Geol. Bull. Univ. Peshawar, 1989, Vol. 22, pp. 65-82

THE GEOLOGY OF THE BESHAM AREA, NORTH PAKISTAN: DEFORMATION AND IMBRICATION IN THE FOOTWALL OF THE MAIN MANTLE THRUST

MATHEW P. WILLIAMS

Dept of Geology, Imperial College, London, SW7 2BP, U.K.

ABSTRACT

The gneisses, granites and metasediments of the northern exposed margin of the Indian plate in the Besham antiform consist of a Precambrian crystalline basement with younger sedimentary cover. These were metamorphosed during the main fabric-forming event of the Himalayan orogeny, a ductile simple shear dominated deformation of the footwall of the MMT during southward overthrusting of the Kohistan Arc. Deformation intensity and ductility decrease southwards. Subsequent thrusting brought together internally imbricated blocks which have different deformation/metamorphic histories. High grade rocks thrust over low grade rocks within each block define an inverted metamorphic gradient produced by post-metamorphic thrusting. Major cross folding producing the Besham antiform, plus brittle faults are expressions of the later N–W directed backthrusting and E-W compression and uplift of the Besham area.

INTRODUCTION

In N. Pakistan the Indus-Tsangpo Suture separating the Asian and Indo-Pakistan plates bifurcates around the Kohistan Arc, an island arc sequence with its base exposed in the south and its top in the north (Bard et al., 1980; Bard 1983; Coward et al., 1982), (Fig. 1). The Southern Suture is represented along most of its length by the Main Mantle Thrust (MMT of Tahirkheli et al., 1976, 1979), a north dipping thrust zone up to several kilometres thick of melange consisting of a mixture of serpentinites, greenschists and some blueschists (Kazmi et al., 1984; Lawrence et al., 1989). The Northern Suture is thought to have closed in the mid Cretaceous (Coward et al., 1986), while the Southern Suture closed about 53-50Ma ago (Patriat and Achache, 1984).

As the Indo-Pakistan plate was subducted beneath the Kohistan arc, metamorphism and ductile S-directed simple-shear dominated deformation occured in the footwall of the MMT. During the later stages of S-directed overthrusting, major thrust imbrication brought internally imbricated thrust blocks together. Each block has different deformation/metamorphic histories until the later stages of imbrication. The Besham block lies between the Hazara block to the east and the Swat block to the west (Treloar, 1989).

The Besham area, located in the east of the Swat, and northwest of the Hazara Divisions

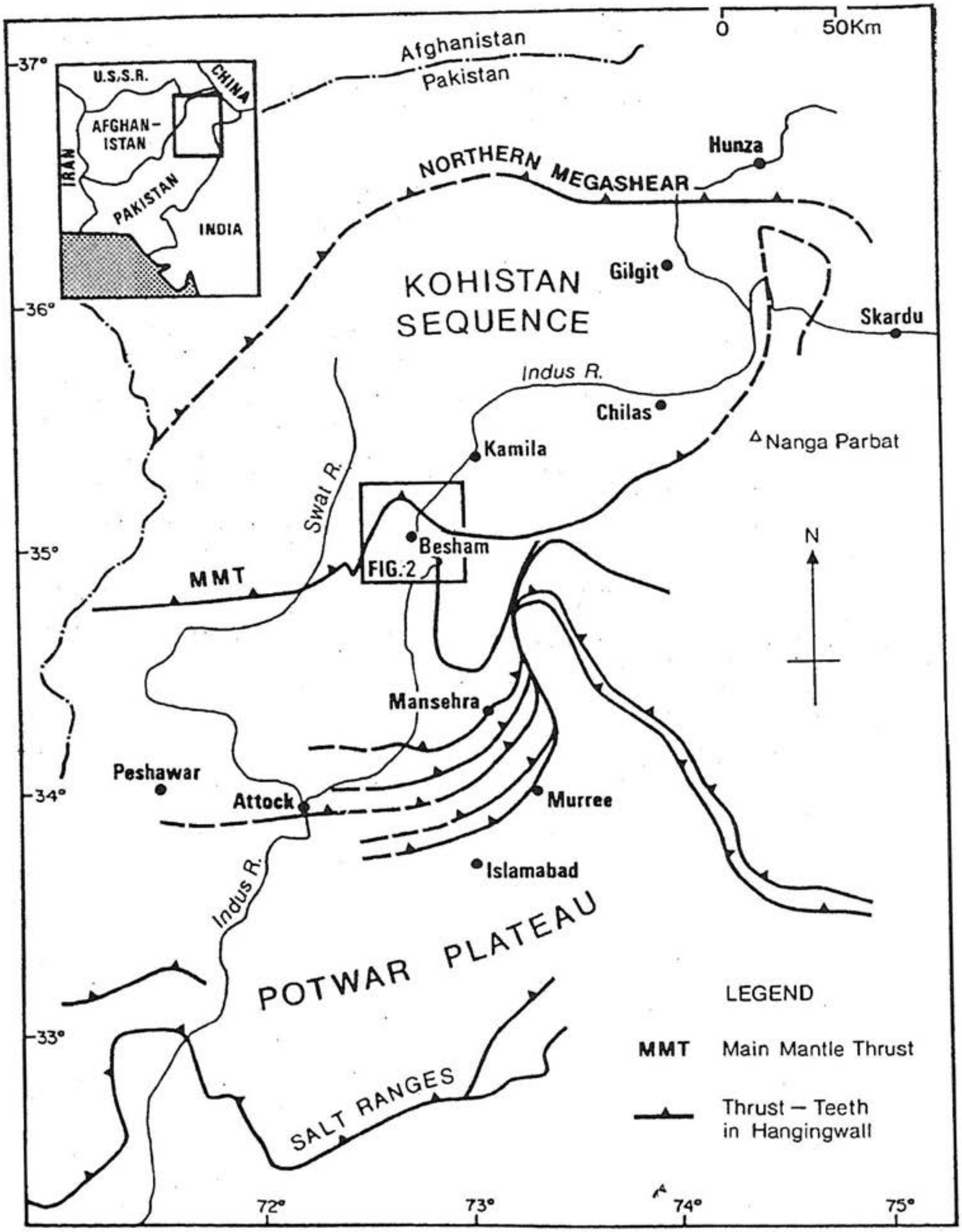

Fig. 1. Outline map of North Pakistan to show the position of the Kohistan Island Arc between the Indo-Pakistan and Asian plates; some of the main thrusts S of the Main Mantle Thrust (MMT), some of the main towns, and the location of Fig. 2.

of the North West Frontier Province of Pakistan, is bisected by the Indus River. It lies at the northern exposed edge of the Indian plate where the MMT is embayed northward due to a major antiform in the footwall. The terrain is of steep scrub-covered hills with the lowest valley bottom at an altitude of around 1100m, rising to 4000m peaks.

No regional mapping of the area had been attempted before this study, work being restricted to isolated topics and localities, and no correlations have been made with adjacent areas. Tahirkheli (1979) was one of the first to write about the geology of the Besham area, defining the "Besham Group comprised of metasedimentary rocks" and including the gneisses, the Chail Group comprised of pelites and the carbonates of the Banna Formation. However, Ashraf et al. (1980) and Butt (1983) assigned the pegmatites, granites and gneisses of the Besham area to an intrusion of batholithic proportions, the "Lahor granite"; an idea abandoned by all subsequent workers. A survey of the lead-zinc mineralisation found in a few areas on either side of the Indus was made by Fletcher et al. (1986). They defined three lithological groups: the Besham Group, basement of biotitic gneisses and schists; Pazang Group, metasediments as tectonic pods within the basement gneisses; and the Karora Group, basal conglomerate overlain by graphitic phyllites and micaceous quartzites.

The rocks of the area can be separated into several groups, though the term "group" is applied very loosely. Throughout the area the rocks can be differentiated into two kinds: quartzo-feldspathic crystalline basement, and cover sequences of pelite and carbonate metasediments. Near the Indus river the Besham Group granite and gneiss complex is the basement, and is overlain uncomformably by the Karora Group metasediments (Fig. 2). The sequence has been repeated by thrust imbrication, and folded by a major upright N-S striking antiform. To the east, on the eastern limb of the antiform, the basement is of Tanawal Formation metasediments and Mansehra granite, overthrust by the Banna Group sedimentary cover sequence. To the west, the basement is of Manglaur Crystalline Schists and Swat granite overlain by cover metasediments of the Alpurai Schists.

The crystalline basement rocks were affected by one or more pre-Himalayan tectonic event prior to deposition of the cover sedimentary sequences. The cover sediments only show the effects of Himalayan deformation and metamorphism. Evidence of the pre-Himalayan event (s) can be seen in many areas including Besham (Williams et al., 1988). Here the basal conglomerate of the Karora Group cover sequence contains clasts of most of the lithologies of the Besham Group: the various gneisses, the metapsammites, plus undeformed grandiorite clearly indicating deformation prior to deposition of the Karora Group. Kazmi et al. (1984) report evidence of pre-Himalayan tectonism in Swat where the Manglaur Crystalline Schists contain relict garnet porphyroblasts which have been crushed, replaced and stretched parallel to the present day fabric. Also, xenoliths of schists and gneisses occur in areas of undeformed Swat granite intruding the Manglaur Schists. In the Hazara block, the Mansehra granite which intrudes and is concordant with the Tanawal Formaton metasediments is dated at 516±16Ma (Le Fort et al., 1980). In a few localities west of Mansehra, andalusite and chiastolite in the metamorphic aureoles of the granite overgrow an older slaty cleavage in the Tanawal Formation sediments. South of Abbottabad in the Tanakki village area, a Cambrian sedimentary sequence, the Abbottabad Formation, unconformably overlies the Precambrian Hazara Slates, and contains clasts of cleaved Hazara Slate in its uncleaved non-metamorphosed basal conglomerate. This evidence clearly indicates the occurrence of widespread pre-Himalayan tectonics prior to deposition of the cover sediments and earlier than intrusion of the Manseha granite.

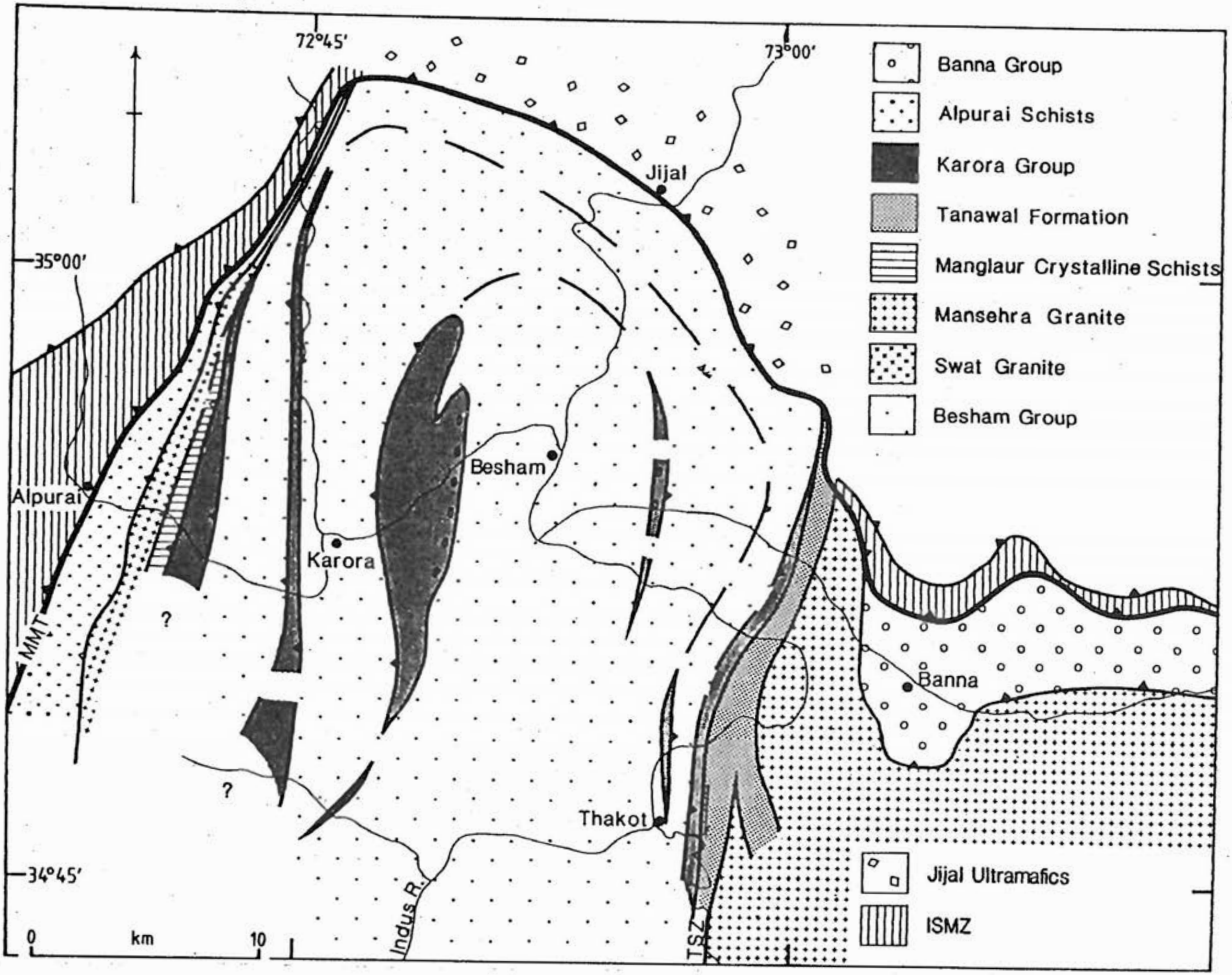

Fig. 2. Geological map of the Besham area; MMT-Main Mantle Thrust, TSZ-Thakot Shear Zone, ISMZ-Indus Suture Melange Zone.

It is not known however, whether the deformation and metamorphism is of the same age in each area or not, but it must have occurred in the Precambrian or earliest Palaeozoic.

GEOLOGY

Besham Group

The Besham Group comprises a heterogenous mixture of biotitic gneisses and schists (most of uncertain paragenesis), granitic gneisses, metapsammites, amphibolites, blue-quartz pegmatites and other pegmatites, weakly deformed hornblende-granodiorite, mylonites, phyllonites and undeformed microgranites. The gneisses are medium to coarse grained, with fabrics of variable strength paralleling the pronounced lithological banding. The metapsammites are often fine grained with a granoblastic texture, e.g. the top of each of the thrust slices west of Besham (where biotite is an essential phase), but are coarse grained and more arkosic in other areas. Lead-zinc sulphide deposits occur within the metasediments of the Besham Group in several areas, the largest being at Lahor and Pazang on the west and east banks of the Indus, respectively. The deposits occur in folded stratigraphically controlled lodes which have been extensively remobilised during Himalayan shearing and later faulting so that they are now also partly structurally controlled. The gneissic textures and fabrics with a quartz, feldspar, muscovite, biotite, garnet and hornblendic-amphibole mineralogy are the products of the pre-Himalayan high-grade deformation and metamorphism with its associated granite and pegmatite intrusion.

Pegmatite and amphibolite sheet intrusion sub-parallel to the fabric and banding is very common throughout the Besham Group. Most of the pegmatites are less than 2m wide, and have a weak internal fabric (though some are highly sheared), while others discordant to the fabric are undeformed. Most have sheared contacts, but undeformed intrusive contacts are also seen. Most of the amphibolites are sills less than 1m thick which are slightly discordant to the external fabric. They have strong internal fabrics parallel to the external fabric rather than to the sill margins. The few discordant amphibolite dykes have no internal fabrics. Some amphibolites are cut by pegmatites. Boudinage has commonly isolated pods of pegmatite and amphibolite within the gneisses.

All the above lithologies are overprinted by Himalayan shear fabrics whose intensity varies from pervasive mylonites and phyllonites, to areas of narrow anastomosing discrete brittle-ductile shear zones where the earlier gneissic fabrics are largely unaffected. In the latter areas rare narrow bands of mylonite are a few metres wide at most. As a whole the deformation is most intense in the north and decreases southward. Immediately below the MMT north of Besham there are quartzo-feldspathic mylonites and blastomylonites several hundred metres thick (Lawrence and Ghauri, 1983). Isoclinal SE-facing Z-folds of 2-4m wavelength have axes plunging on average at 25-30°/025°, parallel to the mineral stretching lineation in the mylonites. The metamorphism is not pervasive, occuring only in conjunction with shearing, as the anhydrous gneissic assemblages have resisted change in areas of low strain. Like the intensity of deformation, the metamorphic grade decreases southward. In the mylonites immediately below the MMT metamorphism reaches garnet grade, while further south chlorite and mica occur along the brittle-ductile shears.

Largely undeformed fine to medium grained often tourmaline-rich granites intrude the gneisses and mylonites as sheets parallel and occasionally slightly discordant to the Himalayan fabric. One of these granites, practically undeformed and fine grained, cuts the blastomylonites a few hundred metres below the MMT (Treloar et al., 1989a). At Dubair and Shang, north and south of Besham respectively, two semicircular stocks of coarse grained hornblende-granodiorite, each a few kilometres in diameter, cut the gneissic fabrics . The granites were intruded in the stages of Himalayan shearing.

Karora Group

This is a pelite-rich metasedimentary sequence which rests unconformably on the Besham Group. The lithologies present are dominantly folded and crenulated phyllites and schists metamorphosd at greenschist to amphibolite facies. The schistosity is pervasive though of variable intensity. Unlike the basement, carbonate is an important component of the Karora Group.

The sequence begins with a basal conglomerate, resting on an angular unconformity, followed by graphitic pelite, psammitic pelite, calc–pelite and lastly marbles. All lithologies are very fine grained. The conglomerate is polymict, with sub-angular to well-rounded clasts of many of the basement lithologies ranging in size from 10cm to less than 1cm in diameter. The clasts, floating in a psammitic pelite matrix, are of biotite gneisses, granitic gneisses, metaphsammites, blue slates, plus undeformed granodiorite. Although the blue slates are not found outcropping in the area they are very similar in appearance to the Hazara slates found further south. The conglomerate is approximately 5m thick, grading upwards with a rapid decrease in the size and number of clasts into approximately 5m of fine grained psammite and pelitic psammite. There is a sharp change from this psammite to graphitic pelite, in the basal 5m of which there are thin bands 1-2cm thick of fine grained pelitic psammite. The soft well-cleaved graphitic pelite contains folded quartz veins 1-2 cm wide and up to approximately 15cm long. Parts of the graphitic pelite are sulphidic, the sulphides locally remobilised along sub-vertical N-S striking late-orogenic faults. The overlying psammitic pelite, which appears to form the bulk of the sequence, is largely massive and weakly cleaved. It is succeeded by massive calc-pelite and regularly bedded grey and cream coloured marbles. Some of the marbles contain amphibolite sheets up to 4m wide concordant or slightly discordant to the fabric. They are fine grained and have a strong internal fabric.

It is difficult to estimate the thicknesses of the various units, or the sequence as a whole due to complex folding and thickening by shearing and thrusting. Though the conglomerate is para-autochthonous, pervasive ductile shearing has caused clast flattening (axial ratios up to 5:1) in places, while in other localities the strain is taken up by a discrete thrust in the pelitic psammite above the conglomerate. A few undeformed microgranite sheets, none greater than 15m thick, were intruded into the metasediments in the late stages of the Himalayan deformation. The Karora Group is thought to be of Palaeozoic age.

Tanawal Formation and Mansehra Granite.

The Tanawal Formation was first described by Middlemis (1896) as the "Tanol Quartzites" from an area to the north and east of Tarbela, and extended as far north as Batagram by Calkins et al., (1975). I have been able to map the Tanawal Formation up to the Besham area.

The Tanawal Formation is comprised of medium to coarse grained metaquartzites, micaceous metapsammites and some garnet-mica schists which were originally sandstones, silty sandstones and sandy pelites. The metamorphic grade decreases from north to south from sillimanite and kyanite through the staurloite and garnet isograds to biotite grade south of Oghi and Mansehra. The Tanawal Formation is intruded by thick sheets of Mansehra granite, a coarse grained two-mica granite with feldspar phenocrysts up to 5cm in length. Rb-Sr whole rock isotope analysis by Le Fort et al. (1980) dated the granite at 516±16Ma, which is considered to be its intrusion age. This indicates a Precambrian age for the Tanawal Formation. The strong feldspar phenocryst alignment found locally in undeformed granite is an igneous texture while all other fabrics are Himalayan in age. In the north the granite forms strongly sheared augen gneiss and mylonite, while to the south the overall intensity of deformation decreases, though there are mylonite zones representing ductile thrusts in otherwise undeformed granite.

In the narrow zone of interbanded Tanawal Formation and Mansehra granite in the Besham area, the rocks are practically all mylonitic gneisses. Kinematic indicators show a movement direction of east side south which, when corrected for the late folding, implies top side south shear. Where the composition is right the Tanawal Formation metasediments have locally undergone partial melting. In the Allai valley between Besham and Banna there is a sheet less than 10m wide of garnet microgranite rich in zircons. It is intruded parallel to the shear fabric and contains a weak internal L-S fabric.

Manglaur Crystalline Schists and Swat Granite.

These rocks outcrop in several areas in Swat and, between Korora and Alpurai, in a long N-S striking band 2km wide at most. The Manglaur Crystalline Schists comprise medium to coarsly crystalline non-calcareous quartzo-feldspathic garnet mica-schists and schistose gneisses, garnet amphibolite and pegmatite. Between Karora and Alpurai they contain a garnet microgranite indistinguishable in appearance from that on the east side of the Besham antiform in the band of Tanawal Formation and Mansehra granite. The paragenesis of the Manglaur Schists is probably semi-pelitic metasediments.

The Manglaur Schists are intruded by large sheet-like bodies of Swat Granite which I consider to be of the same suite as the Mansehra granite. Cross-cutting igneous relations between the granite and Manglaur Schists can be clearly seen south of Manglaur in Swat, but not in the Besham area. Most of the Choga body of the Swat granite outcropping between Karora and Alpurai is sheared to augen gneiss, with some mylonite also present.

Alpurai Schists

Outcropping in a narrow NNE-SSW strking band on the western margin of the Besham antiform and throughout Swat, the Alpurai Schists lie above the Swat Granite and Manglaur Schists. From work in Swat, Lawrence and coworkers (Kazmi et al., 1984; Lawrence et al., 1989) argue that the Alpurai Schists lie unconformably on the granite gneiss, a contact subsequently severely tectonised during fabric development and thrusting. Tectonism has removed all evidence of the unconformity in the Besham area.

The Alpurai Schists comprise black non-calcareous garnet-mica-schists, calcareous garnet-mica-schists, calc-schists, marbles and associated amphibole-quartz-garnet rock. The latter, in layers 3-6m thick, concordant with bedding and fabric in the marbles, have a composition which suggests a volcanoclastic paragenesis. The presence throughout the schists of kyanite and staurolite indicate high grade metamorphism. The coarse grained well developed frequently crenulated schistosity is in places severely folded indicating strong ductile deformation. The garnet porphyroblasts, commonly reaching 1-2cm in diameter, often have inclusion trails rotated relative to the external schistosity. The basal section of the Alpurai Schists is a quartzo-feldspathic mica-schist containing a large amphibolite sill, locally as thick as 100m. Its geochemistry implies derivation from an intrusive tholeiitic basalt magma (Ahmad, 1986).

Banna Group

Outcropping between the Mansehra granite and the Indus Suture Melange Zone (ISMZ) in Allai-Kohistan, this group of fine grained sediments comprises graphitic and non-graphitic pelite, calc-pelite and marble. Their metamorphic grade is very low, and deformation varies from brittle to brittle-ductile, being more brittle with decreasing age of deformation. As a consequence of complex folding and thrusting it has not been possible to define the original sedimentary sequence of the Banna Group or its thickness. However, a characteristic coarsly spotted grey marble occuring at the base of the sequence provides a useful marker over much of the area. The weakly metamorphosed calc-rich sediments of the Banna Group have been emplaced onto the high grade mylonites, gneisses and schists of the Tanawal Formation and the Mansehra granite by a major backthrust moving northwestward from the external zones south of the Mansehra thrust.

STRUCTURE

The Himalayan event can be separated into two distinct periods. The first is related to N to S simple shear dominated deformation with metamorphism occuring in its early stages and the second is due to E-W cross-folding and related brittle-ductile shearing with later brittle faulting. The sequence of deformation is summarised in Table 1.

TABLE 1. SUMMARY OF THE DEFORMATION SEQUENCE.

Post-D3	:	N-S striking steep brittle reverse faults with E side up movement
D3	:	Major antiforming by upright en-echelon NNE and SSW plunging folds. Open parasitic folds are common throughout.
Early-D3	:	Top side E ductile shear bands and minor thrusts. Backthrusting of Banna Group towards NW
D2a	:	Imbrication - by NW to SE brittle thrusting in the Besham block - by N to S ductile thrusting in the Hazara block
D2	:	Progression of D1 locally producing a crenulation cleavage which may obliterate S1, and SE to S facing F2 folds having flat lying axial planes
D1	:	Main fabric forming event, produced by pervasive N to S ductile shear. F1 intrafolial isoclinal folds sheathed with axes rotated parallel to the mineral stretching lineations.

The first phase of the S-directed shear (D1) formed the main fabric (S1), which varies in intensity depending on the locality and the lithology involved. The overall intensity and ductility of deformation decreases southwards. In the Besham Group, in the immediate footwall of the MMT there are large thicknesses of ductile mylonites and blastomylonites. Further south around Besham, deformation is largely along anastomosing discrete brittle-ductile shear zones, with some scattered narrow bands of mylonite. S1 fabrics in the Besham Group are usually sub-parallel to the pre-Himalayan fabrics. The pelites of the Karora Group have a strong phyllicity or schistosity; their grain size depending on the grade of metamorphism reached. Where S2 is weak or absent as in the psammitic pelites, S1 is seen to be sub-parallel to bedding.

Mineral lineations presumably parallel to the stretching direction plunge gently north or south, paralleling the F1 fold axes which presumably have been rotated by continued shear into the shear direction, (Fig. 3). Some of the F1 folds are strongly sheathed. They indicate a direction of overthrusting approximately towards the south.

D2 is essentially a progression of D1, although it is less ductile and less pervasive. In more competent lithologies, S2 is a crenulation of S1, while in the pelites of the Karora Group S1 has been strongly overprinted by S2. Locally, where S2 is dominant, the only evidence for S1 lies in the form of intrafolial rootless isoclinal F1 fold hinges preserved as quartz sweats. Some quartz sweats show F1 refolded by F2 folds, and have a strong S2 cleaveage. Ductile tight to isoclinal F2 folds have axial planes and associated cleavage lying at a small angle to S1. The scale of F2 folds varies, rarely having amplitudes greater than 1-2 metres in the Besham Group, but of 10s to 100s of metres in the Karora Group. In the Besham and Karora Groups the facing direction of the F2 folds varies considerably from S to E, and averages towards the SE when the effects of the later folding are removed. The F2 fold axes show a wider scattering of orientations than F1, presumably due to less severe rotation during shearing. While there are few folds in the mylonitic paragneisses of the Tanawal Formation in the Besham area, further SE in the Hazara district all the F2 folds face south indicating a continuation of north to south directed shear.

Thrust imbrication (D2a) is the third and final phase of the southward overthrusting which brought the blocks approximately to their present day positions (Fig. 4). I use the term D2a to retain consistency with earlier publications (Coward et al., 1982; Treloar et al., 1989a, 1989b), which defined both the D2 crenulation event and the later D3 cross-folding event.

Imbrication of the Besham and Karora Groups in the Besham block repeated the basement-cover sequence twice. Movement occurred along brittle-ductile thrust faults from NW to SE. There is no well developed fabric associated with the thrusting, as the thrusts are sub-parallel to, or cutting up through S1 and S2. Within the imbricate slices thrusting was towards SE and in the first cover slice in particular, are seen to be post-dated by NW moving back-thrusts.

Within the Hazara block, imbrication occurred along north-dipping thrusts directed southwards. The local strongly developed fabrics associated with the thrust imbrication in the north decrease in intensity and ductility southwards, though all except those in the far south are more ductile than the thrusts in the Besham block. This may be due to imbrication beginning earlier and under more ductile conditions in the Hazara than in the Besham block.

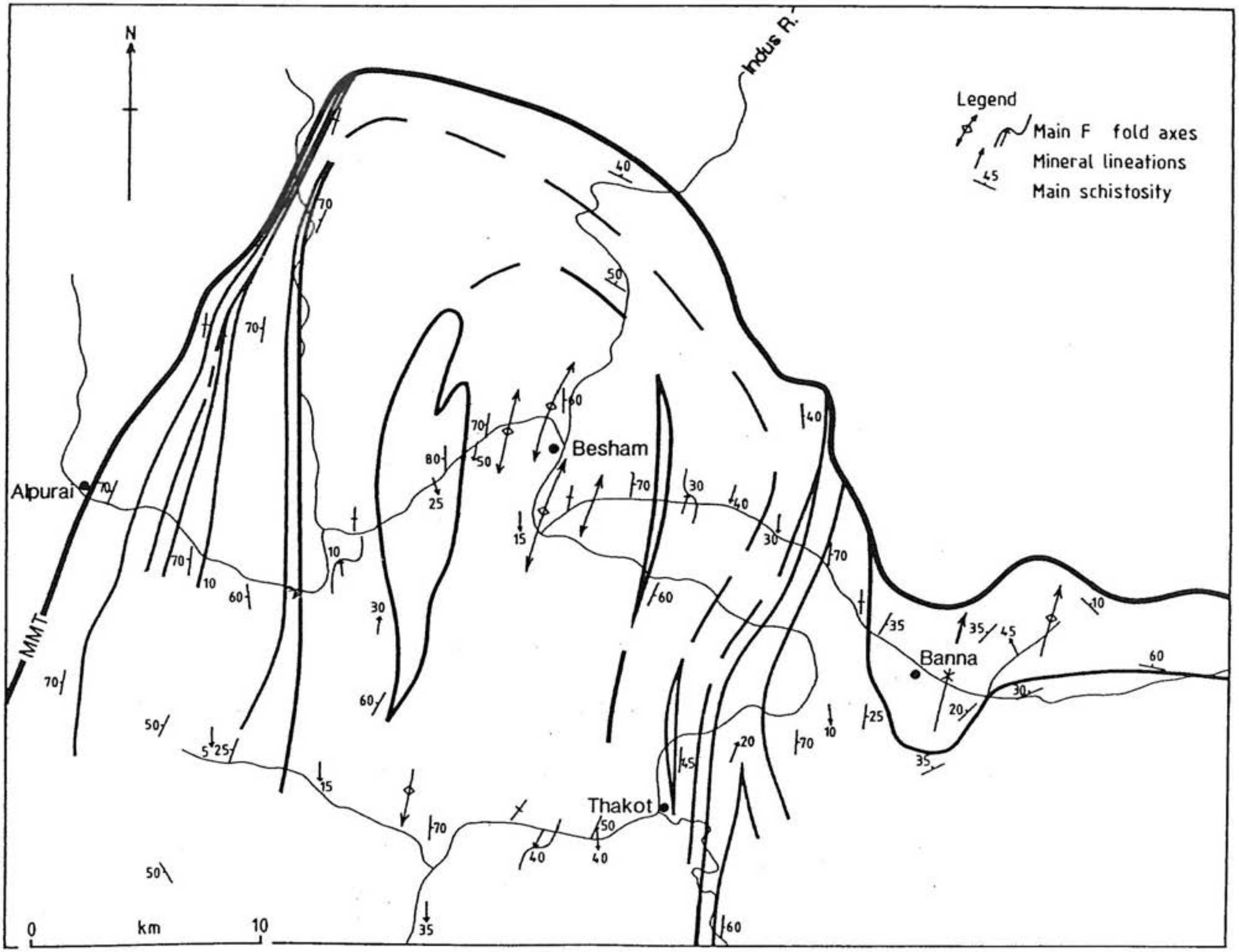

Fig. 3. Map showing the orientations of stretching mineral lineations and main F3 fold axes in the Besham area.

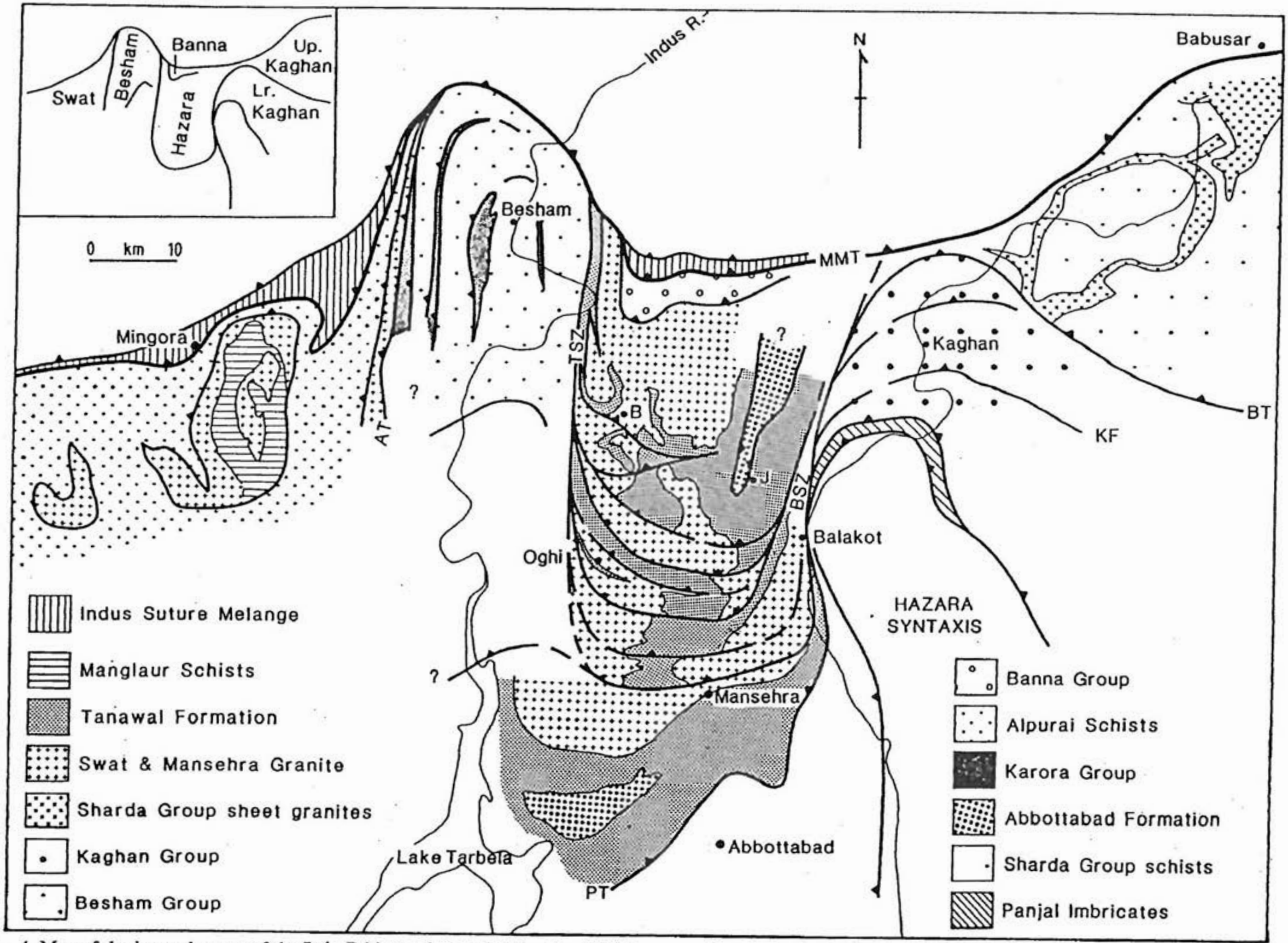

Fig. 4. Map of the internal zones of the Indo-Pakistan plate underlying the MMT between Swat and the Kaghan valley, with an inset showing the boundaries of the tectono-stratigraphic blocks. Compiled from our own work, Calkins et al (1975), Ghazanfar &Chaudhry (1986), and Lawrence et al. (1988). B-Batagram, J-Jabori, AT-Alpurai Thrust, PT-Panjal Thrust, BT-Batal Thrust.

At the base of the Hazara block there is a near vertical N-S striking mylonite zone several kms thick, the Thakot Shear Zone (TSZ), separating the Besham and Hazara blocks. Movement along it is dextral. The Hazara block structurally overlies, and was thrust southwards over the Basham Block (Fig. 5).

Neither mylonites nor other strong shear fabrics are present in the sediments of the Banna Group. In the marbles there are tight, ductile, S-facing F1 and F2 folds with flat-lying axial planes, and in the graphitic pelite there are isoclinal, rootless fold hinges. The dominant fold types in the marble are NW or NNW-facing angular folds with a weakly developed cleavage and associated NNW directed minor thrusts. Close to the Main Mantle Thrust Zone, tight, angular folds of the same generation have a strong cleavage and face S. These folds, and the way in which the basal thrust carrying the Banna Group sediments cuts up through an imbricated sequence of Mansehra granite and Tanawal Formation imply that the Banna Group sediments were emplaced by a northward moving backthrust which buttressed against the MMT Zone (Fig. 6). The backthrusting occurred after imbrication of the Hazara block and before the D3 folding.

The change from N-S simple shear dominated compression to NW-directed bacthrusting and E-W compression was accompanied by a marked decrease in ductility and a lowering of temperature and pressure. The most obvious effect is the major upright folding of the Besham area (D3) (Fig. 7). In the axial area centered around Besham, a series of en-echelon upright folds plunge NNE and SSW defining a dome (Fig. 3). Open, rounded, parasitic folds with amplitudes of 10s cms to about 1km occur throughout the area. There is no associated cleavage except locally in the graphitic pelites of the first cover slice where it is vertical and strikes N-S.

Brittle-ductile shear bands and minor thrusts with a movement sense of top side E formed during the early stages of D3. Later backthrusting towards the NW then became common. Chlorite is the only new mineral, and is found along the shear planes. The direction of movement is shown by Riedel fractures, slickensides and offset markers.

Further uplift continued after the folding, as shown by N-S striking brittle steep reverse faults with movement up on the east side. Found in both the Besham and Karora Groups east and west of the Indus, these faults are frequently grouped in zones up to 10m wide. The fault gouge and adjacent fault walls are sulphide stained. The sulphides were remobilised from the scattered deposits in the Besham Group. This faulting only occurs in the Besham block which has been uplifted at a greater rate than the adjacent Hazara and Swat blocks.

METAMORPHISM

The grade of metamorphism, while constant within any one thrust slice, varies from slice to slice. There appears to be a jump in metamorphic grade across many of the imbricated thrusts, i.e., the isograds parallel the thrusts. From Besham, there is a westward increase in metamorphic grade from chlorite through biotite and garnet to staurolite and kyanite, Thus the structurally highest thrust slices have the highest grade mineralogy (Fig. 5). The effects of Himalayan metamorphism are best seen in hydrous rocks not metamorphosed by the pre-Himalayan event. Mineral growth occurred easily in the Karora Group, while in the Besham Group the metamorphim is not pervasive as the anhydrous gneissic assemblages have tended to resist change in areas of low strain. In much of the Besham Group it is difficult to distinguish new mineral growth from recrystallised pre-Himalayan mineralogies.

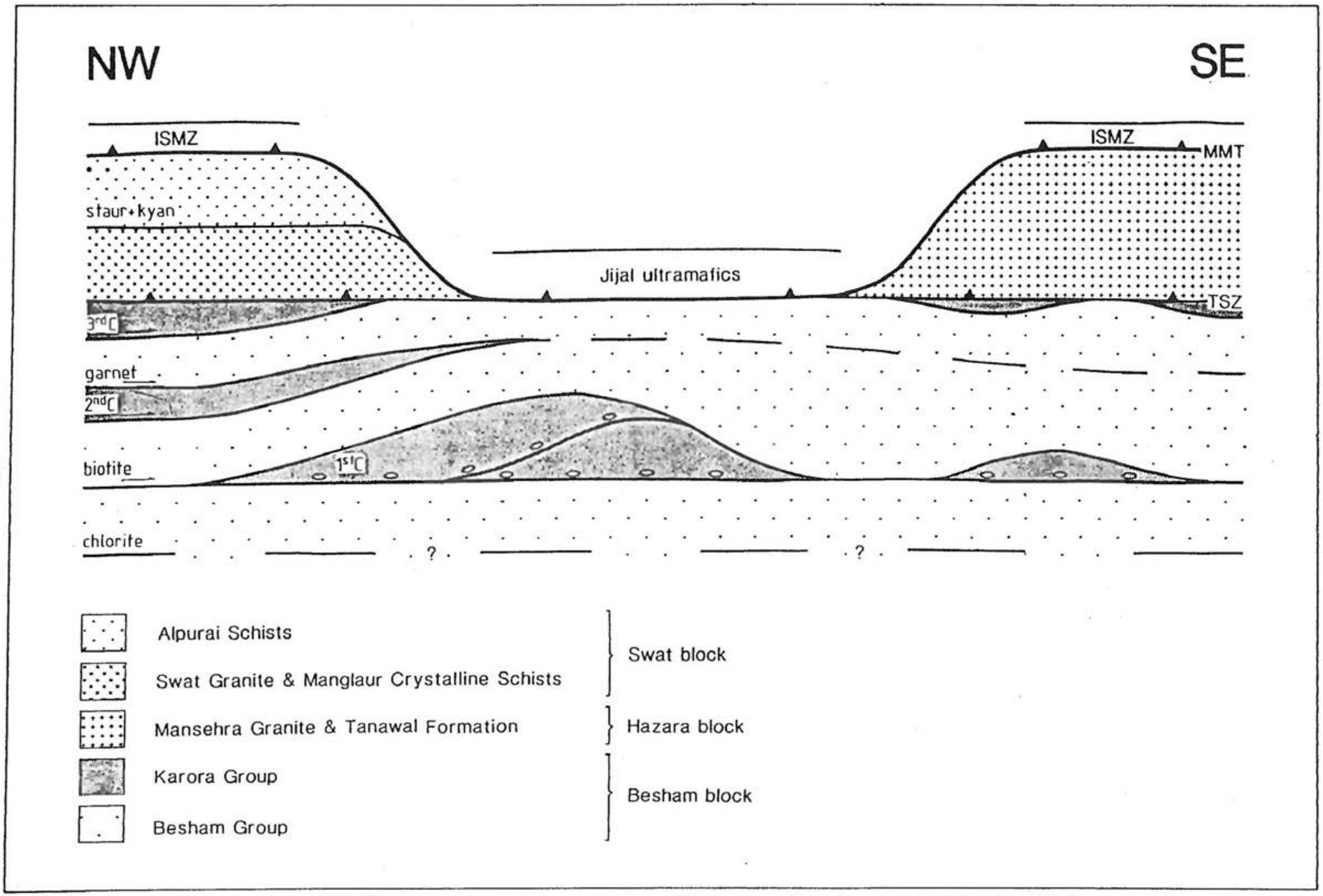

Fig. 5. A schematic pre-D3 section through the Besham area showing the upwards increase in metamorphic grade produced by thrusting of higher grade rocks over lower grade rocks during imbrication, and how lateral ramps in the Main Mantle Thrust have a part in controlling the order of stacking of the thrust-stratigraphic blocks.

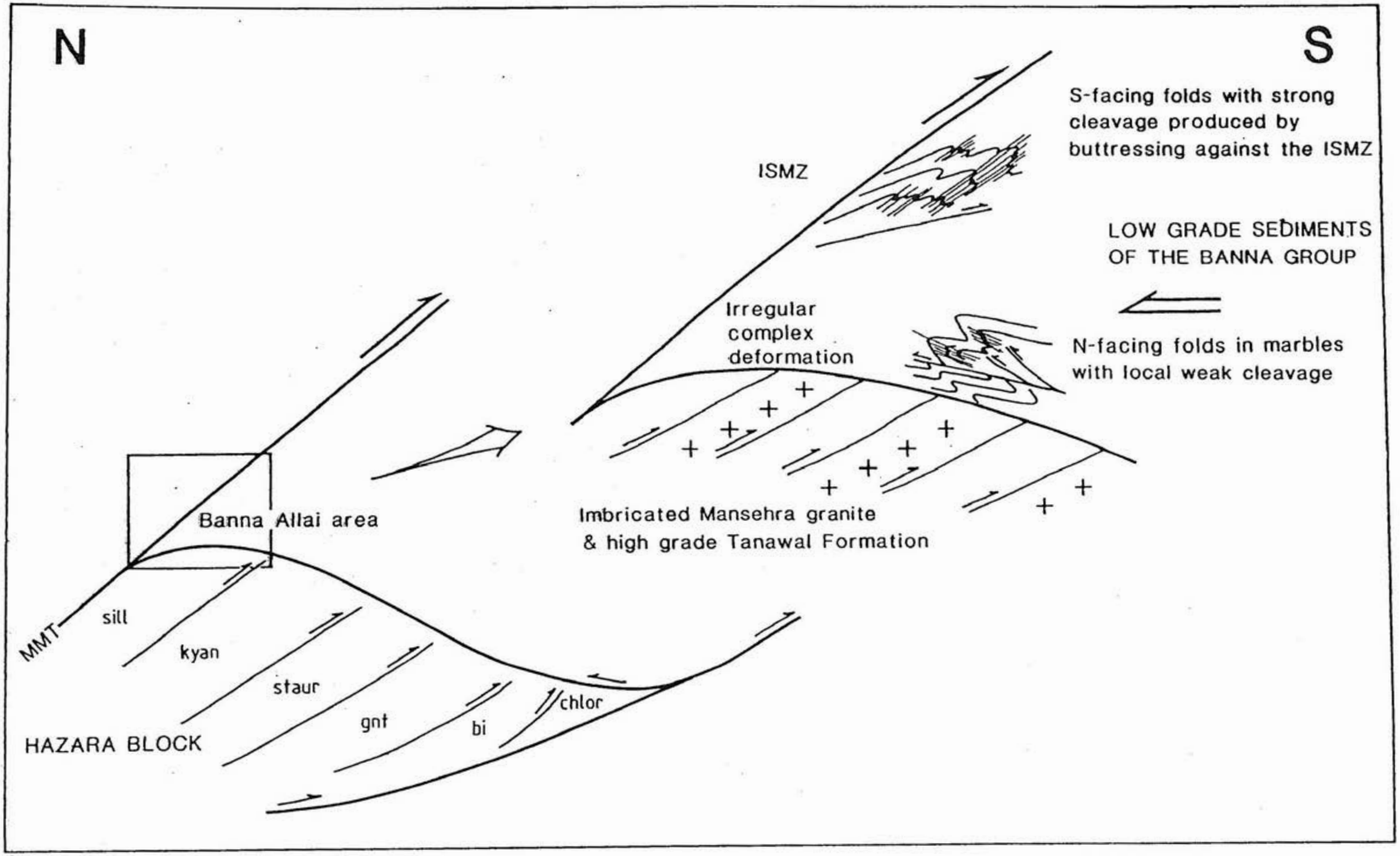

Fig. 6. A N-S section through the Hazara block and overlying sediments of the Banna Group which were emplaced as a N-moving backthrust cutting up through a previously imbricated sequence of Mansehra granite and high grade Tanawal Formation metasediments containing sillimanite. MMT-Main Mantle Thrust, ISMZ-Indus Suture Melange Zone.

In the graphitic phyllite of the first slice of the Karora Group the main fabric is defined by allignment of muscovite, chlorite, biotite (if present), and streaks of graphite. Albite and quartz are also present. Crenulations, tight microfolds and C-S fabrics are often developed, and in some of the psammitic pelites there is a strong quartz C-axis alignment. Fabrics in the second cover slice tend to be better crystallised with biotite as an essential rather than an accessory phase. In the schists of the third cover slice in which garnet (up to 3mm in diameter) is an essential phase, metamorphic differentiation has produced compositional banding.

The overlying Alpurai Schists have coarse grained, sheared, platy schistose fabrics dominated by bent muscovite and garnet porphyroblasts up to 2cm in diameter. Inclusion trails in the garnet are oblique to the fabric, and are often curved or spiralled. The other phases present are quartz, plagioclase, carbonate, clinozoisite, graphite, biotite, chloritoid, kyanite and staurolite, the latter two as ragged porphyroblasts.

Marbles of the first cover slice have a strongly alligned very fine grained granoblastic texture while in other localities they have coarse grained foliated decussate textures. The carbonate phase can be either calcite, as in most of the Alpurai Schists and second cover slice, or dolomite as in the first cover slice. Calcite and dolomite are rarely found together. Many of the marbles in the second cover slice contain tremolite, white mica and pyrite, while quartz and white mica are essential components in the Alpurai Schists.

In the Hazara block there is a similar Barrovian metamorphic gradient, the highest grade rocks in the north are thrust southwards over progressively lower grade rocks, a change mirrored by a southward decrease in ductility. In the Besham area the paragneissic Tanawal Formation contains sillimanite and may be partially melted. Textural evidence indicates that metamorphic mineral growth ended during D2. Treloar et al. (1989a, 1989b) give a more detailed picture of the mineral growth/deformation chronology.

There was negligible metamorphism of the Banna Group, chlorite and white mica being the only metamorphic minerals.

DISCUSSION

It is possible to separate the northern Indian plate rocks into distinct blocks which, while having internally consistent lithologies and deformation and metamorphic histories, differ from each other.

Metamorphism associated with the early stages of approximately S-directed overthrusting continued for longer in the Hazara block than in the Besham block. Imbrication post-dated the metamorphism. The movement direction during imbrication was probably from NW to SE in the Besham block, from N to S in the Hazara block and is thought to be the same in the Swat block, while the Banna Group was emplaced later as a backthrust from S to N. In both the Besham and Hazara blocks, high grade rocks have been thrust over low grade rocks to produce an overall inverted metamorphic gradient. Produced by thrusting of already metamorphosed rocks, this model contrasts with that proposed for the Indian and Nepalese Himalayan where an inverted gradient was produced by a combination of recumbently overfolding earlier isograds and pre-metamorphic thrusting. The metamorphism in the Indian and Nepalese Himalaya occurred as a consequence of thermal relaxation during and after thrusting of the hot, crystalline slab of Precambrian and lower Palaeozoic gneisses over the cold Proterozoic sediments along

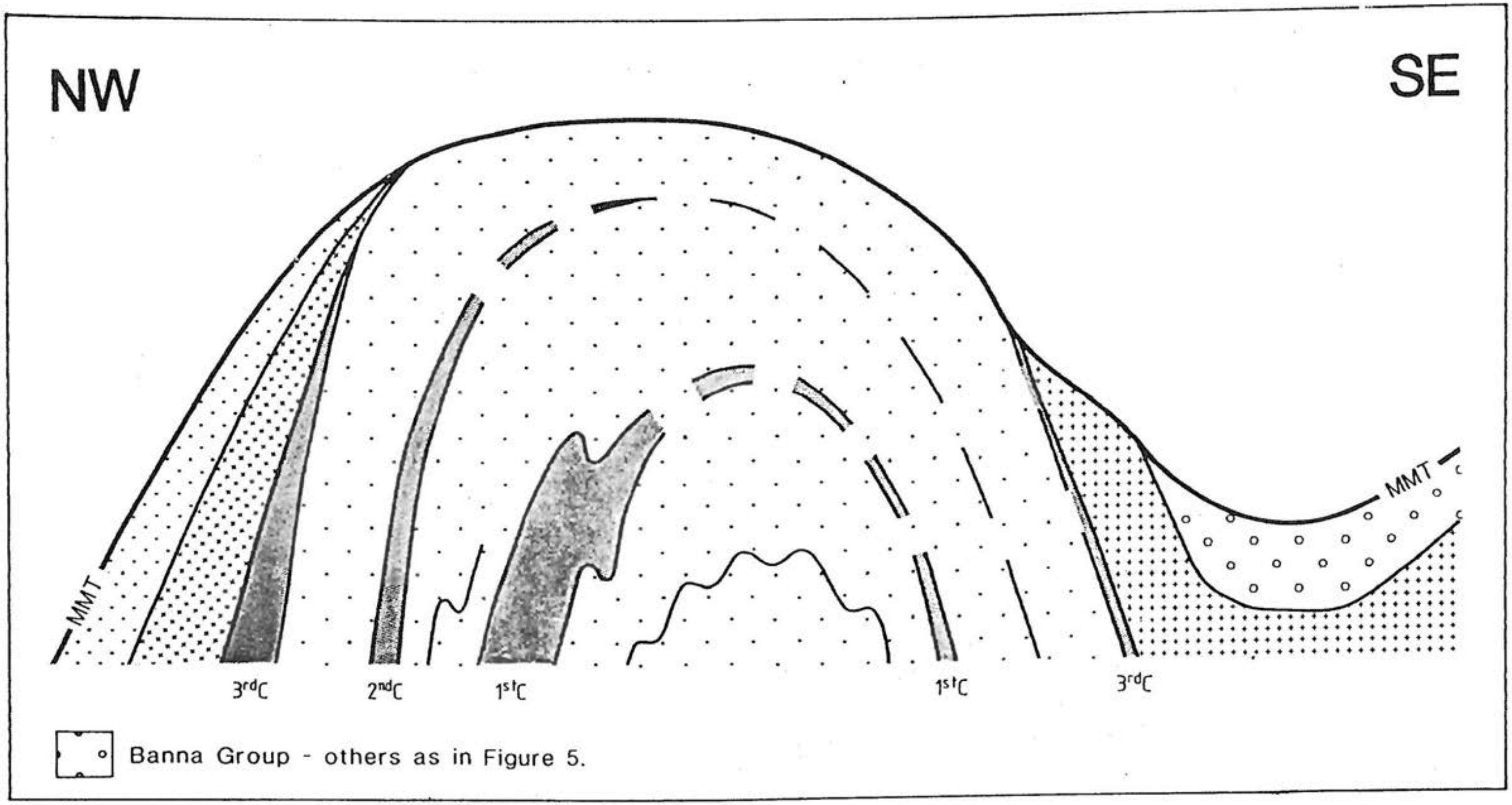

Fig. 7. A schematic post-D3 section through the Besham area.

the Main Cental Thrust Zone. In Pakistan the S directed overthrusting occurred as the Indian plate was subducted beneath the Kohistan Arc. As the Indian plate thickened by imbrication beneath the arc, the uplift caused a decrease in the ductility of deformation.

The Hazara block is separated from the Besham block to the west by the dextral Thakot Shear Zone (TSZ), and from the Kaghan valley sequences and the Hazara Syntaxis to the east by the Balakot Shear Zone (BSZ) (Fig. 4). Within the Hazara block the E-W striking N-dipping imbricating thrusts swing into the TSZ and BSZ and can be regarded as splays from a sole thrust. This, and the mylonite zones acting as lateral ramps (subsequently steepened during D3) allowed the Hazara block to be thrust southwards over the Besham block during D2a. The mylonites in the Choga body of the Swat Granite and the Manglaur Schists on the western margin of the Besham block may have served a similar function.

The Swat and Hazara blocks occupy the same structural position relative to the Besham block, and the similarities in basement lithologies suggest a lithostratigraphic correlation between the Manglaur Crystalline Schists and the Tanawal Formation.

Uplift which began during imbrication continued during the cross folding. The D3 antiforming of the Besham area, and later E-side-up reverse faulting within the Besham block, and possibly also on its western margin has resulted in greater uplift of the Besham than the Hazara block. The cross folds developed for the same reasons as the Hazara Syntaxis; the consequence of interference between SW directed thrusting of the Pir Panjal of the main Himalayan arc, and S directed thrusting of Kohistan.

Acknowledgements: I am grateful to NERC for providing research studentship (GT4/86/GS/121). The kindness and help of the staff of the NCE in Geology at Peshawar University is very much appreciated, in particular Professors M. Qasim Jan and R.A.K. Tahirkheli.

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