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WSW-TRENDING DEFORMATION BETWEEN BABUSAR PASS AND TOSHE GALI AREA, NORTHERN PAKISTAN

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ABSTRACT

The Himalaya and Karakoram Mountain ranges of northern Pakistan are the product of multiple deformational phases from continental collision events that trapped the Kohistan island arc between the Asian and Indo-Pakistan plates to the development and emergence of the Nanga Parbat syntaxis. Field work along the Main Mantle Thrust (MMT) and within the Indo-Pakistan plate rocks in the area between Babusar Pass and Toshe Gali was aimed at an understanding of the kinematic relationship between these deformational phases. The MMT is the suture between rocks of the Indo-Pakistan plate and rocks of the Kohistan sequence. Workers in adjacent areas have found evidence that the MMT has southeast-directed transport of the Kohistan rocks over the Indo-Pakistan plate. In the study area that deformation has been overprinted by a ductile fabric that has top-to-the-WSW sense of shear on a shallowly WSW- plunging stretching lineation. This ductile fabric is pervasive at the MMT contact, within the Indo-Pakistan plate cover sequence below the MMT, but decreases in intensity in the Indo-Pakistan plate basement rocks and the Nanga Parbat gneiss. If this ductile fabric represents normal fault movement then this deformation may have been responsible, in part, for the exhumation of the Nanga Parbat massif.

INTRODUCTION

The process of continental collision and continued convergence often results in a complex tectonic history with multiple deformational phases. Recent studies have begun to recognize deformational phases with distinct kinematics in collisional orogens such as the Alps (Dietrich & Durney, 1986; Schmid et al., 1987; Hubard & Mancktelow, 1989), the Himalayas (Molnar & Tapponier, 1975; Burchfiel & Royden, 1985; Pecher & Scaillet, 1988), and the Appalachians (Bobyarchick, 1988; Snoke & Frost, 1990). These deformational phases may include thrust faults, normal faults, or strike-slip faults in the setting of convergent orogen. Understanding the role of these deformational phases must start with recognition of the structures that resulted from these deformational events, followed by analysis of the kinematics history of the structural blocks, and determination of the relative, or absolute if possible, timing of deformation.

The Himalaya and Karakoram mountains of northern Pakistan are a prime example of the consequence of the complex collisional process. In this region an island arc complex (Kohistan arc) collided with the Asian continent and was then sandwiched between the Asian and Indo-Pakistan plates during final collision (Tahirkheli, 1979). Convergence between the Asian and Indo-Pakistan plates continues to the present. The suturing of the Kohistan arc with the Asian plate and the Indo-Pakistan plate is thought to have a northwest-southeast trending transport direction (Pudsey, 1986; Greco et al., 1989). Adjacent to the Kohistan arc Zeitler et al. (1982) found evidence for rapid exhumation of the Indo- Pakistan plate rocks of the Nanga Parbat massif during the last 10 million years. Some of the Nanga Parbat deformation may have had WNW transport along the NNE-SSW trending thrust fault with the Nanga Parbat massif in the hanging wall. SW-trending stretch ing lineations in Indo-Pakistan plate rocks southwest of Nanga Parbat are evidence for yet another deformational phase in north west Pakistan. In this paper we document structures from an area adjacent to the Nanga Parbat syntaxis where structures from different deformational events have been superimposed.

TECTONIC SETTING

The complex geologic and tectonic history of northern Pakistan juxtaposed rock types from a variety of geological environments. The Kohistan island arc sequence, situated between Asian plate rocks to the north and Indo-Pakistan plate rocks to the south, consists of deformed mafic rocks, gabbroic intrusives with some sediments and volcanics now metamorphosed to greenschist and amphibolite facies (Coward et al., 1986). The northern boundary of the Kohistan sequence (Fig. 1) is known as the Northern Suture or the Main Karakoram Thrust (MKT) and may represent the closing of a backarc basin. Pudsey (1986) presented evidence for a north west-southeast trending compressional phase of deformation in this zone and she constrained the timing of initial suturing to be 100-80 Ma.

The southern limit of Kohistan is the Main Mantle Thrust (MMT), a probable western continuation of the Indus Suture Zone which represents the site of closing of the Tethyan ocean basin (Gansser, 1979). Timing of the MMT suture is thought to be Upper Cretaceous to Eocene (Bard et al., 1980) with a southeast-directed transport of Kohistan rocks over the Indo-Pakistan plate (Treloar et al., 1989; Greco et al., 1989). The magnitude of thrust displacement along the MMT may have been as much as 100

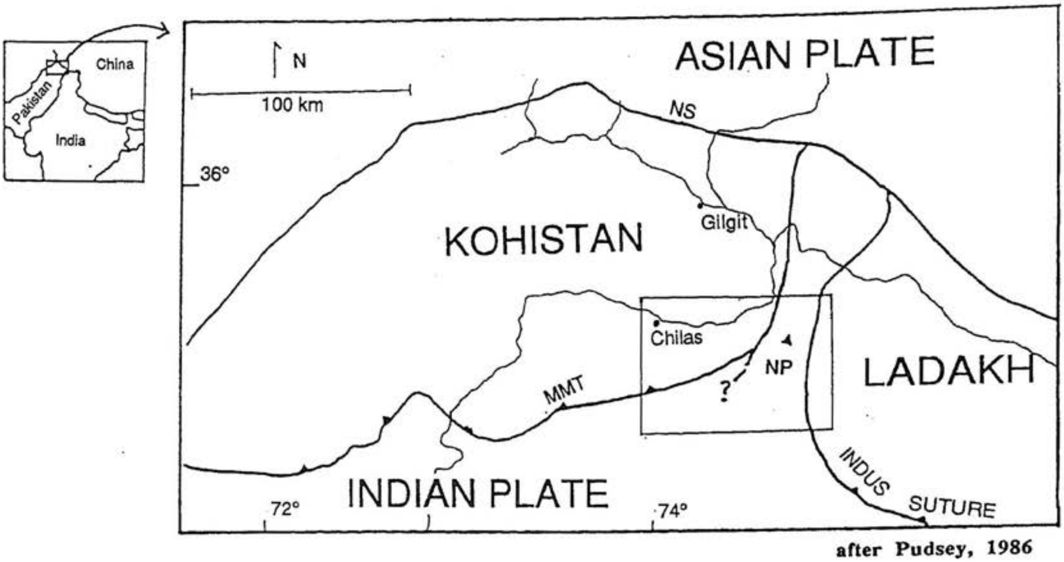


Fig. 1. Generalized geologic map of the northwest Himalaya show ing the major regions discussed in the text. NS- Northern Suture, MMT- Main Mantle Thrust, NP- Nanga Parbat, (after Pudsey, 1986).

km (Coward, 1983; Butler et al., 1988; Greco et al., 1989). So the MMT is clearly a suture of major importance. Its relationship with the Nanga Parbat syntaxis, however, is unclear (Fig. 1). Butler et al. (1988) favour a model where the western boundary of the syntaxis represents a lateral ramp. Verplanck (1986) suggests that the western boundary of the syntaxis is a west-directed thrust which post-dates the MMT.

Indo-Pakistan plate rocks are also found east of the Kohistan arc in the topographically high Nanga Parbat syntaxis. This antiformal promontory of the Indo-Pakistan plate rocks separates the Kohistan complex from another island arc complex further east, the Ladakh arc (Fig. 1). Early maps outline the contact of the Nanga Parbat massif with these island arc sequences as a syntaxial bend of the MMT/Indus Suture Zone (Tahirkheli, 1980). Detailed work found this contact to be more complex in that it is characterized, in places, by late brittle deformation which involves alluvial fan gravels (Lawrence & Ghauri, 1983). Recent mapping in this region by Madin (1986), Rehman (1986) and Butler et al. (1989) has confirmed the presence of very young and possibly active NNE-SSW trending faults (including the Liachar fault) on the western edge of the Nanga Parbat syntaxis. There is evidence that some of these faults have had dextral strike-slip movement while others are thrust faults with Nanga Parbat as their hanging wall. The thrust faults dip to the E-SE, thus transport of the Nanga Parbat massif has been to the west, over the Kohistan complex. Rapid exhumation of the Nanga Parbat massif may be interrelated with deformation along these young faults which bound the massif. Fission track studies (Zeitler, 1985) provide evidence for rapid unroofing rates, at times as high as 7mm/yr, during the last 10 Ma. These rapid unroofing rates contrast with slower rates for neighboring Kohistan complex of 1 mm/yr.

The eastern side of the Nanga Parbat massif is bounded by a steeply dipping, NE-SW trending fault zone, the Stak fault. This structure is locally associated with fault gouge indicating at least some brittle deformation (Verplank, 1986). Kinematics, amount, and timing of deformation on the Stak fault are not well understood.

We present here the results of preliminary field work in a remote area east of Babusar Pass. Our work was aimed at understanding the structural development of this region from the time of thrust deformation along the MMT to the rapid unroofing of the Nanga Parbat massif. Specifically we located the MMT in this area, mapped fold geometry, and documented an ubiquitous shallowly WSW-plunging stretching lineation.

BABUSAR PASS-TOSHE GALI

Geology

The study area extends from Babusar Pass in the west, to Toshe Gali in the east, and north to Buner in the Indus valley (Figs. 1 & 2). Mafic rocks of the Kohistan island arc are separated by the MMT from basement and cover rocks of the Indo-Pakistan plate. Specifically, the MMT was mapped at a contact of green epidote-bearing metavolcanics (?) of the Kohistan sequence in the hanging wall and pelitic rocks of the Indo-Pakistan plate cover sequence in the foot wall. All rocks have preserved amphibolite facies metamorphism.

This study primarily focused on Indo-Pakistan plate rocks. In the western part of the study area the uppermost rocks of the cover sequence consist of pelitic schist containing the assemblage: garnet-biotite-quartz-plagioclase-muscovite. The pelitic schist is underlain by a calc-silicate horizon and amphibolite. Further east, in the Chukawai valley, similar pelitic assemblages also contain abundant kyanite. Amphibolites of the Chukawai valley and the lower Barai valley are garnet-bearing. A distinctive augen gneiss unit parallels the upper Barai valley and is found in the Biji valley to the east (Fig. 2). Textural evidence support pre-tectonic metamorphism throughout the area.

At the junction of the Biah valley and the Chukawai valley, Indo-Pakistan plate basement rocks are exposed. These rocks are gneissic and contain abundant granitic material. The transition from cover to basement is transitional and is marked by an in crease down section of granitic material. The granitic enclaves are likely to be the product of in-situ melting as there are not through-going dikes of this material.

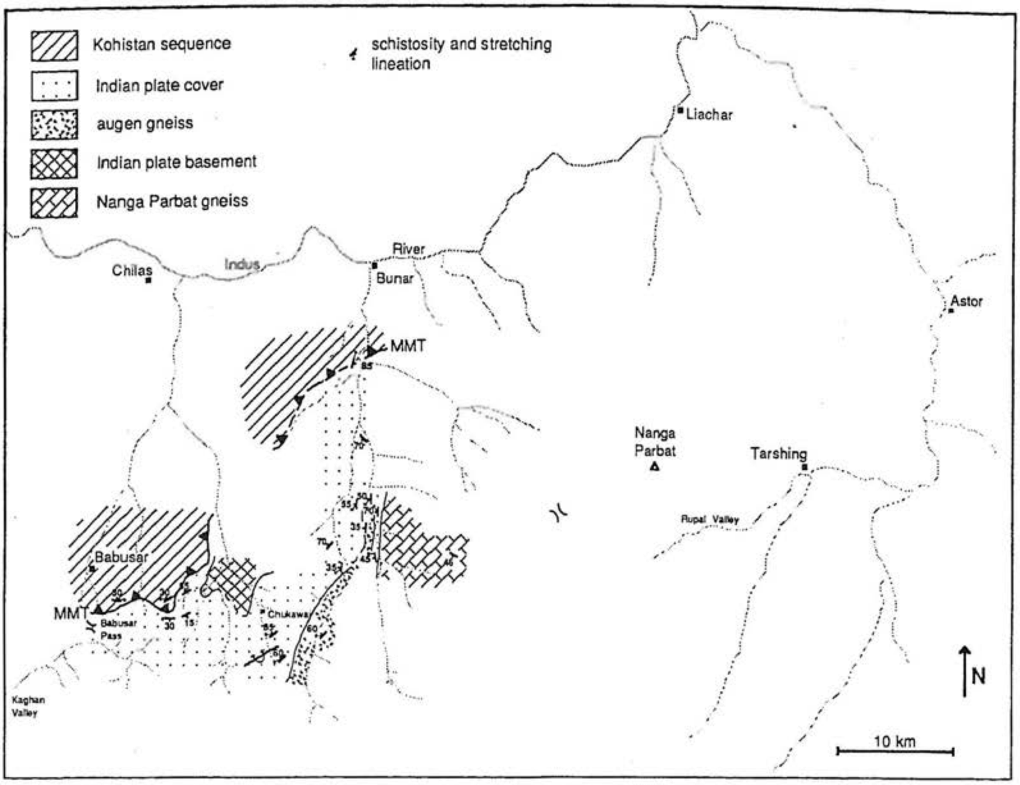


Fig. 2. Geologic map of the study area including structural data from 1989 season.

Further east, in the Toshe Gali area, the Nanga Parbat gneiss is similar in lithology to the Indo-Pakistan plate basement rock to the west, but contains less granitic material.

It should be noted here that further west, in the Kaghan valley, Pognante and Spencer (1991) have found eclogite assemblages in Indo-Pakistan plate rocks. These eclogites represent the first true high-pressure assemblage in the continental units of the Himalayan belt. Metamorphism occurred at $T=650\pm50$ °C and $P = 13$ kbar (Pognante & Spencer, 1991). These eclogites are therefore classified as "medium temperature" eclogites (Carswell, 1990). The assemblage probably formed in a tectonically thickened continental crust and may represent the deepest derived rocks of the Indo-Pakistan plate known so far.

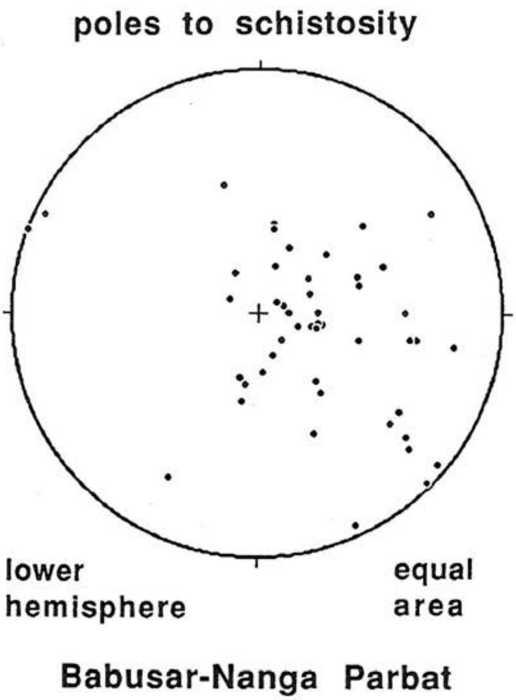
Amphibolite facies metamorphism has been documented in regions to the west and north of the study area (Ghazanfar & Chaudhry, 1986; Butler et al., 1988; Greco et al., 1989). To the north of the study area Chamberlain et al. (1989) have used mineral rim thermobarometry to calculate pressures and temperatures for a few samples from the Kohistan complex ($P=8\pm1$kbar, $T=600\pm100$ °C) and the Nanga Parbat massif ($P=8\pm1$kbar, $T=550\pm100$ °C). PT paths for several of these samples show decreasing PT conditions for Kohistan rocks and increasing PT conditions for Nanga Parbat rocks supporting an interpretation of thrusting of Kohistan arc over Indo-Pakistan Plate rocks. Other then these data little is known about the PT history of the Indo-Pakistan Plate rocks in this region.

Structure

The deformational history of Indo-Pakistan plate rocks adjacent to the MMT is quite complex. To the west of the study area evidence exists for SE-directed transport of the Kohistan rocks over the Indo-Pakistan plate (Greco et al., 1989). In the study area no such evidence exists. If there was SE-directed transport, evidence for it has been overprinted by a pervasive shallowly SW-plunging stretching lineation. Folds are found in the Indo-Pakistan plate rocks at all scales.

In the study area, schistosity of Indo-Pakistan plate rocks and Kohistan rocks is, primarily, NW-dipping (Fig. 3). In the eastern part of the study area, closer to Nanga Parbat, the schistosity strikes slightly more to the north than in the western part. From the map (Fig. 2) and the stereoplot (Fig. 3) it can be seen that the schistosity is folded about NE-SW trending axes. Just east of Babusar Pass the folding style is open. Indo-Pakistan plate basement rocks are exposed in the core of an open fold. In the upper Chukawai valley folding style is different as seen by the presence of an overturned nappe-scale fold. Greco et al. (1989) also found evidence for large scale folding of Indo-Pakistan plate rocks in the Kaghan valley to the west. The fold axis for the Chukawai fold is parallel or sub-parallel to the dominant stretching lineation which is shallowly plunging to the WSW (Fig. 2 & 4). The lineation is also parallel to fold axes of hand-sample and outcrop-scale folds suggesting the rotation of pre-existing or synchronously developed folds into this major deformation direction.

The W - S50W trending stretching lineation is ubiquitous in the study area and has a shallow plunge (Fig. 4). This lineation is recognized by pressure shadows around garnet porphyroblasts, rodding of quartz, and alignment of elongate minerals. The lineation is found in the rocks of the Kohistan sequence and the Indo-Pakistan plate cover sequence in the vicinity of the MMT contact, as well as in the folded Indo-Pakistan plate rocks (including the augen gneiss) of the Biah and Chukawai valleys. Indo-Pakistan plate basement rocks and the Nanga Parbat gneiss are not pervasively lineated. Butler et al. (1989) report a stretching lineation with the same WSW orientation in Kohistan rocks north of the proposed study area, near the western margin of the Nanga Parbat massif. They attribute the present orientation to be due to rotation during a flattening deformation during syntaxis development. Such an explanation is probably not plausible for the pervasive, shallowly-plunging lineations found in the proposed study area and in Kaghan valley as these areas are further away from the syntaxis. Flattening deformation during syntaxis development is more likely to be a local phenomenon.



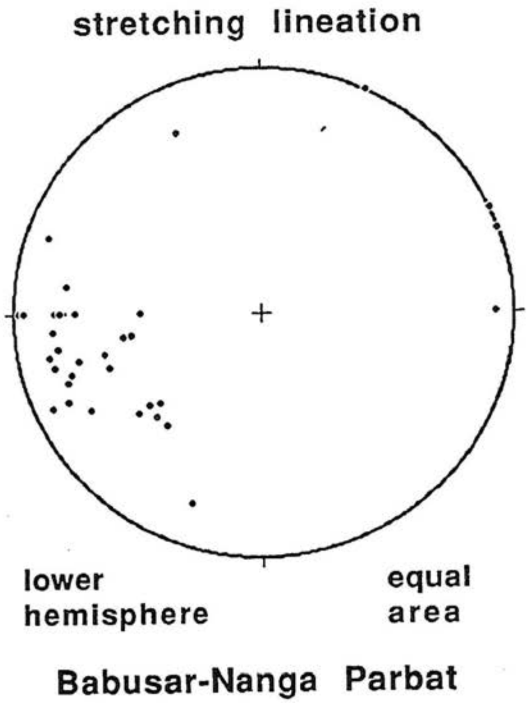


Fig. 3 (Left). Lower hemisphere, equal area plot of poles to schistocity between Babusar Pass and Toshe Gali.

Fig. 4 (Right). Lower hemisphere, equal area plot of stretching lineation data collected between Babusar Pass and Toshe Gali.

Simple shear fabrics are associated with the WSW lineation and are seen in the field and in oriented thin sections. These fabrics include shear bands, asymmetric augen, asymmetric pressure shadows, preferred grain shape orientation of quartz, and preferred crystallographic orientation of quartz. Preliminary analysis of fabrics shows top-to-the-SW sense of shear in all cases across the study area. These results are consistent with the quartz c-axis results of Greco, (1989) from rocks of the adjacent region in the Kaghan valley to the west. The present orientation of the lineation, plunging to the SW, together with the lower grade over higher-grade metamorphic gradient, suggests that this fabric is the result of ductile shear along a normal fault zone. The fabric clearly overprints any fabric related to southeastward emplacement of the Kohistan sequence over the Indo-Pakistan plate rocks and implies that the top-to-the-SW normal fault movement post-dates nappe emplacement. It is conceivable that this normal fault movement is related to the unroofing of the Nanga Parbat massif, thus making Nanga Parbat somewhat of a metamorphic core complex. Lawrence and Ghauri (1983), Madin (1986), Rehman (1986), and Butler et al. (1989) have identified brittle faults on the west side of Nanga Parbat which they relate to the recent unroofing of Nanga Parbat. Perhaps the ductile normal fault is the early expression of this unroofing process and the brittle faults are a younger expression. Clearly more work needs to be done to understand the relationship between the ductile fabric, the brittle faults, and the rapid unroofing of Nanga Parbat.

CONCLUSION

The existing geology of northern Pakistan is the product of a complicated tectonic history. During this tectonic evolution the kinematics and PT conditions of local deformation changed through time leaving us with a rock record of multiple deformation or, in some cases, with only the latest phase or phases of deformation. Continental subduction along the MMT and exhumation of the Nanga Parbat massif are two recognized phases of deformation in northern Pakistan. During preliminary field work in an area between Babusar Pass and Toshe Gali we found evidence of deformation (a ubiquitous WSW, shallowly-plunging, stretching lineation) that may be distinct from MMT deformation but possibly is related to exhumation of Nanga Parbat. Kinematic analysis indicates top-to- the-SW sense of shear along the MMT and in Indo-Pakistan plate rocks between Babusar Pass and Toshe Gali. This ductile normal-sense of shear deformation predates brittle fault development in the Liachar/Raikot areas, though both deformation phases may have played a role in the unroofing of the Nanga Parbat massif.

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