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# THE HIGHER HIMALAYA CRYSTALLINE UNIT, UPPER KAGHAN VALLEY, NW HIMALAYA, PAKISTAN

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## ABSTRACT

*Kaghan valley, in north Pakistan, provides an unparalleled cross-section of the Indian Plate in the Himalaya, with all of the tectonic units, structural features and metamorphic grades of the Indian Plate exposed in one valley. The Higher Himalaya Crystalline of the NW Himalaya, which crops out in the upper reaches of the valley, is a complex sequence of granites, gneisses, Calc-pelites, metapelites, marbles, amphibolites, quartzites and eclogites. It is bound by two major thrusts: The Main Central Thrust (MCT) to the south and the Main Mantle Thrust (MMT) to the north, which have subsequently led to the exposure of some of the deepest level rocks of the Indian plate during its collision with the Asian plate. A complex deformational history of pre-, syn-, and post- "Himalayan" age is associated with a pre- to syn- deformational upper amphibolite (kyanite to sillimanite) to eclogite facies metamorphism which reached in places over 650 °C, as evidenced by minor insitu granitization.*

*The Higher Himalaya Crystalline of Kaghan Valley is structurally positioned between three major syntaxes: the Hazara - Kashmir Syntaxis (HKS), the Kaghan Syntaxis (KS) and the Nanga Parbat Syntaxis (NPS) which are interpreted as forming due to a change in transport direction. Between the Kaghan Syntaxis and the Nanga Parbat Syntaxis, the Higher Himalaya Crystalline consists of a polyphase, superposed folded domain which produces the Burawai syncline, the Besal anticline and synclines and other large scale features located to the south in Neelum Valley. The fold interference patterns are affected by the extreme ductility of the rocks and caused the rotation of, not only the first fold axis, but also the whole interference structure itself, as seen by the asymmetric shape of a Besal antiform.*

*A provisional tectonic analysis of the features observed suggest that the first southwestwards-directed phase of nappe transport led to a thickening of the tectonic pile, and that thickening was followed by a northeast-southwest directed*

*deformation. This is in accordance with movements suggested for the formation of the Hazara-Kashmir and the Kaghan syntaxis and leads to the sugges tion of a similar model, with a further increment of anticlockwise transport direction change, for the formation of the Nanga Parbat Syntaxis.*

## INTRODUCTION

The Himalaya forms one of the most prominent features in the topography of the world. They form the northern boundary of the Indian sub-continent in a huge 2500 km long arc, which is approx imately 320 km wide, between India and the Tibetan plateau and covers the countries of Nepal, Bhutan, Sikkim and Pakistan (Fig. 1). The Himalayan orogenic belt resulted from the continental collision of the Indian and Asian continents in the Cretaceous- Early Tertiary along suture zones, part of which are still active today. It is an outstanding area for the study of geology as:

The extent of the belt is immense (12,000 $km^2$ for the metamorphic core alone).

Extreme relief and the moderate northward dip of the tectonic units conspire to produce exposures of crustal sections which exceed 10 km in thickness.

The central part of the Himalayan belt include well documented examples of major thrust faults with demonstratable offsets in excess of 100 km, abundant granitic plutons related to tectonic activity, and large scale, low angle normal faults which partially accommodate unroofing of the metamorphic core. It is, therefore, possible to get a direct evaluation of the relative importance of these in the structural, metamorphic and tectonic evolution of a mountain belt.

The orogen is young and still evolving, allowing current tectonics to constrain the past.

This paper aim the several structural, metamorphic and tectonic problems that occur in understanding the complex features seen in an area in Kaghan Valley in NW Himalayas in Pakistan.

## TECTONIC SETTING OF THE NW HIMALAYA, PAKISTAN

The recent opening of the NW Himalayan region (Fig. 2), in terms of accessibility, has made the area one of the best for studying Himalayan tectonics. Numerous valleys are now accessible from the Karakorum Highway to provide a full section of mountain belt preserved in one country (Tahirkheli, 1982; Tahirkheli et al., 1976).

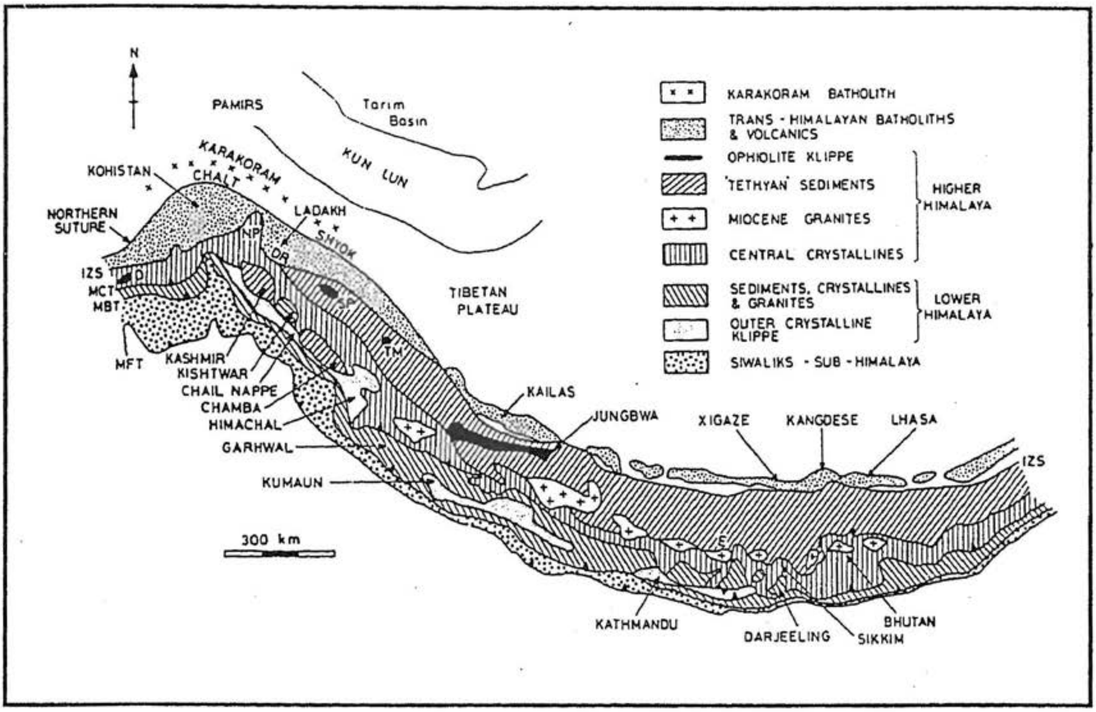



Fig. 1. Map of the Himalaya showing the main tectonic zones (after Windley, 1983). The western syntaxis area is distinctive by the marked change in trend of the major Himalayan thrusts.

The main subdivisions described above were generally defined primarily in the Nepal and Indian Himalayas, based on geomorpho logical, structural and pre-Cenozoic litho-stratigraphic packages. Only recently have workers been able to correlate some of the well known Himalayan features, such as the Mylonite Zone (Greco et al., 1989) as the Main Central Thrust (Ghazanfar et al., 1986) to separate the Higher and Lesser Himalaya and the Murree Thrust as the Main Boundary Thrust (Calkins et al., 1975) to separate the Lesser and Sub-Himalaya (Fig. 3). Coward et al. (1988) has made the most comprehensive survey of the Indian plate region of the NW Himalaya.

In major contrast to the central Himalaya, the structural anomalies of syntaxes exist in the NW Himalaya: the Hazara-Kashmir syntaxis, The Kaghan syntaxis, the Nanga Parbat-Haramosh syntax is, as well as other less well known ones such as Besham syntaxis and the Kalabagh syntaxis. In essence, they are a set of en echelon folds that span the whole of the NW Himalaya and evidence exists that the Asian plate also has similar structures in the Pamir region. That such an abundance of unusual structures occur, which can be found in other orogenic belts, although not as concentrated, need further exploration. The change in the direction of the Indus-Tsangpo suture zone from northwest in Ladakh to west-southwest in Kohistan may reflect the edge of the Indian shield, or give evidence that a different structural evolution for the

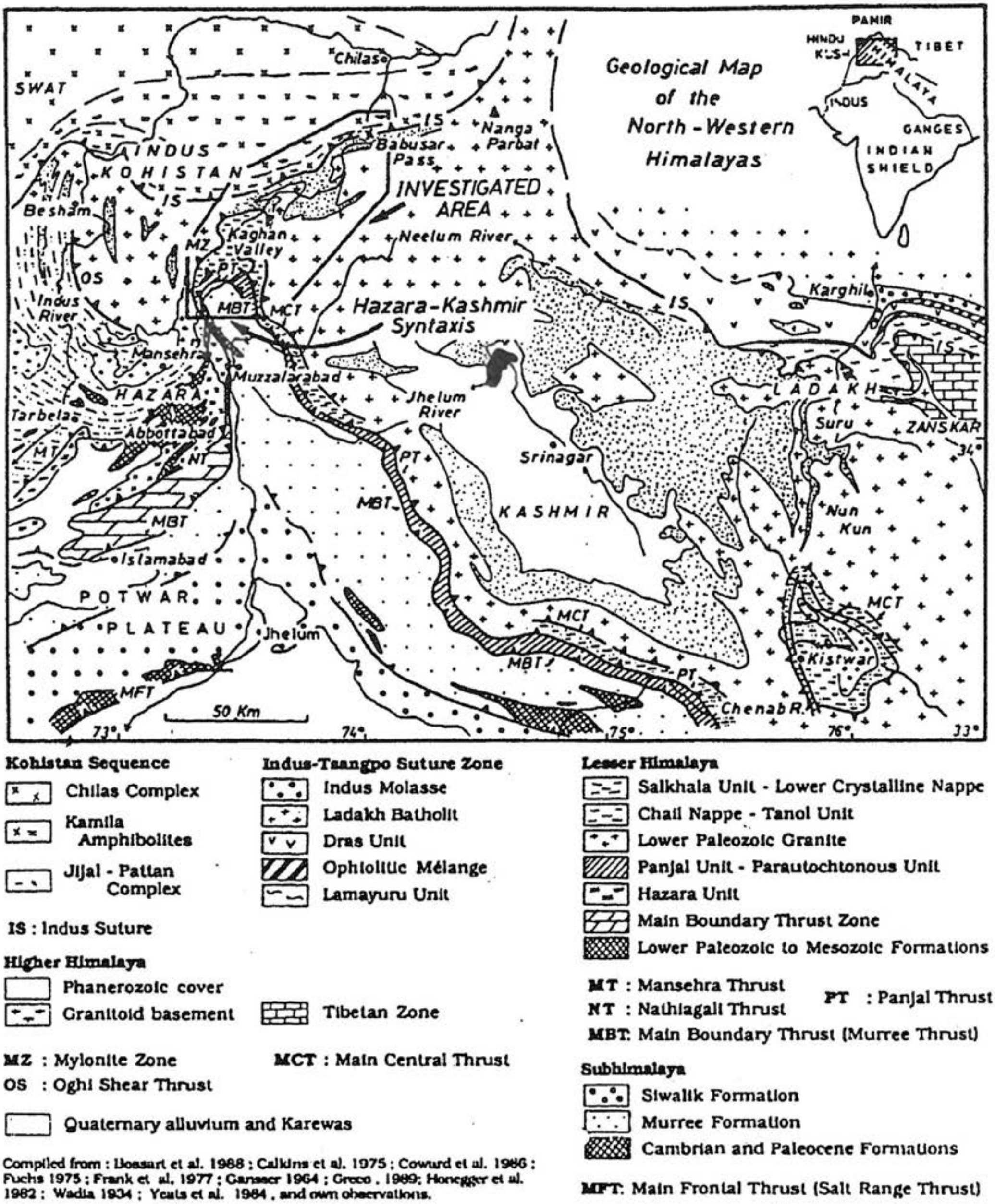


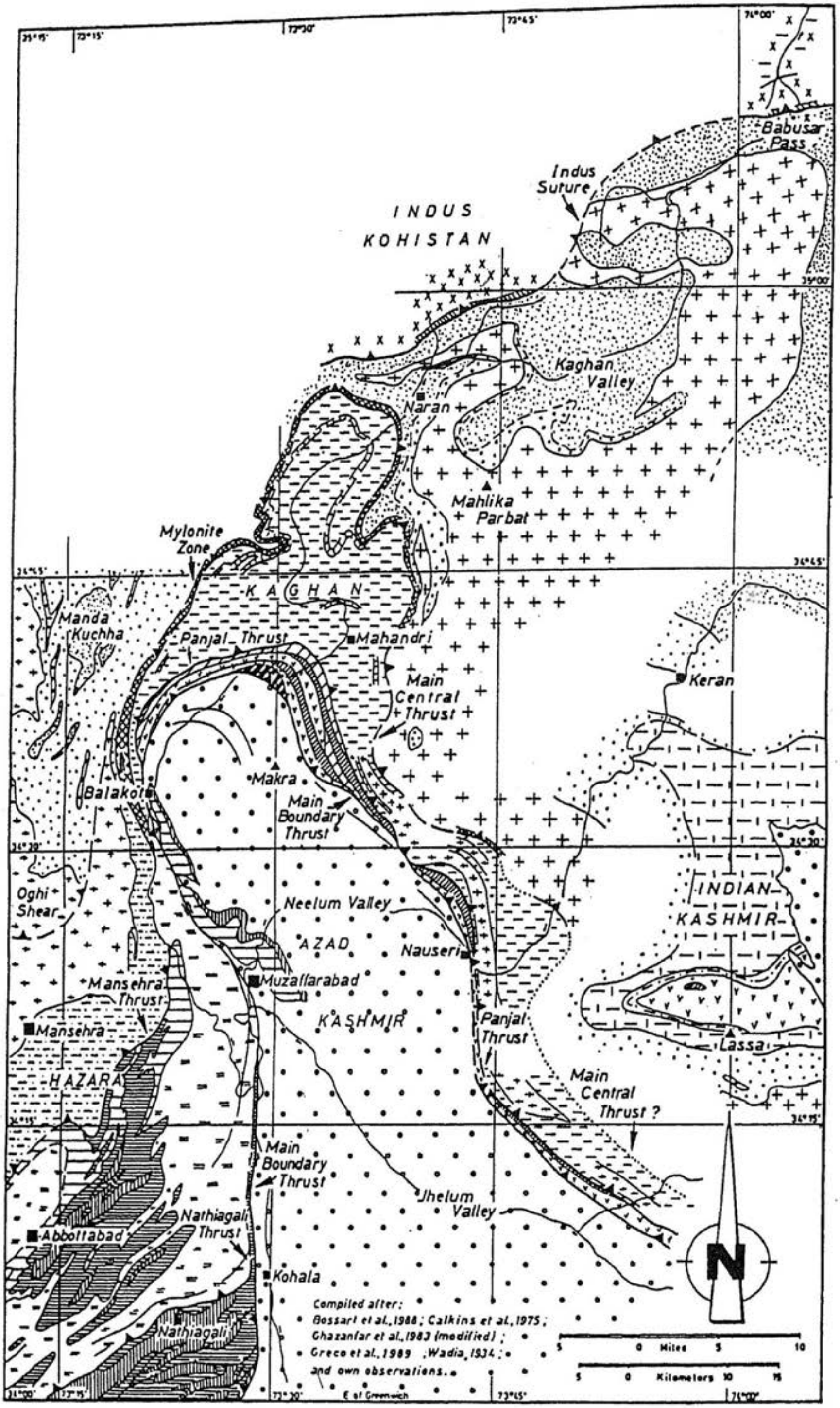

Fig. 2. Geological map of the northwestern Himalaya showing the regional setting of the Higher Himalaya Crystalline in the Kaghan Valley area and the area investigated (after Greco et al., 1989).

region as a whole has occurred. Nevertheless, workers are generally agreed that the whole area is not one of simple thrust ing to the south, as in the central Himalaya, but of two major transport direction movements which have been superposed onto each other to form the complex terrane. Bossart et al. (1988) studied the Hazara-Kashmir Syntaxis and explained its formation due to anticlockwise transport movement from southwest-northeast to southeast-northwest. Greco et al. (1989) used a similar model for similar features in the Lesser and Higher Himalayan Crystalline. Possibilities exist for similar explanations of the structural features in the Besham area, as well as the Nanga Parbat area.

## KAGHAN VALLEY, NW HIMALAYA

Kaghan valley provides us with an extraordinary crosssection through the tectonic units of the Indian Plate (Fig. 3). Geographically, from Babusar Pass, at the head of Kaghan Valley, to Balakot at its mouth, there is only a distance of 165 km or 100 miles where the valley is drained by Kunhar River which runs from northeast to southwest. The crosssection from southwest to northeast up the valley in unique in the whole Himalayas. Essentially, all four major tectonic units of the Indian plate are passed through (Fig. 4) - the Sub-Himalaya, the Lesser Himalaya, the Higher Himalaya Crystalline, the Tethyan Himalaya (Higher Himalaya Crystalline Cover) as well as the Kohistan Island Arc Sequence. These units are bounded by, or have incorporated within them, virtually all of the major thrusts that make up the large scale tectonic features of the Himalayan mountain belt. Near Paras, 25 km from the mouth of Kaghan valley, the Main Boundary Thrust separates the Sub-Himalaya and the Lesser Himalaya. The Lesser Himalaya incorporates the Tethyan Panjal unit and the Panjal thrust, with its imbricate sequences. Near Naran the Main Central Thrust separates the Lesser from the Higher Himalaya Crystalline and the Higher Himalayan Tethyan Cover. Finally, the Indus-Tsangpo suture or the Main Mantle Thrust separates the Higher Himalaya Crystalline from the Kohistan sequence at Babusar Pass.

Most importantly, from a structural point of view, Kaghan valley gives a great insight into some of these structural oddities that are present in the Himalaya. No less than three of the syntaxes can be found in the Kaghan valley. These the structural anomalies where the main linear trends of folds and faults show a marked deflection from the main structural trend and a general curving of these features can be seen. At the mouth of the Kaghan valley (Fig. 4), The Hazara-Kashmir Syntaxis occurs, folding the Main Boundary Thrust and the Panjal Thrust. Near Naran and Batal, a smaller, yet similar in shape, Kaghan Syntaxis is found where the Main Central Thrust is folded. This syntaxis is considered controversial by Ghazanfar & Chaudhry (1986) as they trace the MCT from Chlalayyan south to Balakot but find no evidence that the MCT curves towards Jura in the Neelum valley (Greco et al., 1989). They have traced the MCT much further north to Sharda in the Neelum Valley, suggesting that the Kaghan Syntaxis' is merely an extension of the Hazara-Kashmir Syntaxis. Finally, at the head



Babusar Pass
Indus Suture
INDUS
KOHISTAN
Kaghan Valley
Naran
Mahlika Parbat
Mylonite Zone
KAGHAN
Manda Kuchha
Panjal Thrust
Mahandri
Main Central Thrust
Keran
Makra
Balakot
Main Boundary Thrust
Oghi Shear
Neelum Valley
AZAD
Nauseri
INDIAN
KASHMIR
Mansehra Thrust
Muzaffarabad
KASHMIR
Panjal Thrust
Mansehra
Lassa
HAZARA
Main Central Thrust ?
Main Boundary Thrust
Jhelum Valley
Nathiagali Thrust
Abbottabad
Kohala
Nathiagali
N
Compiled after:
Bossart et al., 1988; Calkins et al., 1975;
Ghazanfar et al., 1983 (modified);
Greco et al., 1989 ; Wadia, 1934 ;
and own observations.
Miles
Kilometers
E of Greenwich

of the valley, we see the beginnings of the Nanga Par bat-Haramosh Syntaxis where the Indus Suture is folded between the Higher Himalayan and the Kohistan Island Arc.

From a metamorphic point of view, from Balakot to Babusar, we pass from the External or unmetamorphosed zones (south of the Panjal Thrust) to the Internal or metamorphosed zone (north of the Panjal Thrust) of the Indian Plate (Coward et al., 1988). Within the Internal zone, we traverse through a complete metamorphic assemblage of greenschist facies in the Lesser Himalaya, to amphibolite and eclogite grade in the Higher Himalaya Crystalline and granulite facies in the Kohistan unit. Even within the Higher Himalayan unit we can see that temperatures reaches very high, at least 650 °C as evidenced by the first ever recording of Himalay an eclogites and minor insitu granitization.

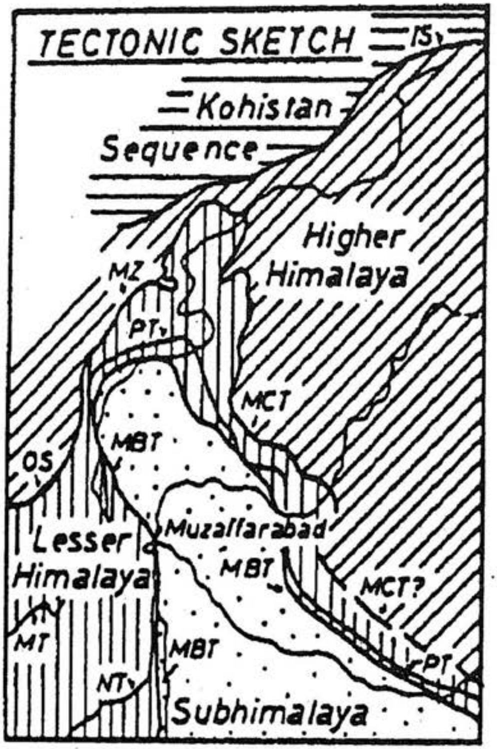
## UPPER KAGHAN VALLEY, NW HIMALAYA

The whole area of upper Kaghan valley can be regarded as the Higher Himalaya Crystalline, being emplaced between the Main Central Thrust and the Indus Suture (Fig. 4). In plan view, it has a wedge-like shape between the two thrusts and seems to show only minor effects related to the emplacement (e.g, retrogression related to the Indus Suture, as well as with the MCT).

Work in Kaghan valley has been done so far by two main groups: firstly the University of Punjab, Pakistan, who mapped the whole of Kaghan Valley, and then the Swiss Federal Institute of Technology, Switzerland, who have worked so far essentially on the Hazara-Kashmir and Kaghan syntaxes. Recent work now covers the area between the Main Central Thrust and the Main Mantle Thrust, between Babusar and Naran. For Upper Kaghan Valley, the following investigations have been carried out: Gansser (1979) - described the 'Main Central Thrust' in Kaghan Valley; Tahirkheli (1979) - described the Indus-Tsangpo Suture or the Main Mantle Thrust; Bossart (1988) - which describes the Main Central Thrust; Ghazanfar & Chaudhry (1985) - geological mapping from the Main Central Thrust to Battakundi; Ghazanfar et al. (1986) - general stratigraphy between the Main Central Thrust and the Indus-Tsangpo Suture; Chaudhry et al. (1986) - metamorphic paper about the Higher Himalaya Crystalline in Upper Kaghan Valley; Ghazanfar et al. (1986) - describes the location of the Main Central Thrust; Greco et al. (1989) - geological mapping from the Main Central Thrust to the Indus-Tsangpo Suture; Chaudhry & Ghazanfar (1987) - geology of Upper Kaghan Valley.

Fig. 3. Geological map of Kaghan valley and adjoining area, NW Himalaya. The Higher Himalaya Crystalline is divided into a basement (which here incorporates the Lower Paleozoic cover due to their deformational similarities and shown by the crosses and large dots) and cover sequence (shown by the small dots), with bed repetition suggesting fold interfere

The Upper Kaghan nappe, as this area is now known, can be regarded as the area: north (from Batal) of the Main Central Thrust, south of the Indus Suture, west of a line roughly drawn SE from Babusar Pass, which is roughly the junction between the Kaghan Valley and the Nanga Parbat Syntaxis (in fact, the Nanga Parbat Syntaxis should also be incorporated into the same tectonic unit as no absolute evidence has yet been found that there is a marked structural discontinuity between the two structures) and, as yet, an unspecified area in Neelum valley.



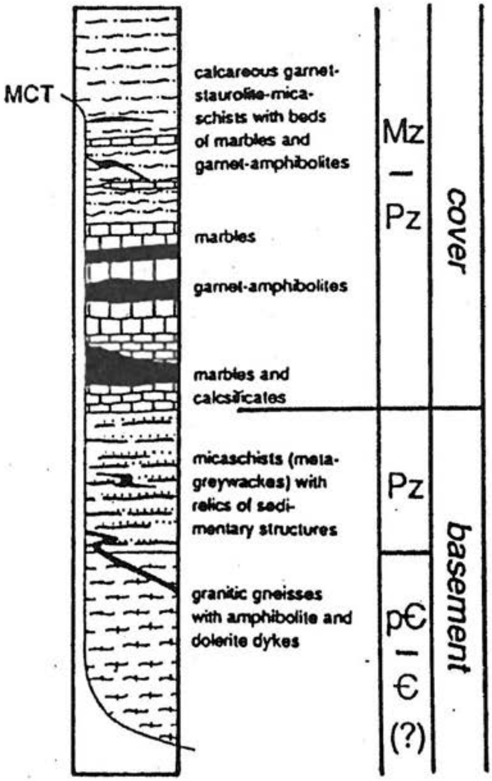




Fig. 4(Left). Tectonic sketch of Kaghan Valley, NW Himalaya. The NW to SE flowing Kunhar river makes a complete cross-section through all the major units of the Indian Plate (after Greco, 1989).

Fig. 5(Right). Stratigraphic profile of the Higher Himalaya Crystalline in Upper Kaghan Valley (after Papritz, 1989). The basement cover division of the Greco et al. (1989) can be seen, with the Panjal Traps occurring at the base of the cover.

## Stratigraphy

The determination of the stratigraphic relationships that exist in the Higher Himalaya Crystalline is difficult, mainly due to the high level of structural deformation under which they have gone. Two main subdivisions of the stratigraphy have been described:

Firstly, a lower basement unit, its autochthonus, possibly Lower Paleozoic cover and finally a Late Paleozoic-Mesozoic cover (Fig. 5) (Greco et al., 1989). The lower granitoid basement consists of gneisses, granite-gneisses with amphibolites and dolerite dykes; a Paleozoic cover consists of metapelites, which are usually without carbonates. There is much local migmatization and intrusion by two-mica granites, as well as incipient anatexis. These two groups are considered as the metamorphic, magmatic and sedimentary products of the Late Pan-African event and, therefore, classed as an entity (basement). A "Tethyan Zone" cover of carbonate schists, marbles and quartzites with, at the base, extensive amphibolite layers, is recognized. Some of the amphibolite rock samples seems to suggest a volcanic origin, as rims can be seen to occur around the feldspar. It is, therefore, suggested that these represent the Panjal Volcanics. This conclusion is reached due to the coherent stratigraphy, geochemical similarity with known Panjal Volcanics and similar stratigraphic sequences seen in the Higher Himalaya Crystalline of the Ladakh area. However, This "Tethyan" unit of Late Paleozoic to Mesozoic age is still controversial and detailed analysis and correlations are saved for future publication. Finally, late stage pegmatites and tourmaline filled leucogranites of Himalayan age cut through all the lithological units.

This basement-cover division was divided on a tectonic / unconformable / disconformable break (Greco et al., 1989) at the base of the Permian Panjal Traps. The three contacts all appear very conformable - there is certainly no high strain zone, so we are probably seeing unconformities. These contacts do not show a metamorphic hiatus, although lithologically the transition is very sharp. For example, the contact from the sillimanite-bearing granitoid basement to its garnet-biotite bearing metagraywacke cover, is an easily mappable contact, but shows no metamorphic or structural discontinuity. Similarly, from the metagraywackes to the continuous amphibole layers, the contact mapped is basically just one of a stark lithological contrast, rather than an abrupt metamorphic or structural contact. The reason for such a phenomenon can only be explained, at present, due to the similar metamorphic and deformation history that the units have undergone. This has obliterated all the previous deformation and metamorphism from the basement units. Finally, some mylonitisation occurs between the contacts of the granitoid basement and surrounding metapelites which is perhaps not uncommon for areas that have undergone such high deformation. However, as these contacts do not continue along strike for great distances it could be that they are localized accommodation features, associated with movements between the layer of the more competent basement to the less competent cover.

A second sub-division of the stratigraphy in Upper Kaghan nappe was based on lithology i.e., granitegneiss, migmatites, amphibolites and calc-pelites (Precambrian). They were all thought to be part of the same group called Sharda Group where everything is conformable and no distinct contacts between major lithologies were found (Ghazanfar et al., 1986). In view of the above revision of stratigraphy, this classification is now accepted too broad for the complex Higher Himalaya Crystalline unit and the above classification is more acceptable.

**Structure**

Structurally, the Higher Himalaya Crystalline in Upper Kaghan Valley is one of a complex history although it should immediately be noted from the geological map, that, there is a continuation and reoccurrence of some of the basement and cover sequences. Structurally speaking, everything that is seen in Upper Kaghan is very different from the structural regimes below the Main Central Thrust. Below the Main Central Thrust, there has been one of brittle, rather than ductile deformation, as seen for example in the Panjal imbricate zone, where a localized thrust or imbrication structure was the general accommodation feature. Above the Main Central Thrust, however, the accommodation of the tectonic compression is essentially by folding, as expected for a more ductile deformed terrain.

Work so far indicates that the whole area can be divided into two structural domains - Burawai domain to the southwest and the Besal domain to the northeast. These features are not so simple as they appear as, in fact, the evidence points to the fact that they are superposed folds. Interpretations of these structures is helped by observing good marker horizons of the amphibolite and granite layers.

Structural data that has been collected so far, in very general terms, shows the lineations with an almost ubiquitous northeast- southwest trend, which is interpreted as the initial southwest thrusting direction. The general trend of the mineral stretching lineation is considered to represent the tectonic X direction of the finite strain state. In a simple shear regime such as thrusting, the lineation will be sub-parallel to the direction of tectonic transport. In general terms, the major first phase of deformation with early formed folds and their associated intersection lineation generally lying very close to the X stretching lineation - a feature best explained by the rotation of fold axis by high strains. The main schistosity is overprinted by small scale crenulation folds and a crenulation cleavage. On a large scale, these trend northeast-southwest with a southeast dip in the Burawai domain and north-south with a east dip for the Besal domain.

In summary, there are two main groups of structures that can be found: The linear structures, such as the first phase fold axis and the mineral lineation and the second phase crenulation cleavage axis - all of which rotate into sub-parallelism; the tectonic planar structures, such as the first phase schistosity and the second phase crenulation cleavage, which are all also sub-parallel. This rotation into sub parallelism with the shortening direction is a very common feature of ductile deformation.

The supervision observed does not seem to fall under a simple classification. It appears to be a series of domes or basins of the Type 1 classification (Ramsay, 1967), which, due to the high ductility environment in which they were found, resulted in the rotation of the first formed fold axis sub-parallel to the second tectonic transport direction. As such, the interference pattern that occurs is possibly a Type 1 to 3, where 1 is the dome itself and 3 is the convergence and divergence pattern of the first formed fold axis (Fig. 6). This explains the unusual shape of the Besal antiform where on plan view it has a shape of a figure "S". The reason for perhaps the differences in the Besal and Burawai structures is probably competence, where the excellent Type 3 patterns are seen in the basement rocks and the more Type 1 patterns are seen in the cover rocks. This feature can be observed on a large scale on the southeastern limb of a Besal antiform, where there is a progressive decrease in the limb dip as we go near the core and up the vertical relief. The opposite occurs on the northwestern limb: there is a steep limb dip on the north and a shallow limb dip on the other side.

It is, however, necessary to note that, in the Higher Himalaya Crystalline, an area of high grade regional metamorphism, the interference pattern is not as clearly recognizable as would be expected from the lower tectonic units. This is because many of the earlier structural elements, such as the primary compositional banding and the possible pre-Himalayan deformation, will have been obliterated by the main deformation forming event - i.e., the northeast-southwest thrusting. It should be noted that there is a slight change in orientation of these second phase structures as a traverse is made up the valley and that the change in structural orientation is similar to the trend of the Indus-Tsangpo Suture, suggesting an intimate relationship.

A consideration should be made on the various ways in which these domal and basin structures by superimposition can occur. They can form, for example, by: basement-cover accommodation, change in principal stress directions during orogenesis, or change in the tectonic shortening direction responsible for the formation of fold. From those possibilities of understanding the way in which a superimposed fold can form, the main indication of fold is more appropriate, has to be seen from a regional point of view. This will be taken into account during the tectonic synopsis.

In summary, the structures around the Besal area have been mapped as basin and domal structures. They seem to be a continuation of the Burawai basin, although some obvious differences occur: the two main strikes of the basin and domes, which are a doubly plunging structure, are "early east-west", followed by a progressively continuous "late north-south", being arcuate at the two ends (i.e., the east and west ends) of the fold. The early fold axial trace is refolded by the latter. Excellent amphibolite and granite layers act as good marker horizons that can be traced throughout the whole structure. The difference in trend of this basin and dome at Besal with the Burawai structure is noticeable, suggesting that the Besal structures have been more influenced in their appearance to its proximity to the Indus Suture.

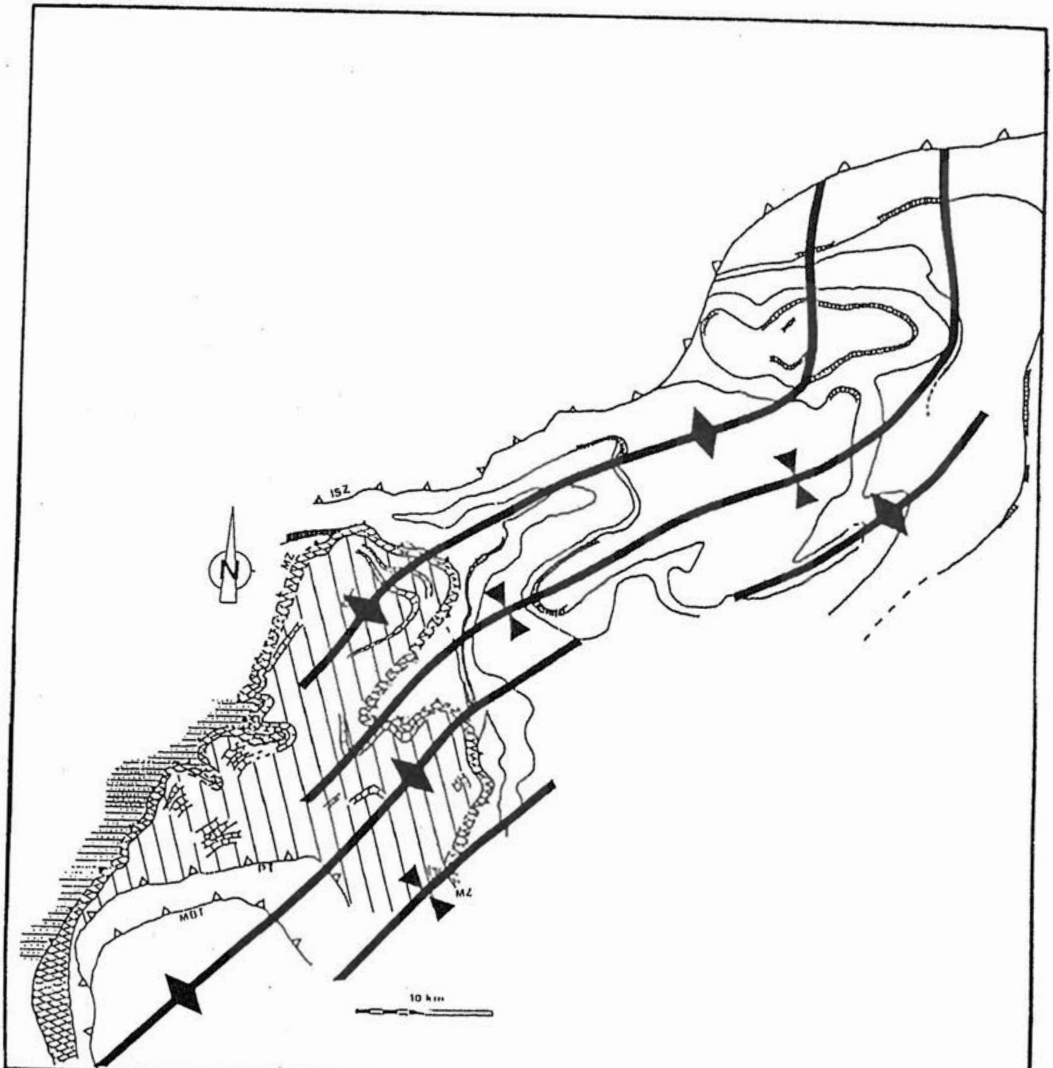



Fig. 6. Geological map of the Higher Himalaya Crystalline in Upper Kaghan. The large scale tectonic interpretation is shown, dividing the area by late stage anticlines (diamond symbol) and synclines (X symbol) and therefore domes and basins.

A proposed working hypothesis for deformation is:

D1: Thrust formation (Indus-Tsangpo Suture followed by the Main Central Thrust) - deformation continued throughout early stages

D2: Southwest-northeast transport movement producing major fold & foliation

D3: Southeast-northwest regional fold superposition, crenulation cleavage formation; D3 probably a progression (i.e., anticlockwise rotation transport direction) of D2

D4: East-west regional fold compression - a progression of D3 - led to the basin and dome formation.

It is noted that, all these movements agree with those suggested for Hazara-Kashmir/Kaghan syntaxes and possibly the Nanga Parbat-Haramosh syntaxis (Fig. 7):

i.e. From SW-NE to SE-NW for the Hazara Kashmir syntaxis
From SSW-NNE to E-W for the Higher Himalaya Crystalline (Burawai synform)
From S-N to E-W for the Higher Himalaya Crystalline (Besal antiform and synform)
From S-N to E-W for the Nanga Parbat-Haramosh syntaxis

This could explain very well the time-relationships in the area, the uplift of the Nanga Parbat-Haramosh syntaxis today and why, in southern Kaghan valley, there are no neotectonic effects.

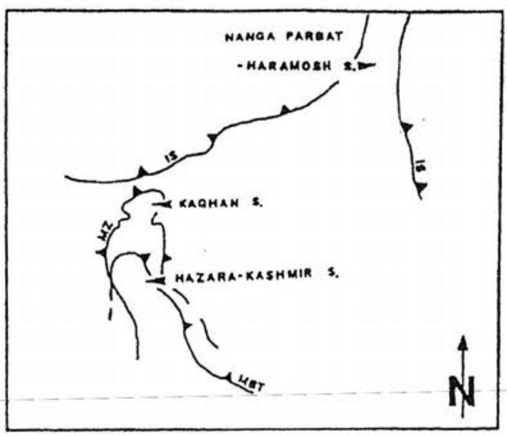



Fig. 7. The three NW Himalayan syntaxes. The Upper Kaghan nappe lies between the Kaghan and Nanga Parbat-Haramosh syntaxes.

**Metamorphism**

A summary of the metamorphic features in the Higher Himalaya Crystalline from Kaghan Valley has been attained, so far, only from field evidence, which are certainly very complex. The only data, therefore, available for this area is from hand samples and thin sections. However, a very interesting working hypothesis seems to be developing and some examples of the metamorphic considerations are:

1) The basement granitoids are considered to be part of an old magmatic suite - evidence for this comes from petrological and age determined samples for similar samples in the same tectonic position (Le Fort et al., 1981). Also, the lack of non-measurable tectonic contacts and metamorphic contact overprint seems to support this assumption. No evidence of pre-Himalayan metamorphism was found in the Upper Kaghan area. This does not suggest that it was not present, but perhaps that the high grade of Himalayan aged metamorphism and removed the possibility of finding it.

2) The main metamorphic event is that of a mainly prograde, pressure dominated metamorphism, essentially Amphibolite facies with kyanite - staurolite - garnet - biotite assemblages. This certainly reached over $650^{o}$ C as evidenced by the occurrence of eclogites and in situ granitization. It appears syn-tectonic with the first-second main phase of deformation. In 11 locations so far in the Higher Himalaya Crystalline, the presence of omphacite (sodium-calcium clinopyroxene) - pyrope (magnesium rich garnet) eclogites are noted. They are found in elongate lenses and are the first known recording of eclogite facies metamorphism in the Himalaya. This would indicate a very high pressure/medium temperature assemblage, which, considering the proximity to the suture, could easily be attained.

3) A later metamorphic event is then suggested to have occurred. Kyanite overgrows the main M1 event and garnets are commonly found with post kinematic quartz rims around them. This suggests, at least, a temperature cooling event almost certainly associated with uplift, which must have been rapid to preserve these features in the first place.

4) Finally, as we reach a proximity to the Indus Suture, a zone of retrogression is found, with very low grade rocks and quartz - muscovite - chlorite assemblage, suggesting mineral instability related to a decrease in temperature and pressure conditions. This event is probably associated with the second- third main phase of deformation.

In summary, the amphibolite and eclogite facies metamorphic conditions that occur in the Higher Himalaya Crystalline were clearly attained in the first deformational phase, possibly obliterating any pre-Himalayan age metamorphism. Metamorphic conditions remained high after the tectonic thrusting phase with a pressure dominated event forming the kyanite and the garnet rims. Retrogression associated the uplift and/or overthrusting of the Kohistan Island Arc is local. Evidence, so far, suggests that the main metamorphic event is syn-tectonic to D2 and generally all upper amphibolite facies, although there seems to be some zonation present. Eclogites have been found and need further investigation. Virtually all the key metamorphic minerals were found: sillimanite, kyanite, garnet, biotite, chlorite and talc. Certainly this high metamorphism reached melting for some layers and formed the late stage granites, which at outcrop scale comprise of upto 50% area. It, therefore, suggests a Himalayan age for this melting followed shortly by rapid uplift, which fits reasonably with observations made so far for the area.

## Tectonics

The geology of the NW Himalayan area shows extremely characteristic features that need explanation. The occurrence of marked changes in strike of major structural discontinuities suggests that a tectonic scenario different from that in the more central parts of the Himalaya occurs. A simple model to explain their formation can be put forward. This model, one of a anti-clockwise change in transport direction, was first used to explain the formation of the Hazara-Kashmir syntaxis by Bossart et al. (1988). It was further established that the Kaghan syntaxis can be explained by a similar model (Papritz, 1989) and subsequently that its application to Upper Kaghan Valley also applies. In general, the deformation can be summarized into broad large scale tectonic events. The first phase is characterized by the formation of the nappes and the thrusts that separate them. Several large, isoclinal recumbent folds and sheets are formed in the Higher Himalayan Crystalline which later led to the formation of the Main Central Thrust. This phase is mainly related with the formation of the main deformational structural elements (penetrative foliation and stretching lineation), and is similar to that defined in Kaghan Group (Ghazanfar et al., 1985). All sense of shear indicators indicate that the Higher Himalaya is thrust over the Lesser Himalaya, with the deformation concentrated in the Main Central Thrust. The ancient shearing direction can be deduced from the orientation of the stretching lineation in the units, which has a SW-NE orientation and the thrusting direction of Higher Himalaya is directed towards 230°. The regional convergence direction of the first tectonic shortening direction is, therefore, SW-NE.

These first phase structures are deformed by a second deformational phase of shortening. The primary orientation of the penetrative foliation is altered by folds with a fold axis that is sub-parallel to the stretching lineation and the thrusting direction. The orientation of the stretching lineation is not altered by the later folds (Papritz, 1989). Interference patterns of Type 1 and 3 are present (Ramsay, 1967) and can easily be explained by the aforementioned change in tectonic shortening directions i.e., that the first southwestwards-directed phase of nappe transport led to a thickening of the tectonic pile, and that thickening was followed by a northwest-southeast directed deformation. A large- scale interference pattern of the two superposed phases led to the doming of the area and resulted in the tectonic uplift of relatively deep crustal levels of the Himalaya and the Upper Kaghan nappe to where it crops out today (Fig. 7).

## CONCLUSION

The Himalayan mountain belt is an excellent example of a continent-continent collision zone, in terms of modern plate tectonics theory. The NW Himalayas provide a well exposed section through this mountain belt where the deformation that resulted from this collision can be studied. The resulting structures can be studied at a field-scale level with an aim of interpreting large scale tectonic features. Upper Kaghan Valley is an important area of exposure of the Higher Himalaya Crystalline, as it is situated between the major syntaxes that make up the NW Himalaya. Modern structural geology techniques can be used to determine the deformational history of the area (Ramsay, 1967; Ramsay et al., 1983, 1987) and are incorporated with metamorphic and stratigraphic studies in the area to build up a tectonic synopsis. In future publications this will be related and compared to current models for the Himalaya and relative plate tectonic theory.

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