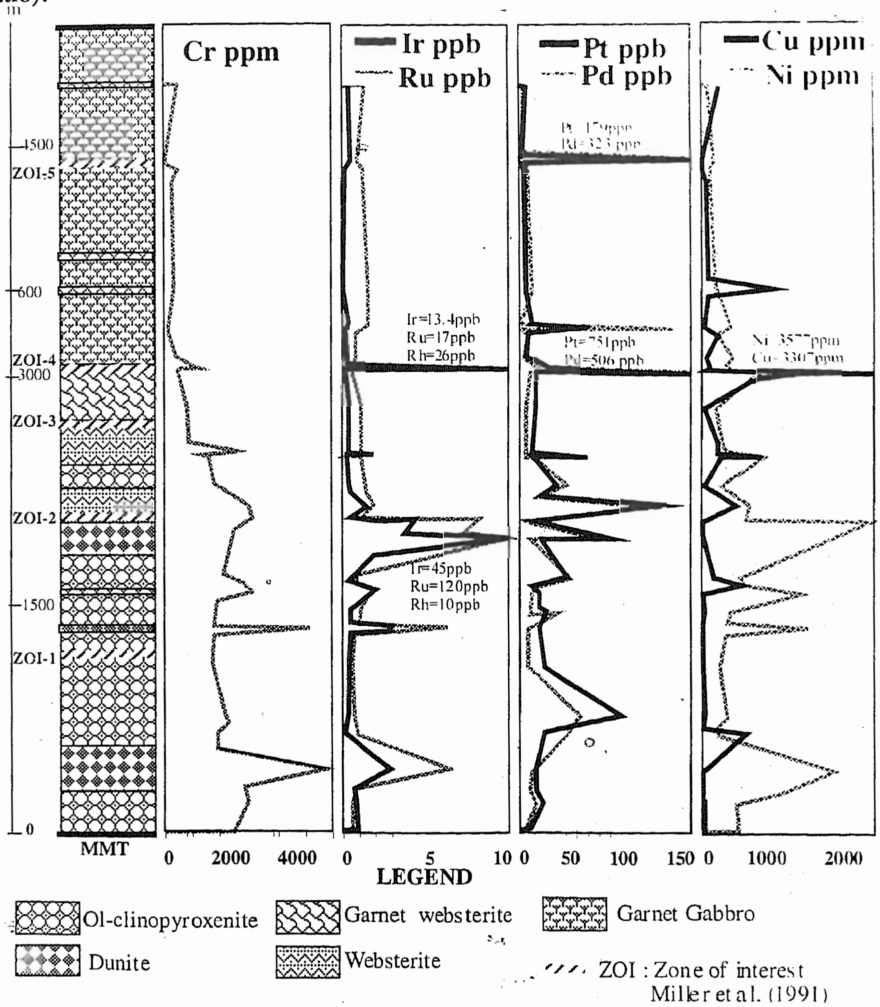

Fig. 1. PGE Distribution in the Jijal complex along the Dubair valley.
PGE analyses by 1CP-MS, LGCA, Grenoble, Cr-Ni-Cu by XRF - GEOLAB, Islamabad.

The Masherbrum greenstone unit : Transported arc or ophiolitic suture?

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During summer 1997, field work has been conducted in Hushe, Thalle, and Skoro valleys (NE Pakistan). Main aim of this campain was the study of volcanic rocks throughout the suture zone.

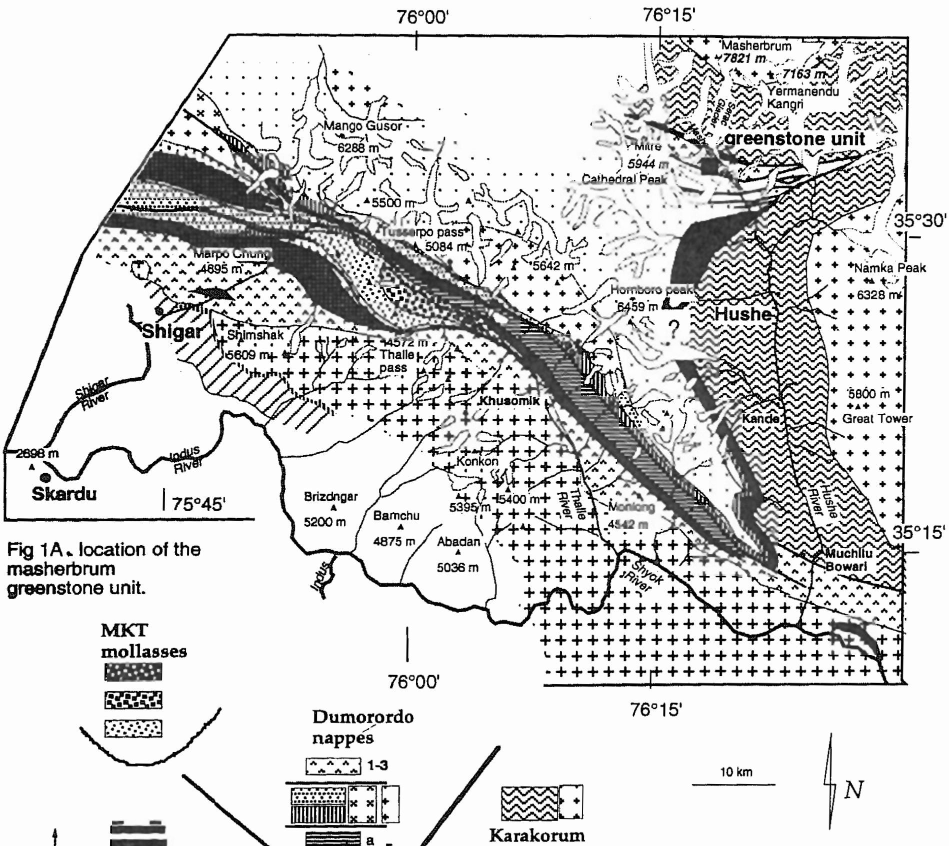
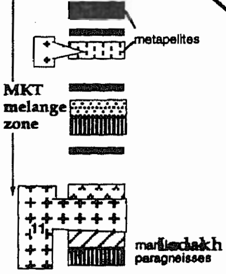


Fig 1A. location of the masherbrum greenstone unit.



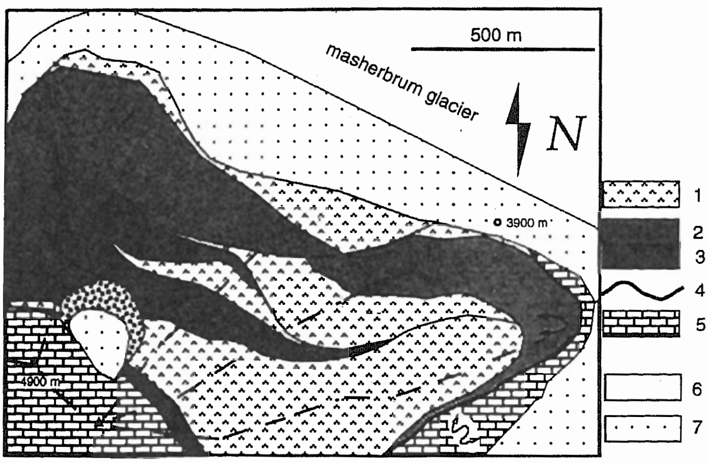


Fig 1B. **Geological map of the Masherbrum greenstone unit, on the right side of the masherbrum glacier.**
6 : glaciers, and 7 : quaternary deposits.

In the northern part of this zone, a narrow strip of basic rocks, the Panmah ultramafic unit, has been interpreted as an ophiolite in an intra Karakorum Mesozoic suture (Searle et al., 1989). Thus, it seems important to compare these basic rocks with the Shyok suture zone volcanic rocks.

Our observations of this unit, on both sides of the Masherbrum glacier (see Figure 1B) have shown numerous imbricated scales, viz :

- ultrabasites of harzburgitic composition (cartoon 3, Fig. 1B),
- gabbros locally flaserised and doleritic dykes (1).
- Lavas and greywackes (2).

These lithological associations suggest some ophiolitic affinities compatible with the interpretation of an oceanic crust relict.

Structurally, the basic rocks are separated from crinoid bearing limestones (5, Fig. 1A-B) by a folded tectonic contact (4, Fig. 1B). Both the basic and the sedimentary units are metamorphosed in the greenschist facies and lie on the Hushe gneiss unit, metamorphosed in the amphibolite facies. This metamorphic contrast and the structural relations show that the basic + metasedimentary units form a klippe on the Hushe gneiss.

Preliminary geochemical data (major elements, REE) suggest an arc signature. The basic rocks of the Masherbrum area could possibly be related to the Kohistan-Ladakh volcanics, located 30 km southwestwards, on the south side of the MKT.

The timing of prograde metamorphism in the Himalaya

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Since collision between the Indian and Eurasian plates at 55-65Ma some 2500-3000 km of shortening has occurred, resulting in major deformation and thermal disturbances in the collisional zone. The metamorphic belt is now represented by the High Himalayan Crystallines (HHC), a thick sequence of metamorphic rocks thrust over low grade rocks to the south and bound to the north by sedimentary rocks. Here we summarise garnet Sm-Nd and P-T data from the Garhwal and Zanskar Himalaya which directly constrain movements within the HHC in the period 37-23Ma. These data, in conjunction with other chronological data from across the Himalaya, unravel the major controls on Himalayan metamorphism and confirm a simple, foreland-propagating thrust model.

The Garhwal and Zanskar Himalaya of India expose a complete section from the Lesser Himalayas through the HHC and into the overlying Tethyan sediments in several river valleys. The HHC in both areas varies from chlorite zone to sillimanite zone gneisses. Leucogranitic magmas intruded in the HHC were formed by crustal melting at around 20Ma which was followed by rapid cooling (Metcalfe, 1993; Noble & Searle, 1995).

Garnet dates from both Garhwal and Zanskar indicate that the upper structural levels of the HHC had thermally equilibrated around 35Ma while growth continued until 23Ma at lower levels near the MCT. Core temperatures and pressures for both Garhwal and Zanskar are $\sim 550^{\circ}C$ and 3-7 kb and for garnet rims are $\sim 650^{\circ}C$ and 7-10kb. Growth occurred during rapid burial; clearly linking the metamorphism with thrusting to the north of the HHC. In the lower grade MCT zone petrological studies in the Garhwal region show complicated polymetamorphism suggesting that metamorphism was also thrust controlled.

These data in association with the 49Ma age obtained for eclogites in Pakistan (Tomarini et al., 1993), the less than 6Ma for garnet growth beneath the MCT of Nepal (Harrison et al., 1997) and cooling histories obtained from Garhwal suggest that a simple forward propagation model of the deformation since collision may be applicable along the whole length of the Himalaya. In addition the data imply that the HHC were not being unloaded until orogenic collapse in the Early Miocene resulted in rapid exhumation. Erosion of the HHC, therefore, did not contribute to the change in the Sr isotopic composition of the worlds oceans before 30Ma.

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Metcalfe, R. P., 1993. Geol. Soc. Spec. Publ. 74, 485-509.

Leading edge of the Himalayan thin-skinned thrust system in Pakistan: The Salt Range

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The 180 km, ENE trending Salt Range is the leading edge of the progressive, south migrating Himalayan thrust front. The presence of a basal salt layer is manifested by the very narrow cross-sectional taper ($< 1^{\circ}$) and great width (150 km N-S) of the overthrust wedge. Integration of approximately 450 km of seismic reflection data with available surface geologic, magnetostratigraphic, and exploration well data delineate different tectonic features in the Salt Range. These data reveal a concealed duplex structure under the roof sequence, help to determine the footwall and hangingwall geometries of the leading edge at successive evolutionary stages, estimate the lateral extent of a basement normal fault, constrain the ages of different structural features, and define lateral variations in the deformational style within the leading edge. We suggest an out-of-sequence evolutionary model of the Salt Range.

The newly interpreted, concealed duplex structure is the earliest structure of the Salt Range formed during 9-7 Ma. It evolved along a décollement that first ramps within the Salt Range Formation and then across the platform sequence to follow shady horizons of the overlying Murree Formation. The northern ramp is localized in the central Salt Range due to the development of the basement normal fault, around 7 Ma, in the north of concealed duplex structure. It is offset 15 km farther south along a lateral ramp in the western Salt Range, and is entirely within the sedimentary sequence. In the eastern Salt Range, however, it continues within the sedimentary sequence beyond the end of the basement normal fault and then changes into an oblique ramp. The development of basement normal fault interrupted the southward progradation of the thrust wedge. A thick salt pad, formed between 5-6 Ma on the down-thrown side, allowed the thrust wedge to ramp over the northern ramp at about 5 Ma. The topography, newly built by the ramping, resisted the southwards progradation of the thrust wedge and caused further out-of-sequence thrusting in the north. This was followed by the major horizontal translation of the thrust wedge over the roof sequence flat started about 2 Ma. A 13° of counter clockwise rotation has occurred along the northern ramp and the concealed duplex structures.

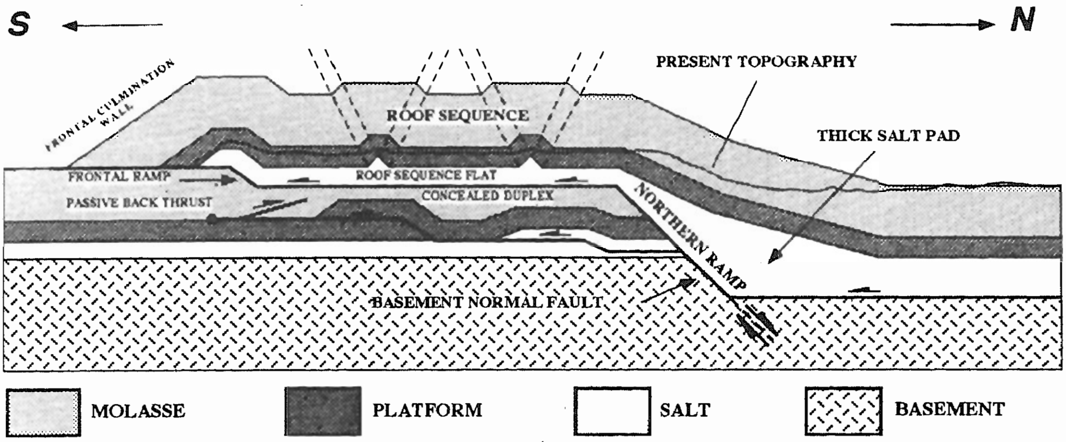

Fig. 1. Terminology used for the different stratigraphic units and structural features in this study. Note that thick salt pad forms a wedge-shaped geometry due to the buttressing effects of the northern ramp localized by the basement normal fault. Also note the deformation of the roof sequence into sharp, salt cored anticlines and broad, flat synclines.

Geoarsenic hazards in Bangladesh

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Arsenic calamity in Bangladesh is serious problem like in West Bengal, India. Investigation has been carried out since 1996 with the members of the Research Group for Applied Geology (RGAG) and the Asia Arsenic Network (AAN) of Japan in 20 districts of Bangladesh. Field experience and available data show that the high arsenic concentration in groundwater above the guideline value for drinking water by WHO was found in Chapai, Nawabganj, Rajshahi, Kushtia, Natore, Pabna, lshwardi, Meherpur, Panchagarh, Jessore, Chuadanga, Comilia, Chandpur, Narayanganj, Faridpur, Bagerhat, Dinajpur, Sathkhira, Rajbari, Rangpur and Kurigram. Out of 64 districts in Bangladesh, the RGAG and the Research Group of Geology and Mining Department of Rajshahi University suspect that goundwater of more than 30 districts may be contaminated with arsenic. To give safe water to the people more investigations in the whole country is essential.

The source of arsenic in grounwater is as yet unknown. But it is now widely belived that the high arsenic levels in the groundwater in Bangladesh and West Bengal (India) have a natural source (World Bank 1997). Groundwater in Bangladesh relates to sandy alluvial deposits are considered to be arsenic free. However, the possibility that wells pumping from the deeper coarser deposits infiltrate groundwater with a high arsenic content should not be overlooked. To understand the arsenic problem surfaced in Bangladesh, it is very much essential to see the picture of surface and groundwater occurrences, its distribution and concurrent uses under different geological and hydrogeological settings of the country.

However it is established as a mineralogical source with mobilization resulting from natural geochemical processes. High arsenic concentrations are associated with reducing groundwater rich in ferrous iron, abstraction from Quaternary confined and semi-confined alluvial or deltaic aquifers. To know the basic understanding of the source and mobility of arsenic it is essential to investigate the sampling depth and aquifer provenance. Arsenic affected areas on the Ganges Delta are so vast covering the approximate areas of 34 districts out of 64 districts. The areas of these 34 districts are 65,000 km^2 and the population is about 51 million which is about 42.5% of the total population of the country.

Principal manifestation of chronic arsenic poisoning resulting from accumulation of arsenic in body by drinking arsenic contaminated water in Bangladesh includes pigmentation disorders (skin blackening), conjunctivitis, melanosis, depigmentation, keratosis, hyperkeratosis, gangrene in limbs and malignant neoplasm. Already more than 1,000 arsenic related cases have been reported from the highly affected areas. The true extent of the health problems is as yet unknown due to lack of proper investigations.

The RGAG and ANN members jointly with the Rajshahi University scientists have carried out a survey and the result of investigation have been discussed. The results includes the relationship between ORP (mV) and As (ppm) as well as pH and ORP (mV). We know groundwater contamination or pollution involves changes in the physiochemical and microbiological characteristics or even in the contact of radio-nuclides of water as a result of anthropogenic activities which render it less useful for future use (Handa, 1994).

To save these huge population of the area all sort of international help is essential to solve this arsenic problem. If precautionary measures against arsenic contamination are not taken immediately, consequences like death of many people will be inevitable and massive. An awareness-raising about the issue among the people should be the first step for precaution.

Preliminary geochemical studies on the granitoids of the Karakoram batholith, Ladakh, India

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The Karakoram mountains are mainly constituted by sedimentary rocks with restricted metamorphic and igneous rocks. Among the igneous rocks, volcanic rocks are confined to the basal part of the Karakoram basin and are related to the Permian rifting. Granitoids of the Karakoram batholith dominate in the south. Metamorphic rocks are always associated with these granitoids in the eastern Karakoram. These rocks represent the southern margin of the Asian plate in the Nubra-Shyok valley of Ladakh. The Karakoram batholith and metasediments are in direct contact with the ophiolitic mélange of the Shyok tectonic zone. To the north, batholith has intruded the Upper Paleozoic black argillites of the Karakoram Tethys. Granitoids from this composite batholith show hypidiomorphic granular, porphyritic and cataclastic textures. Main rock types are biotite granite, biotite-hornblende granodiorite, augen gneiss and mylonite gneiss. On the basis of preliminary geochemical (major and trace elements) studies, granitoids can be grouped into two groups. The more basic rocks with SiO_2 61.92-65.42% show higher concentration of TiO_2, MgO, FeO, CaO and Sr and low K_2O, Rb and Pb. The rocks of granitoids of this group are metaluminous and belongs to I-Type. The other group with higher SiO_2 (68.55-74.06%) is peraluminous with high K_2O, Rb and Pb and are S-type granitoids.

However, both I-type and S-type show well defined and smooth variation trends when major and trace elements are plotted against SiO_2. Such trends are expected due to fractional crystallization. The granitoids of Karakoram batholith are produced by syn-collision and volcanic arc magmatism.

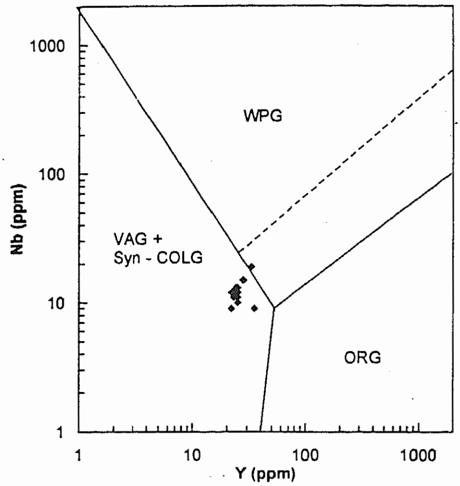

Fig. 1. Y vs Nb tectonic discrimination diagram for granitoids of the Karakoram batholith. WPG: Within - Plate Granites; VAG: Volcanic Arc Granities; Syn-COLG: Syn- Collision Granites; ORG: Oceanic Ridge Granites.

Mineral chemistry and tectonothermal evolution of the crystalline sheets in the Kathmandu region, central Nepal: Relation to geodynamic context

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The amphibolite to granulite-grade rocks in the Kathmandu and Gosainkund region are divided into three tectonic units on the basis of structure, lithology and metamorphism [1]. The Gosainkund Crystalline Nappe (GCN) corresponds to the Higher Himalayan Crystallines, thrusting over the Lesser Himalaya (LH) and the Kathmandu Crystalline Nappe (KCN) along the Main Central Thrust (MCT) (Fig. 1). To the south, the Lesser Himalaya (LH) is also thrusted by the KCN along the Mahabharat Thrust (MT).

We have made some systematic traverses with the microprobe in garnets from all three units. In the KCN, when climbing structurally in the section, the almandine and pyrope contents decrease and the grossular and spessartine contents increase. In the GCN, when going structurally from base to top, the contents of garnet end-members present no systematic variation, with the exception of the upper part, when sillimanite starts to show and correlatively, almandine content decreases and spessartine content increases. The muscovites from the KCN are rich in Fe content while the compositions from other two units are rich in Al content. Most of the biotite compositions belong to the annite compositional field. The inverse relationship of Ti vs. Mg number (Mg/(Mg+Fe)) shows an increase in the latter when going from top to bottom of the KCN. The LH biotites resemble the bottom composition of the KCN whereas the

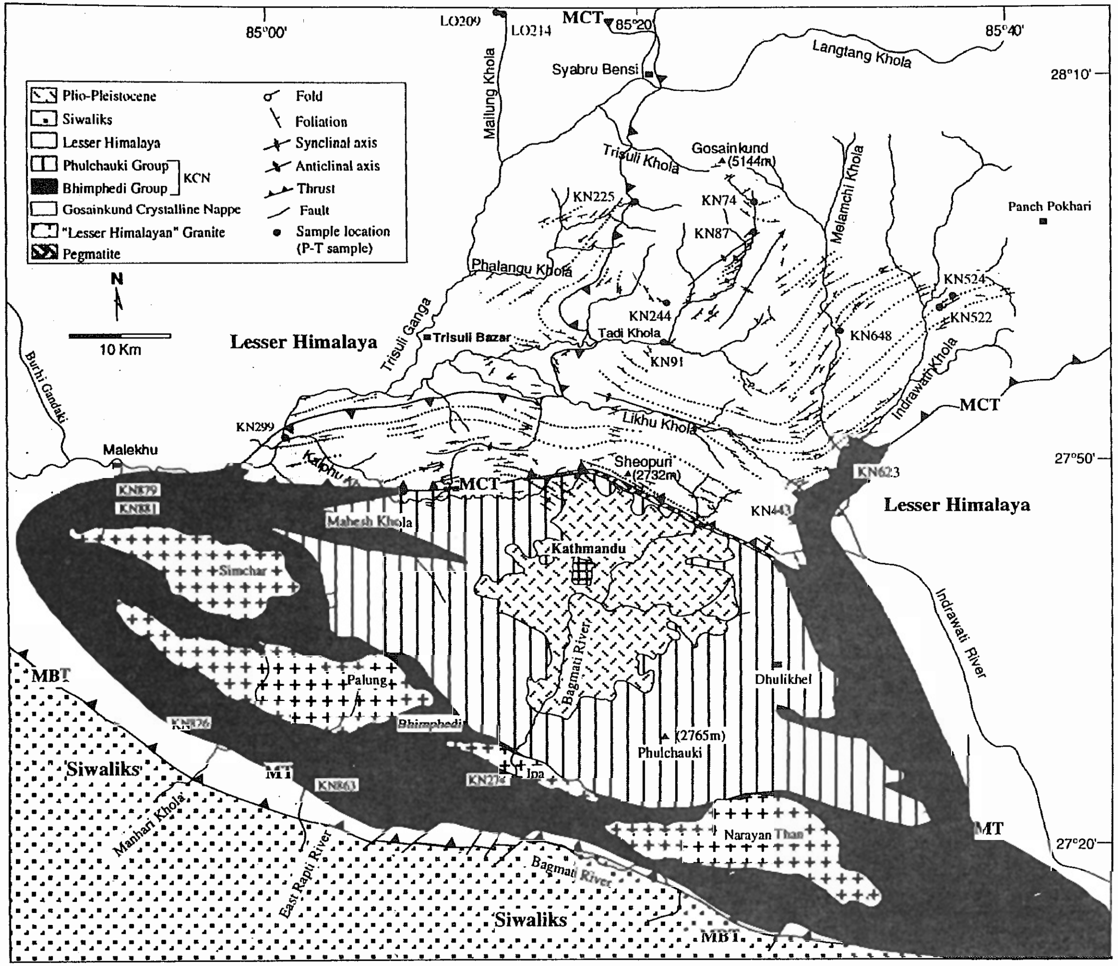

Fig. 1. Geological map of Central Nepal with foliation trajectories in the studied area (modified after Stöcklin, 1980)

GCN biotites are quite scattered. However, the Ti-Mg trend does not seem to relate directly to the grade of metamorphism. The different chemistry of each mineral from one unit to another suggests that they are separated different tectonic units.

We have selected 18 metapelitic samples from all three units for thermobarometric study. Both conventional and thermocalc methods are used to calculate the pressure and temperature conditions. The upper LH sample records syn-MCT metamorphic conditions of 750±150 MPa and 566°±136°C (quoted at 2σ). The KCN samples record P-T conditions from 720 to 900 MPa and 484°-700°C. The P-T conditions recorded from the GCN are 583-890 MPa and 588-754°C. In the upper section of the GCN, the sillimanite bearing assemblage could correspond to a pressure and temperature drop of 170 MPa and 60°C respectively, when using the core to rim differences.

The pressure and temperature obtained in the upper LH and the GCN show that the pressure gradually decreases from the MCT to the upper section of the GCN, and the temperature increases steeply from the upper LH, continuing across the MCT and culminating at about 5 km structurally above the MCT. After a slight decrease, the temperature trend flattens and remains at around 700°C up to the highest level of the GCN. This metamorphic evolution shows the good preservation of inverse metamorphism. The HP-HT metamorphic condition of the GCN is different from the MP-MT metamorphic condition of the KCN rocks, that have their own lithology, stratigraphy and metamorphism [1]. The GCN and KCN units are separated by the MCT, north of Kathmandu. The consistency of P-T estimates in the MCT and MT zones suggests that the main deformation was synmetamorphic and probably records the underthrusting of the Lesser Himalaya below the Higher Himalayan Crystallines along the MCT or below the KCN along the MT.

The MCT zone transects geometrically the KCN and the MT. The comparison of thermobarometric results between these two nappes suggests that the activity of the MT would have been followed by the activity along the MCT. The absence of brittle deformation in the MCT and MT zones confirms that the late exhumation of the KCN and the GCN is accomplished by movement along Main Boundary Thrust (MBT). This late movement could be also responsible for raising the Kathmandu region from its surroundings.

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Kameng orogeny (1.8-1.9 Ga) from the isotopic evidence on the Bomdila orthogneisses, Kameng sector (NEFA), India

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The existence of the Proterozoic/Pre-Himalayan tectonometamorphism and orogeny in the Himalaya is highly debated and disputed [1-13]. Naha and Ray [1,2], working in the Simla klippe of the Himachal Lesser Himalaya concluded that the large scale recumbent folding and thrusting (F1 and D1) in the Lesser Himalaya is related to the Tertiary Himalayan orogeny and the first metamorphic event (amphibolite grade) which follows the earliest deformation couldn't be Precambrian in age. Powell and Conaghan [3, 4] and Pickett et al.[5] also expressed the same view while working in the Chandra valley of Himachal Himalaya. It was P.K. Mehta [6,7], who first postulated the existence of Pre-Himalayan (Cambrian) regional metamorphism based on the

Rb/Sr whole rock and mineral dates of the Mandi granite (545 ± 12 Ma) from the Kulu-Manali sector and concluded that the F1 folding and the accompanying high grade regional metamorphism belong to the 500-600 Ma orogenic cycle in the Himalaya. This conclusion was based on the available radiometric dates at that time i.e. 500-600 Ma Rb/Sr whole rock granitic and 320-370 Ma muscovite ages. This was contested and criticised by Powell and Conaghan [8] and Zeitler et al., [13] and many others.

Since 1977, there have been abundant reports on the existence of Palaeo-Proterozoic to Meso-Proterozoic granitoids and gneisses all along the Himalayan belt, right from Pakistan to Eastern Arunachal Himalaya [14,15]. These Palaeo-Proterozoic to Meso-Proterozoic granitoids and gneisses, which generally show S-type geochemical character with a strong tectonic fabric, are tectonically emplaced within the Proterozoic cover sequence and hence are termed "Basement Wedges" [16,17]. These rocks may be part of Indian Cratonic units which were later reworked during Himalayan orogeny. These granitoids and gneisses exhibit marked similarity in litho-stratigraphic setup, grade of metamorphism, mineralogy and geochemical signature etc. throughout the length of the Himalayan chain and are the key rock types of the Precambrian Himalaya to unravel tectonometamorphic, deformational and orogenic history.

I have concentrated on the above said problem using multi-isotopic study (Rb/Sr, U/Pb/ Pb/Pb and Sm/Nd) on the Bomdila orthogneisses (Basement) from the Kameng sector, Arunachal Lesser Himalaya (NEFA) to unravel their crustal history and to answer the question "Are there any tectonometamorphic events in the Pre-Himalayan northern edge of the Indian sub continent, other than the primary continent forming processes?"

The Kameng sector is divisible into east and west Kameng sectors and is part of the Arunachal Lesser Himalaya (NEFA). The Bomdila gneisses are part of the west Kameng sector which comprises dominantly Bomdila Group of rocks. The gneisses are the basement to the overlying low to medium grade metasediments/supracrustal rocks. The metasedimentary succession can be divided into the Tenga, Dedza and Dirang formations which all occur as schuppen or thrust sheets with the associated intrusives. The metasediments/supracrustal rocks are thrust over by the high grade metamorphic rocks of the Northern Sela Belt along the Main Central Thrust (MCT).

Petrographically the gneissic samples show quartz, potash and plagioclase feldspars and micas (both muscovite and biotite) as the dominant mineral phases with sphene, zircon, apatite and epidote as the accessory and minor mineral phases. Alignment of micas forms the foliation, which is of tectonic origin. Geochemically, the gneisses are peraluminous with calc-alkaline nature and are dominantly granite to quartz-diorites and manzogranites. They are orthogneisses with S-type geochemical character and plot in the volcanic arc and collision granite fields of the Nb-Y discrimination diagram signifying an active continental margin.

One sample of the Bomdila orthogneiss collected at Rupa (AP-7) and another sample collected at Kalaktang (AP-3) have been dated using the conventional U-Pb zircon method. The U-Pb discordia of the sample AP-3 yields 1874$\pm$24 Ma (2σ) as the upper intercept and 147 $\pm$24 Ma (2σ) as the lower intercept with MSWD 0.32. The upper intercept is interpreted as the age of crystallization of the zircon and the lower intercept may not have any geological meaning but may be related to the Himalayan orogeny or quasi continuous lead loss. The AP-7 sample from the same suite (about 15 km away from the AP-3 sample), yields U-Pb zircon age of 1827 $\pm$ 95 Ma (2σ) as the upper intercept and 91$\pm$20 Ma (2σ) as the lower intercept with MSWD 0.404. This age agrees with the other reported ages for the granitic rocks from the Himalaya on west of the Kameng belt [11,14,15,18] and indicates a widespread plutonism around 1800-1900 Ma. The Pb-Pb data of the step leached titanite [after Frei & Kamber 19] define an isochron yielding 1781±9 Ma (2σ) with MSWD 1.1. This is the first report of a palaeo-Proterozoic titanite from the gneisses in the Himalaya from Pakistan to India. The age of the titanite can be interpreted as the date of crystallization or formation of the titanite under amphibolite facies metamorphism (M_1 metamorphism). This palaeo-Proterozoic tectono-metamorphic event converted the magmatic protoliths to muscovite-biotite gneisses. The strong association of titanite with biotite in the foliation and near absence of titanite in the thin section away from the foliation, are clear indications for the tectonometamorphic origin of the titanite. Interestingly, such a palaeo-Proterozoic foliation producing event had earlier been reported [20] in these rocks, based on the whole rock Rb-Sr data, which was also supported by S.K. Acharyya [21].

Rb/Sr whole rock data on the basement gneisses at Kalaktang give an errorchron corresponding to an age of 1706 ± 80 Ma with an initial Sr ratio of 0.7055 ± 0.066. The 1706 ± 80 Ma errorchron age can be interpreted as the age of Rb/Sr resetting on whole rock scale due to the earliest tectonometamorphic event on these rocks defined by the age of Pb-Pb step leached titanite. Rb/Sr whole rock data on a second unit of granitoids (Chuck Bridge, Tenga) which are intruded into the Bomdila basement gneisses, yield an errorchron of 1.1 Ga with a high initial Sr ratio of 0.798 ± 0.0019. This clearly indicates recycling of older material in the source for the second intrusives, indicating at least one cycle of basement remobilization.

Rb/Sr whole rock and muscovite pairs gave ages ranging between 1000-1685 Ma. This, together with the fact that the muscovite has interfingered with the biotite and shows its presence only in the foliation, is a strong evidence for the existence of Proterozoic tectonometamorphism in the Himalaya. These are the highest muscovite ages reported so far from the gneissic rocks of the entire Himalayan belt. The 1685 Ma age may be seen as the closure of the Rb/Sr system after the first tectonometamorphic event (also reflected by the whole rock date of 1.7 Ga), the youngest may reflect growth or resetting of the muscovite due to intrusion of Chuck Bridge Tenga granitoid suite (ca. 1.1 Ga). The intermediate ages may depict mixing ages between earlier events and the Himalayan orogeny. Rb/Sr dating of whole rock and biotite pairs hold invariably negative that is to say '*future ages*'. Although this indicates partial resetting of the Rb/Sr system during the Himalayan orogeny, it also means that the growth of the biotite is clearly older. It is important to note at this stage that there are several reported Proterozoic K-Ar ages of biotites ranging between 700-1700 Ma from the Pakistan Himalaya as well as Pamirs [unpublished data of 22; and J.R. Arrowsmith, Pers. Comm.]. In recent years, several studies have clearly shown the existence of the Precambrian folding/deformation/orogeny in the Lesser Himalayan tectogene [23,24,25].

I have dated six samples of the Bomdila orthogneisses by Sm-Nd method, which gave the following T_{DM} model ages, as per the model proposed by Goldstein et al. [26]: AP-3 → 2.60 Ga; AP-5 → 2.75 Ga; AP-7 → 2.61 Ga; AP-201 → 2.86 Ga; AP-202 → 2.45 Ga; AP-203 → 2.60 Ga., indicating thereby that they have been derived by reworking of the Archean crust. These Archean orthogneissic ages are again first of their kind in the Himalayan geochronology. Therefore, the 1.8-1.9 Ga plutonic event is part of an orogenic episode during which older Indian cratonic material was reworked in the Arunachal Himalaya. It was immediately followed by a tectonometamorphic event at 1781 ± 9 Ma, which converted the magmatic protoliths into the muscovite-biotite gneisses. From the name of area, where I found the evidence of a palaeo-Proterozoic tectonometamorphism, I call this orogeny the "Kameng Orogeny" in the Himalaya. Thus, the present study reveals the existence of 1.8-1.9 Ga (zircon, U/Pb age) and 2.6 Ga (Sm/Nd model ages) old gneisses, 1781±9 Ma old M_1 high grade amphibolite facies metamorphism and 1685-1000 Ma muscovites and 1.1 Ga old granitoids from the Kameng sector of India.

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Rb-Sr dating of Rilo granite, east Kameng, district Arunachal Lesser Himalaya, India

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The area investigated is a part of the highly dissected mountain region in the Kameng Sector of the Arunachal Lesser Himalaya (NEFA). The Kameng sector in the Arunachal Lesser Himalaya constitutes both the East and West Kameng sectors. The east Kemeng sector exclusively lies within the east Kameng district of Arunachal Pradesh. The present study deals Rb-Sr dating of Rilo granite from the east Kameng Sector.

The east Kameng sector is mainly comprised of metasedimentary formations, gneisses and granites. The metasedimentary sequences can be divisible into Khetabari Formation and Tenga Formation. The Khetabari Formation consists of garnet-staurolite-kyanite-sillimanite schist, mica and graphite schists, fuchsite quartzite and amphibolites. This formation can be tentatively correlated (?) with the Dirang Formation in the west Kameng sector. The Tenga Formation consists of dolomite with minor chert bands, green and black phyllite and massive quartzite. The gneisses in this area are generally termed as Ziro gneiss . The gneisses are mainly of biotite ± muscovite ± garnet type, traversed by pegmatitic and late stage fluids and vein quartz. The regional trend of the litho-units varies from NNW-SSW to E-W with moderate to steep south easternly dips. The litho-stratigraphy in the area can be worked out as follows (modified after Saha et al., [1]:

Rilo Granite

__________ Intrusive contact __________

Ziro Gneiss

__________ Intrusive contact __________

Tenga Formation

__________ Unconformable contact (?) __________

Khetabari Formation

The garnet-staurolite-kyanite-sillimanite schist and fuchsite quartzite of the Khetabari Formation occur as a narrow band close to its contact with the overlying Tenga Formation, south of Chyang Tajo. Both the Khetabari Formation and Tenga Formation occur in the form of east-west trending large elliptical enclaves within the Ziro gneiss [2]. The Rilo granite has been found intruded into both the metasedimentaries and the Ziro gneiss and are well exposed around Rilo ($27^0 12'$ N : 93^0 09′ E). The Rilo granite is hard, non-foliated but shows some effects of strain under thin section.

Petrographically the granitic samples show quartz, potash and plagioclase feldspars, biotite and hornblende as the dominant mineral phases with sphene, zircon, apatite, epidote, zoisite and allanite as the accessory and minor mineral phases. Sphene is in the form of well developed big crystal aggregates with prominent parting. It is characteristically developed in the vicinity of both hornblende and biotite. Most oftenly, it is found directly sitting on the hornblende/or biotite but at times is also found to interfinger with both the minerals. Hornblende seems to be the earlier phase than the biotite in paragenesis. The biotite appears to be of two types, one of brown variety and the other green in colour. Allanite is the marker mineral in this rock. It is euhedral and shows light reddish brown to dark reddish brown pleochroism and is rimmed by zoisite. Based on the presence of allanite, this rock can be classified as the REE enriched rock.

Rb-Sr dating of Rilo granite define an isochron corresponding to an age of 413 ± 19 Ma with an initial strontium ratio of 0.7127 ± 0.0016. The MSWD of the four point isochron is 1.08. I interpret the 413 ± 19 Ma age of the Rilo granite as the emplacement age. The high initial strontium ratio of this granite suggests that the granite is of crustal derivation and probably the protoliths were of metadesimentary rocks.

Preliminary Rb-Sr dating of Seppa gneisses, collected on the Seppa-Rilo highway yielded an age of 500 Ma. These seppa gneisses may be correlatable to the Ziro gneisses, for which the type area is in the adjacent lower Subansiri district and are dated at 500 Ma [3].

The Rilo granite has an intrusive contact with the Seppa gneises/Ziro gneisses and is non foliated. Hence the deformation/tectonic event which produced gneissocity in the Seppa gneisses is restricted to Seppa gneisses only and the Rilo granite is unaffected by it. So the gneissic foliation producing event of the Seppa gneisses was prior to the Rilo granitic intrusion. This is a strong evidence against the theory advocated by many Himalayan protogonists that all the gneissic foliation of the gneisses/granitoids in the Himalayan chain is due to the Himalayan Orogeny [4 - 8] and others.

Several such indirect evidences for high grade tectonometamorphism and orogeny in the Himalaya at around 500-600 Ma was proposed by many distinguished workers. For example, a) Mehta [9, 10] reported a 500-600 Ma old high grade metamorphic event/orogeny from the Himachal Himalaya, b) Garzanti et al., [11] proposed a Cambro-Ordovician orogeny in the northwestern Himalaya based on the sedimentary evidence, c) Valdiya [12] proposed a Pre-Ordovician deformation based on the Proterozoic and Paleozoic sedimentary record, d) Bhargava and Bassi [13] reported a tight folded biotite-garnet schistose enclave within the 495 Ma old Rakcham granite from the Himachal Himalaya, e) Baig et al., [14] reported a Late Precambrian to Early Paleozoic Hazara Orogeny from the Pakistan Himalaya, f) Pognante and Lombardo [15] and Pognante et al., [16] reported that the high pressure granulitic relic bearing metabasics from the Lahul-Zanskar High Himalayas were intruded by Early Paleozoic granitoids. The granitoids preserve the Himalayan metamorphic overprint. But the relic granulitic assemblages in the metabasics do not. Hence the high pressure granulitic relics within the metabasics represent an older Pre-Himalayan metamorphic event incompletely obliterated by Himalayan orogeny. So the granulitic metamorphism within the Lahul-Zanskar Slab may be atleast 549 ± 70 Ma old.

The well developed augen gneissic foliation of the Mansehra gneiss of the Pakistan Himalaya may be related to the Neo Proterozoic-Cambrian orogeny. This contention was supported by Prof. M. N. Chowdhary, University of Panjab, Lahore, Pakistan. Although several indirect evidences support the existence of a 500-600 Ma orogeny in the Himalaya, a direct isotopic evidence on any metamorphic mineral grown during the orogeny remain elusive so far.

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Multistage role of tectonic deformation on uranium mineralization in the neogene fluviatile Middle Siwaliks of the Potwar plateau, Pakistan

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The evolution of uranium mineralization in the Middle Siwalik (Nagri and Dhok Pathan formations) of the Potwar plateau is characterized by syn-to post-tectonic sedimentary deformation through space/time. This indicates a sequence of regional events, providing channel ways and media for remobilization and uranium trapping with some reductants or along permeability/porosity barriers.

The syndiagenetic traps are mainly tectonically induced and associated in space i.e., on the lesser slopping, down thrown side of stream checking and reactivated basement faults. The post middle Siwaliks tectonic deformation caused uranium epigenctic remobilization and its down dip concentration. It is enhanced to increasing slope and/or oxidation i.e., on the upthrown side of stream checking faults, water table checking lineaments.

Detailed analysis of different tectonic elements and their chronology and uranium favourability criteria (availibity, remobilization and trapping) in each tectonic regions of the Potwar plateau (PP) has been carried out. Some interesting correlation parameters have been revealed after studying the impact of the tectonic setting on the uranium mineralization. All the 81 uranium anomalies in the middle Siwalik are grouped into 8 first rate and nine second rate anomalous zones : depending upon extent, nature and controls of radioactivity/mineralization. All the four tectonic regions of the PP, i.e. North Potwar Deformed Zone (NPDZ), South Westem Potwar Plateau (SWPP), East Potwar Plateau (EPP) and South East Potwar Plateau Corner (SEPP Corner), show different tectonic controls of individual anomalies as well as anomalous zones. In NPDZ the anomalous zones are controlled by minor NW-SE faults and the tight synclinal structures. In the SWPP, the control of uranium is down faulted blocks and incipient gentle folds. In EPP and SEPP corner the anomalous zones are located along W-E to NE-SW thrust faults, mainly on the northern flank of anticlinal structures.

Distribution pattern of uranium occurrences and their relationship with tectonic features (ductile and brittle) indicate western Potwar plateau comparatively more favourable than the eastern Potwar plateau. In SWPP appear to be the most favourable area for uranium exploration due to good source (synsedimentary arial volcanisin), syn to digenetic remobilization/trapping evidences in the central western Potwar along down faulted blocks and incipient gentle folds as well as epigenetic post tectonic remobilization/trapping along Salt Range Thrust (Fig. 2).

There are six large scale tectonic units in the SWPP namely:

- Either NE trending, north to south; lower Soan trough, Tamman ridge, Dhok Mosahib Wala trough to the NE and Chakarala basin to the SW (a composite unit most likely subdivided by secondary ridges and troughs), western Salt Range.
- Or NW-trending; from west to east; southern Kalabagh Salt Ranges, Pachnand ridge (rather subdued, but partly closing and possibly offsetting the Dhok Mosahib Wala trough and Chakarala basin).

Moreover, the matallotects might be further enhanced by the possible remobilization or trapping action of oil drived products migrating upwards through deep seated active faults from known underlying oil reservoirs and source rocks through release of $C0_2$, H_2S etc. in the underground waters. Evidences of such migrations upwards have been noted nearby majority of significant anomalous zones located over or close to known oil structures i.e., Jand (Dakhni oil field), Pindigheb (Dhulian), Khaur (Khaur), Tamman Talagang (Kot Sarang), Joyamair (Joyamair), Adhi (Adhi), Dina (Lehri gasfield), Chakarala (Dadhumber oil structure), Dhok Masahi Wala (Dhermud) producing or now barren.

At anomalies level, Pana Khel anomalous sandstone horizon Jand in Upper Nagri Formation indicates genetic relationship with hydrocarbon derived reducing fluids. Oil products contribution is also visible in the form of solid bitumen collected around the Nikki anomaly (Chakarala). It is first clue on the migration of oil products as far as the lower DPF.

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Pressure-Temperature evolution of garnet-bearing rocks from the Jijal complex (western Himalayas, northern Pakistan): from high-pressure cooling to decompression and hydration of a magmatic arc

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The Kohistan terrane located in the western Himalayas is an oceanic arc of Early Cretaceous age accreted to the Asian plate and subsequently obducted onto the Indian plate. It can be observed along a complete tilted section from ultramafic/mafic rocks to supracrustal volcanics. The 150 Km^2 Jijal complex constitutes the lowermost exposed part of this arc, and consists of rocks that probably crystallized in the vicinity of the crust/mantle boundary.

Petrographic observations of garnet-bearing rocks of the Jijal complex attest to the magmatic origin of several mineral species like garnet, plagioclase, clinopyroxene and amphibole, which are incorporated within, or pseudomorphosed by metamorphic minerals. According to experimental data on crystallization of basaltic magmas at high-pressure [1], garnet may appear on the liquidus of partially hydrated basalts if pressure reaches 2.0 GPa. Very high-pressure granulite, amphibolite and greenschist facies assemblages partly or completely overprint the magmatic assemblage. Consequently, many incompatible phases are present at the thin section scale. Very high-pressure granulite assemblages consist of garnet, clinopyroxene, plagioclase, quartz, ± amphibole. Most of these minerals are unzoned but their composition varies from grain to grain attesting to disequilibrium at the scale of the thin section, probably due to relict compositions inherited from the magmatic stage. However, most garnets are zoned and display a net increase of grossularite content at their rims, compensated by a simultaneous decrease in the almandine and pyrope contents; this results either from an increase in pressure under isothermal conditions, or from an isobaric cooling, the latter being more likely if magmatic garnet crystallized around 2.0. GPa. The jadeite content of clinopyroxene ranges from 7-19 wt.% and increases toward the rims of magmatic clinopyroxene grains; this increase is also compatible with isobaric cooling of the initial magmatic assemblage. Moreover, the Ca-tschermak content of clinopyroxene ranges from 1-16 wt.%, with Al^{vi}/Al^{iv} increasing toward the rims of the grains. Thermobarometric calculations based on Grt-Qtz-Cpx-Plnet transfer reaction and Grt-Cpx exchange reaction give P-T estimates covering a very wide range of 1.2-1.9 GPa and 750-1150°C. If the magmatic sequence of the Jijal complex is continuous, then the calculated depth-pressure range largely overpasses its thickness, estimated at around 12 km [2]. Similarly, the temperature range shows that relict magmatic compositions have probably been included in the calculations. Therefore, these values reflect disequilibrium or rather a mixing of magmatic and metamorphic equilibria. Nevertheless, average pressures and temperatures calculated for garnet and clinopyroxene cores are 60 MPa lower and 45 °C higher than those calculated for the rims. Consequently, the post-magmatic stage of metamorphism is a very high-pressure granulite facies resulting from nearly isobaric cooling. The superimposed lower grade hydrous assemblages consist of tremolite-anorthite corresponding to amphibolite facies conditions, tremolite (anthophyllite)-epidote of the transitional epidote-amphibolite facies, and finally actinolitic hornblende-chlorite assemblages of the greenschist facies. The above assemblages attest to a switch of the isobaric cooling path to a major decrease in both pressure and temperature.

This magmatic and metamorphic evolution can be correlated with already known tectonic stages:

- the 120-80 Ma [3] magmatic stage of the arc (magmatic assemblages);
- the partial cooling during the 80-65 Ma-old post-accretion stage (very high-pressure granulite facies conditions);
- the abduction of the arc onto the Indian plate, starting at around 65 Ma [4] (hydration of the granulitic assemblages with the development of amphibolite to greenschist facies assemblages).

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Geology of the Ladakh-Karakorum suture zone (NE Pakistan)

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During summer 1997, we investigated the MKT zone (or Shyok suture zone), between the Shigar and the Shyok valleys. On the northern side of the MKT, in the Karakorum, we have distinguished two metasedimentary units: (i) a low-metamorphic unit, characterised by limestones (1 & 3, Fig 1). In those limestones up to now very poorly mapped and dated, we have found several occurrences of fossils (mainly bryozoa and crinoid), leading to a Late Paleozoic age, (ii) underlying this unit, an amphibolite facies metapelitic unit (5, Fig 1), passing (?) to the Hushe series (Searle et al., 1989).

South of the Karakorum units, an imbricated pile of sedimentary, volcano-sedimentary, volcanic and plutonic rocks is observed, bounded by steeply-dipping irregular contacts, with intricated serpentinised ultramafic rocks (7). Thus, in this area MKT is a complex mélange zone, rather than a well defined contact as described farther West.

The base of the volcanic series (9) are made of alternating basaltic flows (locally displaying pillow-lava structures) and greywackes. Towards the top of the series the lavas are more differenciated and are interbeded with pyroclastic deposits.

The volcano-sedimentary units (the "Greenstone Complex") is made of reworked volcanic and sedimentary deposits, with: (i) metric to hectometric-scale basic volcanic blocks enclosed in a carbonaceous matrix (unit 8b) and (ii) olistolithes constituted of limestone and sandstone blocks enclosed in a shaly volcano-detritical matrix (unit 8a).

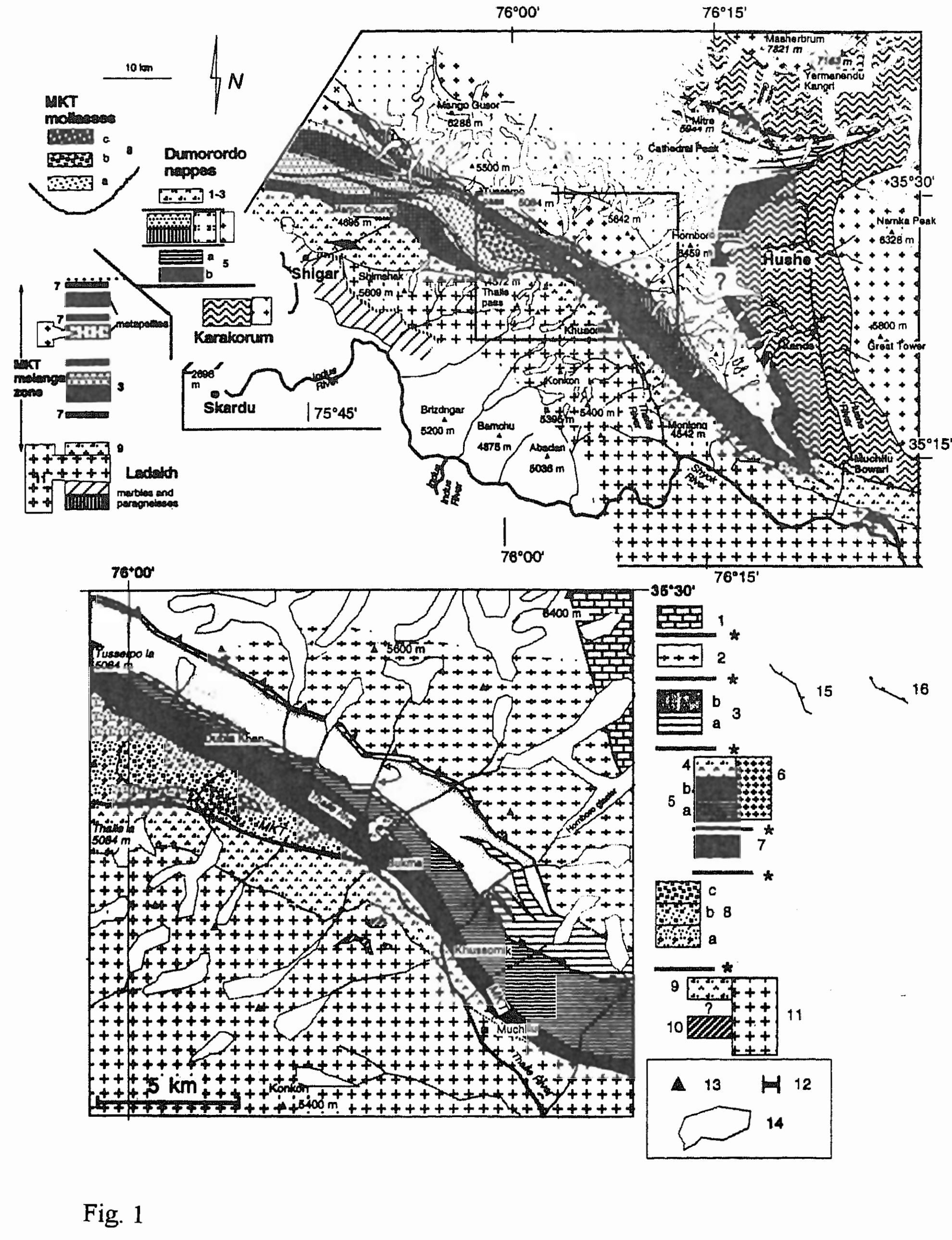
76°00'
76°15'
10 km
N
MKT molasses
Dumorordo nappes
Karakorum
MKT melange zone
metapelites
Ladakh
marbles and paragneisses
Skardu
Shigar
Hushe
75°45'
35°30'
35°15'
Masherbrum 7821 m
Mitre
Cathedral Peak
Namika Peak
Great Tower
Indus River
Shyok River
5 km
Tussepo la
Thalle la 5084 m
Khussomik
Konkon
Hombore glacier
MKT

Fig. 1

Those series are overlained by late discording molassic deposits, with a shallowing upwards sequence (unit 8c).

To the south, the plutonic rocks (diorites and granodiorites, 11) of the Ladakh batholith intrude the volcano-sedimentary units (9) of the suture zone. Hectometric non-assimilated blocks of marble (10) are visible inside the northern part of the pluton.

The lithological and geochemical characters of the volcanic rocks show some affinities with volcanic series of the Shyok suture zone between Karakorum and Ladakh of northwestern India and of the MKT zone between Karakorum and Kohistan.

Geophysical studies of the Xinjiang Geotransect: a transect across the West Kunlun- Tarim- Tianshan, NW China*

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Location: The Xinjiang Geotransect, from south to north, starts from Quanshuigou near the Karakorum Mountains and ends at Kuitun in the North Tianshan Mountains. It crosses the West Kunlun Mountains, runs northward along the Hotan river cutting through the Tarim Basin and then stretches along the Kuche-Kuitun line crossing the Tianshan Mountains, totaling about 1200 km. The transect extends further northwards, crossing the Junggar basin, to reach Burqin in the South Altay Mountains in northern Xinjiang.

Geological framework: The marked tectonic landform of Xinjiang is characterized by two basins, i.e. the Tarim and Junggar basins, along with some young mountains around them: the Karakorum, West Kunlun, Altun, Tianshan, and Altay Mountains. The three tectonic systems and general geodynamic evolution concerning the geological framework of Xinjiang are well known: Karakorum-West Kunlun-Altun, as a collision belt between the Indian plate and Eurasian plate, are marginal mountains of the Qinghai-Tibet Plateau; Tarim is a part of the Sino-Korea plate (other views hold that it is an independent plate); and the Junggar basin belongs to the Kazakhstan plate; the building of the Tianshan Mountains is due to the collision between the Tarim plate and Kazakhstan plate in Palaeozoic. However, some major problems still need clarification:

- What is the contact relationship between the mountains and the basins in the lithospheric cross section along the Xinjiang Geotransect? Is the Tarim plate underthrusting the West Kunlun Mountains in the south and Tianshan Mountains in the north?
- What are the dynamics for the uplift of the Tianshan Mountains during the Cenozoic? The molasse-type sediments (age: Q_1) over the front of the mountains indicate the recent building of the Tianshan Mountains in Quaternary. What is the relationship between the building of the Tianshan Mountains and the uplift of the Qinghai-Tibet plateau during the collision of the Indian and Eurasian plates?
- What is the lateral and vertical distribution of the geophysical structures of the crust and upper mantle along the transect? Can we trace back the evolution history of the continental deformation after the continent was formed, such as the intracontinental deformation,

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petrologic characters of the seismic Moho beneath the basin and the mysterious crustal root of the orogen, based on the geophysical imagery of the cross section?

Geophysical survey and preliminary results: The conducted geophysical surveys include wide-angle seismic reflection and deep refraction sounding, magnetotelluric sounding (MT), as well as gravimetric, magnetic and heat flow measurements (used in the Tarim basin only), and petroleum seismic reflection profile with the recording time being 6 seconds (crossing the Tarim basin only). In addition, near vertical deep seismic reflection profile, from the front of the West Kunlun Mountains to the southern Tarim basin, will be done late this year.

The Bouguer gravity anomaly map was compiled based on the 1: 2,500,000 Bouguer Gravity Map of the People's Republic of China by means of data resampling with the average point spacing 10 km. The mean square error of the anomaly is less than 3.0 $x/10^{-5}m/s^2$. The analysis of modern earthquake epicenters shows that the West Kunlun and Altun Mountains form the northwest boundary of intense seismisity in the Qinghai-Tibet Plateau. The accurate determination of focal depths is direct evidence for the transition between brittle and ductile deformation within the crust: 30-40 km for the West Kunlun and Tianshan and 20km for the Tarim basin. The imagery of gravity data processing shows that the West Kunlun terrane has thrust northward and the North Tianshan terrane southward over the Tarim basin since the Cenozoic. Deep seismic sounding indicates that there is a deep root under both the West Kunlun and Tianshan Mountains. Deep seismic sounding discovered south-dipping Moho under the Tarim basin which is underthrusting the West Kunlun Mountains and its subduction shape will be brought to light by deep seismic reflection profiles.

Golmud - Ejin Geotransect: the lithospheric structures and geodynamics in northern Tibet revealed*

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The Golmud-Ejin Geoscience Transect (GET) is located in northern Qinghai-Tibet plateau. It starts from the northern margin of the Kunlun mountains, then runs northward across the Qaidam Basin, the Har Lake, the Qilian mountains, the Hexi Corridor and the Beishan Mountains, and ends at Ejin near the Sino-Mongolian border, with total length about 900 km. The GET is connected with the Yadong - Golmud Geoscience Transect in the south. This Transect has shown that the Indian plate has underthrust northward beneath the Himalayas and the Tibet block, and the crust of plateau has got shortened and thickened (Wu and Gao, 1991; Gao and Wu, 1995). The lithospheric structures and geodynamics in northern Qinghai-Tibet plateau are revealed by the GET. The lithospheric structures and geodynamics were disputable, which are related to the compression northerly of the Indian plate and the interaction with the Eurasian plate. These must not be ignored for complete understanding of the mechanism of the uplift of the Qinghai-Tibet plateau.

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During 1992-1993, the multidisciplinary field surveys of geology, geochemistry and geophysics and comprehensive analysis of the data have been carried out in the project. In the geophysics, the wide-angle seismic reflection and deep refraction sounding, surveys of gravity, magnetic, heat flow and MT have been operated along the transect. On the other hand, a deep seismic reflection has been carried out from the north Qilian mountains to the Hexi Corridor.

Based on the preliminary results of the surveys in the transect and the comprehensive interpretation of the geological, geophysical and geochemical study, as the tomography of regional earthquakes and the image of remote sensing and the data of gravity and magnetic fields, five terranes have been identified in the corridor of the transect (from south to north, they are: the Qaidam Terrane, the Central-South Qilian terrane, the North Qilian terrane, the Southern Beishan terrane and the Northern Beishan terrane).

The analysis of the modern epicenters shows that the Altun mountains and the Qilian mountains are the north boundary of the intensive seismisity area in the Qinghai-Tibet plateau, which is consistent with the configuration of the plateau defined by the filtering imagery of the gravity field and the landscape of the plateau shown by the stereoscopic topographic image. The quick uplift of the Altun mountains and the Qilian mountains in Late Cenozoic is coincident with the time of the Himalayan orogeny, they are controlled by the same geodynamic process.

The seismic reflection profile shows that since Cenozoic the south Qilian fault zone has violently overthrusted southward on to the Qaidam Basin. The Cenozoic sediments, including the molasse of Early Quaternary, in the southern edge of the Hexi Corridor is much thicker than that in the northern edge. A large thrust fault has been discovered by deep seismic reflection profile in the Hexi Corridor to the north Qilian mountains. This discovery is of great importance for the geodynamic study in the northern part of Tibet. The significance of the discovery is that it shows that the Alxa landmass is underthrusting southward beneath the Qilian mountains like the MBT in Himalaya. This large thrust fault is named North Border Thrust (NBT).

Deep seismic sounding proves that the Moho under the Qilian mountains is deeper than the basins both in the north and south, and the analysis of tomography imagery of seismic body wave also shows that there is a deep root under the Qilian mountains. The unevenly distributed seismic velocity indicates the feature of segmenting in the Qilian mountains and the different types of deformation. In the Beishan area, a series of Early Mesozoic thrusts southward have been revealed and several reflection groups dipping northward discovered by seismic reflection profiles probably representing the old suture. It means that the Early Mesozoic thrusts southward were possibly controlled by the southward compression, and the effect is only limited in the upper part of the crust instead of the whole crust. Comprehensive comparison of the geophysical field (gravity and magnetic) filtered imagery and the remote sensing imagery has distinguished the surficial deformation and structural traces of the lithosphere of the transect domain. In the later, three particular areas of deformation can be divided into: the Qaidam, the Qilian and Beishan areas. The Beishan area is characterized by nearly east-west extension and north-south shortening deformation. The Qilian area shows the feature of complicated lozenge extending to the northwest. The basement of the western part of the Qaidam Basin tilts to the west. The Altun fault extends to the north in two ways, one of which, probably represents the main way, and runs along the NBT across the transect.

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Initiation and development of northwestern Lesser Himalayan foreland basin: an overview

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Excellent sections are available in northwestern Lesser Himalayan region of India and Pakistan to document the evolution of foreland basin that has taken place south of rising Himalayas. The present Indo-Gangetic basin is the southern most and youngest in a series of foreland basin development which include the Siwaliks and Eocene-Oligocene i.e. mainly Murree Group basins, which are the oldest, highly tectonically disrupted and most uplifted of all such basins.

The present paper attempts to understand initial stages of development of these foreland basins spanning the first 25 m.y. of this development. It is based on investigated sequences in Dharampur-Kumarhatti section, Dagshai type section and Subathu section in Shimla Himalayas and Kalakot, Sind-Khatuti sections in Jammu Himalayas.

The transition of a marine to continental basin is best studied in Dharampur, Dagshai and Kalakot sections. Transition is marked by a thick orthoquartzite band extending along the length of the basin delineating the transition. In most of the sections studied it is generally marine sequence below the orthoquartzite band but in Dharampur-Kumarhatti section, which makes an exception, some red beds are below this orthoquartzite band. It is generally believed, that a thick orthoquartzite layer may have been coeval with India -Asia collision and all sediments above represent initial stages of subsiding basin.

The initial stages of this subsiding basin are characterised by alteration of sandstone and shale usually red in colour to multiple palaeosol horizons with reworked nodular beds. They are poorly fossiliferous in nature except for some organic debris along with thin shale partings. Next stage of development in the foreland basin are Kasaulis which suggest a certain degree of stability and uplift of Murrees.

Metacarbonates from the Lesser Himalayas: Do they have potential for palaeomagnetic studies?

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Quantitative investigations for Tertiary block rotations around vertical and horizontal axes on both sides of the Main Central Thrust (MCT) require palaeomagnetic results from the metasediments of the Lesser Himalayas. However, medium grade metamorphism and related magnetic overprints limit the use of palaeomagnetism and therefore no data are available from the area close to the MCT. In low grade metamorphic carbonates the formation of pyrrhotite has been reported by Rochette (1987). Thermoremanences (TRM) or partial TRM (PTRM) carried by such pyrrhotite are obtained during earlier works in the low grade metamorphic carbonates from the Tethyan Himalayas (Appel et al., 1991; 1995). The stable secondary remanence directions obtained from the maximum unblocking temperature of 300-320 °C (pyrrhotite) are related to remanence acquisition below the transition of ductile to brittle deformation during exhumation and cooling (200-400 °C in carbonates Kirby, 1985; Carter & Tsenn, 1987). As cooling events can be dated, such secondary remanences would provide useful information on the tectonic evolution of the Himalayan belt, i.e. regional and local block rotations.

Based on this knowledge, the medium grade metacarbonates close to the MCT have been investigated for secondary thermoremanences carried by pyrrhotite. Totally, 21 sites with about 10 cores per site have been sampled in the Burhi Gandakhi, Darondi and Marsyandi valleys (Central Nepal) and 8 sites from the Alaknanda valley (Garwhal Himalayas, India).

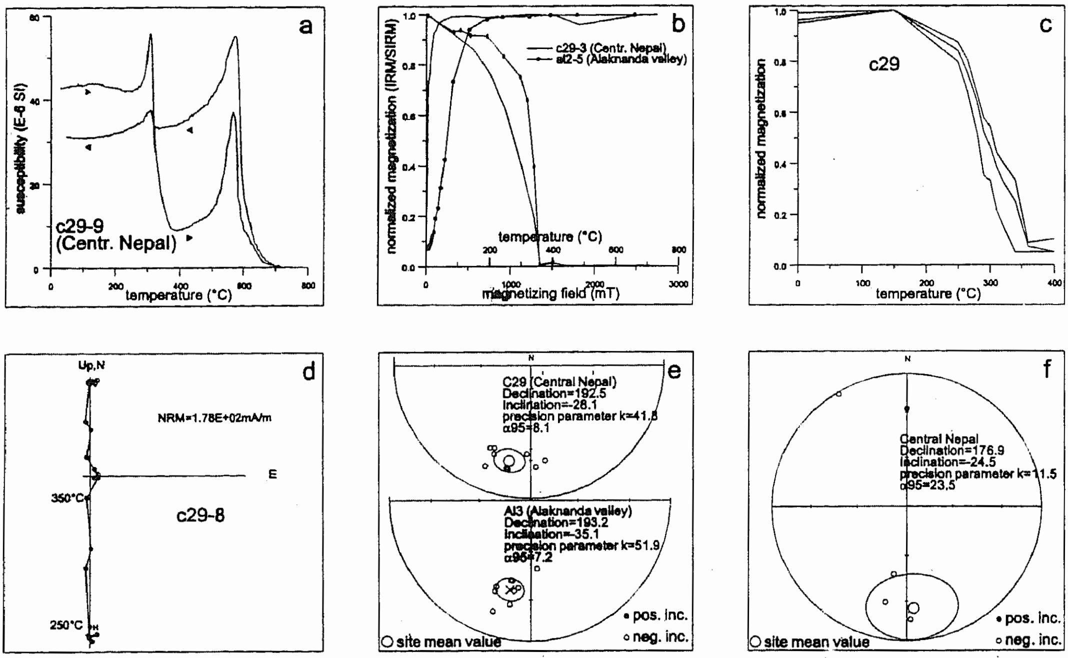

Fig. 1. (a) Low field susceptibility vs temperature; (b) IRM acquisition & thermal demagnet-isation of saturation IRM; (c) Thermal demagnetisation of NRM. (d) Orthogonal vector projection of thermal demagnetisation; (e) Equal area plot of single specimen directions (in situ); (f) Equal area plot of site mean directions of Central Nepal.

Some magnetite and hematite, evidence for pyrrhotite in medium grade metacarbonates is provided. A systematic distribution of pyrrhotite according to the grade of metamorphism or stratigraphic differences could not be observed and the content of pyrrhotite is varying strongly within sites. Ferrimagnetic pyrrhotite is clearly identified by a Hopkinson peak around 300 °C in thermomagnetic runs of low field susceptibility (Fig. 1a). Thermal demagnetisation curves of IRM (Fig. 1b) and NRM (Fig. 1c) also show the dominance of pyrrhotite and reveal narrow unblocking spectra between about 250-350 °C (Fig. 1c). Different coercivities for pyrrhotite are obtained from IRM acquisition (Fig. 1b). Saturation already at 200-300mT indicates relatively soft magnetic pyrrhotite for Central Nepal, whereas in the Alaknanda valley hard magnetic pyrrhotite (saturation>500mT) is observed. These coercivities are confirmed by alternating field demagnetisation. Nevertheless, thermal demagnetisation of NRM separates a stable characteristic remanence in many of the specimens. A single component behaviour is observed in most cases (Fig. 1d). Mainly, individual specimen directions show good grouping within sites (Fig. 1e). The site mean directions of both areas are significant with a precision parameter k>10 (Fig. 1f, Fig. 2), demonstrating that medium grade metamorphic carbonates from the Lesser Himalayas may indeed be useful for further palaeomagnetic studies.

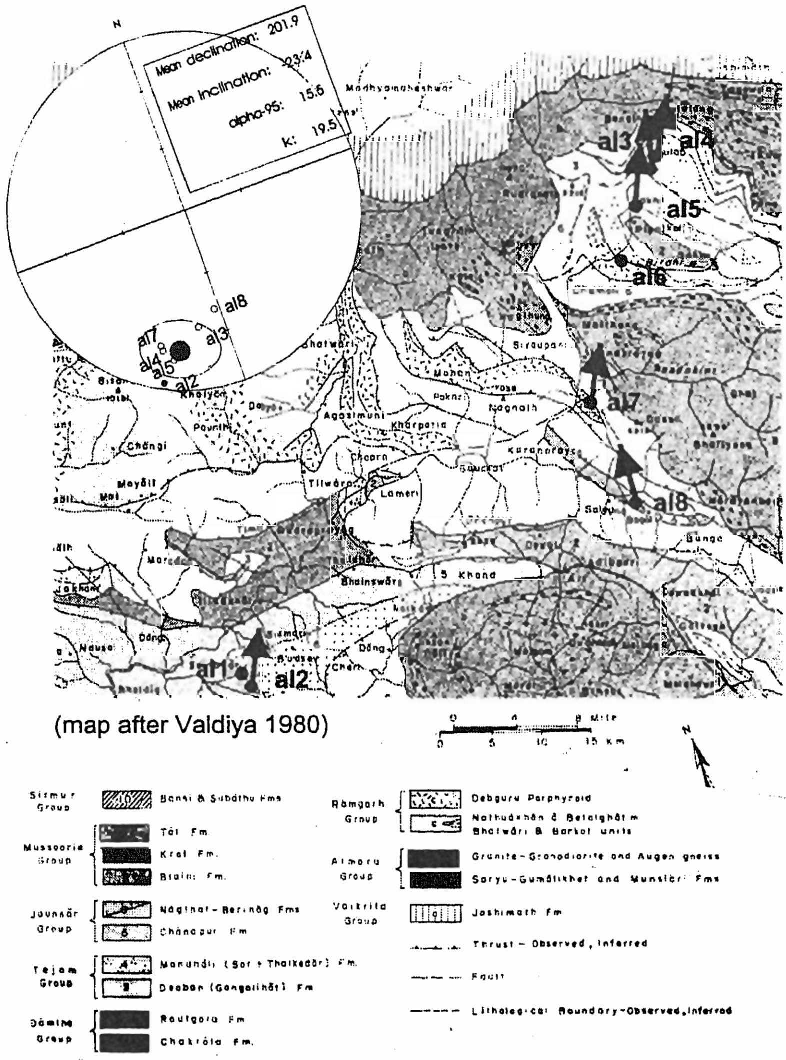

Fig. 2. Geological map of the Alaknanda valley with the in situ declination values of the remanence directions in respect to the ambient field. Equal area plot of the site mean directions (big point: mean direction).

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Magmatism and deformation within Nanga Parbat-Haramosh Massif, Pakistan Himalaya

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Background: A general association of young plutonism, deformation, and cooling within the Nanga Parbat-Haramosh Massif (NPHM), Pakistan Himalaya, is clearly recognized (e.g., Zeitler & Chamberlain, Tectonics, 1991). Previously reported leucogranite crystallization ages for NPHM are markedly younger from those reported elsewhere in the Himalaya. Undeformed leucogranite dikes within the massif give U-(Th)-Pb zircon and monazite ages of <2 to 7 Ma (Zeitler & Chamberlain, Tectonics, 1991; Schneider et al., EOS, 1997) with the youngest ages found near the summit regions. Leucogranite dikes occurring near or within major shear zones are typically emplaced into tension gashes that are at a high angle to the principal shear zone orientation and with fracture geometries that are suggestive of subvertical opening. Larger intramassif plutons include 1) Tato, U-Pb zircon rim ages of ~1 Ma (Zeitler et al., Geology, 1993), 2) Mazeno Pass, U-Th-Pb zircon and monazite ages of ~1.4 Ma and 3) Jutial, U-Th-Pb zircon and monazite ages ~10 Ma (Schneider et al., EOS, 1997). The Tato and Jutial plutons lie on the NPHM western margin and have intruded into the active Raikot-Liachar fault system; the Mazeno Pass pluton has intruded along the northwestern tip of the Rupal-Chhichi shear zone (RCSZ). This shear zone is comprised of a large belt of NW dipping, porphyroclastic granitic orthogneiss with a ubiquitous non-coaxial fabric that is consistent with accommodation of southeast vergence of southern NPHM (Edwards et al., 12th HKT, 1997a). Notably, the RCSZ is coincident with a rapid increase in Ar/Ar biotite cooling ages to the southeast (Schneider et al., EOS, 1997). Another significant break in biotite cooling ages occurs across a broad ~N-S trending zone in southwest NPHM. Argon biotite cooling ages on the western side of this zone are 20-30 Ma, whereas on the eastern side (towards the summit) cooling ages are 6 Ma and younger (Schneider et al., EOS, 1997). We present here new geochronologic data from leucogranites within NPHM, which, together with new field observations (Edwards et al., this vol) and previous data (summarized above), can provide significant new constraints on the spatial and temporal association between plutonism and deformation within NPHM.

New Data: Edwards et al. (this vol) report a large plutonic sequence (the Jalhari granite) that grades into granitic and porphyroclastic orthogneiss as a result of syn to post-deformational plutonism. This granite and gneiss belt is a ~5 km wide, ~30 km long N-S trending zone that marks the large cooling age discontinuity on the southwest corner of Nanga Parbat. Sense of

shear is east side up, consistent with upward and westward displacement of NPHM. Ion microprobe Th-Pb monazite analyses of a deformed, biotite-rich portion of the Jalhari granite (near the village of Diamroi) yielded ages between ~3 and 9 Ma. These ages fall along a line which increases with increasing Th/U ratios. Backscatter/SEM images of the analyzed monazite grains indicate some that have a non-uniform texture, notably lacking clear core-rim zoning patterns. This chaotic textural pattern is too fine to allow analysis of any single composition within a grain, despite the very small beam size (~15-20 microns) of the ion microprobe. However, a few texturally homogeneous grains were analyzed; these yielded the youngest of our obtained ages (~3-4 Ma). Near Garal, 13 km south of the village of Diamroi, we sampled an undeformed medium grained granite, which is adjacent to, and possibly part of, the same Jalhari granite. Ion microprobe analyses of monazite grains yielded Th-Pb ages of 12 Ma. Th/U ratios of these monazites fall along the same trend as those of the Diamroi (deformed) granite. Our interpretation of the Jalhari granite is as follows:
1) an initial pulse(s) intruded and crystallized as young as ~12 Ma, 2) ongoing synkinematic magmatism (as represented by the patchy monazite grain textures indicative of multi-stage growth history) resulted in further pulses that juxtaposed deformed and undeformed portions of the granite, and 3) final crystallization was around 3.5 Ma. This 3.5 Ma lower age limit is consistent with our cooling ages on the southwestern side of the massif, inboard and east of the Jalhari granite belt.

In southern Nanga Parbat, we sampled a small (tens of cm) little-deformed granite dike which discordantly cuts orthogneiss of the Rupal-Chhichi shear zone in northern Chhichi Gah. Like the Jalhari granite, this granite dike also yielded a scatter of Th-Pb monazite ages, in this case between 9 and 17 Ma; these ages also fall along an increasing line with increasing Th/U ratios. BSE/SEM images of the monazites show a similar appearance to the monazites of the Jalhari granite. Biotite cooling ages from the northern section of Chhichi Gah give ages of 9-10 Ma (Schneider, unpub data). As within SW NPHM, the cooling ages are concordant to the lower Th-Pb monazite age. We infer that most of the displacement along this ('outboard') portion of the RCSZ occurred prior to 9-10 Ma and, similar to the shear zone associated with the Jalhari granite, plutonism was focused within the shear zone.

Discussion: Our new results indicate a fundamental association between plutonism and the major NPHM shear zones. None of the numerous granites seen within NPMH are of large areal extent and we infer that there has not been a widespread melting event (c.f., High Himalaya leucogranites, e.g., Harrison et al., Geology, 1997) but numerous anatectic pulses over the last ~10 Ma (Butler et al., 1997). Magnetotelluric studies show that there is no significant partial melt zone directly beneath NPHM (Park & Mackie, GRL, 1997), consistent with anatexis that is restricted to small volumes and/or distinct episodes. The observed proximity of granites to shear zones suggests to us that these anatectic episodes may be related to deformation. We propose a conceptual model where crustal thickening and/or decompression melting promotes small amounts of melting and deformation enhanced melt extraction (e.g. Thompson & Connolly, Earth-Sci. Rev, 1995) allows melt migration to existing (or resulting) shear zones. This process may be strain rate sensitive, whereby local anatexic episodes are a result of higher strain rates. With deformation enhanced melt migration, sufficient increase in melt percentages are rapidly attained, initiating melt migration that likely focusses within the shear zone (e.g. Brown, Earth-Sci. Rev, 1994). These melt-filled shear zones are then sites of thermally weakened material that are the focus of further deformation, including when the material is cooling through the solidus.

This creates a positive feedback situation whereby the presence of melt enhances deformation, and within the existing weak (shear) zone periods of granite emplacement continually reoccur.

Thrust and normal faulting in the Everest - Lhotse massif, Khumbu Himalaya, Nepal

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Two large-scale north-dipping normal faults cut the Everest massif at the top of the High Himalayan slab in Nepal. The upper fault the Qomolangma Detachment follows the north side of Everest from above the "Yellow Band" at ca. 8500 m on the South Face down to the Rongbuk glacier, and places unmetamorphosed Ordovician mudstones and limestones above biotite-grade marbles, calc-silicates and greenschists (Everest series pelites). The lower normal fault - the Lhotse Detachment places middle greenschist grade pelites formed at temperatures below $\sim 450^0$C and calc-silicates above sillimanite-K-feldspar grade gneisses formed at temperatures above 650^0C, tourmaline + muscovite $\pm$ biotite $\pm$ garnet leucogranites with abundant sills and dykes.

The mid-greenschist grade Everest pelites, some 2000 m thick on the SW face of Everest form a northward tapering wedge bounded by normal faults below and above. A major thrust fault - the Khumbu Detachment bounds the base of a ~6-7 km thick sheet which consists of a series of flat-lying leucogranite sheets extending more than 25 km south of Everest. The leucogranite peaks of Ama Dablam, Kangteiga and Tamserku are all part of the same sheet, which, if originally continous, implies that granitic melts made up to 20% of the High Himalayan slab in this section.

Both the normal faults at the top of the slab and the Khumbu thrust at the base of the leucogranite sheets were mechanically and temporally linked, resulting in the southward extrusion of rocks formed at ~12-30 km depth within the High Himalayan slab.

Northwest-directed shortening at Nanga Parbat: An active tectonic regime regionally controlled by strain partitioning along the Himalayan arc and locally accelerated by topographic stress at the Indus river gorge

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A very active regime of northwest-directed shortening in the Nanga Parbat area is manifested by both earthquake and geologic data, including brittle faults in crystalline rock and structures in Quaternary sedimentary rocks of the Indus and Gilgit valleys. Northwest and northeast directed shortening at Nanga Parbat and along the Himalayan front a few hundred km to the south, respectively, are at a wide angle and are thought to reflect distinct elements in the collisional regime. Northwest shortening at Nanga Parbat is interpreted as internal deformation within the Himalayan overriding block. At the scale of the Asia-India continent collision, northwest-directed shortening at the northwestern terminus of the Himalayan arc is interpreted as the result of strain partitioning along the arc. Earthquake focal mechanisms show radial convergence across the arc. Radial convergence with an undeforming footwall block (India) requires arc-parallel extension in the hangingwall block (Tibet), which is indeed geologically and seismologically observed. This "intraplate" deformation in Tibet is driven by strain partitioning. Relative to the Himalayan arc, northwest convergence at the terminus of the back arc in Nanga Parbat is along strike and in the same direction as arc-parallel extension in Tibet, the main portion of the back arc, and may balance it out, at least in part. Thus, Nanga Parbat is interpreted to be structurally the western boundary of Tibet.

Many earthquakes in and near the Nanga Parbat massif were recorded by the ~60-station network we deployed on and around the massif during 1996 and from a more modest deployment in 1995. 130 single-event focal mechanisms were quality selected from the 340 accurate hypocenters located in the vicinity of the massif (100x100 km). The massif is particularly active on the northwestern flank, where topographic relief is the largest. The seismicity is very shallow, from above sea level, to a maximum depth of 6 km bsl where it is sharply cut off below the axis of the massif. Focal mechanisms suggest a subhorizontal detachment at this boundary. This detachment ramps up into a thrust fault toward the northwest aiming toward the mapped surface trace of the Lichar thrust. Transport on this structure is generally to the northwest. Footwall-block seismicity is limited to the western side of the NPA. Hangingwall-block antithetic thrusting is illuminated on the southeastern side of the massif and correlates with mapped structures. While we resolved some earthquakes on thrust faults, most of the observed seismicity is from a set of subparallel shallow normal faults striking west to southwest and dipping south to southeast. These faults accommodate extension approximately in the same direction as the transport on the underlying thrust fault. Seismogenic normal faulting is concentrated in the region with highest relief on the western limb of the antiform, between the Indus river and the Nanga Parbat ridge. This faulting can be interpreted as gravity-driven collapse of the eastern wall of the Indus gorge by book-shelf-like block rotation about horizontal-axes and also as flexural slip in the overturned northwestern limb of the Nanga Parbat anticline. The superposition of shallow horizontal extension above crustal shortening at Nanga Parbat may exemplify the effect of topographic stress in regions of convergence and mountain building.

The rapid uplift of the Nanga Parbat massif is associated with the northwest-verging Nanga Parbat antiform (NPA) and the southeast-dipping Lichar thrust fault which outcrops along the northwestern flank of the massif. The Lichar fault and the NPA are interpreted to be coupled active structures (a thrust fault and a fault-propagation fold) that accommodate much of the northwest shortening, but, generally, not all of it. Previous and ongoing work by others suggest a continuous belt of northwest shortening from the western Syntaxis to the Main Karakorum Thrust, for over 200km along strike of the NPA. Furthermore, preliminary results from a survey of brittle and Quaternary tectonic structures in the Indus and Gilgit valleys show west- to northwest-directed shortening in the Kohistan terrane, suggesting that this shortening is, generally, over a belt broader than the massif. Northwest shortening in Kohistan is coupled with two prominent Quaternary transcurrent fault zones, one along the Gilgit River valley, left-lateral and striking west-northwest, the other along the Indus River valley, right-lateral and striking west-southwest. These faults are interpreted to serve as accommodation structures separating broad belts of northwest shortening south of the Indus and north of the Gilgit rivers from a much narrower portion of the belt in between. Along the portion of the belt flanked by the Indus gorge and the outcroping Lichar thrust, shortening seems to be confined to the massif, within and east of the Indus gorge. This tectonic model is supported by the earthquake data which show a remarkable lack of seismicity west of the Indus river, across from the very active northwestern flank of the Nanga Parbat massif. This remarkable pattern of regional shortening is thought to stem from the effect of the Indus gorge on the tectonic regime. A very large stress is derived from the combined effect of the weight of the mountain and the lack of weight along the gorge. The tectonic regime responds to this superposed topographic stress by increasing the rate of slip on the Lichar thrust in an attempt to fill the gorge from below. This attempt is futile, given the effectiveness of the river to remove material and to maintain its grade. In this hypothesis, the northwest-directed shortening is taken up completely at the gorge, where the gorge is parallel to the massif. Effectively, therefore, the southwest trending portion of Indus river between the Astor and the Diamir confluences casts a stress shadow to the northwest and shunts the shortening. Topographically driven accelerated slip on the basal thrust along this portion of the gorge may also account for the height along the corresponding portion of the Nanga Parbat massif. Once established, the drainage pattern in active mountain building orogens may have a much greater effect on the tectonics than vice versa.

Litho and stream sediments survey for gold and base metals in areas around Timargara and Samarbagh, district Dir, northern Pakistan

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The area of study (about 900 sq. km.) is lying within the Kohistan arc terrane in the northern part of Pakistan. It is located immediately north of the Main Mantle Thrust (MMT) in Dir district. It has a complex geology and is mainly composed of amphibolites, metadiorites, metagabbro-norites, metagranodiorites, metagranites and metavolcanics with subordinate amount of hornblendites, ultramafites and tonalites. The area has already been investigated for preliminary geology, however, no detail geochemical investigation has been carried out for precious and base metals mineralization. This study is mainly based on rocks and stream sediments (both pan-concentrates and -80 mesh fine fraction) geochemical survey for gold and base metals in order to delineate areas likely to contain mineralization and be worthy of follow-up work.

The area has been divided into 56 drainage cells ranging from 2-50 km^2 with an average density of about one site per 15 km^2. From each cell a pan concentrate and -80 mesh fine fraction were collected for mineralogical and geochemical studies. The visible gold as piece (>0.5mm), speck (0.5-0.3mm) and color (<0.3mm) was identified in the pan concentrates of certain streams, mainly in the north eastern and north western portion of the study area. However, no nugget of gold has been noticed in the pan-concentrates. The specks and colors are generally angular to subangular, sometime irregular to rectangular in shape and bright yellow in color. The pan concentrates are dominantly composed of magnetite whereas zircon, quartz, pyroxene, garnet, hornblende, feldspar, tourmaline, chromite and rock fragments occur as minor constituents. The floats were also examined for alteration and other geological phenomen a at each site.

Samples of Rocks and stream sediments (both pan concentrates and fine fraction) have been analyzed for Au, Ag, Cu, Zn, Pb, Co, Ni, and Cr. The geochemical data have been studied and evaluated by considering various geostatistical methods. Geochemical maps have also been prepared on the basis of single and multi-eliments consideration in order to pin point areas of most interest. These studies show that pan-concentrates have higher concentration of base metals as compared to that of fine fraction and are, therefore, silicate-bound rather than sulfide-bound in stream sediments. The higher concentration of Cu, Pb, Zn, Ni, Cr, Co and Ag could be related to the bed rock rather than to specific mineralization in the area. The anomalous gold, however, could not be directly related to the bed rock but it could possibly be related to the existence of gold-bearing mineralization, most probably in the form of quartz veins, in the north and north-eastern part of Samarbagh. Further detail geochemical survey is, therefore, recommended for follow-up in the region.

Evidence of Palaeo-proterozoic orogeny (deformation, metamorphism and magmatism) from Satluj valley, NW Himalaya

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The Wangtu Gneissic Complex (WGC) with profuse intrusion of Palaeoproterozoic granites and pegmatities exposed in the domal upwarp in the deeply dissected valley of the Satluj river in the Himachal Pradesh (India) represents the para-autochthonous occurrence of the oldest crystalline basement underlying the NW Himalaya. The WGC is dominantly a gneissic terrain (30 sq km) comprising of orthogneisses (2070±5 Ma) occurring as layered parallel bands with sillimanite-kyanite schists, quartzites, calc-silcates and orthoamphibolites. The involvement of sillimanite and kyanite in the tight isoclinal folding along with other micaceous minerals suggest peak metamorphism to be pre- to syn-tectonic in nature. Further, the presence of sillimanite-kyanite schist xenoliths in the gneisses and the involvement of the metamorphic minerals (kyanite, sillimanite) of the xenoliths and the feldspar phenocrysts of the granitic rocks in the deformation resulting in orthogneisses suggest the early phase granitic melt emplacement to be syntectonic to the deformation and peak metamorphism. Various stages of early deformation (D1) which accompanied the Palaeoproterozoic metamorphism and syntectonic magmatism have been observed in metasediments and orthogneisses of the WGC in an area about 1 sq km, presently exposed in the core of the Wangtu Dome. Somehow, this part of the Wangtu Dome escaped the effects of Tertiary Himalayan deformation, commonly present in the peripheral part of the dome, and remained as tectonically resistant enclave.

Mineralogically and geochemically the orthogneisses are similar to undeformed granites which intrude them suggesting similarity of the source rocks. The granitic rocks of the WGC are meta-aluminous to peraluminous in composition. The fine grained varieties are higher in SiO_2, Na_2O, K_2O, and lower in TiO_2, Fe_2O_3(T), MgO, and CaO than the coarse grained varieties. The fine grained granitic rocks of the WGC show more fractionated LREE (La_N/Sm_N = 3.4 -13.6) and HREE (GdN/LuN =1.8-4.0) ratios, similar to the REE patterns of the Proterozoic granitic rocks and suggest derivation of the magma from deeper crustal level. It is further supported by its low Sr_i ratio (0.7046). Both the fine and the coarse grained granitic rocks have phenocrysts of orthoclase with triclinicity value of 0.25-0.26, the size and the content of which vary considerably.

The presence of undisturbed xenoliths of orthogneisses and other components of the WGC in the younger more or less unfoliated granite-pegmatite phase (1870±10 Ma) supports the passive or permitted emplacement of the late kinematic granitic melt, marking the terminal phase of Palaeoproterozoic deformation. This is possible only if the rate of the net extension exceeds that of the compressional strain rate produced by the buoyancy of the emplacing magma. Such a situation in the WGC, which had been undergoing compression-related deformation and metamorphism, cannot be achieved unless the area is rapidly uplifted, causing fast removal of its cover rocks and/or inducing the decompression/extension. The widespread occurrence of such Palaeoproterozoic granitic rocks along the central crystalline axis of the Himalaya from Besham (Lower Swat) and Nangaparbat-Haramosh in the NW Himalaya to Bombdila in the NE Himalaya suggest this granitic magmatism to be a regional phenomenon.

All the evidence from the WGC in the Lesser Himalaya supports an orogeny-related deformation, metamorphism and granite magmatism during Palaeoproterozoic, culminating in extension induced passive emplacement of granites, aplites and pegmatites and rapid erosion of the cover rocks. Similar tectono-magmatic scenario has been recognised for the Higher Himalayan Crystallines (HHC), 20 km upstream in the Satluj Valley, by the author and also in the HHC of the Nepal Himalaya by others during Oligo-Miocene, marking the culmination of the Himalayan Orogeny-related deformation, metamorphism and decompression induced crustal anatectic (leucogranite) melt generation and emplacement.

Lake basins evolution recorded from lacustrine deposits on Tibetan plateau

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Uplift of the Tibetan plateau in the late Cenozoic has been responsible for the appearance and intensification of the Asian monsoon system which had been obviously changing the environment status of East Asia, even the global climate. At the same time, it had been strongly remodelling its own landscap of the Tibetan plateau. But arguement about the time and amplitude of uplift is still unsolved. However, lake basins evolution and geomorphological development on the plateau can provide evidences for the tectonic movement.

In the Gyirong basin, on the north slope of the middle Himalaya, there is a 300m thick exposure composed of lacustrine and fluvial facies deposited from Late Miocene to Early Pleistocene. Its magnetic polarity shows a magnetic sequence with a chronology from more than 7Ma B.P. to 1.66Ma B.P. But in the basin of Kunlun mountain pass, north part of the Tibetan plateau, there is a 670m thick exposure composed of lacustrine and fluvial deposits which is uplifted to the top of main Kunlun ridge.

Age of the exposure's bottom is about 3.4Ma B.P. and its top is about 0.7 Ma B.P. In the Zoige Basin, northeastern part of the Tibetan plateau, there are several hundred meters Quaternary deposits. A 310m deep lacustrine core has been obtained in 1993. According to the sedimentary stratigraphy and synthetical analyses of multiple environmental proxies, the palaeoclimatic and palaeoenvironmental changes over the past 920ka B.P. have been reconstructed. The age of the basin may be estimated at about 1.2 Ma B.P. In the Tianshuihai basin, northwestern Tibetan plateau , over 200m thick of Quaternary deposits had been detected using geophysical methods. A 57m deep lacustrine core has been drilled at the elevation of 4840m a.s.l. in 1995. The age of the core bottom is ca. 240 ka B.P. (based on U-series datings in the Geochemistry Lab. of University of Southern California) and the top, ca.17 ka B.P. (^{14}C datings). These data have provided valuable palaeoclimate and palaeoenvironment information about the last interglacial/glacial cycle and the penultimate glacial period.

These results suggest that the evolution of the lake basins in the southern Tibetan plateau is quite different from that in the northern plateau. The formation of the Gyirong basin can be directly linked with the Himalaya uplift. Otherwise, fault and depression of the basins in the northern Tibetan plateau was closely related to strong and rapid rising of the whole plateau in the late Pliocene and Quaternary. So, the conception of the uplift of Himalayas is qualitatively different to that of the rising of whole Tibetan plateau.

Mesozoic tectonic evolution of Neo Tethys: petrologic evidence from Muslim Bagh area, Balochistan, Pakistan

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The northwestern tectonic margin of Indian continent in Pakistan is marked by the Waziristan-Muslim Bagh-Bela ophiolite suture zone. In the regional geotectonic context the ophiolites included in this suture belong to Late Cretaceous Tethyan ophiolite belt. The Muslim Bagh ophiolite complex is harzburgite type ophiolite which occupies an area of about 800 km^2 and is represented by 17.5 km thick slab of oceanic lithosphere, representing a complete and continuous sequence from ultramafic tectonite to sheeted dyke complex. This ophiolite complex is considered to have formed during 82-81 [1] and tectonically emplaced onto the northwestern margin of Indian plate during 71-65 Ma.[2].

The microprobe data on orthopyroxene and olivine from ultramafic tectonite hold higher (91-94) Mg # (Mg/Mg+Fe^{2+}) and higher (0.37-0.47 wt.%) NiO contents which suggests their residual upper mantle origin. The chromian spinel in dunite and harzburgite generally has higher Cr # (>0.56) (Cr/Cr+Al) relative to abyssal peridotites. The clinopyroxenes from wehrlite and pyroxenite from ultramafic cumulates have higher (82-93) Mg #. These features are consistent with a higher degree of partial melting (30-45 %) of a depleted mantle source and high pressure crystal fractionation (>10 kbar) in the magma chamber.

Similarly bulk chemistry of gabbro from mafic cumulates and metadolerites from sheeted dyke complex belong to low-K quartz tholeiite series. In trace elements chemistry they are enriched in LILE and depleted in HFSE relative to N-MORB and their average Nb/Y, Zr/Nb, K/Rb, Ba/Zr, La/Sm, La/Sm, La/Ce and La/Nd ratios are more consistent with back arc basin basalt relative to N-MORB or island arc basalt (IAB). The LILE enriched N-MORB normalized patterns and moderately LREE enriched chondrite normalized REE patterns are also consistent with the back-arc basin basalts. The mélange zone beneath the Muslim Bagh ophiolite complex is named as Bagh complex. The basaltic-andesitic volcanic rocks occur in five different horizons of Bagh complex. The intra-plate alkaline volcanic rocks are found in three localities. The Middle Triassic volcanic conglomerate occurs within the intercalated shale, micritic limestone and chert sequence, whereas olistoliths of Late Cretaceous (81 Ma) basaltic pillow lavas and hyaloclastite occur in the tectonic slivers of Bagh complex in north as well as south of the Muslim Bagh ophiolite complex. The tholeiitic basaltic-andesitic pillow lavas occur in two localities, in the Bagh complex. The major and trace element chemistry suggests MORB type geochemical signatures for the northern pillow lavas [1], whereas southern pillow lavas (78 Ma) and associated cumulate gabbros exhibit island arc like geochemical signatures [3].

It is suggested that middle Triassic intra-plate alkaline volcanics may represent oceanic islands formed by hotspot activity close to the site of the initial rifting of the Neo Tethys ocean basin. This rifting was further evolved into the mid-oceanic ridge where MORB type volcanics were subsequently erupted during Late Jurassic to Late Cretaceous. During Middle to Late Cretaceous two north dipping intra-oceanic convergence zones with associated arcs were developed within the Neo Tethys, which got fore-arc and back-arc separations. The northern (long-lived) convergence zone is named as Zagros-Chagai-Kohistan-Ladakh convergence zone and southen (short-lived) is named as Semale-Bela-Muslim Bagh-Waziristan convergence zone. The Muslim Bagh ophiolite complex represent the fragment of oceanic lithosphere which was developed during Late Cretaceous (81-78 Ma) in the back-arc basin of the latter convergence zone. The Late Cretaceous (81 Ma) intra-plate alkaline volcanics may represent the mantle plume activity of Reunion hotspot, and were erupted during the passage of Neo-Tethys ocean floor prior to the passage of Indian plate over it [4].

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Petrogenesis of non-foliated leucogranites from Muslimbagh ophiolite complex, Balochistan, Pakistan

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The Muslim Bagh ophiolite complex is one of the best exposed ophiolite in Pakistan representing a complete and continuous sequence from ultramafic tectonite to sheeted dyke complex. Small bodies of leucogranites occur in the middle part of the sheeted dyke complex.

Two phases of leucogranites are identified, the earlier one is foliated and occurs as pockets and large xenoliths within the metadolerites (amphibolite) and the latter one is non-foliated and occurs as dykes and small lenticular bodies within the same rock.

The non-foliated leucogranites are granodioritc-granitic (68.21-80.48 wt.% SiO_2) in composition and sodic and calc-alkaline in nature. They are medium to coarse grained and sub-poiklitic in texture. The main minerals identified include plagioclase (An_{8-38}), quartz, hornblende and biotite. Apatite and rutile occur as accessory minerals and hematite and minor magnetite found as opaques. The plagioclase is slightly dusted with clay minerals and sericite, whereas hornblende and biotite are partially replaced by chlorite.

In major elements they are depleted in TiO_2 (0.11-0.41 wt.%), MgO (0.26-1.77 wt.%) and K_2O (0.17-0.33 wt.%) and enriched in Na_2O (3.55-3.79 wt.%). In trace elements they are enriched in Rb (8-13 ppm), Sr (156-161 ppm) and Ba (95-157 ppm) and depleted in Zr (50-126 ppm), Nb (0.6-2.7ppm) and Y (16-47 ppm) as compared to mid-oceanic ridge type granites. In primordial mantle-normalized trace element diagrams they exhibit enrichment in LILE relative to HFSE, show positive spikes on K, Ba and Sr with negative Nb anomalies. In various tectonomagmatic discrimination diagrams they either plot within the field of volcanic arc granites or overlapping fields of volcanic arc granites and mid-oceanic ridge type granites. On the basis of these studies it is suggested that these leucogranites were fractionated from a parent basaltic magma which was generated in a sub-oceanic mantle source and modified by LILE enriched subduction related fluids. Such tectonomagmatic environments are usually produced in back-arc basins or suprasubduction zones. These studies strongly support the similar conclusion reached by earlier petrochemical studies of mafic and ultramafic rocks from Muslim Bagh ophiolite complex [1] and indipendent geochemical sudies on analogous rocks of Bela ophiolite complex [2].

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Multichronometry of Tso Morari eclogites: Ordovician plutonism, Tertiary eclogitization and inheritance

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The occurence of eclogites in the Tso Morari unit (East Ladakh) has been attributed to the subduction of Indian continental margin [1]. Some of these rocks were retrogressed in amphibolite facies, while others apparently totally escaped eclogitization. As dating eclogitic rocks exposes numerous difficulties, we applied a variety of geochronological methods in order to obtain a consistency check.

Sm/Nd internal isochrons were obtained on the undeformed Polokonkala granite (Ch216e), on a metagreywacke of intermediate metamorphic grade (Ch 223d) and on an eclogitized metapelite (Chl57a) (20±2kbar, 550±50°C). Two Ap-Grt-WR isochrons on the former two samples show a low MSWD = 0.5, meaning that Grt (± inclusions) is in isotopic equilibrium with WR and Ap. Both whole rocks give very high model ages (t_{DM} > 2 Ga) implying recycling of cratonic material. The granite has an Ordovician age of 458±14 Ma; it is unaffected by Himalayan overprint, while the metagreywacke was reset probably in the Tertiary (17±56 Ma). The Ordovician age for the undeformed Polokongkala granite is consistent with the 487±25 Ma Rb/Sr isochrone age [2] on the same granite, and confirms the relationship between the Polokonkala granite and the Ordovician orthogneiss recognized all over the Rupshu and Nyimaling area [3]. The occurrence of these Ordovician granites, typical of the Indian continental margin [4], confirms the stratigraphical evidences of Colchen, [5] which related the Tso Morari unit to the Indian subcontinent. For Chl57a we obtained a two-point Grt-WR age of 53 ± 8 Ma, which can be explained by three possibilities. (i) The "age" is too old, as it suffers from Nd inheritance; as this rock also has a tDM > 2 Ga, a small modal percentage of old relics would have a large influence. (ii) The "age" is a true age, and it dates the eclogitization and the early subduction of the Indian margin at the Lower Eocene. (iii) The "age" is too young, as it is possible that the Sm/Nd system did not achieve initial isotopic equilibrium in eclogite-facies metamorphism [6]. Whatever the uncertainty, this result confirms the Himalayan origin of the Tso Morari eclogites and this Lower Eocene age is consistent with the paleomagnetic data [7] and the stratigraphic observations [8] which suggested that the onset of the Indian continental subduction started between 57 and 53 Ma (Paleocene to Ypresien). Note that an age of 44±3 Ma was obtained for the Kaghan eclogites [9]; [10].

Rb/Sr internal isochrons were obtained on the metagreywacke, CH 223d, and the metapelite, CH 157a. For the latter, a two-point MS-WR line gives a 93±4 Ma apparent bulk age; for CH 223d, Ms -Ap -WR define an isochron with MSWD=0.02 and t=45±4 Ma. These contradictory results on arguably contemporaneous metamorphic rocks suggest again that isotopic inheritance plays a substantial role in the Tso Morari eclogites. We can compare the present results with those by Linner [11], who reported a 26.6±0.5 Ma two-point MS-WR line on eclogite and two MS-WR ages around 50 Ma on a mylonitic gneiss.

$^{10}Ar/^{39}$-Ar data from three HP-LT white micas (metapelite CH 157a and two metabasalts, CH 165d and CH 266a) all have Cretaceous apparent ages but show clear evidence of mixed generations. The $^{40}Ar/^{39}Ar$ "age" is too old, as the Indian crust that was to become an eclogite, still was south of the Equator in mid-Cretaceous. The coincidence of the Rb/Sr and $^{40}Ar/^{39}Ar$ ages for CH 157a strongly argues that Ar and Sr are partly inherited; this also implies that the general use of "excess Ar" to explain the old Ar ages of HP micas is unjustified.

Discussion: Our data apparently show a large heterogeneity. However, the pattern of the samples so far analysed can be explained by a comparatively simple interpretation. The Indian protolith (Ordovician orthogneisses with a Proterozoic prehistory; Upper Paleozoic sediments of older provenance) underwent very extensive, but not complete, isotopic equilibration during Early Tertiary eclogitization. The degree of isotopic inheritance varies for the different isotopic chronometers (e.g. CH 157a). Note that inheritance is not controlled by a "closure temperature" (which would be higher for Grt than for Ms) but rather by the extent of mineral neoformation.

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Basin evolution and Himalayan uplift during Paleogene: Evidence based on sedimentary architecture from the outer northwestern Himalaya, India

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The Paleogene sequences demonstrate four types of depositional patterns initiating with the shallow marine argillaceous sediments followed by tidal flat carbonates and estuarine siliciclastic facies. A major transgression during Late Paleocene (60 Ma) originated shallow marine strata on a narrow shelf. The Subathu Formation in its lower part containing sandy-shale and clay-shale with subordinate amount of conglomeratic and argillaceous limestones deposited at an accumulation rate of 1.56 cm per thousand years during Thanetian-Ypresian, The upper 50 m of impure limestone and mud-shale rhythmite deposited at a rate of 1 cm per thousand years during Lutetian in the Jammu foothills, India, assuming 40% compaction in the sediments after deposition.

The record of definite Oligocene fauna [1] and Oligocenc-Early Miocene equivalent palaeomagnetic dates [2] suggest for no major hiatus at the boundary between the Subathu Formation and the Murree Group. The basal Murree red beds showing bidirectional palaeocurrents and tidal bundles are rich in sandstones associated with laminated mudstones, siltstones and pedogenic calcrete bands. Mud-pebble intraformational conglomerates at some levels below the sandstone indicate a short break in the sedimentation. The sand-mud and silt-mud alternations in the middle part are followed by sand dominated fining upward cycles in the upper part of the Murree Group. Based on 17% maximum compaction [3] during burial, sedimentation rate estimates come around 9.10 cm per thousand years during the deposition of

Murree rocks. The erosion of earlier deposited sediments and intraformational breaks might be responsible for a low value of sedimentation rate. The low sedimentation rate may also be due to low altitude source terrain considering the climate as warm with limited precipitation through the occurrence of pedogenic features in the lower part and warm and humid [4] in the upper part.

The lithic sandstones represent a recycled orogenic provenance containing the rock fragments of phyllite, quartzite, volcanic rocks, chert, siltstone and mudstone. The probable sources have been Lesser Himalayan rocks exposed in the north. The siltstone and mudstone clasts, typically of the Murree Group, indicate recycling of the earlier deposited sediments and shifting of the depositional sites towards south in a fold-thrust belt. The cyclic sequences of the Subathu Formation developed in a subsidence oriented peripheral foreland basin and the rocks of the Murree Group formed in the basin conçurrent with uplift in the source terrain.

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Geochemistry and field relationship of collision related Conozoic Tos Leucogranite of Parvati valley, Himachal Pradesh, NW-Himalaya

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Collision of Indian plate with Eurasian plate has caused crustal-scale thickening, remobilisation and thrusting of the Proterozoic basement of the Indian plate and its cover into an extensive deformed and polymetamorphosed High Himalayan Crystallines (HHC) belt [1-3]. The collision tectonics are followed by intracontinental crustal shortening and stacking along the Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT) [4,5].

Leucogranites, often a distinctive minor component of many metamorphic terranes, are of great interest to geologists working in mountain belts. The mechanism of leucogranite petrogenesis can provide important information about tectonic and metamorphic processes occurring during orogeny [6]. Emplacement of specific leucogranites can provide key stratigraphic information about the timing, rate and magnitude of these processes [7].

The upper structural levels of the HHC show extensive migmatisation and are intruded by Late Cenozoic leucogranites. These are very well exposed as kilometre-sized plutons near the upper boundary of the HHC with low-grade metasediments of the Tethyan Sedimentary Zone. This interface appears to be a major structural break of Miocene age [7]. These Late Cenozoic high Himalayan leucogranites are of special interest for the Himalayan evolution as these are one of the rare magmatic products of the Himalayan Collision Zone and indicative of crustal melting.

The traverse along the Tos Nala and main Parvati valley reveal a good cross-section of rocks belonging to Lesser Himalayan Proterozoic Sedimentary Zone and Higher Himalayan Metamorphic Belt. The Lesser Himalayan Proterozoic foreland is exposed within the NW-trending approximately 100 km long linear Kulu-Rampur Window. The window contains extensive 2509 ± 94 Ma old Rampur Volcanics [Sm-Nd whole-rock age - 8, interstratified with the carbonaceous phyllite and Manikaran Quartzite, which is intruded by the 1840 ± 70 Ma old Bandal granitoid [Rb-Sr whole rock age - 9-11]. The Higher Himalayan Metamorphic Belt is exposed on the hanging wall of the folded MCT and its splays [12] and is known as the HHC. The HHC predominantly incorporates the pelitic and psammitic sequences. The base of the pile is characterised by the chloritised garnetiferous schist, which shows mainly retrogressed metamorphism. However, at higher structural level, the rocks are of higher metamorphic grade, which goes upto kyanite-staurolite grade at the base of the biotite granite.

The MCT is exposed near Manikaran and the trend of the MCT is parallel to the main foliation which strikes at about N 140° and dipping at 45° towards northeast. Towards higher structural level the strike remains almost the same with decreasing dip. The contact between the metamorphics and the biotite granite is exposed near Gwacha and Tos village and is parallel to the main foliation of the metamorphics striking N 115° with dip of 20° towards northeast. The contact between the metamorphics and the biotite granite appears to be tectonised because the granite rocks show development of foliation near the contact, whereas they are massive towards centre. The leucogranite appears to have intrusive relationship with biotite granite.

The development of S- & C- surface is also noteworthy within the metamorphics. The average surface is striking at N 185° with dip of 40° towards east and average C-surface is N 180°/48°/eastward. Near the MCT the angle between S- & C- surface is less (about 10°), whereas at higher structural level it increases and goes upto 40°. Again the angle between S- & C- surface decreases within the biotite granite. This also indicates that the contact between biotite granite and metamorphics is tectonised.

Major and trace elemental analysis of 14 samples of biotite granite and leucogranite was carried out using energy dispersive XRF technique. All the samples are peraluminous in character, having Al_2O_3/Na_2O+K_2O+CaO ratio > 1.1. When the nonnative calculations are plotted onto the quartz-orthoclase-plagioclase plot of Streikeisen [13], they fall within Granite field except one sample. For the major elements, although there is very narrow range of variations in composition, correlations between some of the major elements do exist. In particular, if SiO_2 is used as a differentiation index, there is positive correlation with Na_2O + K_2O and an inverse correlation with FeO (Total), MgO and TiO_2, whereas other major oxides do not have any correlation with SiO_2. Zr, Ba and Cr indicate negative correlation with SiO_2,. There is positive correlation in CaO, Y, Sr and TiO_2 with Zr, as differentiation index. On Rb Vs. (Y + Nb) basis, most rocks classify as syn-collisional granite but some as volcanic arc granite [14].

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A regional tectonic framework of Karakoram terrane : Interpretation from recent stratigraphic, geochemical and geochronological data

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The Karakoram mountain range occupying a significant tectonic unit in the north of Himalayan syntaxial belt and Indus suture subduction zone of Indian and Asian plates. The Karakoram block extends 700 km with a maximum width of 150 km from Afganistan-Pakistan border eastward to western Tibet along the NW frontier of Pakistan and India with the Chinese province Xinxiang. In the Indian territory the eastern Karakoram lies to the north of Shyok suture zone and two distinct geological terranes are conspicuous of the eastern Karakoram. A southern terrane is dominated by granitoids and metamorphic rocks whereas northern sedimentary terrane mainly constitute Tethyan segment of Karakoram. The Karakoram batholith is a major magmatic body of granitic rocks intruding metamorphic and sedimentary formations of Palaeozoic to Mesozoic age, occupying the elevated terrane in the north of Nubra-Shyok valley. The rock types are mainly granites, granodiorites and tonalites. Geochemically, the granites of Karakoram batholith are classified as granodiorite, quartz-monzonite and this complex body represent both I and S-type granitoid. Recently dated samples of Karakoram leucocratic syn-collisional S-type granites gives a Rb/Sr age of 83 $\pm$ 9 Ma. It is inferred that the oldest 1-type Jurassic-Early Cretaceous granites in the eastern Karakoram region represent pre-collisional subduction related tectonic setting, whereas the Late Cretaceous S-type granites have a syn-collisional tectonic setting. This magmatic episode has been followed by the post-collisional-Miocene granite. Thus the oldest I-type Jurassic- Early Cretaceous granites may have a precollisional subduction related tectonic setting followed by the syn-and post-collisional S-

type Late Cretaceous and Miocene granites. The synthesis of the data confirms that the accretionary and collision processes in the Karakoram region had been initiated prior to the Indo-Eurasian collision. This result is pointer to suggest that the Shyok Suture Zone was active subduction related feature earlier to the activities along the Indus suture zone. The successive magmatic activities have acted as stitching plutons leading to the accretion to Karakoram terrane with the Asian plate. Further north of Karakoram batholith, the sediments of Permo-Carboniferous and Mesozoic Tethyan sequences were deposited during Upper Palaeozoic and Mesozoic. This sequence has yielded plant fossils, whereas the overlying marine beds include gastropods and corals ranging in age from Triassic to Cretaceous.

In the Nubra- Shyok valley the rocks of the Shyok suture zone are represented by distinct set of highly compressed tectonic slices. These slices have been transcurrently displaced by active Karakorarn fault in the region. The complex interplay of rocks in the Shyok suture zone begin with the Saltoro Flysch. Three different types of sedimentary sequences have been encountered in the Saltoro Flysch. The lower sequence begins with highly metamorphosed calcareous succession. For the first time we have recorded the occurrence of bryozoans fossils of Late Jurassic age from a thinly bedded recrystallised limestone horizon of the calcareous succession. This sequence is succeeded by black shales and slates indicating euxinic deeper marine reducing enviromnent. Further north in the Shyok valley, this sequence is succeeded by volcanogenic turbidites intruded by basic dykes. The Saltoro- Molasse is an apron like sedimentary succession unconformably lying over Saltoro Flysch. The Shyok ophiolitic mélange is a very compressed altered zone having basic volcanics, recrystallised limestone, purple-green-black shales and phyllites, polymitic meta-conglomerate and serpentinites.

Recently aquired geochemical data and the rare earth element plotting suggest the chondrite normolized rare earth element (REE) distribution are enriched in LREE and relatively unfractionated HREE with marked negative Eu anomaly, suggesting a volcanic arc granite setting. Similarly, the mantle-normalised diagram shows a marked Nb depletion which inforce the presence of typical subduction related calc-alkaline magmatism in the region. The plots are also indicative to the e-type MORB and OIB related transitional seamounts signatures in the Shyok volcanic zone. Keeping in mind the recent data, a review to the interpretation of Karakoram block has become imperative.

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Geological relationship between the Chilas complex and the Kamila amphibolite belt, northern Pakistan: Implications for the tectonic development of the Kohistan island arc

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The Kohistan terrain in the western Himalaya, northern Pakistan, is regarded as a tilted island arc type crust sandwiched between the Asian and Indian continental crusts [1]. The Kohistan island arc is bounded along the south by Main Mantle Thrust (MMT), and along the north by Northern Suture (or Main Karakoram Thrust, MKT), which can be divided into some geological units.

The Chilas complex is a huge basic intrusion about 50km wide and elongates 300km almost parallel to the MMT and the MKT, which is composed mainly of gabbronorite and several masses of ultramafic-mafic anorthosite association [2]. It has been interpreted as the magma chamber root zone of the Kohistan island arc [3]. On the other hand, the Kamila amphibolite belt is composed of highly deformed amphibolite-facies meta-plutonic and meta-volcanic rocks with calc-alkaline geochemistry [4] situated to the south of the Chilas complex.

Geological relationship between the Chilas complex and the Kamila amphibolite belt is not yet confirmed, although they are main constituents of lower crust in the Kohistan island arc. Some people consider that the Chilas complex and the Kamila amphibolite were originally the same, but the Chilas complex was metamorphosed to granulite facies and the Kamila amphibolite belt to amphibolite facies [5,6]. On the other hand, it is considered that the Chilas complex and the Jijal complex are lower crusts of different island arcs and they are separated by the Kamila shear zone (Kamila amphibolite belt) [6]. Accordingly, northern part of the Kamila amphibolite belt is hydrated and recrystallized product from the gabbronorite of the Chilas complex.

The geological relationship between the Chilas complex and the Kamila amphibolite belt is fundamentally important to consider the geologic development of the Kohistan island arc, because they are main constituents of lower crust in the Kohistan island arc. In this paper, we present detailed geological and geochemical data around the boundary between the Chilas complex and the Kamila amphibolite belt and discuss on the relationship between them.

In the Swat valley, the Chilas complex is bounded on the south by the Kamila amphibolite belt. Around the boundary several xenoblocks of the Kamila amphibolite are observed in gabbronorite of the Chilas complex and gabbronorite dikes of the Chilas complex occur in the Kamila amphibolite. At the lower reaches of Miandam river which is a small branch of Swat river coming from the east, a xenoblock (about 20x5m) of the Kamila amphibolite occurs in gabbronorite of the Chilas complex. The amphibolite and gabbronorite are at just contact to each other and a foliation develops in both the amphibolite and gabbronorite which is oblique to the lithologic boundary. The amphibolite is composed mainly of hornblende and plagioclase, in which original plutonic texture still persists. Under the microscope, hornblende and biotite are aggregates of fine crystals exhibiting a decussate texture, which indicates thermal effect. On the other hand, the gabbronorite is composed mainly of plagioclase, clinopyroxene and orthopyroxene with minor hornblende and biotite, which is slightly deformed, but there is no evidence of thermal effect. Therefore, it is evident that the Kamila amphibolite was intruded by gabbronorite of the Chilas complex and suffered contact metamorphism and after that a foliation was formed in both the gabbronorite and amphibolite by ductile deformation, which may be related to the collision of Kohistan to the Asian continent.

The eastern part of the Chilas complex is bounded on the north by amphibolite. At the upper reaches of Khanbari river, which is a small branch of Indus river coming from the north, the gabbronorite of the Chilas complex and amphibolite are at just contact to each other. The amphibolite is composed mainly of hornblende and plagioclase, in which original plutonic texture still persists. Under the microscope, hornblende and biotite are aggregates of fine crystals exhibiting a decussate texture. On the other hand, the gabbronorite is composed mainly of plagioclase, clinopyroxene and orthopyroxene with small amount of biotite and hornblende, which is slightly deformed. Therefore, it is evident that the amphibolite was intruded by the gabbronorite of the Chilas complex and suffered contact metamorphism. The northern amphibolite may correspond to the Kamila amphibolite, because these features are just like those in the Swat river.

It is important to note that the Chilas complex is a large intrusive body in the Kamila amphibolite belt.

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The distribution of clay minerals in Patala Formation of the Potwar basin: implications for palaeo environments

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During the Paleocene, the predominantly shaly part of the Patala Formation was deposited in Potwar basin, stretching from the Salt Range in the south to the Kala Chitta Range in the north. The paleoenvironments interpreted by the diagenetic sedimentational control of the clay minerals in the basin by analysing the clay mineral composition in 99 samples. The samples contain

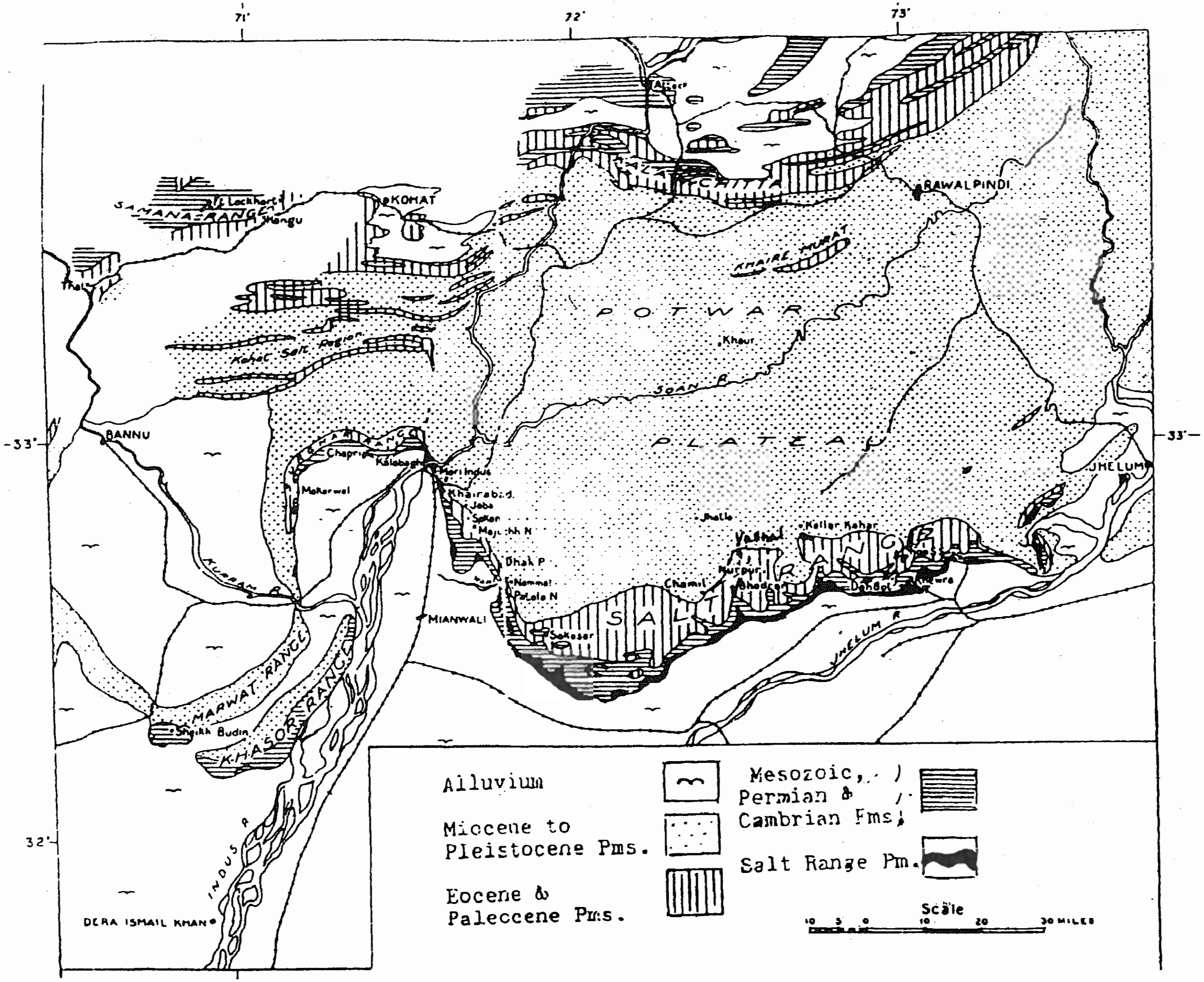

Fig. 1. Geological map of the Potwar plateau.

kaolinite, illite, chlorite and a mixed-layer clay mineral of illite/montmorillonite. It is concluded that the kaolinite/illite and chlorite minerals are the detrital clay minerals, brought into the depositional basin due to erosion of the source rocks exposed in the south of partly diagenetic origin. The clay minerals composition from the south to north show that the kaolinite decreases while illite and chlorite increase. The decrease of kaolinite in Kala Chitta Range is most likely due to sedimentational/ depositional control, because coarse-grained kaolinite was deposited in abundance in shallower parts and hardly transported into the deeper parts of the basin towards north. The fine-grained illite and chlorite minerals were transported and deposited in abundance in the deeper parts of the basin. No significant variation observed in mixed-layer clay mineral. The crystalinity indices of illite and kaolinite decrease in the Kala Chitta Range as compared to the Salt Range. The decrease in crystallinity in clay mineral again verify the transportation, and deepening of the depositional basin from south to north.

Preliminary environmental geochemistry of surface and subsurface waters from Peshawar Basin, north Pakistan

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The Peshawar basin of the North-West-Frontier-Province (NWFP) of Pakistan is a semi-circular low-lying broad depression (≅8000 km^2) situated at the southern margin of foot hills of Himalayas and north-west of the Indus plain. Unplanned urbanization and industrialization due to a very high rate of population increase have affected the major cities of NWFP, particularly those situated in Peshawar basin. Air is highly polluted in the major cities and industrial estates, and both surface and underground water are also facing a significant threat. This study is part of a large project concerning surface and subsurface water pollution related to major and trace elements, particularly heavy metals, in Peshawar Basin. Here we present the major element chemistry of the various types of waters from the basin. On the basis of stratigraphic correlation five types of semi-confined aquifers, namely, Khyber piedmont aquifer (west and south-west), Attock-Cherat piedmont aquifer (south and south-east), Lower Swat-Bunner piedmont aquifer (north and north-east) and floodplain and lacustrine aquifers in the central part of the basin have been identified. A total of 112 water samples collected from surface (river) and subsurface water (shallow, dugwell; deep, tubewell) have been analyzed. Majority of the surface and subsurface water samples appear to be *hydrogencarbonatic (Ca-Mg-HCO_3 type) and sulfatic (Cl-SO_4 type)* of the Alkaline Earth Fresh Water With High Contents of Alkalies.

Sodium-chloride (NaCl) and magnesium-sulfate ($MgSO_4$) are the major ionic pairs in these waters. Based on the major ions comparison with quality standards of drinking waters, most of the waters of the Peshawar Basin are classified as normal waters. A few dugwells (shallow water) from the Khyber and Attock-Cherat piedmont aquifers (Zahairabad and Ghari Chandan respectively), a dugwell and two tubewells from lacustrine aquifer of the central part of the basin (Amman Kot) indicate relatively higher concentrations of sodium, calcium, magnesium, potassium, iron, chloride, sulfate, and total dissolved solid (TDS) as compared to the standard Maximum Contaminant Level (MCL) of potable water. The high concentrations of these radicals at these locations, in the basin, can be attributed to, (a) the presence of evaporites at the depth, e.g. gypsum, limestone, dolomite and halite etc., (b) water logging and salinity, c) greater use of fertilizers. No contamination from sources related to industrialization and urbanization has been noticed in waters of these areas.

The changing glacial landscape of Zanskar, NW Indian Himalaya

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Understanding the geomorphic evolution of high mountain environments is now of significance in the development of a strategy to deal with high magnitude natural events in such areas, particularly in developing countries. High mountains contain important geological and geomorphological evidence for global climate change, for example, with respect to the impact and evidence of glaciation. However, any correlation between mountain glaciation and climate change is complicated in present orogenic belts by active tectonic uplift and its effect on the large scale weather patterns. Furthermore, there is the problem of establishing a chronology of glacial events and their synchroneity with climatic forcing events. This poster reports on the geological evidence from a critical area to understand Pleistocene landscape evolution in the Indian Himalaya.

Zanskar occupies an area of the High Himalaya mountain range which is transitional between the summer monsoon dominated southern ranges and the more and interior of Ladakh/Tibet. General understanding of the tectonic evolution of this area indicates that the axis of uplift has passed southwards across this area during the Pleistocene with the more southern ranges, such as the Pir Panjal, being relatively young uplift features. As these mountains have been uplifted, Zanskar would have become increasingly isolated from precipitation sources and this should be reflected in more restricted glacial extent with time.

Field investigations have shown that the geomorphological evidence in Zanskar is complex with areas recording preglacial valley forms as fragments of gentle, broad valley cross profiles as a series of benches 2-300 m above the present rivers. Geomorphological evidence for early glacial events is poorly recorded as a series of erratics and tillites on these palaeosurfaces. However, glacial erosion has altered the overall valley profiles and subsequent glaciations are found in a more typical alpine setting although of less spatial extent, reflecting more efficient and deeper glacial valley forms. Later glaciations are recorded by moraine systems further up the glacial influenced valleys reflecting increased isolation from precipitation sources and valley deepening.

Calculations of ELA have been attempted for a transect across the main ranges from the Pir Panjal to Ladakh. Although the data is of a preliminary nature due to the poor quality of the available topographic maps, an overall trend can be established indicating increased values northwards for each glacial event. Values have been recalculated to account for migration of the axis of tectonic uplift. This shows that the southern ranges were not sufficiently high for the early glaciation and that the ELA was lower in Zanskar at this time but with succeeding glacial stages, ELA values have risen with time. This, however, is tentative given the paucity of reliable tectonic data for this area.

Regional framework of Arunachal Pradesh Himalaya and tectonics of eastern Himalayan syntaxis

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The easternmost segment of Himalaya, earlier referred to NEFA (North Eastern Frontier Agency), is now designated as the Arunachal Pradesh (AP) Himalaya. All the major tectonic zones and principal thrusts from western Himalaya extend to this sector striking ENE to NE-WSW to SW. Further eastward the regional strike takes a turn around eastern Himalayan syntaxis with NW-SE trend.

The Sub-Himalaya zone principally comprising of Siwalik group rocks extend in a belt, 3-5 km thick, and is separated from the overlying Gondwana group and the Lesser Himalayan metamorphics along the Main Boundary Thrust (MBT). Foraminifera bearing Early Eocene beds occurs as thin slice between the Siwalik and the Gondwana groups in Siang district and is also observed overlying the Miri quartzite in the window zone of Lesser Himalaya.

The Lesser Himalayan formations, lying between the MBT and the Main Central Thrust (MCT), are divided into three principal groups, viz. the Gondwana group, the Buxa-Miri group and the Bomdila group. The narrow belt of the Gondwana group is sandwitched between the Siwaliks and the Lesser Himalayan metasedimentaries. The Gondwana group, composed of Damuda sandstone and Rangit pebble slate, has yielded plant fossils and invertebrate fauna of Lower Permian age. The Buxa-Miri group is composed of mainly quartzite, limestone, dolomite and phyllite. In eastern Siang, Abor volcanics is also included in Lesser Himalayan formation. The Buxa-Miri group is Late Precambrian in age, whereas the age of Abor volcanics is controversial. The metamorphics of the Bomdila group occur as thrust slabs overriding the Buxa, Miri and Gondwana formations. It consists of foliated biotite gneiss, deformed granite and low to medium grade metamorphics ranging from chlorite to kyanite grade. The Higher Himalaya Crystalline (HHC) is represented by high grade metamorphics and leucogranites of Sela group. The MCT located at the base of Sela group is characterised by shear zone and kyanite-sillimanite bearing gneisses.

Around the eastern Himalayan syntaxis in AP Himalaya, the regional strike is NE-SW on the western limb whereas the regional strike acquires NW-SE trend on the eastern limb. The eastern limb has different tectono-stratigraphy than from that of the western limb. The eastern limb is made of NW-SE trending Mishmi Formation, Tiding Formation and Lohit plutonic complex. The Mishmi Formation consists of an inverted metamorphic sequence showing progressive grade of metamorphism from chlorite to kyanite. The Tiding Formation is composed of tremolite-actinolite schist, limestone, serpentinite and volcanics. It is thrust over the metamorphics of Mishmi Formation and in turn is overlain along the Lohit Thrust by the Lohit plutonic complex. The Lohit plutonic complex is made of tonalite and granodiorite with metasedimentary enclaves.

The Tiding Formation containing serpentinite lenses, volcanics and limestone, is corretable to the ophiolite and associated sedimentary belt of the Yarlung Zangbo suture. The tonalite-granodiorite of the Lohit plutonic complex represents eastern extension of the Gangdese plutonic belt of the Trans Himalaya. The two belts of ophiolitic and the plutonic units show a curvature in the regional strike from E-W and NE-SW on the western limb to NW-SE in the eastern limb. Similarly the rocks of Mishmi Formation, representing the Lesser Himalayan metamorphics, also display similar bend in its regional strike. The bending of the regional strike across the eastern Himalayan Syntaxis suggests the occurrence of a large crustal scale fold with its axial trace trending in NE-SW direction.

Seismotectonics of the Kangra-Chamba region, Himachal Pradesh, northwest Himalaya

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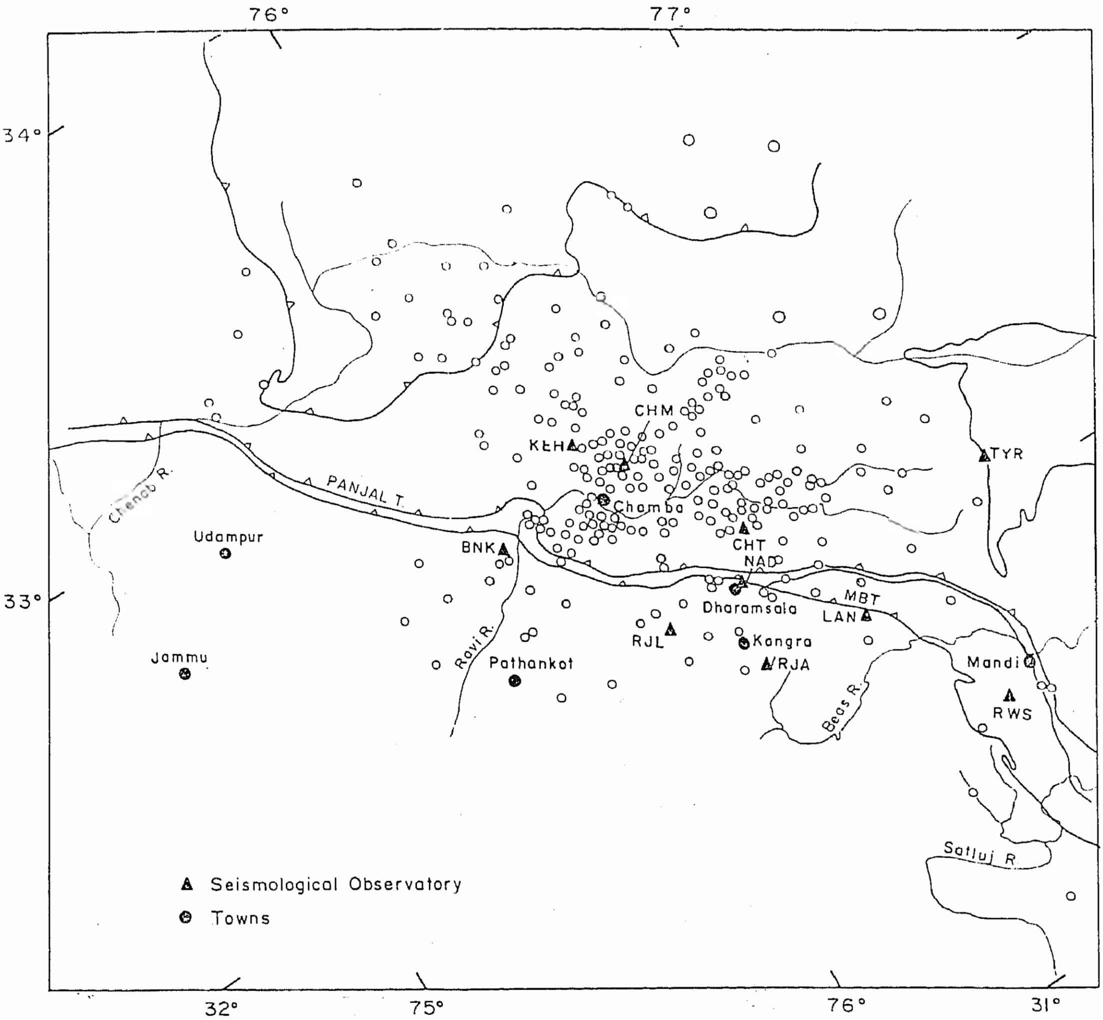
The 1905 Kangra earthquake of Himachal Pradesh took 18,815 human lives and caused extensive damage to property and affected land-form changes. This earthquake was felt over a wide area extending laterally for a distance of about 250 km from Kangra to as far east as Dehradun. The epicenter of Kangra earthquake was located at 32.5 °N - 76.6 °E and it had a shallow focus with magnitude of 8.6 and intensity reaching X in the epicentral region. The epicentre was located close to two tectonically active faults called the Main Boundary Thrust (MBT) and Panjal Thrust (PT). These parameters were derived from the damage survey conducted by Middlemiss (1910) immediately after the earthquake. Even today, this damage survey report is the only source of information for this event. Many workers made detailed analysis of this report to give a possible rupture model for this earthquake (Molnar, 1987; Chander, 1988).

The earthquake affected Kangra-Chamba region is encompassed by four tectonic zones, viz., the Sub Himalaya, the Panjal Imbricate Zone (PIZ, Lesser Himalaya), the Chamba nappe and the Higher Himalaya Crystalline (HHC). The MBT demarcates a tectonic boundary between Cenozoic (Siwalik and Dhramsala) on the rock units of PIZ. The Panjal Thrust (PT) separate the Chamba nappe sequence to the south from the underlying PIZ. The Chamba nappe slides southward over the Zanskar HHC along the Chenab normal fault. The Chamba nappe is made of 10-12 km thick sequence of predominantly very low grade meta sedimentaries ranging in the age from Late Pre-Cambrian to Jurassic. The whole sequence is thrust over the PIZ to the south along PT, and the PIZ in turn thrust over the Cenozoics along the MBT. The PT and the MBT are closely spaced from few kilometers to few hundred meters. These two thrusts are located at the base of the Dhauladhar range which rises abruptly to 4000 m from the Siwalik foreland basin sedimentaries.

Until recently, local instrumental monitoring of seismicity in the region was relied chiefly on the regional seismographic array operated by the India Meteorology Department. Effective local monitoring of seismicity started in 1989, by the installation of short period analog instruments by the Wadia Institute of Himalayan Geology. Since 1993, eleven permanent seismological observatories are in operation, around and south of the Dhauladhar range in the Kangra-Chamba region. During the summer months of 1996 and 1997 four more short-period analog instruments were operated for a period of four months in the northern parts of Chamba region. A total of 464 events in the magnitude range 1.6 to 4.3 were recorded, of which 262 events could be located accurately with horizontal and vertical location error less than 5 km. The epicenter distribution shows a very high level of seismicity to the north of Dhauladhar range as compared to the Kangra region in the south (Fig. 1). The high seismicity region falls on the hanging-wall side of the Panjal Thrust and extends to the north over the Chamba nappe. The NE-SW section across the Dhauladhar shows that the activity is mainly restricted to the top 20 km of the crust to the north and the level of activity is much less and diffused to the south of



76°
77°
34°
33°
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75°
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31°
CHM
KEH
PANJAL T.
Chenab R.
Chamba
Udampur
BNK
CHT
NAD
Dharamsala
MBT
LAN
TYR
RJL
Kangra
RJA
Jammu
Ravi R.
Pathankot
Mandi
RWS
Beas R.
Satluj R.
Seismological Observatory
Towns

Fig. 1

Dhauladhar. During the observational period no migratory pattern was observed. Except for the after-shock activity following 24 March 1995 Chamba earthquake, the seismicity rate is almost constant with an average occurrence of 3-5 events per day. The composite focal mechanism solution obtained for a cluster of events having a depth distribution of 10-15 km, indicates thrusting along NNW- SSE striking nodal plane dipping 24°.

The damage reported during the 1905 Kangra earthquake was mainly concentrated south of Dhauladhar range and south of the MBT. Also no major earthquakes are reported in the historical records for the the last 500 years in Chamba and Kangra region. It appears from the seismicity recorded that the Chamba nappe and the Lesser Himalayan sequence, comprising of 15-20 km thick sequence, is actively pushing southward along a detachment giving rise to MEQ activity and accumulation of strain energy in the Chamba nappe region. It is proposed that the 1905 Kangra earthquake rupture initiated at the junction where the Panjal Thrust and the MBT meet the detachment plane and propagated along a shallow dipping plane towards the south. The absence of teleseismically recordable earthquakes, and a high level of microseismic activity in the region between Dhauladhar range and the Higher Himalaya Crystallines indicates that the region is accomodating strain under a characteristic tectonic setting and has the potential of generating major event.

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On the tectonic characteristics and the geological evolution of the Qinghai-Tibet plateau

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The Qinghai-Tibet plateau is essentially a complex relatively independent tectonic system formed during the Meso-Cenozoic. The southward migration of the tectonic belts is very pronounced. Successively formation the Qilian Caledonian, the Kunlun variscan, the Bayanhar Indosinian, the Qiangtang Early-Yanshanian, the Gangdise Late-Yanshanian, and the Himalayan tectonic belts occurred. These belts are mostly bounded by the suture zones, among which, the most important ones are the Karakoram-Jinshajiang and the Yarlung-Zangbo suture zones.

The geological evolution of the Qinghai-Tibet plateau may be divided into four megastages: the Pre-Jinning, the Jinning-Variscan, the Variscan-Himalayan and the Himalayan megastages. The structural development during the Pre-Jinning megastage including the Archaeozoic and Proterozoic is not quite known yet: during the Jinning-Variscan megastage ranging from 800 to 250 my, a long period of subsidence of the crust resulted in the accumulation of enormously thick marine sediments. Tectonic movements and magmatic activity were very intense and continental sediments were common during the Variscan-Himalayan megastage. During the period from the late Cretaceous to Eocene, the Qinghai-Tibet Plateau started a new stage (Himalayan megastage) of continental collision. Crustal shortening and thickening and continuous rise laid down the foundation of the tectonic framework of the plateau.

The intensity of tectonic movements of the plateau during Meso-Cenozoic period is stronger in the south and east and weaker in the north and west. The northern part is predominated by upthrusts and schuppen structures, while the southern part is characteristed by overthrusts and nappe structures. Tight compressive folds and compressive-shearing faults are more frequent in the eastern part, and compressive faults are mainly in the western part together with broad and gentle-dipping folds.

The geological and geophysical data indicate that the uplifting of the plateau has probably experienced two stages: the tectonic uplift stage and the isostatic uplift stage. The enormously-thick Palaeozoic and Mesozoic sediments and intrusive rocks provided the material basis for the uplift of the plateau. The deep-seated melting of the crust created the internal conditions for the uplift. The occurrence of schuppen and nappe structures in the upper crust created the external conditions for the thickening, shortening and uplifting of the crust. The combination of these three factors might be the main cause for the uplifting of the Qinghai-Tibet plateau.

Interfolial extension in schists of Lansdowne area, Lesser Garhwal Himalayas, India

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It is well established that the metapelitic rocks of Lesser Himalaya have undergone up to five phases of deformation. Out of these the first two are generally believed to have produced ductile deformation signatures. The first phase of deformation is believed to have been responsible for the development of the early deformational foliation i.e. schistosity in the schists and phyllités of the Lesser Garhwal Himalaya. Important fabric elements representing this stage of deformation are schistosity and mineral lineation commonly defined by preferred orientation of flaky minerals, aluminosilicates, quartz, feldspar etc.

In the Garhwal nappe near Lansdowne, garnet-mica-schists show extensive development of boundinaged quartz veins. These boundinaged veins occur within the schistosity plane and show folding alongwith the schistosity. It may thus be safely assumed that the boundinage has taken place prior to the folding and during the D_1 phase of deformation. Boudinage structures are good strain markers because once formed and frozen they will ordinarily not register any strain in response to a stress during a subsequent deformation phase. One boudinage will however only show linear strain along a given direction. Therefore to determine shape of the strain ellipse, three boudinage structures all occurring within the schistosity plane have been used. The technique developed by Tripathi and Gairola (1997) has been used for determination of the shape of strain ellipse at six localities.

Results of the analysis suggests that within the foliation plane, the ellipse shows an extension of up to 3.8 times along the major principal axis. However extension along the minor principal axis varies from 0.76 to 1.27 times. The orientation of the longer axes of these ellipses suggest that during the first phase of deformation, strong extension took place in all the directions in the plain of schistosity. The strain variation from different localities may be due to the deviation of quartz vein - matrix viscosity contrast from place to place.

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Strain analysis from qaurtzites and granitic gneisses in the vicinity of north Almora thrust and Lansdowne thrust from Lesser Garhwal, Himalaya

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The lesser Himalaya in Garhwal consists of a large assemblage of rocks that show evidences of strain accumulated throughout their deformation history. The strain distribution in these rocks can be used to estimate the finite strain during different phases of deformation that have affected these rocks.

Three dimensional strain analysis has been carried out in the massive quartzites of Garhwal Group, schistose quartzite of Dudatoli-Almora Crystallines and granitic gneisses of Lansdowne. The massive quartzites are intercalated with metabasites and are of Middle Proterozoic age (Shanker et al., 1989). These rocks are tectonically overlain by the Dudatoli-Almora Crystallines along North Almora Thrust and are constituted of quartzites, schistose quartzites and garnet-mica schists of Early Proterozoic age (Shanker et al., 1989). The Lansdowne granitic gneisses are tectonically the topmost unit in the Garhwal synform and show well developed thrust related shear fabric.

Strain analysis has been carried out in eighteen localities in the three units. Strain has been estimated from quartz grains on microscopic scale and feldspar grains on megascopic scale on two orthogonal surfaces for each sample and 2D-strain analysis has been done using Rf/ϕ method of Lisle (1985). From these 2D results, the 3D-strain analysis has been carried out by the method of Burns and Spry (1969).

The foliation in the massive quartzites is poorly developed and is a product of shearing (Singh & Gairola, 1996). In Lansdowne granitic gneiss too the foliation is due to shearing along the thrust plane (Tripathi & Gairola, 1997). In both these localities the deformation path shows plane strain along XZ with some deviation that may be attributed to local rheological variations. The deformation in these rocks appears to be primarily due to brittle-ductile shearing. In the schistose quartzites of Dudatoli-Almora Crystallines the schistosity is well developed and the deformation path is flattening along Z which is the characteristic of schistosity development phase. The results also indicate that the Lansdowne granitic gneiss and the Garhwal Group post date the first phase of deformation (during which schistosity was developed).

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Rb/Sr and $^{40}Ar/^{39}Ar$ age limits on HT deformation in the STDS of the Chomolungma-Cho Oyu region, S-Tibet

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In an attempt to better constrain movements along the South Tibetan Detachment System (STDS, [1]) muscovites from both deformed and undeformed leucogranite bodies of the Chomolungma - Cho Oyu region involved in this major structure have been dated with the Rb/Sr and Ar/Ar techniques. The leucogranite bodies whose muscovites were dated are:

1. the prominent sill of foliated leucogranite cropping out along the eastern side of the Rongbuk valley from its confluence with the Gyachung Chu up to the Camp 3 area on East Rongbuk glacier. This leucogranite corresponds to the "muscovite granite gneiss" of the Chinese geologists [2]. It was sampled on the western side of east Rongbuk glacier just south of camp 2, and in the prominent cliff at the entrance of the Rongbuk valley;
2. a discordant leucogranite dyke hosted in North Col Formation structurally just above the STDS, which was found on the western side of the upper Chienchin valley, about midway between the two localities mentioned above.
3. the discordant, undeformed and strongly differentiated leucogranite pluton exposed on both sides of Pusi La, south of Cho Oyu [3], which is structurally homologous of the Rongbuk Monastery pluton 25 km to the east. Like the latter, the Pusi La pluton crosscuts both the ductile shear zone and the low-angle normal fault which comprise the STDS in the Chomolungma - Cho Oyu area.

Muscovites separated from these bodies yielded: 18.0 $\pm$ 0.2 Ma (Rb/Sr Wr-MS isochron) and 14.8 $\pm$ 0.1 Ma (Ar/Ar plateau age) for the foliated leucogranite sill at the snout of Rongbuk valley, 17.7 $\pm$ 0.2 Ma (Rb/Sr Wr-MS isochron) and 16.5 $\pm$ 0.1 Ma (Ar/Ar plateau age) for the same sill near Camp 2, 16.7 $\pm$ 0.2 Ma (Rb/Sr Wr-MS isochron) and 14.8 Ma $\pm$ 0.1 (Ar/Ar plateau age) for the discordant dyke of the Chienchin valley, 16.5 $\pm$ 0.1 Ma (Ar/Ar plateau age) for the Pusi La leucogranite pluton. The new Ar/Ar data are in excellent agreement with the older K/Ar data for the Rongbuk valley of Wager [4], who reported an average age of 15.5 Ma on two muscovites from the foliated leucogranite sill at the snout of Rongbuk valley, and 15.6 Ma for one muscovite from the same sill near Camp1 in east Rongbuk glacier.

Rb/Sr Wr-MS isochron ages are systematically older than the $^{40}Ar/^{39}Ar$ ages by 3 to 1 Ma. Since Carosi et al. [5] observed solid-state deformation microstructures in this sample, we interpret the closure of the Rb/Sr system in the muscovites of the foliated leucogranite to date the end of Sr isotope exchange during ductile deformation, i.e. movement along the ductile shear zone under high T (between 500^{o} and 600 ^{o}C). On the other hand, the K/Ar system dates later closure ("cooling", cessation of shearing and fluid circulation). We conclude that the ductile shear zone of the STDS has been active (at high T) before 18 Ma; emplacement of the Chienchin dyke in a brittle regime at (or just before) 16.7 Ma dates a waning stage of deformation; by about 16 Ma shearing on the STDS had totally died off. The latter estimate agrees with the conclusions by Hodges et al. [6], while the new Rb/Sr data provide a lower limit for the formation age of the foliated leucogranites.

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Neoproterozoic-Early Palaeozoic geotectonic events vis-a-vis the palaeotectonic evolution of the northern margin of the Indian subcontinent

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The Lesser and Higher Himalayan sedimentary and metamorphic units constitute the northward extension of similar rocks exposed in the northern half of the peninsular shield. The Middle Proterozoic (1600 m.a. onwards) was a period of stable platform sedimentation represented by the Shali-Deoban-Larji and their equivalents in the Lesser Himalaya and the Lower Vindhyan (Semri Group) in the Peninsular region. The carbonate sedimentation continued till around 900 m.y. and was followed by dominantly clastic facies (with occasional carbonates) represented by the Simia-Jaunsar sequence and their equivalents in the Lesser Himalaya and the Upper Vindhyans (Kaimur and Rawah groups) in the Peninsula region. To the west of the Aravaili massif, however, we have magmatic and metamorphic activity dated around 870-860 Ma (Erinpura, Kirana group) and 750-725 Ma (Malani Group).

After 725-700 Ma, the peri-cratonic margin of the Indian plate was differentiated into a number of basins delimited by major basement highs, faults and mega-lineaments. While the Aravaili acted as a barrier between the Trans-Aravaili and the main Vindhyan basin, one of its splays the Chandigarh-Bilaspur high divided the Krol basin (sensu stricto) from the western basin in the Punjab reentrant and Jammu and Kashmir (J&K) parautochthonous belt. Though the overall sedimentation during Vendian and partly Upper Riphean (700-570 m.y.) was under shallow tidal flat environment, the sedimentation in the basins to the west of the Aravaili massif and in the Lesser Himalaya was characterised by evaporitic horizons. Thick horizons of salt and gypsum occur in the Salt Range, Lesser Himalaya in J & K and Himachal Pradesh and the Trans-Aravaili Vindhyan basin, while in the main Vindhyan basin, limited desiccation is observed in the uppermost Vindhyans- the Bhander Group. The evaporite forming conditions were favoured during 650-550 m.y., when the Gondwana margin in India, Arabia and Persia was situated in the tropical and sub-tropical latitudes. In contrast to the evaporitic basins, the Krol basin was non -evaporitic and continuous sedimentation from Blaini upto Tal (650 to 550 Ma ?) is observed. In the initial phases, the Blaini, lnfra-Krol and Tal are more or less uniformity distributed for about 400 km, however, the Tal sediments (Cambrian onwards) are restricted to the central half only.

After the Cambrian deposition, most of the region was uplifted and underwent erosion. Thus the Ordovician to Carboniferous sequence is missing and Permian rocks occur over older rocks in Salt Range, J & K, Garhwal, the Trans-Aravaili Vindhyan basin and the main Vindhyan basin. The period 700-500 Ma is also important in that it coincides with the Pan-African Cycle and the Lesser and Higher Himalaya is characterized by numerous anorogenic granitic plutons (600-500 Ma) and metamorphic activity.

This paper deals with the palaeotectonic evolution of the peri-cratonic margin of the Indian plate during the Middle Proterozoic to Early Palaeozoic period.

Nature and signficance of Phugtal-Manali-Rupar super-lineament in the geotectonic evolution of Western Himalaya

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The NW Himalaya is characterized by numerous transverse structures which have exercised profound control on sedimentation, basin configuration and tectonic evolution both during, and prior to the Himalayan orogenesis. Many of these structures are active even today as is evident from seismic and neotectonic activity being recorded along these. Most of the structures described as megalineaments extend from the northern fringes of the Peninsular region and traverse through the lndo-Gangetic alluvial plains (IGAP) and the Outer and the Lesser Himalaya, but their influence further beyond is not so evident. However one such structure trending NNE-SSW has been observed in the Western Himalaya in Himachal Pradesh which is traceable for over 400 km from the IGAP through the Outer, Lesser and Higher Himalayas and even though the Tethyan region upto the Indus-Tsangpo suture zone. The zone to be referred to as the Phugtai-Manali-Rupar Superlineament zone (PMRZ) is prominently displayed on topographic, geologic and tectonic maps and also the satellite imagery. The paper discusses the characters and influence exercised by the PMRZ in the palaeogeography and palaeotectonic evolution of the Western Himalaya since the Late Proterozoic. Analysis of geological, tectonic and other data reveals that the PMRZ has been active since Late Precambrian times and has exercised an overall dextral wrench effect. A conservative estimate reveals a horizontal shift of over 50 km and this has produced the largest reentrant in the outer Himalaya the Punjab Reentrant. The Tertiary belt which is over 100 km wide to its west narrows down to 10-20 km on the east. The reverse is true of the Lesser Himalayan sedimentaries which narrow down from 100-150 km in the east to less than 1-2 km in the west. From Mandi through Dharmsala and Dalhousie, the narrow belt extends as a schuppen zone upto the Hazara syntaxis. The metamorphic thrust sheets have advanced much to the south to its east. Topographic contrasts are also well marked across it. Thus in the west from Kangra valley at 800-1000 m, the Dhauladhar rises to beyond 5000 m in just 5-6 km while these heights are attained on the eastern side in about 100 km or so. Abrupt changes in the facies of sediments, extension of various major structures are also noticeable features. Neotectonic activity in the form of recent changes

in drainage, seismicity, lateral and vertical ground level changes has also been recorded from the region of its influence.

The structural and thermal evolution of the High Himalayan slab, Suru valley region, NW India

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The structure of the High Himalayan Crystalline metamorphic unit in the region of the Suru river valley in western Ladakh, NW India, consists of a series of large scale (~2 km thick), SW-facing Helvetic style nappes. These nappes have shallow, originally northward-dipping axial planes which have subsequently been deformed by a later, lower domal event, centred around the Suru Dome near Panikhar.

The extreme nature of the topography combined with the structural complexity of the area provide an excellent three-dimensional study of the structure of the HHC through a 20 km-thick crustal section.

The metamorphic rock types are mainly interbanded metapelites, calc-silicates, metacarbonates and amphibolites, with sheared pre-Himalayan granitoid bodies, most notably the interbanded granite/amphibolite Sankoo nappe at the top of the slab. Kyanite is the stable aluminosilicate phase over most of the area, with grade decreasing northwards through staurolite and garnet to biotite towards the top of the slab at Sankoo, and south-westwards of the Suru Dome, consistent with the folded isograd model suggested by Searle and Rex (1989).

Microstructural analysis combined with field correlation has revealed at least three phases of deformation D1, D2 and D3 in the overlying nappes, and a later D4 event which is only present in rocks of the Suru Dome. D1 and D2 are seen as inclusion trails in garnets, particularly of the Donara nappe, where S1 is crenulated by D2, while D3 is believed to be responsible for the regional S2 foliation defining the large scale structures, which are parallel to bedding. This is thought to be in equilibrium with an M1 metamorphic event which reached up to kyanite grade (Stäubli 1989). However, the relative timing of porphyroblast growth to deformation is not always consistent. Garnets often show syn-tectonic spiral inclusion trails, with a distinguishably different matrix foliation, but some samples have garnets which appear to be post-tectonic. The same is true for staurolite and kyanite porphyroblasts where found, especially in rocks of the Donara nappe. The most likely explanation for this is a continuous deformational-metamorphic process, with bulk composition and structural depth affecting the relative porphyroblast-deformation timing. Consequently, it is proposed that the mapped isograd pattern is not so much a result of post-metamorphic folding but a syn-deformational feature. The D4 event is the result of doming at deeper levels during the M2 event (Searle et al., 1992), producing a new S3 matrix foliation which did not greatly affect the overlying nappes. This M2 event is believed to be related to an increase in temperature/ decrease in pressure, related to movement on the MCT and ZSZ.

Thermobarometric studies (Searle et al., 1992) indicate P-T conditions averaging 650-700 °C at around 8 kb for rocks at the core of the Suru Dome, at the time of dome formation, although pressures of 10-11 kb are sometimes recorded in rocks of the overlying Donara nappe which is believed to preserve a record of the earlier M1 event. More detailed thermobarometry has not been able to resolve significant P-T differences between different parts of the Donara nappe and surrounding areas. This may arise from either of, or a combination of two principal effects; that it is extremely difficult to obtain P-T estimates with an accuracy better than ± 1kb and 50 °C , which becomes significant when considering crustal differences of 3-4 km; and that peak metamorphic temperatures occurred at roughly the same time as nappe formation, leading to minimal temperature differences across the nappe structure. It is from these rocks, and those at shallower levels, that we hope to be able to decipher the earlier, prograde part of the P-T path.

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On the stability of Landslide-dammed lakes in the Annapurna Himal, Nepal

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Researching the stability of lake-damming landslide barriers is most important, as the failure of a dam may cause a hazardous flood in the main valley downwards. Detailed analysis of the landslide deposit and the conditions of stability is therefore necessary to prevent catastrophies.

Due to active morphodynamics and high relief-energy the Himalayas are predestinated for landsliding and linked lake-damming phenomena. That is why various dimensions and ages of landslide-dammed lakes have been reported from this area (Gansser, 1987; Uhlir, 1997; Yagi, 1992 and 1997; Yagi et al., 1990; Weidinger, 1997;369 Weidinger & Ibetsberger, 1996 and 1997). But what is the reason that some of these kinds of natural dams fail and break within the first days, whereas a few of them keep stable for very long periods (Costa & Schuster, 1988; Schuster, 1986).

We know that this may partly depend on the size of the dislocated landslide-mass, the shape of the landslide deposit and the different lithological behaviours of the involved materials, which built up the bar. But despite of all more and more important factors are appearing, which must be considered, the more complete the stand of research is going to be!

The pre-destinating geomorphologic conditions (due to glacial overprint during the last main glaciation as well during the late- and post-glacial) makes the Marsyandi valley in the Annapurn region of Nepal well known for giant massmovements mainly affecting corbonatic lithologies (Hagen, 1969). Two new examples of massmovements and rockavalanches from the sequence of the High Himalayan Crystalline (Colchen et al., 1986), which have so far never been described and investigated, were noticed by the author during his fieldtrips through this valley in spring 1993 and spring 1995 (project of the "Austrian Science Fondation", Nr. P09433-Geo). The sampled data should provide new information on the above mentioned topic.

One of the most important sites is the rockavalanche of Tal (this name means "lake"). Near this small village, just 7 km south of the confluence of the Dudh Khola with the main river, the landslide, which occured perpendicularly to the valley from E to W, dammed a lake of more than I km in length, around 300 m in width and around 100 m in depth. Today this lake is filled up with sediments of the lake and alluvions of the river (Fig. 1). Successive decrease of the potential of hazards by natural lowering of the level of the lake's water (erosion of the landslide barriere) as it was mentioned by Weidinger (1997) as well as Weidinger and Ibetsberger (1996 and 1997), can not be recognized in the area of Tal. No signs of a failure of the major dam can be detected. The question is: why?

The reason for this is that the landslide occured in form of a rockavalanche. The dislocated gneissic mass lacks in finely grained material exclusively containing boulders of a diameter from 0.2 - 10 m. As the most important effect after the event, it could be noticed additionally that a secondary stabilisation of the dam by "cementation" with sediment due to waterflow between the hudge boulders of the landslide-material must have had occured. This is a major purpose for stabilizing input to a natural dam (Shaller, 1991). So, the hydrologic circumstances, the rate of sedimentation of filling up the lake and the rate of seepage through the deposit of the landslide were important for the stability of this landslide bar and the period of the lake's life acting as a potential hazard. That is why the dam did not fail and the lake disappeared within historic time due to sedimentation in this special case (compare the name of the village, which was obviously founded on the shore of a lake).

We are confrontated with a different situation, if we move further up the valley. Suddenly another question arises; are there indications for a giant massmovement and an instable, dammed lake near the villages of Latamrang and Thanchauk?

Signs and field-data, which underline this hypothesis, have also been collected in a part, which is just 15 km from Tal, the valley upwards, between the confluence of Dudh Khola and the village Chaine. Although one is still in the gneissic material of the HHC, the geological and morphological features (most of the rudimentary landslidematerial is eroded) in this region around the named villages are anormalous over a distance of 4 km, partly along both sides of the valley.

Three indications were noticed giving evidence that some kind of massmovement must have had occured in this area damming up the river to a long but narrow lake:

i) extensive occurance of exotic sediments and rock-fragments, showing susceptibility to massive erosion and an unusual mechanism of accummulation,
ii) widely ranged, heavily shattered and brecciated hardrocks along the base of the landslide, perhaps due to mechanical stress during the movement, and
iii) lake sediments behind this former barriers, the valley upwards.

Although this postulated massmovement occured in crystalline rocks, in a direction from SW to NE, the estimated volume (> I billion cubic meters) was to big for developing some kind of rockavalanche. Sledge-like movement of the masses led to heavily shattered and brecciated landslide-deposits. Outcrops of this material as well as the eC-test (Scharmm & Weidinger, 1996. Weidinger et al., 1995 and 1996) show that the lying parts of the dislocated crystalline rocks were almost pulverized. It is easy to understand that the occurance of such a material gave chance to extensive seepage and connected internal erosion in form of channels within the natural barriers. That was the main reason, why one of this giant natural dams, which are usually stable for thousands of years (Yagi, 1997), exceptionally failed after a relative short period of some hundred years. The period, for which the lake existed, can be proved by counting the beds of the seasonally changing lake-sediments behind the bar, whereas the dating of the event itself is still in progress.

The study has shown that the rockavalanche of Tal and its dammed lake correlates with the international researched and so far available data. In contrary the giant landslide near Latamrang and Thanchauk did not keep stable-despite of the fact of its giant size and its uniform crystalline lithology - due to the occurance of heavily shattered rocks along its base.

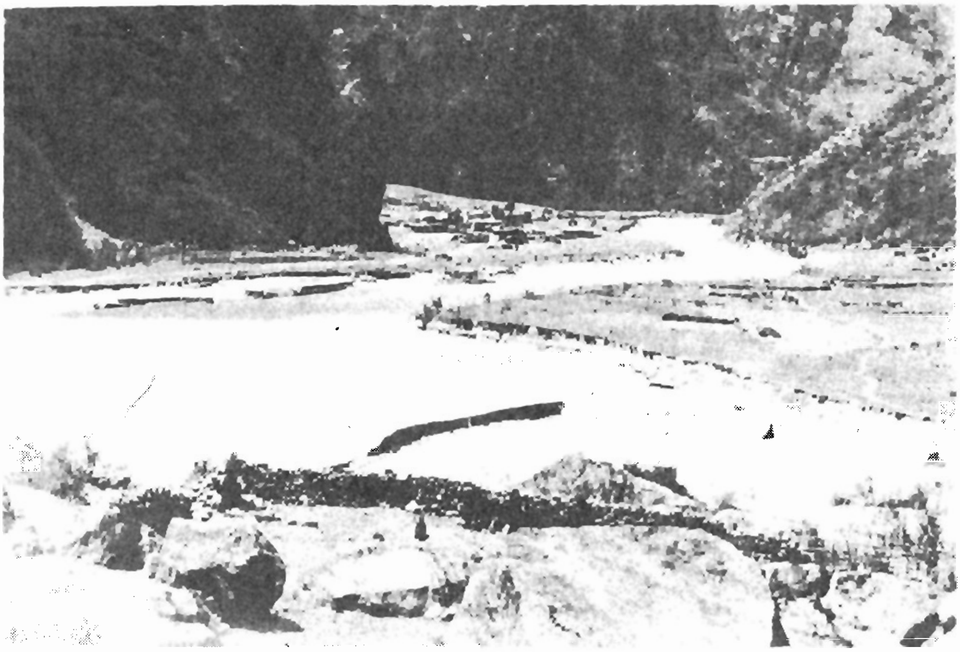

Fig. 1. Former basin of the lake in the Marsyandi Valley near the village of Tal (upper centre), which was dammed by boulders of the rockavalanche (in the foreground), today filled up with lake and alluvial sediments on both sides of the river. Foto: J.T. Weidinger.

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Fluid flow in the Nanga Parbat-Haramosh Massif: the use and interpretation of argon isotopes

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An extensive dataset of 175 $^{40}Ar/^{39}Ar$ analyses of mica separates are presented from the Nanga Parbat-Haramosh Massif, an actively deforming syntaxial region that forms the western Himalaya. Three critical areas were selected for sampling in order to distinguish genuine spatial and temporal patterns of cooling from the spurious effects caused by inherited excess argon. The majority of ages are interpreted as recording regional cooling due to rapid exhumation within the last 10 Ma. Younger ages of less than 1 Ma from leucogranite sheets and plutons approximate to intrusion ages, and support field evidence for magma emplacement into relatively cool country rocks by fracture flow rather than by diapirism.

The widespread occurrence of "excess" argon, i.e. gas of unknown composition trapped at the time of closure, results in anomalously old ages that require multiple total fusion analyses of single grains to determine the true ages of geological events. The use of isotope correlation diagrams for multiple analyses enables some confidence to be placed in the resulting age, and the composition of non-radiogenic argon trapped at the time of closure may be used as a tracer of fluid pathways. In the interior of the massif, incorporation of excess argon suggests the presence of magmatic and/or metamorplfic fluids at depth, while in the Liachar shear zone on the western margin of the massif, the incorporation of argon with an atmospheric composition suggests circulation of meteoric fluids at shallower levels.

Where did Nanga Parbat come from?

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The Nanga Parbat-Haramosh Massif (NPHM) is the most northerly exposure of Indian Plate basement, and forms a syntaxial loop at the northwestern end of the Himalayan orogen. It is bounded to the north by the Main Mantle Thrust (MMT), locally overprinted by more recent strike-slip and reverse faults that separate the NPHM from the Kohistan-Ladakh island arc terrane. The NPHM has long been considered to be a westward extension of the Higher Himalayan Crystalline Unit (HHC), which outcrops further east in the main orogen, in part because of its similarly high metamorphic grade, and in part because both the HHC and NPHM host tourmaline-bearing leucogranite bodies of Miocene age or younger. The leucogranites from both regions have similar geochemistry, indicating generation from a pelitic source by vapour-absent "decompression" melting (Harris and Inger, 1992).

However, several discrepancies have become apparent in recent years between the P-T-t path followed by the NPHM and HHC terranes. For example, leucogranites at Nanga Parbat have crystallisation ages as young as 1 Ma (Zeitler and Chamberlain, 1991), compared to typical ages of 18 to 22 Ma for Higher Himalayan leucogranites (Harrison et al., 1997). Geochronological studies have revealed that Nanga Parbat is currently being exhumed at a rate of at least 3 mm/y (Whittington, 1996), that has resulted in an elevated geothermal gradient and exceptional topography, thus promoting vigorous fluid flux throughout the massif. These factors have in turn led to a second melting episode, generating small cordierite-bearing restitic assemblages localised in shear zones that are not observed in the main orogen (Whittington et al., 1998). Thus the timing of both exhumation and anatexis at Nanga Parbat differs from that seen in the central Himalayan orogen.

Isotopic systematics of rocks of the NPHM and the HHC in Zanskar, the nearest outcrop of HHC to the NPHM, suggest different histories for the two terranes. NPHM leucogranites are exceptionally radiogenic, with ($^{87}Sr/^{86}Sr$) ratios of about 0.877 and ε_{Nd} of -23 (presentday), compared with ($^{87}Sr/^{86}Sr$) ratios of 0.74 to 0.78 and ε_{Nd} of -13 to -17 for High Himalayan leucogranites from Zanskar (Ayres, 1997). When plotted on an errorchron diagram, Nanga Parbat basement lithologies display a trend corresponding to between 2100 and 2400 Ma, while Zanskar rocks display a trend corresponding to about 500 Ma, for both Rb-Sr and Sm-Nd systems. Supporting evidence Proterozoic events from the NPHM terrane comes from (I) amphibolite sheets which cross-cut the oldest gneissic fabrics are characterised by Nd model age of 2200-2400 Ma; (ii) previously published zircon core ages from the NPHM cluster around 1850 Ma for the Iskere gneiss, and 500 and 2500 Ma for the Shengus gneiss (Zeitler et al., 1989; Zeitler et al., 1993). Thus isotopic evidence suggests that the NPHM basement is much older than the HHC unit, and the two cannot be correlated.

These results pose the question of whether the NPHM basement unit is unique to this area, exposed locally by the exceptional exhumation history of Nanga Parbat, or does it outcrop elsewhere in the Himalayan orogen? Lesser Himalayan lithologies, exposed in the footwall of the MCT in the main orogen, are comprised of a metasedimentary succession, but have attained a much lower metamorphic grade. Published zircon ages from the Lesser Himalaya (1870 to 2600 Ma, Parrish and Hodges, 1996) are quite distinct from those found in the HHC unit (800 to 1000 Ma, ibid.), but match ages from the NPHM. While Himalayan-age granite magmatism is unknown in the Lesser Himalaya, the abundance of pelitic lithologies makes this sequence a fertile source, and the Nanga Parbat leucogranites reproduce the isotope systematics that would be expected if these rocks were melted during decompression. Cambro-Ordovician granites do occur in the Lesser Himalaya, and the leucogneisses found in the southern NPHM may represent their metamorphosed equivalents. An orogenic event of this age may also explain the presence of 500 Ma ages in some zircon cores from the Shengus gneiss, but clearly did not result in isotopic homogenisation on a bulk-rock scale.

Hence in answer to the question, where did Nanga Parbat come from, it is possible that the c. 30 km of erosion experienced by Nanga Parbat in the past 10 Ma has exposed Lesser Himalayan basement rocks through the Kohistan island arc terrane. This raises a further question, what happened to the HHC rocks overlying the Lesser Himalayan sequence? Work in progress on the margins of the NPHM that seeks to address this question (Foster et al., this volume) is further complicated by the lack of a well-defined MCT in northern Pakistan, in contrast to the relatively uniform stratigraphy seen in the main orogen..

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The main Pre-Himalayan and Himalayan deformation phases in the Pin Valley (Spiti, Tethyan Himalaya, NW India)

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The main deformation phases recorded in the High Himalayan Crystalline (HHC) and the overlying Tethyan Himalaya (TH) are considered to be the result of the collision and following shortening between the Indian and the Eurasian plates at about 55-65 Ma. Barrovian peak metamorphism followed crustal thickening and thermal relaxation in the Late Eocene to Early Oligocene. Rapid cooling of the HHC occurred around 20 Ma as a result of extrusion between thrusts and normal faults. The presence and amount of any deformation predating these Himalayan events is less constrained and still controversial. In the Pin Valley, deformation and low-grade metamorphism within a succession of Precambrian to Jurassic sediments was investigated along a 25 km long section normal to the main NW-SE trending fold train. The recorded structures can be divided in three deformation phases:

Pre-Himalayan deformation phase: The rocks of the Haimanta group are unconformably overlain by Ordovician red conglomerates and sandstones of fluvial to shallow marine facies at the base suggesting surface uplift, erosion and transgression. This unconformity cuts close-tight upright mesoscopic folds within the Haimanta group 13 km S of Muth, with fold axes plunging towards the NW. However, the initial fold geometry and shape is strongly overprinted by redundant superposition of younger folds with a similar orientation of fold axes and axial planes. An important observation is the transgression of Ordovician basal conglomerates on a NW - dipping fault within the Haimanta group (7 km SSE of Muth) with a dip-slip component of about 70 m, indicating a pre-Ordovician age of extensional faulting.

The components of the Ordovician basal conglomerates are mainly derived from the Haimanta Group. These components reveal no evidence for a pre-depositional deformation and therefore the Pre-Ordovician deformation in Spiti area is probably restricted to local faulting and folding due to regional exhumation of this area.

First Himalayan deformation phase: This deformation caused the large-scale NW-SE trending fold trains of the synclines and anticlines in Spiti. The axial planes of the horizontal SW-vergent folds dip steeply ($\sim 60^{\circ}$) towards the NE. The first order folds have amplitudes of up to 2-3 km, but higher order folds exists at all scales and metapelitic layers developed an intense crenulation cleavage. Several thrusts as well as fault-propagation folds with both, hanging wall anticlines and footwall synclines, developed during this deformation stage. $^{40}Ar/^{39}Ar$ dating of newly formed Illite in cleavage domains from highly crenulated rocks gave ages between 42 Ma and 45 Ma. These are the youngest ages found in the Pin Valley and can probably be correlated with crustal thickening and formation of large amplitude SW verging folds.

Second Himalayan deformation phase: A shallowly NE dipping spaced axial plane cleavage ($\sim 20^{\circ}$) overprints the older structures. The intensity of this deformation increases towards the SW, creating mesoscopic SW-vergent folds deforming the earlier axial plane cleavage. Fault-propagation folding and thrusting of the earlier event were overprinted as well. However in the investigated area, the deformational overprint of the second phase is less penetrative than the earlier deformation phase and no large-scale folds or fold interference patterns are observed. Preliminary observations suggest that this deformation event dominates at lower structural levels and can be probably related to movement along the MCT.

The widespread Pre-Ordovician angular unconformity may be possibly related to the extensive intrusion of granitic rocks with collisional geochemical characteristics at around 476 Ma at relatively high structural levels within the Haimanta Group. The observed Pre-Himalayan warping of the Haimanta Group in the Pin Valley and the molasse-type Ordovician transgression can be best explained by a semi-stable foreland on the edge of an orogenic belt in this area.

Cenozoic sequences at the northern margin of western Kunlun

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Western Kunlun forms the northwestern margin of the Qinghai-Tibet plateau, and furnishes, meanwhile, the southern margin of the Tarim basin. Well developed Cenozoic deposits at the northern margin western Kunlun can, to a large extent, reveal environment change and the uprising of the Qinghai-Tibet plateau.

The a Paleocene usually rests conformably or disconformably on the Cretaceous, conglomerates and pebbly coarse sandstones are common at the base of the Paleocene in the eastern part. The rest consists of evaporites and red, gypsum-bearing sandstones and mudstones. The Eocene comprises mainly red sandstones, gypsum beds and greyish green calcareous mudstones and limestone beds rich in bivalve fossils (dominated by ostreids). The Oligocene is of similar lithology, but large-sized bivalves become less. The Miocene comprises entirely of continental red deposits and lies conformably on the Oligocene. The Miocene is unconformably overlain by a red, consolidated clastic sequence which is usually referred as molasse. The molasse sequence coarsens upwards and has a thickness of 2000-3000 m. The age of the molasse is normally considered to be Pliocene to early Pleistocene, but it remains possible that the lower boundary of the molasse is of a late Miocene age. The molasse sequence is usually steeply dipped or being upright. It is unconformably overlain in many places by late Pleistocene loose, horizontal fluvial and pluvial pebble beds. Both late Pleistocene pebble beds and older deposits are cut by latest flowing water to a depth of 50 to more than 100 m.

Judging from the deposits at the northern margin of western Kunlun, we know that a marine environment was sustained from the (Late) Cretaceous to the Oligocene, although it was already retreated to the western part by the time of Oligocene. Continental environment took over in the Miocene. Rapid and accelerated rise of the Kunlun occurred from the Pliocene (possibly late Miocene) to early Pleistocene. This is evidenced by the coarsening-up molasse sequence. Resumed uplifting of the Kunlun after a short pause is indicated by late Pleistocene pluvial and fluvial deposits which lie horizontally on molasse sequences. Latest uplifting is indicated by the lower position of present river beds directing northwards to the Tarim basin.

Biostratigraphy and sedimentary development of the Jurassic of southern Tibet

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Expansions of studies of Jurassic strata from central Nepal (Thakkhola area) into southern Tibet reveal that Jurassic strata are well exposed in the area between Nyalam and Gyirong and many correlations can be drawn on the stratigraphy and geologic development of this region. In the Nyalam area the Jurassic strata are divided into the Pupuga, Nieniexiongla, Laiongla, Menbu and Xiumo formations. Fossils found within these strata include foraminifera, ammonites, brachiopods, corals and bivalves, permitting age constraints of individual formations:

Orbitopsella-Lithiotis assemblage indicates a Liassic age for the Pupuga Formation; a *Witchellia-Dorsetensia* assemblage defines the Aalenianearly Bajocian age of the Nieniexiongla Formation and a *Sonninites Spiroceras* assemblage indicates a late Bajocian age for the Laiongla Formation. The Menbu Formation contains abundant ammonites such as *Parapatoceras, Streblites, and Virgatosphictes,* indicating a Bathonian to Kimmeridgian age for this formation. The *Aulacosphictes-Virgatosphictes* assemblage within the Xiumo Formation suggests a Tithonian age.

Lithologically, the Jurassic of southern Tibet is highly variable, being dominated by limestones and marine terrigenous clastic rocks deposited in a shelf environment. The shelf bordered the Indian continental plate, which at that time was incorporated within the Pangea supercontinent. Limestones comprise about 60 percent of the sedimentary strata, with 12 microfacies recognized. Intercalations of quartzitic sandstone, oolitic and skeletal limestones enclosing larger foraminifera and abundant Lithiotis indicate a nearshore depositional realm with periods of shallow-water carbonate platform development for the Pupuga Formation. Slightly deeper neritic depositional evironments existed during Late Liassic, with shallowing occuring during Early Bajocian, as indicated by benthic foraminifera, bivalves and brachiopods. Abundant necton represented by ammonites in the overlying Menbu Formation and predominance of marine shales indicate an outer neritic to upper epibathyal depositional environment.

The sedimentary facies in concert with their fossil assemblages document two major depositional cycles. Each bigins with deposition in shallow neritic environment followed by progressive deepening into outer neritic depositional setting, in turn followed by a shorter period of renewed shallowing. The first cycle extends from the Earliest Jurassic to Early Bajocian. The second one from Bathonian to the Tithonian. Shallow water carbonates containing abundant foraminifera, bivalves and ammonites and the quartzose sandstone intercalations near the top of th Xiumo Formation, indicate reestablishment of an inner continental shelf depositional setting during Tithonian, which culminated in deposition of shoreline sandstone at the bigining of Cretaceous.

The Jurassic depositional cycle in southern Tibet has been interrupted by at least two major depositional diastems during which hardgrounds developed and chamositic oolite was deposited. These deposits mark a major sea-level rise. The other major lithologic changes, such as oscillation between shallow water carbonate platform and marine shale depositional regimes, could denote either eustatic sea level changes, or climate changes resulting from continental plate motion, or variability in continental margin subsidence. Comparison of the Tibetan, Italian and circum North Atlantic Jurassic provide additional constraints for the recognition of major eustatic sea level changes, however, the current geologic data from Tibet is still not detailed enough to allow firm conclusions.

A brief review of tectonic evolution of Tethys and uplift of the Qinghai-Tibet plateau

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Synthetic studies of paleobiogeopraphy, sedimentography and paleomagnetism from the Qinghai-Tibet plateau show that the Indian plate and the terranes of the Qinghai-Tibet plateau accreting to Eurasia during the Late Paleozoic to Mesozoic did not drift northward across a vast ocean. During this period only an epeiric sea, a narrow Tethys sea, rather than a "vast eastward opening Tethys" lay between India and Asia. With the acquisition of the data of geodetic leveling, GPS and fission track, the uplift rates of the Qinghai-Tibet plateau (QTP) have been generalized. The uplift process of the QTP can be divided into three major stages, i.e. the slow uplift stage in the Late Cretaceous-Oligocene, the intermediate uplift stage in the Miocene-Pliocene and the rapid uplift stage in the Pleistocene-Holocene. The uplift rates were increased with time. There are likely two abrupt periods: one is around Late Miocene and the other around Late Pliocene-Pleistocene. Based on the recent geological and geophysical data, this paper suggests that the causes of the rise of the QTP are complex and heterogeneous, involving many factors. Our preliminary synthesized study indicates that the compression from India terrane and the resistivie force (or hysteresis effect) firom the rigid blocks (the Tarim and Yangtze terrane), the thermal effects or expansion, and the isostatic adjustment in the late periods are the three major factors leading to the crustal shortening, thickening and uplifting of the plateau.

Sm-Nd dating of superposed replacements in mafic granulites of the Jijal complex, northern Pakistan

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The northern part of the Jijal complex (NJC) in the Kohistan arc is a rare example of the lower crust of an island arc. Two stages of replacement under the granulite facies conditions are observed in mafic to ultramafic rocks of the NJC. In the earlier stage, garnet clinopyroxene granulite (garnet+clinopyroxene+plagioclase+quartz) replaced two-pyroxene granulite (orthopyroxene+clinopyroxene±hornblende+plagioclase±quartz) and patches of relict, the two-pyroxene granulite, were left in the garnet-clinopyroxene granulite. In the later stage, many pod- and lens-shaped bodies of garnet hornblendite (garnet+hornblende +clinopyroxene) replaced the garnet-clinopyroxene granulite. The two-pyroxene granulite and the garnet-clinopyroxene granulite are nearly equivalent in chemical composition and distinct from the garnet hornblendite.

Sm-Nd isotopic systems have been studied in these three rock types. Samples for dating were collected from road-side sections along the Karakoram Highway around lat. 35°07′ N and long. 73°00′ E (near the Pattan village). Whole rock and mineral isochrons define the following ages: 118 ± 12 Ma for KU66A (two-pyroxene granulite), 94.0±4.7 Ma for PD6B (garnet-clinopyroxene granulite), and 83 ± 10 Ma for PDI5B (garnet homblendite). Errors in ages are quoted as 2σ. The age of KU66A shows that the protolith of two-pyroxene granulite had been formed before the Kohistan-Asia collision which is dated between 102 and 85 Ma [1, 2]. The age of PD6B agrees with a 91.0 ± 6.3 Ma Sm-Nd age of KU66 (the garnet-clinopyroxene granulite from the same outcrop of KU66A in this study) in an earlier report [3]. All the above ages are consistent with relative order of the formation of the three rock types. The earlier replacement took place before c. 90 Ma (PD6B, KU66) and the later probably before c. 80 Ma (PDI5B). The result implies that these events in the NJC are related to the Kohistan-Asia collision (Fig. 1; Table 1).

TABLE 1

Sample No.		Sm (Ppm)	Nd (ppm)	$^{147}SM/^{144}Nd$	$^{143}Nd/^{144}Nd$	$\pm 2\sigma$
KU66A	Opx	1.076	2.705	0.2405	0.512887	0.000018
	Cpx	9.370	20.631	0.2747	0.512917	0.000010
	PI	0.2831	2.198	0.0779	0.512764	0.000012
	Wr	1.866	5.220	0.2162	0.512853	0.000024
KU66*	Grt	1.497	1.006	0.9003	0.513299	0.000020
	Cpx	2.805	10.852	0.1563	0.512862	0.000011
	PI	0.0709	0.8942	0.0480	0.512790	0.000014
	Rt	0.0285	0.1728	0.0999	0.512810	0.000060
	Wr	2.058	6.074	0.2049	0.512867	0.000015
PD6B	Grt	1.338	0.9319	0.8684	0.513323	0.000015
	Cpx	3.687	10.929	0.2040	0.512904	0.000012
	PI	0.1221	0.956	0.0773	0.512842	0.000013
	Wr	1.073	2.861	0.2267	0.512926	0.000013
PDI5B	Grt	0.7607	0.2899	1.587	0.513611	0.000024
	Cpx	1.810	4.431	0.2471	0.512885	0.000008
	Hbl	2.992	6.392	0.2831	0.512891	0.000008
	Wr	2.042	4.090	0.3020	0.512941	0.000014

Abbreviations: Grt = garnet, Opx = orthopyroxene, Cpx = clinopyroxene. Hbl = hornblende, Rt = rutile, PI = plagioclase, Wr = whole rock. *: Data from KU66 of Yamamoto and Nakamura [3].

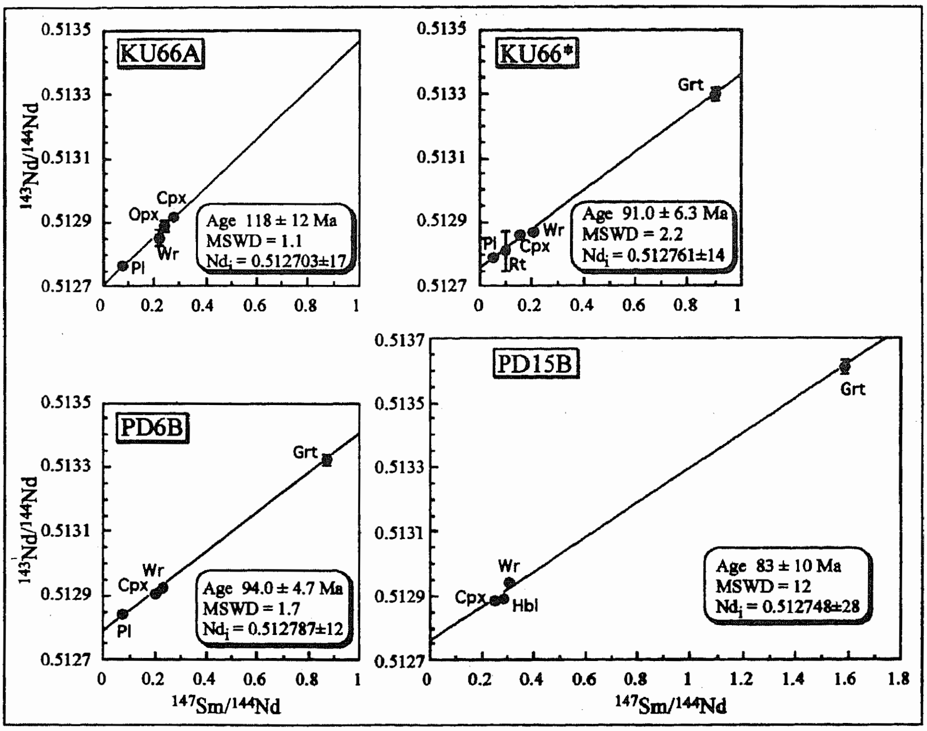

Fig. 1 Sm-Nd isochron diagrams (Nd_i = $^{143}Nd/^{144}Nd$ initial ratio)

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Fission-track evidence for episodic denudation of the Nyalam Higher Himalaya, China

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Recent thermochronological and geological data shed light on the geological process related to uplift of the Himalaya. Fission Track ages from Himalaya orogen zone have been obtained by many scientists. In order to document quantitatively the cooling and denudation history of the Nyalam leucogranites and migmatitic granites, fission track (FT) apatite has been determained on the granites in the Nyalam region of China. Eight fission track ages of apatites from the Nyalam leucogranites and migmatite granites collected at various elevations of Nyalam region have been found to range from 1-8Ma. These ages increase linearly with increasing elevations. Four apatite ages from the Nyalam migmatitic granites yield FT ages in the rang of 0.85 ± 0.09 to 1.71 ± 0.34Ma; Four apatite ages from the Nyalam leucogranites yield FT ages in the rang of 3.79 ± 0.34 to 8.17 ± 0.47Ma. A muscovite $^{40}Ar/^{39}Ar$ age of 14.8 ± 0.6Ma and a biotite age of 16.6 ± 0.5Ma from the Nyalam leucogranite are reported by Maluski (1988). These reflect cooling of the rocks through 300-350°C, probably related to a Middle Miocene pulse of denudation caused by the South-Tibet Detachment Fault above the leucogranite. Scharer (1988) reported monazites U-Pb ages of 16.8 ± 0.6Ma from the Nyalam migmatitic granites, Maluski (1988) also reported mica $^{40}Ar/^{39}Ar$ ages of ~ 8.7Ma for the rocks, these data constrain the cooling history of the Nyalam migmatitic granite. It indicate that the cooling of migmatitic granite in the Quaternary was three to four times the magnitude of cooling between 8 and 1Ma, implying a distinct pulse of rapid denudation in the Quaternary. The average denudation rates increase from 0.5mm/yr in Pliocene to over 3mrn/yr in the Pleistocene. These data reveal that the Nyalam Higher Himalaya underwent episodic denudation, one major pulse in the Miocene which was mainly tectonic denuation, and another in the Pliocene Quaternary, which was a young, rapid and accelerating uplift and erosion.

Recognition and significance of the A'nyemaqen ophiolite and Yushu non-ophiolite on the NE Qinghai-Tibetan plateau

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Recently we carried out a geological investigation from Maqen of East Kunlun down to the south of Yushu on the NE Qinghai-Tibetan plateau. New results give the evidence of the paleo-

Tethys oceanic crust represented by the A'nyemaqen ophiolite and, on the other hand, the suspicion on the existence of the so-called Yushu ophiolite. This paper is going to present the difference in occurrence and lithology of the rocks in the two belts and their tectonic implications.

The A'nyemaqen ophiolite, with an age of Permian to Triassic, occurs along the southern margin of the East Kunlun mountains. It extends over 1,000 km from Maqen westward to Muztagh where ultramafic blocks more or less crop out but not much work has been done yet. The ophiolites in this belt crop out as isolated tectonized blocks dominantly in the Permain and lower Triassic deep sea sedimantary sequence with interbeds of volcanic rocks. Individual ophiolitic blocks are mostly less than 1 km^2 in outcrop area but a few up to 10 km^2. The ophiolitic units found in the belt are abyssal peridotite, ultramafic and mafic cumulate, gabbro, sheeted dike, and oceanic floor basalt with radiolarian chert layers. In particular, four suites of volcanic rock, i.e., oceanic floor basalt, island-arc basalt and andesite, back-arc basin basalt and post-collision intermediate-acid volanic rock, are found in the region.

In the Yushu region there are many small mafic and ultramafic blocks, normally tens to hundreds meters in length. They are regarded as a suite of ophiolitic rocks, extending southeastward to Litang [1,2], or to Jinshajiang [3] and constituting an ophiolite belt separated the Baryan Har terrain on the north from the Songpan Ganze terrain on the south. Pyroxenite-peridotite, gabbro, diabase intrusions, and extrusives are main rock types. The reasons that we doubt the so-called Yushu ophiolite are given below:

1. Pyroxenite-peridotites, sometimes associated with gabbro, were small-scale magmatic intrusions with typical cumulative structure, but now are tectonized blocks, with the characters much different from the abyssal peridotite of ophiolite. Besides, it is characterized in composition by a high abundance of TiO_2, Al_2O_3, CaO and total REE, and low MgO, away from the compositional region of ultramafic cumulates of a common ophiolite, e.g., the ophiolites in south Tibet and Cyprus.
2. Volcanic rocks in the region consist of a tholeiitic series and two calc-alkaline ones, inluding various pillowed, sheet or massive lavas and pyroclastics. They occur conformably and intercalated with marine sedimentary layers. The sedimentary facies and fossils in these rocks suggest that these rocks formed in a marginal sea environment , and the sea water was getting shallower from north to south. As a conclusion, these volcanic rocks were not a part of oceanic crust formed on the sea floor.
3. Compositional features suggest that the gabbro and diabase in Yushu formed not in a same magmatic system. This, in coupled with no occurrence of other ophiolitic rocks in the region, further indicates that there is no ophiolitic association in Yushu. In summary, lines of evidence from the A'nyemaqen ophiolite belt and the strata at its two sides suggest that there was a suture representing the closure of paleo-Tethys ocean along the South Marginal Fault of Kunlun Mountains. The subduction occured during the lower to upper Triassic, from south to the north. The mafic-ultramafic rocks and volcanic rocks interlayered with marine facies sedimentary rocks in the Yushu region are the consequence of an extensional environment at a passive continental margin. The genesis of these igneous rocks were related to the northward drift and subduction of the plate and the closure of the paleo-Tethys ocean.

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Magmatic underplating of the lower crust of the Kohistan arc (N. Pakistan) deduced from Al-zoning in clinopyroxene and plagioclase

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The Kohistan complex, lying in the north-western part of the Himalaya, has been considered as a Cretaceous magmatic island arc, namely the Kohistan arc [1-3]. The complex displays a widely exposed lower crustal section composed of metabasic rocks (amphibolites, pyroxene granulites and garnet granulites) with gabbroic origin. Because the lower crust of the Kohistan arc, commonly, has a mafic composition derived from gabbroic magma, magmatic underplating should be considered as a crustal generation mechanism. During the period of subduction-related magmatism, the underplated materials at middle to deep crustal level could subsequently undergo metamorphism under high-T conditions corresponding to upper amphibolite to granulite facies. Hence metabasites derived from a gabbroic protolith of the lower crust might preserve information of the metamorphism after cooling from magmatic temperature. Metamorphic P-T paths of the rocks would provide a constraint on the overall history of crustal evolution.

The lower crustal part of the Kohistan arc is devided into three geological units: the Jijal complex, the Kamila amphibolite belt and the Chilas complex, from south to north. Yamamoto [4] proposed a tectonic thickening model on the basis of two contrasting P-T paths of garnet-bearing granulites in the Chilas and Jijal complexes. The P-T path of the Chilas complex involved approximately isobaric cooling at relatively low pressure conditions, whereas that of the Jijal complex showed anti-clockwise path at higher pressure conditions. Such anti-clockwise P-T paths may reflect crustal thickening due to magmatic underplating or accretion in the crust [5-7]. It is insufficient, however, to consider models for these P-T paths, because the P-T path for rocks of the Kamila amphibolite belt, which is sandwiched by the Chilas and Jijal complexes, has not documented well. To understand the evolutional process of the lower crust of the Kohistan arc, determination of P-T paths of the Kamila amphibolite belt is needed.

The lower crustal rocks of the Kohistan complex (northern Pakistan) are mostly composed of metabasic rocks such as pyroxene granulites, garnet granulites and amphibolites that were originaly gabbros. P-T trajectories of the relic two-pyroxene granulites, which are the protolith of the amphibolites within the Kamila amphibolite belt have been investigated. Aluminous pyroxene retains igneous texture such as exsolution lamellae developed at core. The significant amount of Al in clinopyroxene is buffered by breakdown reactions of plagioclase accompanied by film-like quartz as a product at grain boundaries between plagioclase and clinopyroxene. Distinct Al-zoning profiles are preserved in pyroxene with exsolution lamellae at core and plagioclase adjacent to clinopyroxene in pyroxene granulites. In the northern part of the Kamila amphibolite belt, Al-contents in clinopyroxene increase toward the rim and abruptly decrease at the outer rim, and anorthite contents in plagioclase decrease toward the rim and abruply increase near the grain boundary between plagioclase and clinopyroxene. In the southern part of the Kamila amphibolite belt, Al-contents in clinopyroxene and anorthite contents in plagioclase simply increase toward margin of the grain. The anorthite zoning in plagioclase is in agreement with the zoning profiles of Ca-tschermaks and jadeite components inferred from variations of Al, Na, Ti and $Fe^{3}+$ in clinopyroxene. Assuming that the growth surface between them was in equilibrium, geothermobarometry based on Al-zoning in clinopyroxene coexisting with plagioclase [8] indicates that metamorphic pressures significantly increase with increasing temperature under granulite facies metamorphism. The peak of granulite facies metamorphism occurred at conditions of about 800 °C and 800-1100 MPa. These prograde P-T paths represent a crustal thickening process of the Kohistan arc during the Early to Middle Cretaceous. The crustal thickening of the Kohistan arc was caused by accretion of basaltic magma at mid-crustal depth.

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Major and trace element composition of post-collisional, peraluminous Garam Chashma granite in Trans-Himalaya, northwestern Pakistan

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Garam Chasma granite belongs to a suit of granitoids of the Asian continental plate in the Hindu Kush Range (Trance Himalaya), northwestern Pakistan. It is located about 30 km northwest of Chitral and northern suture covering an area of about 300 km^2 . The Garam Chashma granite is a discordant and leucocratic rock which intruded into peletic metasediments and amphibolites formed during Barrovian type metamorphism that took place between 40-25 Ma ago. A comparative age of 28-12 Ma has been suggested for the Garam Chasma granite which is same as for some of the Higher Himalaya leucogranites. Petrographically, the major rock forming minerals include quartz, plagioclase, K-feldspar, muscovite and biotite with subordinate garnet and tourmaline. Ratio of muscovite to blotite is not constant. All accessory minerals cordierite has also been reported in the area. Grain size ranges from fine to coarse grained. Texturally the rocks are massive, however, slight to moderate foliation marked usually by muscovite and biotite, espacially near the contact of intrusion can be observed. Aplitic and pegmatitic veins/dikes localising minerals such as garnet and tourmaline are widely spread through out the pluton. A total of about 72 rock samples were collected from the Garam Chasma area. Major and trace components (Ce, Cr, Nb, Ni, Pb, Rb, Sr, Th, Y, Zr, and Ba) were analyzed using X-ray fluorescence spectrometer. On the ternary discrimination diagram, for S and I-type granites, oxide mole values of Al-Na-K, Ca and Fe+Mg predominantly plots on the S-type field suggesting sedimentary source for the Garam Chashma pluton. The silica concentration variation range is very small (71.91-76.08 wt.%). A/CNK ratio is greater than 1 thereby conforming the peraluminous nature of the pluton. Almost all the major elements when plottted against silica, show some sort of depletion trend with increasing silica, whereas Na shows an enrichment trend. Minor depletion trend of K may represent an early formation of K-feldspar along with ferromagnesian minerals during crystalization history of the pluton. Depleting patterns of Ba, Nb, Sr, Ti, and P, commonly found in subduction related magmatism, are observed. Decreasing K/Rb ratios in K/Rb versus Rb plot may be attributed to the fractionation of feldspars.

Furthermore, a chemical compositional comparison based on major and trace elements with two pre-collisional granitold bodies named Tirichmir and Kafristan in Trans Himalaya, located NE and SE of the Garam Chashma respectively, is also performed. Silica concentration ranges for Tirichmir (65.96-72.02 wt.%) and Kafristan (64.26-75.72 wt.%) are higher than that of the Garam Chashma pluton, because of their predominant granodioritic nature. A/CNK plots reveal peralumonous and meta-peraluminous characteristics of Tirichmir and Kafiristan plutons, respectively. In Si versus K plot, potasium shows an enrichment trend in Tirichmir and Kafristan plutons when compared to Garam Chashma. Ca and Fe concentrations are higher than those for the Garam Chashma pluton because of the presence of more mafic minerals. However, higher Ca and Fe concentrations and lower Mg concentration in the Kafiristan pluton than the Tirichmir pluton, are probably due to the higher concentraions of hornblend in the former. Pb, Rb, Y, Th and Zr concentrations show enrichment in mafic fractions of both the granitoids. A positive correlation of Ba and Sr represents fractionation of mineral phases such as plagioclase and K-feldapar of the Garam Chashma pluton and hornblende, feldspars and blotite of the Tirichmir and Kafiristan pluton.

Keywords: Garam Chishma granite, post-collision, major and trace elements, peraluminous, S-type, northwest Pakistan.

Genesis of stratabound scheelite mineralisation, Chitral, Northern Pakistan

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Tungsten mineralisation lies within the Asian plate approximately 50 km to the north-west of Main Karakoram Thrust, which marks the suture zone between the Kohistan complex (Northern Pakistan) and Asian plate. Arkari Formation hosts the stratabound tungsten mineralisation at Miniki Gol, Chitral. This Formation is dominantly composed of garnet mica schist, phyllite, calc-silicate quartzite, marble and tourmalinite. Tungsten minieralisation is mainly represented by scheelite in the study arc. Scheelite has been found in various rock types but is mainly

concentrated in calc-silicate quartzite and subordinate tourmalinite. It occurs as discontinuous patches, stringers and conformable small veins within calc-silicate quartzite and thus can be classed as stratabound type.

Miniki Gol area has undergone at least two phases of deformation and metamorphism which are related to continent-arc collisions during the Cretaceous and Eocene, respectively. The Miniki Gol metasediments are intruded by leucogranites emplaced after the culmination of amphibolite facies metamorphism. This felsic intrusion seem to be contemporaneous with the sencond phase of deformation.

Both the continuity and distribution of scheelite mineralisation appear to be influenced by the internal structure in the calc-silicate quartzite and tourmalinite. Scheelite in these rocks has partitioned along both overprint penetrative foliation and crenulation foilation. The concentration of some scheelite grains in hinges of the kink folds suggests that these foliation planes probably have acted as loci for the epigenetic mineralising fluids. The presence of scheelite grains within the cross-cutting quartz veins also suggests a post-granitic enrichment of the tungsten mineralisation.

The occurrence of calcic-amphibole (hornblende-actinolite), clinozoisite, titanite, calcite, anorthite, grossular garnet, diopside and scheelite fairly coordinates with the skarn mineral assemblage. Except for diopside and grossular garnet, these mineral compositions appear to show a consistent and dcommon trend through out the deposits. This also establishes a genetic relationship between sheelite mineralization and Miniki Gol leucogranite.

The high concentratio of Zr, Hf, Be, Th, U, Ga, Nb, Y, Sn and W in scheelite-bearing calc-silicate quartzite compared to the unmineralised calc-silicate quartzite, psammite and schist implies a hydrothermal activity at the Miniki Gol area.

Moreover, the consistency of the fluid inclusions both within leucogranite and calc-silicate rock also signify a genetic link between the scheelit emineralisation and the possible post-magmatic hydrothermal fluids.

A passive rift and its role in the evolution of southern Indus basin

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The vast sedimentary basin, named as southern Indus basin (SIB), is characterized by several buried structural "Highs" or "Up-warps", like Sibi, Jaccobabad, Khairpur, Mazri, Hyderabad, etc. Most of the geo-scientists considered the existence of these "Highs" due to the presence of subsurface finger-like extensions of the Indo-Pakistan shield. However, these features are still enigmatic and therefore, a tectonic picture of the region in relation to the exposed tectonic structures in the surrounding areas of the SIB, could not be developed so far. The present study is undertaken to elucidate the plausible interpretation for the deep-seated tectonic features related to the SIB and their relationships with the thin skin geologic structures found on the surface.

Aeromagnetic data of the study area between latitude 24° to 28° N and longitude 66° to 70° E, have been re-interpreted in the context of modern plate tectonic concept. The magnetic study has provided satisfactory information about the crystal rock units at the surface and also at different depths in the area of the Bela ophiolites. To analyze the structures and their interrelationships with the tectonic movements through times and the present tectonic picture of the region, in addition to the magnetic analysis, the study on seismicity has also been incorporated to reconstruct a reasonable tectonic picture of the area. Data of epicenters from 1905 to 1981 have been collected from different sources and used to analyze the pattern of seismicity in relation to the proposed tectonic model of the region.

Based on the present analysis, the SIB is identified as an extensional fossil rift basin. A failed-rift crustal feature is inferred overlain by a thick pile of the sedimentary rock sequences, which resulted as a consequence of incipient divergence of the Indo-Pakistan subcontinental plate from the Gondwanaland during Late Paleozoic time. On the basis of the magnetic anomalies trend, the Indus basin failed-rift feature is characterized by "horst and graben" structures and the associated system of transcurrent faults. The association of the seismicity events with the basement crustal features, indicates that the Tertiary re-activation of individual segments of the inferred failed-rift structure, has deformed the overlying rock sequences of the Indus basin and also in the surrounding areas, partially the fold-thrust belt of Pakistan on the western side of the basin.

Land slide hazard zonation in the Hindukush mountains at Golen Gol hydropower project, Chitral: A terrain evaluation approach

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Mitigation of disasters can be successful only when detailed knowledge is obtained about the expected frequency, character and magnitude of natural phenomena which may cause disaster in an area. The zonation of hazard must be the basis for any hazard mitigation project. To map such zones, a terrain classification map (TCM) has been prepared assuming slope as basic element. A land use map (LUM) was prepared using aerial photographs. A combination of TCM and LUM provides fair assessment of slope, vegetation, geology /structure and land use. Five hazard prone zones have been identified i.e. old stable land slides, old active land slides, recently active land slides and potential land slide zones. The interpretation of TCM, lineament map and engineering geological map leads to the conclusion that the area of thrusts and ridges are more prone to land sliding.

Structures in the lower units of the Kohistan arc, NW Pakistan: preliminary results

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In NW Pakistan, the Kohistan paleo-arc, which was developed as an island arc above the northward subduction zone of the Tethyan ocean during the Mesozoic, separates the Indian from the Asian plates. The southern boundary of the Kohistan arc is the so called Main Mantle Thrust (MMT), a crustal scale, northward dipping thrust on which the southern parts of the Kohistan arc have been thrust over India (Fig. 1, overview map).

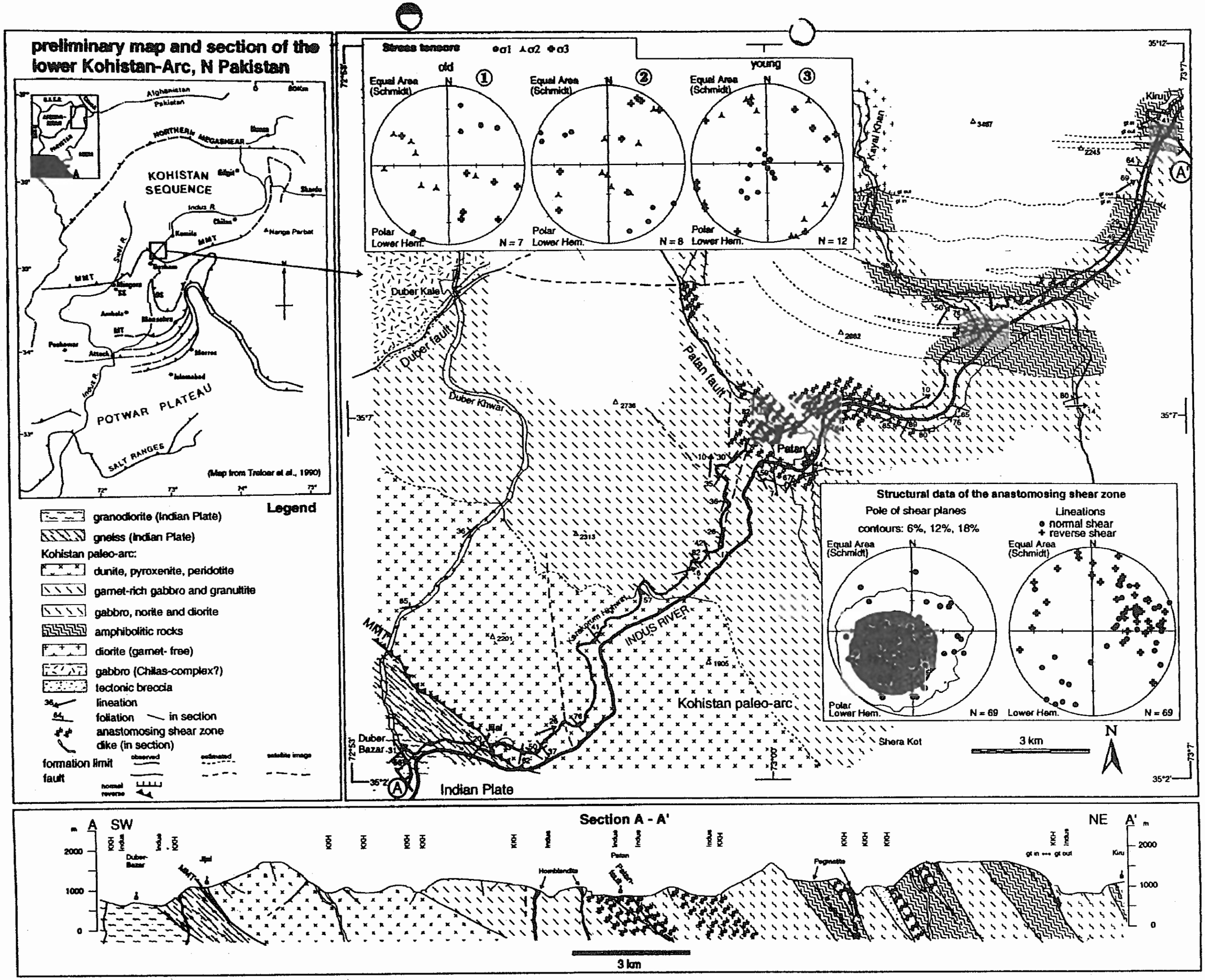
Preliminary results of detailed mapping carried out in the uppermost Indian plate (at Duber-Bazar; Fig. 1) and the low levels of the Kohistan paleo-arc (from Jijal to Kiru) has covered the following lithologies:

Indian units: Granodiorite and strongly foliated gneisses. SW of MMT the gneisses are folded parallel to the SW trending stretching lineation. Kinematic determination shows a dominant southwestward sense of shear.

Kohistan units: The lowest levels of the Kohistan paleo-arc are dominated by dunites, pyroxenites and peridotites. Dikes of greenish chromite-clinopyroxenites cut this ultramafic sequence. Upwards, meta-gabbros (age 101±5 Ma., R. Anczkiewicz, oral com.) with high magmatic garnet content complement the so called Jijal Complex [1, 2]. Ca. 700 m SW of Patan, anastomosing shear zones appear in these garnet rich rocks. The density of the anastomosing shear deformation increases northward in this ca. 3 km wide zone, up to 2 km NE of Patan (Fig. 1). This shear zone is described in more details in a companion poster [3]. To the NE of this anastomosing shear zones, rocks are variable in composition, but mainly comprise of gabbros, hornblendite gabbros, diorites, norites, amphibolites and smaller bodies of nearly pure hornblendite (Kamila Belt). Pegmatites intruded this sequence during and after ductile deformation and correspond to a late magmatic event.

In this poster we present structural data on the anastomosed shear zone. The anastomosed shear zone, developed during finite magmatic stage, shows all deformation facies from undeformed protolith to ultra-mylonite (for details: [3]). The sense of shear on the dispersed, but in average flat to NE dipping shear zones shows dominantly SW directed relative movement of the hanging wall and minor NE directed shear. To the NE of these zone of anastomosing pattern, other shear zones form parallel W-E striking units of amphibolite facies (age 83±1 Ma., [4]). These regular shear zones, containing porphyroclastic garnet, reach a thickness of up to 20 m. Lineations strike NE-SW. The foliation of the shear zones dips more regularly to the NNE and the relation between normal and reverse shearing is balanced. The difference in the features and age (ca. 18 Ma.) between the anastomosed shear zone and the amphibolitic shear zone let us to separate the Kamila shear zone s.s. [4], to the NE, from the Patan ductile shear zone, which is the anastomosed system described here and in the companion poster [3].

The region underwent late, pervasive faulting. Striations record essentially strike-slip and normal faulting. Results of principal stress calculation show three different stress fields: a poorly recorded one has a SW-NE maximum compressive principal stress (σl), a second one has a NW-SE σl, dominantly identified by strike-slip movements. Preliminary analysis of superimposed striations indicates the SW-NE (σl as the older one. The youngest, best represented stress field shows a SW-NE minimum principal stress and steep σl, responsible for normal faulting. The NE dipping Patan-fault is a prominent fault-structure (Fig. 1) which cuts the anastomosed shear zones. Minor offsets in lithology, recent seismic activity [5], rotated blocks (indicated by the change of foliation attitude from mainly W-E to NNE-SSW, south of Patan-fault) and the smooth topography in the widened Indus valley at Patan indicate a still active Patan-fault, but it seems to be a recent and regionally minor fault-contact.



preliminary map and section of the lower Kohistan-Arc, N Pakistan
KOHISTAN SEQUENCE
POTWAR PLATEAU
SALT RANGES
(Map from Treloar et al., 1990)
Legend
granodiorite (Indian Plate)
gneiss (Indian Plate)
Kohistan paleo-arc:
dunite, pyroxenite, peridotite
garnet-rich gabbro and granulite
gabbro, norite and diorite
amphibolitic rocks
diorite (garnet- free)
gabbro (Chilas-complex?)
tectonic breccia
lineation
foliation
in section
anastomosing shear zone
dike (in section)
formation limit
fault
Stress tensors
old
young
Equal Area (Schmidt)
Polar Lower Hem.
N = 7
N = 8
N = 12
Structural data of the anastomosing shear zone
Pole of shear planes
contours: 6%, 12%, 18%
Lineations
normal shear
+ reverse shear
N = 69
Duber Kale
Duber fault
Duber Khwar
Patan fault
Patan
INDUS RIVER
Karakorum highway
Kohistan paleo-arc
Indian Plate
Duber Bazar
Jijal
MMT
Kayal Khan
Kiru
Shera Kot
3 km
Section A - A'
SW
NE
Hornblendite
Pegmatite

Fig. 1

The Patan ductile shear zone must be separated from the Kamila shear zones. Further work on these structures will give more details about the evolution of the "Patan shear zone" and the relationship with the Kamila shear zone.

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Crustal reworking at Nanga Parbat: The Nanga Parbat Continental Dynamics Project

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A considerable amount is now known about the Nanga Parbat massif, which has been the focus of intense study over the past several years by several teams. Our ongoing Nanga Parbat Continental Dynamics Project has been using Nanga Parbat as a natural laboratory to examine processes of pervasive synorogenic crustal reworking, on the basis that the Precambrian rocks of the massif have been deeply overprinted by a recent and intense metamorphic, magmatic, and deformational episode that remains active today. We are currently synthesizing results from investigations in the areas of magnetotellurics, seismology, structural geology, tectonics and neotectonics, geochronology, geomorphology, petrology, geochemistry, and dynamical modelling in order to test hypotheses about mesoscale linking between petrologic, tectonic, and surficial processes.

The Precambrian rocks of the Nanga Parbat massif occur within a northward projection of Indian-plate basement flanked to the west and east by rocks of the Mesozoic Kohistan-Ladakh arc terrane and to the north by rocks of the Asian plate. Originally overthrust from the north (in the early Tertiary) by mafic and intermediate volcanic and plutonic rocks of the Kohistan terrane, Nanga Parbat basement has recently been exhumed by NW-directed thrusting and development of a large north-south oriented antiform. Ferocious exhumation has occurred by mass wasting and glacial erosion, with the nearby Indus River providing efficient removal of debris from the region: fluvial incision rates along the Indus are among the highest in the world, reaching 12 mm/yr (Burbank et al., 1996). The summit massif in the central portion of the antiform is ringed by concentric isograds which culminate in cordierite-K-feldspar grade, and in this region a moderate number of undeformed granitoid dikes and pegmatites as well as a few small bodies of undeformed granite occur. To the south of Nanga Parbat, towards Babusar Pass and the relatively low-grade rocks which occur there, there is a major telescoping of isograds across what is most likely a thrust system of some sort.

Much of the exposed geology at Nanga Parbat is young or the result of ongoing rapid processes. The 7000 meters of relief defined by Nanga Parbat and the Indus River reflect unroofing rates as high as 5 mm per year, as documented at several time scales by geomorphic, petrologic, and fluid-inclusion studies. These rapid unroofing rates are also reflected in the very young cooling ages seen within the Nanga Parbat massif, with mica Ar-Ar ages of as young as 1 Ma and metamorphic monazite ages on migmatites of known P-T conditions of as young as 3 Ma; these data suggest cooling rates for exposed surface rocks of well over 200 °C/m.y., and unroofing in the past 3 Ma of some 15-20 km. Granite ages from 1 to 8 Ma indicate that emplacement in at least some places took place during exhumation, leading to the suggestion that some of the Nanga Parbat granites owe their origin to decompression melting. There is abundant evidence for fluid flow within the Nanga Parbat massif involving circulation of metamorphic and magmatic waters as well as penetration of meteoric water to depths having temperatures of some 600°C. This fluid flow and the high thermal gradients under the massif are attested to by the presence of numerous hot springs, and fluid-inclusion studies suggesting gradients over the top 3km being some 100 °C/km. Active faulting is common within the Nanga Parbat massif, and includes the substantial NW-directed Raikot/Liachar thrust, which places basement over gravels, as well as faults further outboard to the west of Nanga Parbat which have displaced rocks of the Kohistan terrane. The massif is quite active microseismically, but only to depths of some 7 km, presumably reflecting the high thermal gradients and a shallow brittle-to-ductile transition. To date we have found no evidence for significant extensional exhumation and it appears that the extreme exhumation at Nanga Parbat stems from erosion of rocks exposed by reverse faulting.

The relationship between the spatially rather limited metamorphic anomaly at Nanga Parbat and its broad geodynamic setting is an important question to which we are ultimately directing our efforts. Recent reports by J.-P. Burg and coworkers suggest that the geology and active tectonics of Namche Barwa, located at the far eastern end of the Himalayan chain, is remarkably similar to that seen at Nanga Parbat. The location of the Himalayas' two hyperactive metamorphic massifs precisely within the orogen's two great syntaxes is surely no coincidence, and raises interesting questions about the nature and evolution of indentor corners.

Post-collision volcanism at the middle section of Gangdese, south Tibet, possibly indicating the delamination of the subducted Neo-Tethyan slab

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Quite a few sites of post-collision volcanic rocks from the middle Gangdese have been investigated by our recent field work. The detailed field observations along several geological sections, located around 5 km north of Wuyou village, northeastern Xigze are summarized. The ascending sequence of the volcanic rocks is as follows: the lowermost part composed of gentle-dipping andesitic debris-predominated conglomerates, is unconformably underlain by the Andean-type andesites ranging in age from late Cretaceous to the early Tertiary; most of the lower sequence is dominated by variable andesites, with the upper part consisting of volcaniclastites, siltstones and coal beds; the upper sequence is represented by large amounts of dacites and the relevant dacitic volcaniclastites; the uppermost is conformable with the Pliocene subaerial coast-debris sediments. The granitic plugs intruding into the volcanic sequence are ubiquitous. Previous datings by isotopes and fossils (Coulon et al., 1986; Li et al., 1992; Xizang Bureau of Geology and Mineral Resources, 1994) suggest that they formed during the Miocene to the Pliocene, i.e. earlier than the northern Tibet post-collision volcanic rocks (Pliocene till the present-day). The available data of major elements of the samples from the Maquiang area (Coulon et al., 1986) and Yangying geothermal field (Li et al., 1992) demonstrate a range from basaltic andesite, through trachyandesite and trachyte to rhyolite. Moreover, K_2O vs. SiO_2 variation shows that the published data, at least in part, fall into the fields of high-potassium calc-alkaline and shoshonitic series, similar to the northern Tibet post-collision volcanic rocks. What is the origin for the post-collision magmatic suites, especially with intermediate SiO_2 contents and relatively high potassium, is still argued. In particular, the post-collision volcanism from Tibet is well coupled with the formation of the Tibetan plateau, so it has consequently carried a large amount of genetic information on the plateau lithospheric progress. It appears that little post-collision volcanic suites have been well documented except for a little part from the northern Tibet. Nevertheless, we speculatively interpret the post-collision volcanism occurring in the Gangdese area as the result of the asthenospheric intrusion caused by the delamination or the removing of the subducted Neo-Tethyan oceanic lithosphere beneath the southern margin of Eurasian Plate; on the other hand, the IDEPTH results in southern Tibet (Nelson et al., 1996) little related the inferred molten layers of the middle crust to the Neogene magmatism of the Gangdese area. The ongoing chemical analyses of the post-collision volcanic samples from the Wuyou-Maqiang-Yangying area, consisting major elements, trace elements, rare earth elements and isotopes, are expected to refine this hypothesis further.

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Dynamics of crustal deformation in the eastern Tibetan plateau

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The crustal motion of the eastern Tibetan plateau is the key to the understanding of the collision and post-collision intracontinental deformation between South China and India, and to research of the dynamic mechanism and process in Tibetan plateau.

As is well-known, the eastern Tibetan plateau is different from the central Tibet. Much of the eastern margin of the plateau lacks evidence for large-scale young crustal shortning and development of foreland basin. Folds and thrust faults along the plateau margin are commonly oblique to and older than the plateau margin.

In the eastern Tibet, the margin of the plateau extends roughly from the western boundary of the Lanzhou-Linxia basin and cross the Qinling, southwards along the Longmenshan fault belt, the Jinpingshan fault, and Xioajinhe fault, then cuts off the Jinshajiang Lancangjiang-Nujiang tectonic belt, and continues westwards into the eastern Himalayan syntaxis. Since Miocene, the tectonic frame in the eastern Tibet is characterized by a wide right-lateral-shear zone that can be subdivided into three units. The western belt consists mainly of a series of NW-trending *en echelon* right-lateral faults; the central belt - a series of NWW-trending *en echelon* left-lateral faults, and the eastern belt - the western margin tectonic belt of the Yangtze block including the Longmenshan faults, the eastern Xianshuihe faults, the Xiaojiang faults, and the Honghe (Red River) faults.

The crustal extension occurs in the southern Longmenshan, and contrasts with the weak crustal shortening in the northern Longmenshan [1]. GPS results indicate the central-eastern Tibet north of the Xianshuihe fault has been nearly stationary relative to South China (velocity of motion 0-5 mm a^{-1}), but are consistent with the apparent extension in the southern Longmenshan and the weak shortening in the northern Longmenshan [2] respectively. Moreover, the current velocity field determined by GPS reveals that the motion vectors appear to constitute a clockwise rotation vertex about a vertical axis in the Longmenshan and nearby the western Sichuan basin. Paleomagnetic record indicated that the Longxi block has undergone clockwise rotation relative to the Ordos block since 1. I Ma [3]. Therefore, it is suggested that the vertex may involve a wider area north of Qinling, and than our GPS coverage.

Another perfect clockwise rotation vortex feature indicated by GPS occurs in the southeastern Tibet region although the velocity of those sites there is relative high, mostly 5-10 mm a^{-1}[4]. And it seems to rotate about the eastern Himalayan syntaxis and perpendicularly transects up a series of surface structure. The active faults in this region are predominantly left-slip and trend south to southeast, nearly perpendicular to the plateau margin. The vortex motion appears to be not restricted by block boundaries. The velocity vector, on the contrary, is constrained by this vortex, hence causing a further segmentation within a block and along a fault. For example, within Chuan-Dian block, the motion is getting smaller towards southeast, and the direction of vectors changes from SSE to about south and SW. Correspondingly, the motion along the fault, the Honghe fault changes from a strike-slip to oblique-extension and convergence, and even to non-motion at last.

Seismic profile research indicates that the thickening of crust in the eastern Tibetan plateau may result mainly from the development of lower-velocity layer within the middle upper crust and the thickening of the lower crust, and the contribution of individual factors of these two processes to the thickening of crust is - 40%, respectively. But the development of lower-velocity layer may be regarded as an old erogenic process, as most of ductile shear belt in that region is the Miocene and/or older in age [5]. So we may suggest that the major deep process responsible to the young surface deformation in the eastern Tibetan plateau is a material flow--probably--lower crustal flow, and a new model of viscosity sheet well constraining the rheologic process [6]. The two above-mentioned vortices which transect up surface structures may represent the lower crustal flow decoupling from surface deformation. Seismic imagine [7] reveals that the vertices occur in a transitional region from high-velocity area to low-velocity area, especially the apparent gradient between the high-velocity area under the eastern Himalayan syntaxis and the low-velocity area east of the former may result in the dynamic process of material flow.

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Tectonic evolution of the northeastern part of the Qinghai-Tibeten plateau since Mesozoic and uplifting mechanism

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The northeastern part of the Qinghai-Tibeten plateau is a composite terrane which is bounded by Altyn-Tagh fault, Longmen thrust fault and Bangong-lake-Nujiang fault. The composite terrane is composed of Qilian terrane, Qaidam terrane, Kunlun terrane, Bayan Hara-Songpan Ganze terrane and Qiangtang-Changdu terrane. On the basis of geophyscial investigation, it is pointed out that the Alashan craton and Yangtze craton are interward subducted under the plateau from its north and east, respectively. The Altyn-Tagh sinistral strike-slip fault located at the northeast, with the direction of NEE-SWW, shows the characteristic of lithospheric fault which is extending steeply to the depth of 150km beneath the Qaidam basin. It is the same with the Bangong lake-Nujiang fault at the south, which extends northward deeply to the depth of 100km.

When the Paleo-Tethys ocean basin such as Anymaqen ocean basin and Jinshajiang ocean basin (P_2-T_1) began to close, the Paleo-Tethys composite terrane was developed, joined with Qilian-Kunlun terrane, Bayan Hara-Songpan Ganze terrane and Qiangtan-Chengdu terrane. After the Neo-Tethys ocean basin such as Bangong lake - Nujiang ocean basin (T_3-J_1) closed, the Paleo-Tethys composite terrane again joined with Lhasa terrane. During the collision of the terranes, there occurred Indosinian orogeny at the end of early Mesozoic(T_3) and Tanggula orogeny at the end of late Mesozoic(J_3). The deformation characteristics of Indosinian orogeny are shown as a strong convergence and crust shortening at the east side, forming a thrust imbricated slab. And at the west side, ductile strike slip fault, e.g. South Kunlun fault and Jinshajiang fault, formed and made the terranes extruded eastward. At Late Mesozoic, Tanggula orogeny was presented by the Jura-type folding and faulting movement as well as the sinistral strike slipping along the South Kunlun and the Jinshajiang suture zone.

The Cenezoic tectonic events happened at the northeast of the Qinghai-Tibet plateau are as follow:

1. The north part was compressed along NE-SW direction and formed two-directed thrust structures; the east part was compressed along NW-SE direction and formed thrust imbricated slices.
2. The sinistral strike slip movement of the Altyn taugh fault.
3. The basin-mountain system, in which the Qaidam basin was formed at the center of the plateau and the sinistral strike-slip pull apart basin at the north and south side of the Qaidam basin, was produced.

4. In Bayan Hara and Qiangtang terranes (in Hoh Xil), a large scale Cenozoic alkaline volcanic lava erupted.

According to the geophysical data, there exists a large low velocity body at the depth of 250-350km in beneath Hoh Xil region, and low velocity layers in the lithosphere beneath the Qaidam basin. All of these probably reflect that there is a heat drive-force caused by mantle diapir in the interior of the plateau, which may be one of the important mechanism of the Qinghai-Tibet plateau's uplifting.