Pakistan Journal of Hydrocarbon Research
Vol. 19, (June 2009),p.19-28, 11 Figs. 2 Table.

Structural Geometry of a Part of the Southeastern Hazara Fold-Thrust Belt, Khyber Pakhtunkhwa , Pakistan

Muhammad Zahid[1], Sajjad Ahmad[1] Fayyaz Ali[1] and Gohar Rehman[1]

Abstract

The southeast Hazara forms a part of a fold and thrust belt in the Lesser Himalayas of Pakistan. This paper attempts to address the structural geology of a part of southeastern Hazara and explains the geometry and evolution of various structures present within the Hazara Slates and overlying younger rocks. The study area is covered by Pre-Cambrian and Mesozoic-Cenozoic age rocks that have undergone severe deformation, as illustrated by the development of southeast verging thrust faults and associated folds. The structural evolution of the study area is controlled by the deformation associated with Hazara Thrust Zone which is the major tectonic event and has resulted in thrusting of Pre-Cambrian Hazara Slates over the Mesozoic-Cenozoic rocks. Two discrete phases of deformation have been identified in the area, inferred from the cleavage study in the Hazara Slates. Cleavages in the Hazara Slates include a well developed bedding parallel slaty cleavage S1 which is the result of Pre-Cambrian deformation event. Conjugate sets of cleavages S2 and S3 are also present but are much less developed than the S1. These conjugate sets of cleavages are the result of Himalayan deformation events. It is inferred from the fact that joints corresponding to these cleavage sets are present in the overlying younger carbonates. The general trend of the hinge lines of meso and macro-scale folds observed within the Hazara Slates and overlying younger sediments is northeast-southwest, which is indicative of the fact that the area was mainly subjected to northwest-southeast compressive stresses. Our study reveals that Hazara Thrust Sheet plays a pivotal role in the structural evolution of the study area. Dominant slaty cleavage (S1) developed in Hazara Slates indicates Pre-Cambrian deformation event whereas less prominent conjugate cleavage sets (S2 and S3) are associated with the subsequent Cenozoic Himalayan deformation event. The east west trending sequences with dominant southeast directed faults depicts that stresses were directed from north-northwest.

INTRODUCTION

The study area is situated in the southeast of Peshawar Basin (Figure 1). The area is confined between latitude 33° 50' 30" N to 33° 55' 00" N and longitude 72° 59' 00" E to 73° 03' 00" E. The Hazara Hill Ranges represent the passive margin sediments of Mesozoic-Cenozoic age of Indian Plate that have been shortened and uplifted along the Main Boundary Thrust (MBT) (Izzat, 1993). An extensive area of the Hazara District is covered by the Hazara Slates. These slates are severely deformed and reveal structures like folds and small scale faults. The Hazara slates have been correlated with Attock Slates, Dogra Slates and Shimla Slates and are considered to be lateral equivalents (Izzat, 1993). The area under discussion is deformed by two major tectonic events; firstly in Pre-Cambrian time and later on during Cenozoic times giving rise to thrusts which are generally high angle reverse faults. Thus, Pre-Cambrian Hazara Slates is thrusted over Mesozoic rocks. Likewise Mesozoic and Cenozoic rocks are also verging to the south and southeast indicating south directed stresses released during continent-continent collision.

During the present study, mapping on 1:50,000 scale is presented and description for the structural geometry is given in order to enhance the understanding of hydrocarbon explorationists about the geology of the region in general and the area under discussion in particular.

Previous work

Geological investigation of Hazara area started during the 1860's. Wynne (1875), Middlemiss (1896) and Cotter (1993) were among the first geologists who undertook geologic work in this part of Khyber Pakhtunkhwa (formerly known as NWFP). These workers spent a considerable time to establish the stratigraphy of the area. Middlemiss (1896) conducted detailed work on the geology of Hazara for the first time and presented a preliminary geological map of a large part of Hazara. He also described the rock units and gave a generalized account of the stratigraphy and major structures and broadly classified the rock units present in this section into Trias Limestone, Spiti Shale, Grey Limestone, Giumal Sandstone and Nummulitic Limestone. The name "Syntaxis" was introduced by Wadia (1934) for the sharply curving mountain structure in the western half of the area. A geologic report relating to this area has been published by the Punjab University (Shams, 1961). Latif (1970) gave a brief account of the stratigraphy of southeastern Hazara, supported by a detailed geologic map at a scale of one inch to one mile. He classified the litho-stratigraphic units into seven groups separated by unconformities and further subdivided them into twenty one formations (Ghazanfar et al., 1990). He distinguished different formations within the Tertiary "Nummulitic Series" of Middlemiss (1896). His nomenclature was later on accepted by the Stratigraphic Committee of Pakistan. Coward and Butler (1985) published a structural section along the Murree Abbottabad road and viewed the Hazara Hill Ranges as a series of imbricate thrust detaching on the Main Boundry Thrust (MBT). Ghazanfar et al. (1990) explained the geology and structure of Kuza Gali, Dunga Gali--Ayubia area with special reference to hydrocarbon prospects of Attock Hazara Fold and Thrust Belt. Schenellmann and Gnehm (1999) prepared a geologic map and cross section of northwestern Himalayan Fold and Thrust Belt in Hazara. These authors also proposed a kinematic and dynamic model to assess the deformation present in the area. Izzat (1993) explained the variation in thrust front geometry across the

[1] Department of Geology, University of Peshawar, Pakistan.

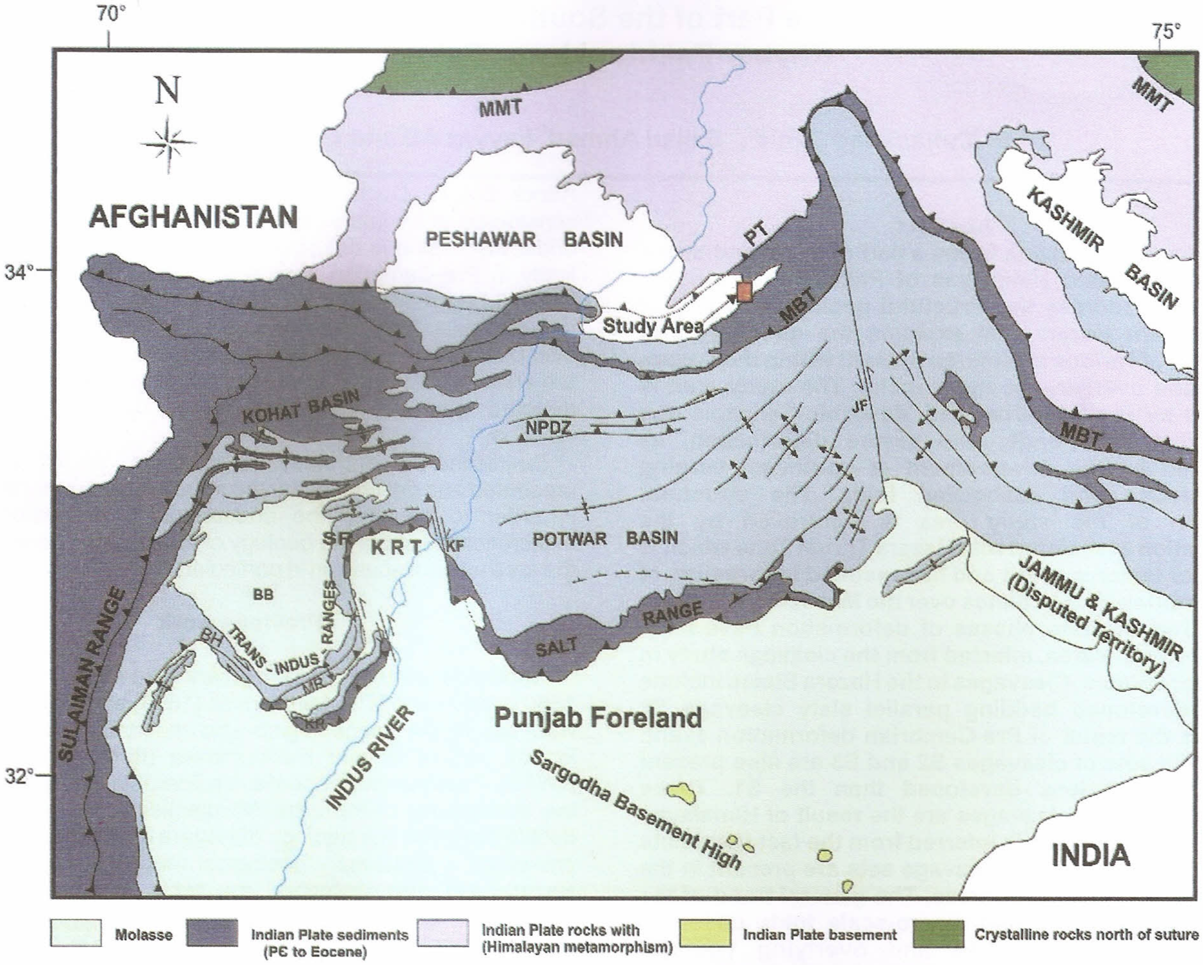


Figure 1- Generalized geological map of the NW Himalayan Foreland Fold and Thrust Belt (modified after Kazmi and Rana, 1982). Inset shows the location of the study area. MMT: Main Mantle Thrust, PT: Panjal Thrust, MBT: Main Boundary Thrust, NPDZ: Northern Potwar Deformed Zone, JF: Jhelum Fault, KR: Khisor Range, BB: Bannu Basin, KF: Kalabagh Fault, KRT: Kalabagh Reentrant, MR: Marwat Range, BH: Bhittani Range, SR: Surghar Range.

Potwar Plateau and Hazara/Kalachitta Hill Ranges. Chaudhry et al. (1998) described the sedimentology of Jurassic to Eocene rocks of Hazara Basin. The present study is undertaken to map a part of southeastern Hazara at a scale of 1:50,000 and to explain the structural geometry of the area.

Regional Geology and Stratigrphy

The Hazara Fold-Thrust Belt is located in the Lesser Himalayas, bounded by Panjal Thrust in the north and MBT in the south. The study area represents a small section through part of a much larger tectonic feature of the southeastern Hazara Fold-Thrust Belt. An extensive area of the southeastern Hazara was mapped by Latif (1970) who described the stratigraphy of the area in the explanatory notes accompanying the geological map. Stratigraphically the area of southeastern Hazara forms a part of the much larger Kohat-Potwar sedimentary basin (Ghazanfar et al., 1990). It shows a fairly complete succession from Pre-Cambrian to Miocene with the notable absence of Middle to Upper Paleozoic sequence in addition to a number of other smaller discontormities (Ghazanfar et al., 1990). The Hazara Fold-Thrust Belt runs in the form of E-W elongated linear belt which turns northwards in the east to merge into the Hazara-Kashmir syntaxis. The exposed rocks within the study area range in age from Jurassic to Eocene. Pre-Cambrian Hazara Formation is exposed in the area along the Hazara Thrust Zone. A comparison of nomenclature of rock units exposed in southeastern Hazara adopted by Latif (1970) and Shah (1977) is given in Table 1. The nomenclature adopted in this study is after Shah (1997). The stratigraphic column of the study area is shown in Table 2.

Main structural elements

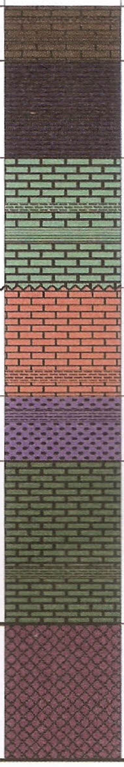
The study area is located in a fold and thrust belt and has undergone intense deformation and shortening as manifested by a number of thrust faults and various large and small scale folds (Figure 2). The overall trend of these structures is northeast-southwest, indicating northwest-southeast compressive stresses. Following is a brief description of the major structural elements of the study area.

Table 1 - Comparison of nomenclature of rock units exposed in southeastern Hazara (after Latif, 1970 and Shah 1977).

Nomenclature of the rock units in Hazara by **Latif (1970)**	Nomenclature of the rock units in Hazara by **Shah (1977)**	Age
Murree Formation (Rawalpindi Group)	Murree Formation (Rawalpindi Group)	**Early Miocene**
.....Unconformity.....	.....Unconformity.....	
Kuldana Formation Lora Formation Margala Hill Limestone	Kuldana Formation Chorgali Formation Margala Hill Limestone	**Eocene**
Kuza Gali Shale Mari Limestone Not mentioned	Patala Formation Lockhart Formation Hangu Formation	**Paleocene**
.....Unconformity.....	.....Unconformity.....	
Chenali Limestone Giumal Sandstone Group Spiti Shale	Kawagarh Formation Lumshiwal Formation Chichali Formation	**Cretaceous**
.....Unconformity.....	.....Unconformity.....	
Sikhar Limestone Maira Limestone group Not reported	Samana Suk Formation Shinawari Formation Datta Formation	**Jurassic**
........Unconformity........	........Unconformity........	
Hazira Formation Galdanian Formation Sirban Formation Kakul Formation	Hazira Formation Abbottabad Formation	**Cambrian**
.....Unconformity.....	.....Unconformity.....	
Tanol Formation Hazara Group	Tanawal Formation Hazara Formation	**Pre-Cambrian**

Table 2 - Composite lithostratigraphic column of the study area (after Shah, 1977).

AGE	FORMATION	LITHOLOGY	THICKNESS	DESCRIPTION
Early Eocene	Margala Hill Limestone		100 m	Limestone with interbedded marl and shale layers
Late Paleocene	Patala Formation		180 m	Marly shale with few limestone beds at places
Middle Paleocene	Lockhart Limestone		242 m	Nodular limestone with occasional marl and shale streaks
Late Cretaceous	Kawagarh Formation		200 m	Medium to thick bedded limestone with shale in the lower part
Early Cretaceous	Lumshiwal Formation		120 m	Predominantly sandstone with minor occurences of shale
Middle Jurassic	Samana Suk Formation		300 m	Medium to thick bedded oolitic limestone with minor shale
Pre-Cambrian	Hazara Formation		250 m	Slate and phyllite with gypsum and graphitic layers



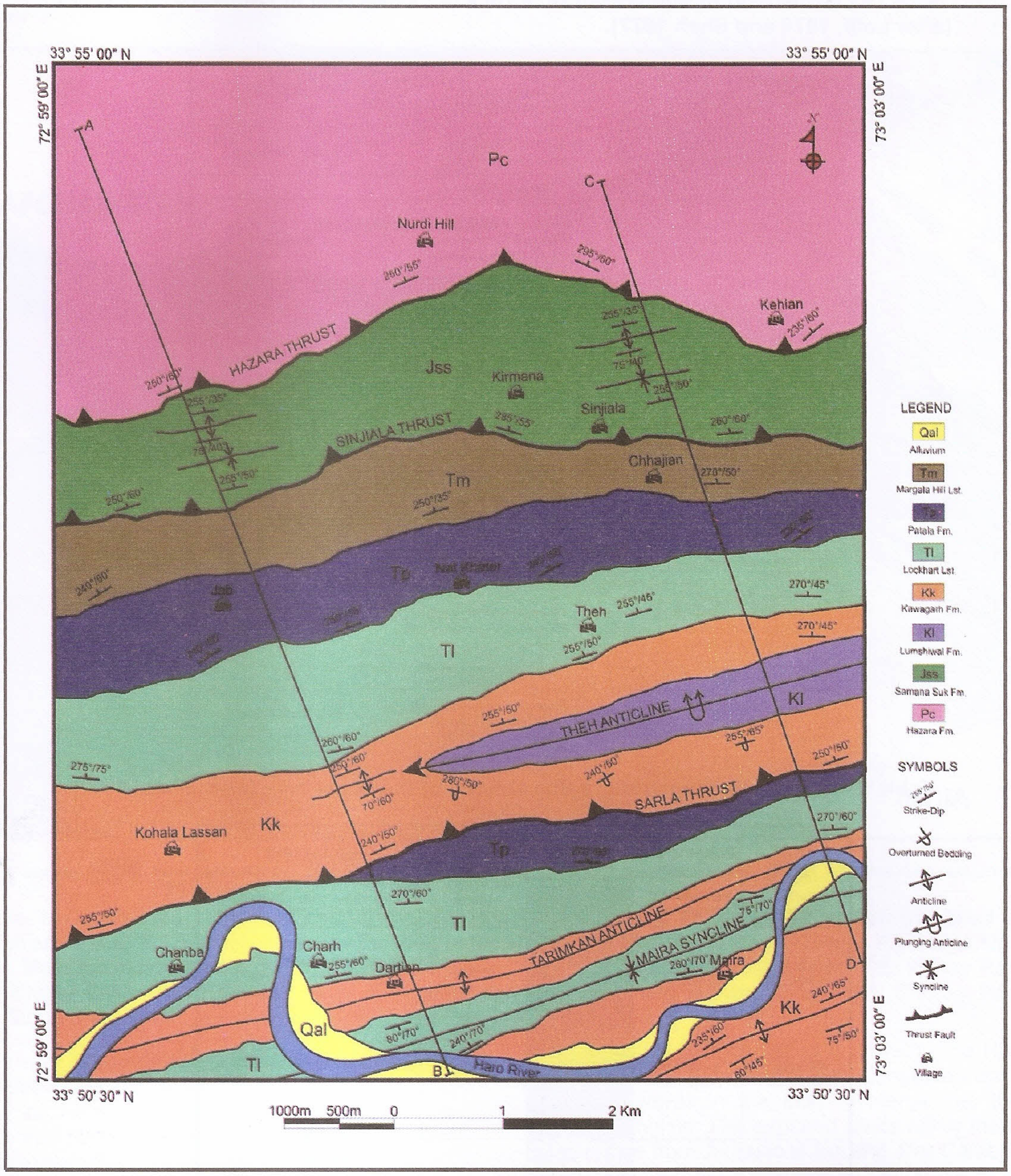


Figure 2 - Geological map of the study area.

I. Folds

The area under study exhibits tight folding and in some areas overturning of the fold limbs has been observed. Major folds observed in the area include Theh Anticline, Tarimkan Anticline and Maira Syncline (Figure 2).

Theh Anticline occurs in the middle part of the study area to the east of the Kohala Lassan village. It contains Lumshiwal Sandstone in its core. The northern flank of the mentioned anticline is undisturbed as it is built by normal sequence of Kawagarh Formation and younger sequences; however, the southern flank is disturbed. Within Kawagarh overturning to the north occurs. It indicates that the fold axis of Theh Anticline is inclined and fold is obviously south verging. Further in the south the Kawagarh Formation is thrusted over Patala Formation along Sarla Thrust. This arrangement shows that the mentioned anticline and its southern flank is bounded by a bundle of south verging thrusts (Figure 2). The trend of the hinge line of this fold is 255° and it plunges towards west.

Tarimkan Anticline occurs to the south of Theh Anticline. The core of Tarimkan Anticline contains Cretacous Kawagarh Formation which is overlain by Lockhart Formation of Paleocene age (Figure 2). Since this anticline hosts relatively younger sequence in its core compared to Theh Anticline in the north so the uplift rate of this anticline is less than that of the Theh Anticline.

Maira Syncline occurs in the southernmost part of the map. The fold axis of this anticline is running in northeast southwest direction nearly parallel to the axis of anticlines in the north and south. Maira Syncline is flanked by Tarimkan Anticline in the north and an unnamed anticline in the south. It is a tight fold with steeply dipping limbs and trends approximately 75°.

Intraformational folding is also observed in Kawagarh and Samana Suk Formation where they are thick and well exposed near Sinjiala and Kohala Lassan villages, respectively (Figure 2).

II. Faults

The study area is a part of a major fold and thrust belt and is therefore characterized by various thrust faults. The major faults observed in the area are Hazara, Sinjiala and Sarla Thrust. Hazara Thrust is the major thrust fault encountered in the northern part of the study area. Along this thrust Precambrian rocks of Hazara Formation are thrust over Samana Suk Formation of Jurassic age. The Hazara Thrust is roughly east-west oriented with undulations and bends and its dip ranges from 50° to 60°.

Sinjiala Thrust occurs to the south of Hazara Thrust and brings Samana Suk Formation of Jurassic age in direct contact with Margala Hill Limestone of Eocene age. This thrust is also roughly east-west oriented with a dip of 60°

Sarla Thrust is the southernmost fault in the study area which, for most part of its length, marks the faulted contact between Kawagarh Limestone and Patala Shale. Towards west Cretaceous Kawagarh Formation is thrust over Middle Paleocene Lockhart Formation along the Sarla Thrust. Sarla Thrust strikes 80° with a dip of 50° NW.

Mesoscopic structures with-in the Hazara Slates.

Mesoscopic structures are the structures visible at the scale of outcrop and hand specimen. Study of such structures help in strain analysis, provides information that can help in the interpretation of regional (macroscopic) structural relations and provide clues about deformation conditions and sense of movement during deformation. The deformation within the Hazara Slates of the Hazara thrust zone is represented by well developed cleavages and a variety of folds.

The Hazara Slates show three sets of cleavages. The first set of cleavages S1 is bedding parallel and is much well developed as compared to the other two. The less developed S2 and S3 cleavages occur as conjugate sets (Figure 3). The deformation within the Hazara Slates appears to be the result of two phases of deformation. The first being Pre-Cambrian (primary deformation) and the second being Himalayan (secondary deformation). The bedding parallel slaty cleavage

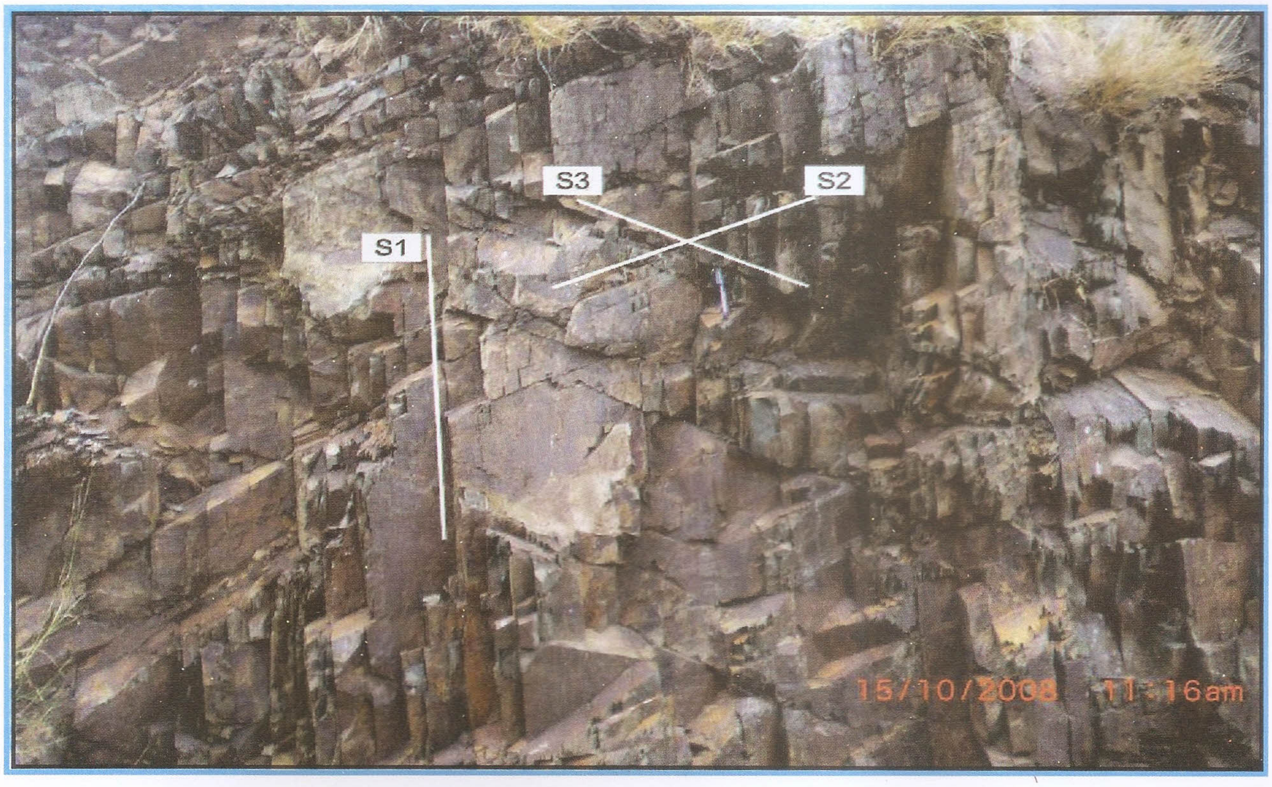


Figure 3 - Hazara Slates showing three sets of cleavages (lat. 33°54'00"N: long. 73°00'30"E). The most prominent set of cleavages is the S1 (330°, 80°). The other two sets, S2 (150°, 20°) and S3 (130°, 40°) occur as conjugate sets and oblique to the bedding parallel cleavage set S1.

S1 is the result of Pre-Cambrian deformation. The S2 and S3 which are less developed as compared to the S1 fabric are most probably the result of Himalayan deformation. This is inferred from the fact that joints corresponding to these less pervasive cleavage sets are also present in the overlying younger carbonates. The rose diagram of cleavage data (Figure 4) is shown in (Figure 5) which is indicative of an overall NE-SW orientation of the cleavages.

A variety of folds, both symmetric and asymmetric, are present in the Hazara slates. Z-folds (Figure 6), W-folds (Figure 7) and kink folds (Figure 8) are most commonly observed in Hazara Slates. The general trend of these folds is northeast-southwest (Figure 9). This overall northeast-southwest orientation of the fold axes indicates that they are the result of northwest-southeast compressive stress. This is in conformity with the overall northwest-southeast shortening accommodated by the Main Boundary Thrust (MBT) and the Hazara Thrust.

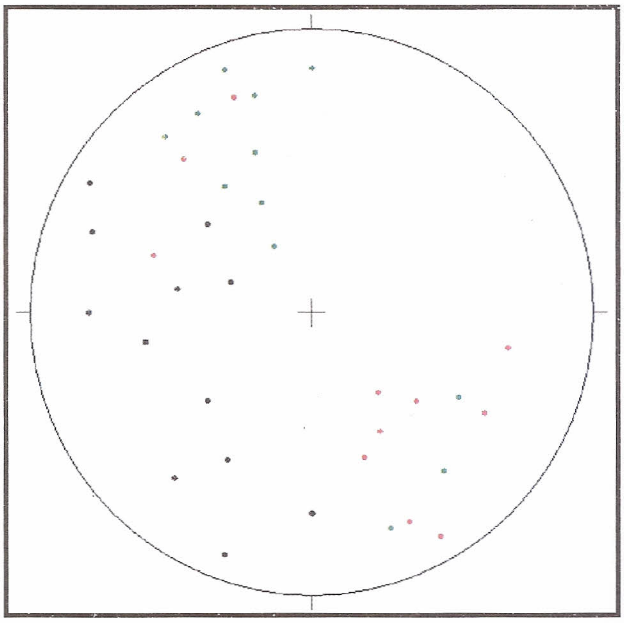


Figure 4 -Orientation data of cleavage sets S1, S2 and S3 within the Hazara Slates
. S1, the most prominent bedding planar cleavage
. S2 cleavages
S3 cleavages

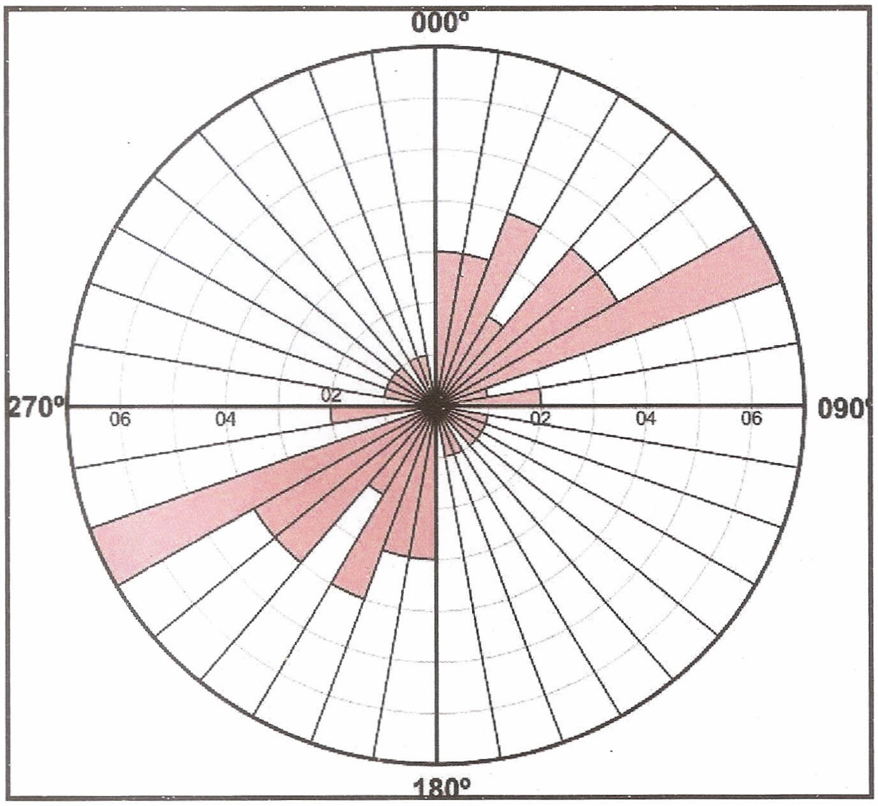


Figure 5 - Rose diagram of the cleavages observed in the Hazara Slates
No. of cleavage measurements = 36
Class interval for compass bearing = 10°
Circular interval representing no of data = 1

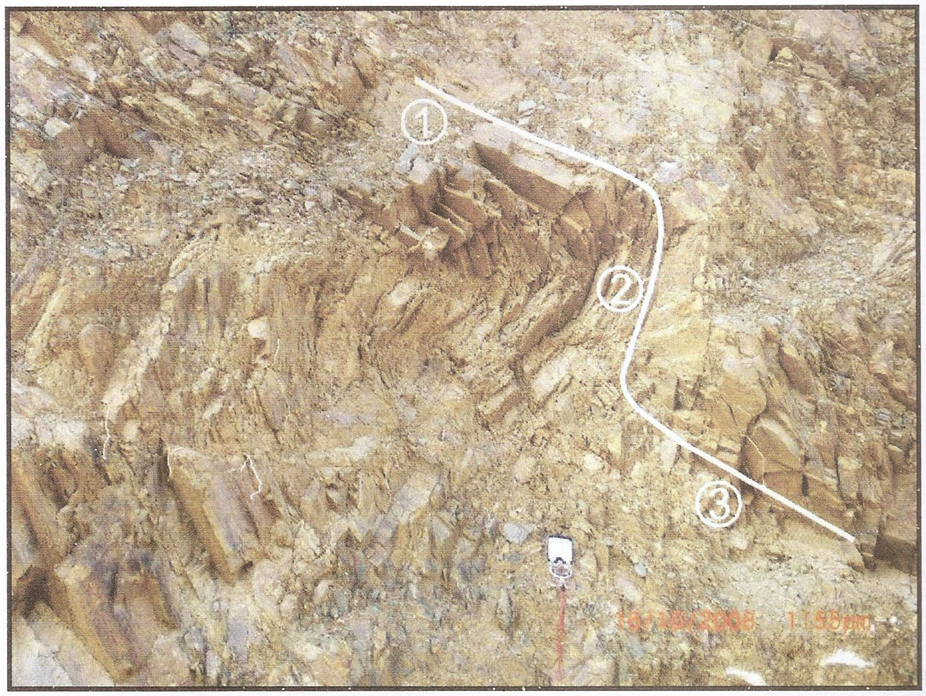


Figure 6 - Southwest looking view of an asymmetric Z fold in Hazara Slates (viewing down plunge); The orientations of the limbs of the fold are;

1. 310°, 50°
2. 170°, 70°
3. 310°, 50°
The hinge line of this fold is oriented 248°, 29°

Figure 7 - Northwest looking view of an asymmetric W fold in Hazara Slates
The hinge line of this fold is oriented 280°, 20°

Figure 8 - A kink fold in Hazara Slates. The orientations of the limbs of the fold are; The hinge line of this fold is oriented 068°, 13°

1. 340°, 80°
2. 150°, 60°
3. 340°, 80°

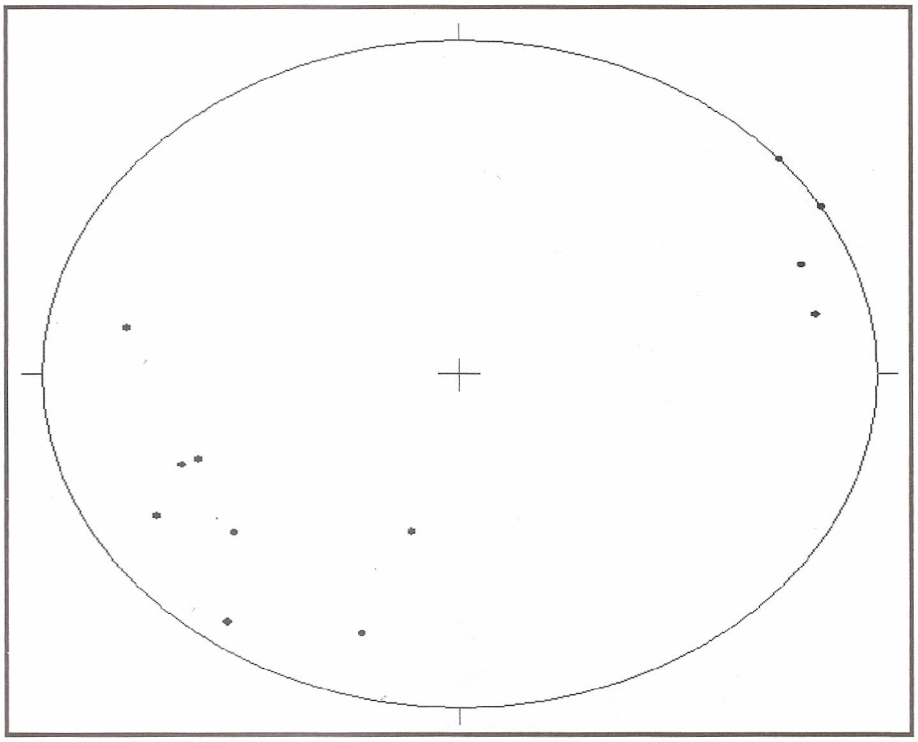


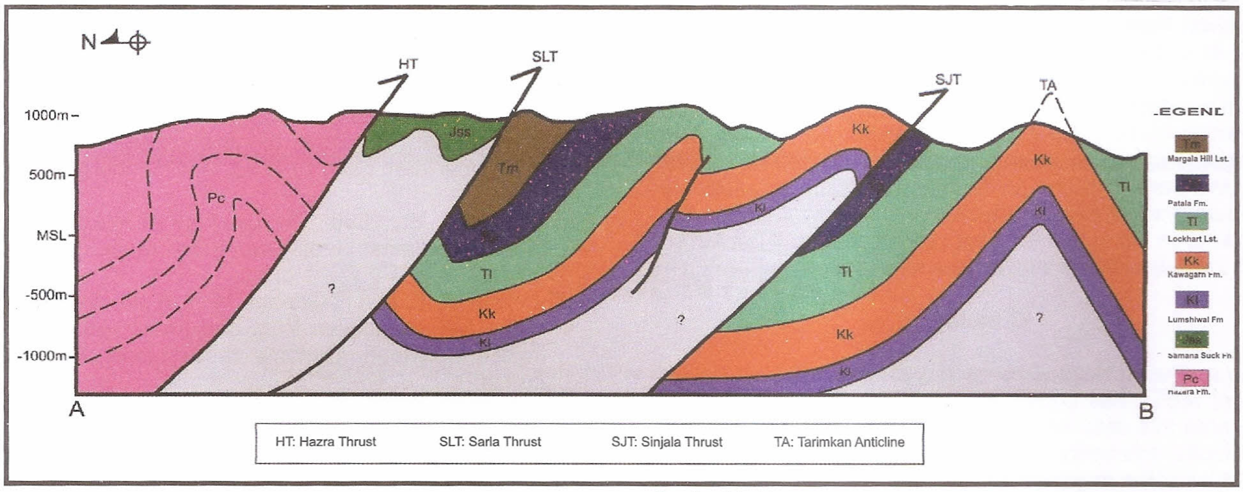
Figure 9 - Equal area plot of the hinge lines of the folds in the Hazara Slates.

Structural transects

In order to explain the surface and subsurface geometries of the exposed structural features, two geological cross sections, one along line AB and the other along line CD of the map have been constructed (Figure 10 and 11). The salient structural features shown in these transects are as follows.

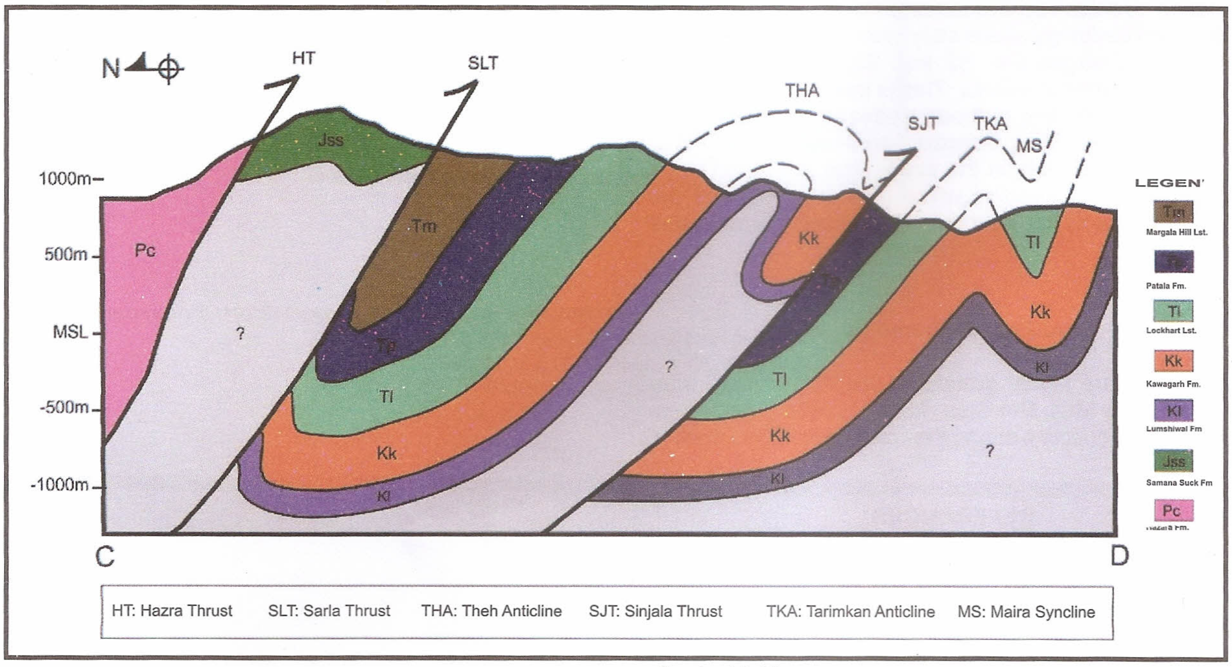
I. Transect along line AB

The structural transect along the section line AB is perpendicular to the trend of the major structures present in the area and is north-northwest oriented. Most of the formations are northwest dipping and the dips are, in general, steep. The northernmost part of the area is covered by the severely deformed Hazara Slates. The Hazara Slates of Pre-Cambrian age are thrust over the Jurassic Samana Suk Formation along the Hazara Thrust. Folding is well developed in the Samana Suk Formation indicating that it has also undergone severe deformation. To the south of the Hazara Thrust, the Jurassic Samana Suk Formation is thrust over the Eocene Margala Hill Limestone along the Sinjiala Thrust which is steeply north dipping. To the south of the Sinjiala Thrust, a conformable sequence of Kawagarh, Lockhart and Patala Formation is present. The Kawagarh Formation is thrust over Patala Formation along the Sarla Thrust. To the south of Sarla Thrust is the Tarimkan Anticline which is cored by Kawagarh Formation.



Scale: V=H

Figure 10 - Geological cross section along line AB of Figure 2.



Scale: V=H

Figure 11 - Geological cross section along line CD of Figure 2.

II. **Transect along line CD**

The cross section line CD is parallel to the section line AB but covers the eastern part of the map. It thus shows the eastern extension of the structures depicted in the section along line AB. The Hazara Thrust, Sinjiala Thrust and the Sarla Thrust show the same sectional geometry as was depicted in the section along line AB. The Hazara Thrust has brought the Hazara Formation on top of the Samana Suk Formation. Sinjiala Thrust is to the south of the Hazara Thrust and has emplaced the Jurassic Samana Suk Formation on top of the Margala Hill Limestone. Sarla Thrust has thrusted Kawagarh Formation over Patala Formation. In between the Sinjiala Thrust and the Sarla Thrust is the Theh Anticline which is not present in the section along line AB. The Theh Anticline has Lumshiwal Formation in its core while Kawagarh Formation forms its limbs. The southern limb of the Theh Anticline is overturned and thus Lumshiwal Formation occurs on the top of the Kawagarh Formation. The Theh Anticline is not visible in the section AB because it runs in the west of the plunge. The Kawagarh Formation is then thrust over the Patala Formation along the Sarla Thrust. The Tarimkan Anticline is present in the southernmost part of the cross section as it was in the cross section along line AB. From both transects it is inferred that in the subsurface a similar geometry is expected.

Conclusion

The southeast Hazara, being very close to the MBT (to the north of MBT), has undergone intense deformation. In the study area this deformation is marked by southeast verging thrust faults, and northeast trending anticlines. This northeast orientation of the major structures suggests that the area has been under the influence of northwest-southeast oriented stresses. The Hazara Slates present in the northern part of the study area have recorded both Pre-Cambrian and Himalayan deformation events. The Precambrian deformation event is marked by the bedding parallel slaty cleavage (S1). The other two sets of cleavages (i.e. S2 and S3) are the result of Himalayan deformation events. This is inferred from the fact that joints corresponding to these cleavage sets have been observed in the overlying Cenozoic carbonates. The hinge lines of most of the folds in the study area are found to be northeast-southwest trending which also suggests that the area is subjected to northwest-southeast compressive stresses.

Acknowledgements

The authors are highly grateful to Mr. Muhammad Irfan Khan, Geologist, MOL Pakistan, for his useful suggestions and constructive criticism during the completion of this work.

REFERENCES

Chaudhry, M. N., M. Ghazanfar, N. Ahsan, and K. R. Masood, 1998. Age, Stratigraphic Position and Provenance of Murree Formation of N-W Sub-Himalayas of Pakistan and Azad Kashmir. In third Geoscience Workshop on Siwaliks (GSP), Islamabad. Bull. Geol. Surv. Pak. 81-89.

Cotter, G. P., 1933. The geology of part of the Attock District west of Longitude 72.45o: Geol. Soc. India Mem., v.55, p. 63-156.

Coward, M. P., and R. W. H. Butler, 1985. Thrust tectonics and the deep structure of the Pakistan Himalaya: J. Geol., Vol.13, p.415-420.

Ghazanfar, M., M. N. Chaudary, K. Pervaiz, M. Qayyum, and R. Ahmed, 1990. Geology and Structure of Kuza-Dunga Gali-Ayubia Area, Hazara-Potwar Basin with a reference to Hydrocarbon Prospects of Attock-Hazara Fold and Thrust Belt: Pak. J. Hydrocarb. Res., Vol. 2; No.2; p. 43-55.

Izzat, C. N., 1993. Variation in thrust front geometry across the Potwar Plateau and Hazara/Kalachitta Hill Ranges, Northern Pakistan. Ph.D Thesis, Imperial College of Science, Technology and Medicine, London.

Kazmi, A. H., and Rana, R. A., 1982. Tectonic Map of Pakistan, 1:1,000,000. Geol. Surv. Pakistan.

Latif, M. A., 1970. Explanatory notes on the geology of Southeastern Hazara to accompany the revised geological map: Wein Jb. Geol. B.A. Sonderban, Vol. 15; 5-20.

Middlemiss, C. S., 1896. The Geology of Hazara and the Black Mountains: Geol. Surv. India, Mem., 26(1), p. 1-290.

Schenellmann, M. and F. Gnehm, 1999. A structural analysis of the NW Himalayan folds and thrust belt in Hazara, Pakistan. Unpub. Diploma thesis; Instt. Geol., ETH Zurich.

Shah, S. M. I., 1977. Stratigraphy of Pakistan: Geol. Surv. Pakistan, Memoirs, v. 12, p.137.

Shams, F. A., 1961. A preliminary account of the Mansehra Area, Hazara District, West Pakistan: Punj. Univ. Geol. Bull; Vol. 1; p. 57-62.

Wadia, D. N., 1934. The Cambrian- Trias sequence of northwest Kashmir. Geol. Surv. India, Rec. 68, 2:1221-176.

Wynne, A. B., 1875. Notes on the Tertiary zone and underlying rocks in the northwest Punjab. Geol. Surv. India, Resc 10(3), 107-132.

PJHR

Received Feb. 20, 2011, revised April 12, 2011 and accepted Aug 17, 2011.