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The Regional Extents of Local Thrust Systems in Jabbari and Rupper Town, South East of Hazara Pakistan

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Abstract. Geological traverse between the town of Jabbri and Rupper, southeast Hazara delineates the stratigraphic and structural element of the area presented by high resolution geological map and cross section of the area. Oldest rocks in this section is Precambrian Hazara formation which is disconformably overlain by a Jurassic to Eocene sequence including Samana Suk, Chichali, Lumshiwal, Kawagarh, Hangu, Lockhart, Patala, Margalla-hill-limestone, Chorgali and Kuldana formations. Located in Lesser Himalayas, under the influence of main boundary thrust (MBT), this area developed several thrust systems from north to south including Hazara thrust, Haro thrust, Sangoda thrust, Rupper thrust. The main regional Hazara thrust has Precambrian rock in its hanging wall thrusted over the Jurassic Samna Suk formation. In lower detachment, there are several local thrust systems within Jurassic-Eocene strata.These thrusts trends in NE-SW direction indicating NW-SE compressional regime with the hanging wall Drag folds showing southward vergence. The stereographic plot of mesoscopic scale folds shows at least three folding events and varying plunging directions between the range of 240º and 290º. Most of the folds are plunging towards west and this is yet another indicator of east-west compressional forces. These folds orientations suggest transpressional deformation rather than pure compression. The balanced restore section shows that there is about 2.5 km shortening along 15 km restored section which makes about 16% shortening along the section.

Keywords: Hazara fault system, main boundary thrust (MBT), lesser Himalaya.

Introduction

Many geologists have investigated the structurally complex Hazara region but most of them focused the stratigraphic account rather on structural account. Wynne (1875) investigated the geology of hazara for the first time followed by Waagen (1872) and Middlemiss (1896). Wadia (1931) first introduced the term Hazara-Kashmir Syntaxes. In 1965, Gardezi and Ghazanfer investigated the Hazara formation near Nathia gali followed by Latif (1970) did detail work in the southeastern part of Hazara region. The northern Hazara hill ranges were investigated by Calkins *et al*. (1975). A structural section along the Abbotabad-Murree road are developed by Coward and Butler (1985) which specifies that Hazara hill ranges are the imbricate thrusts detaching from the main Boundary thrust (MBT). Most part of the Hazara is dominated by the Precambrian Hazara slates, which are the oldest rock of this region exposed to the surface.

Due to tectonic and structural complexity of the area and thick vegetation, there is very little work done in this domain. Primary objective of this work is to develop high resolution geological map and balanced geological cross section, which will enable us to delineate the structural geological setup influenced by regional tectonic events in this region.The findings of this research will be used to update the geological map of the un-addressed domain of the south-east Hazara (Fig 1)

Material and Method

The study area is located in Hazara region of lessor Himalayas. For this research a detail 3 days field excursion was conducted along Islamabad-Murree road. All the details were recorded in field work including sedimentological information for stratigraphic mapping and structural information for structural modelling. All the formation contacts were marked on field with it's GPS coordinates. Sedimentological features like grain size, fossil content and nature of bedding were noted in detail with the help of hand-lens, jacob stick, and geological hammer. All the structural detail including joints, fractures and faults were recorded in field with the help of Brunton compass. The data collected in field were uploaded to computer system for preparing geological maps and cross section. The geological map,

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cross section and restore sections were drawn using Corel Draw X6 graphic software. The equal area stereographic plot of the fold's hinge lines was plotted using Stereonet software.

Geological framework. About 200 Ma ago, the Indian plate split up from the Gondwana land and drifted toward north with an average speed of 10 to 17cm/year (Heldebrand *et al*., 2001; Johnson *et al*., 1976). About 70 Ma ago, the Indian plate come close to the Eurasian plate and closure of Tethys, the intermitted ocean, occurred (Petterson *et al*., 2010; Parrish *et al*., 2006)

The intra-oceanic subduction formed Kohistan Island Arc which accreted to the Pak-Indian plate resulting in formation of Indus Tsangpo Suture Zone (Ding *et al*., 2016; Bignold *et al*., 2001). In late eocene, this agglomerated domain start subduction beneath the Eurasian plate along the Shyok Suture zone and end up with the Andean type orogeny (Searle, 1985). Due to this collision, the world largest mountain ranges, Himalayas formed (DiPietro, 2001). Indian plat recorded a counter clockwise rotation creating many transform faults i.e left lateral Chaman fault (Kazmi, 1979). During this time, some important thrust systems formed. The northern most trust system formed is the main Karakorum thrust (MKT), followed by main Mantle thrust (MMT), main Boundary thrust (MBT), and southern most salt rang thrust (SRT) (Searle, 1991) (Fig. 1)

This area of investigation lies in lesser Himalayas which is composed of Pre-Cambrian to Paleocene rocks uplifted along MBT. This area is highly deformed with several localized thrusts which are splays of MBT i-e from Hazara thrust up to MBT (Tahirkheli, 2019). The local structures of the area are associated with the deformation of Hazara major thrust zone. This Hazara thrust is bounded by MBT, MMT and HKS (Hazara Kashmir Syntaxis) in south, north and east (Ahmad *et al*., 2017; Ali *et al*., 2015; Khwaja *et al*., 2009). The other local thrusts associated with Hazara thrust are Haro thrust, Sangoda thrust and Rupper thrust. All these thrusts including Hazara thrust are NE-SW oriented (Fig. 3)

Result and Discussion

Stratigraphy. The stratigraphy of the study area ranges from Jurassic Samana Suk formation to Eocene Kuldana formation (Fig.2). Samana-Suk formation is grey to dark grey colour, thin to medium bedded limestone. The limestone is oolitic, sandy, pale yellowish in colour

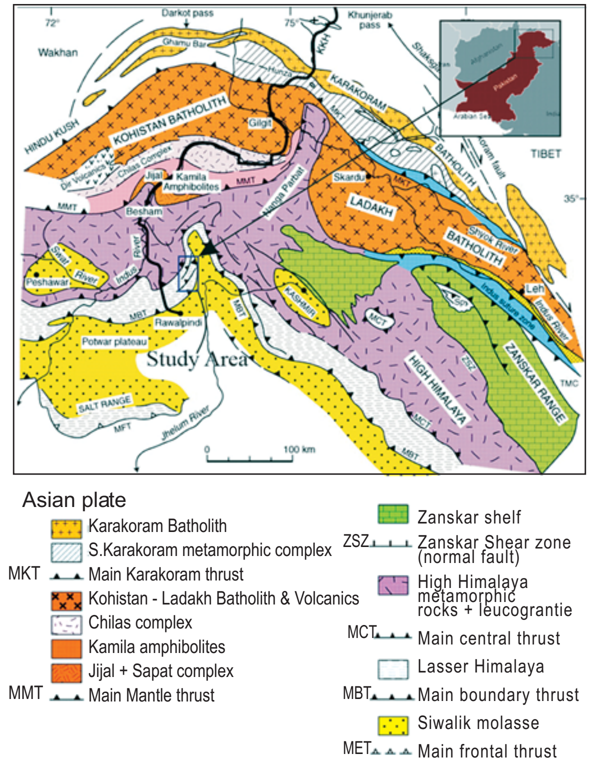

Fig. 1. Geological map of northwestern Pakistan (after Ahmad Hussain *et al*., 2014)

containing shell fragments. Dolomitized beds are also exposed which are dark grey to pale yellow in color and these beds are coarse grained and thick bedded. Stalactites, Stylolite, and Caliche (Plate.1 A, B, C) are indicating fluid flow through the formation, forming cavities (Rahim *et al*., 2020; Saboor *et al*., 2015). Among fossils corals and shell fragment are present. (Plate.1 D). This formation is conformably laying over Chichali formation (Plate.1 E) and in faulted contact with Kawagarh formation at places (Plate.1 F). Chichali formation is dominated by dark grey to bluish grey in colour, sandy to silty glauconitic shale and splintery sandstone (Rehman *et al*., 2016). This sandstone is dominated by light colour cylindrical Belemnites with rusty brown iron nodules (Plate.1 G, H). Yellow bands indicating high concentration of iron are present at places. Its lower contact is conformable with Samana Suk formation and upper contact is gradational with Lumshiwal formation (Malkani *et al*., 2016). Lumshiwal formation is medium to thin bedded, cliff-forming, limestone and coarse to medium-grained greenish grey to light/rusty brown sandstone. The shale is brown in color (Plate. 2 A), highly fractured and folded showing

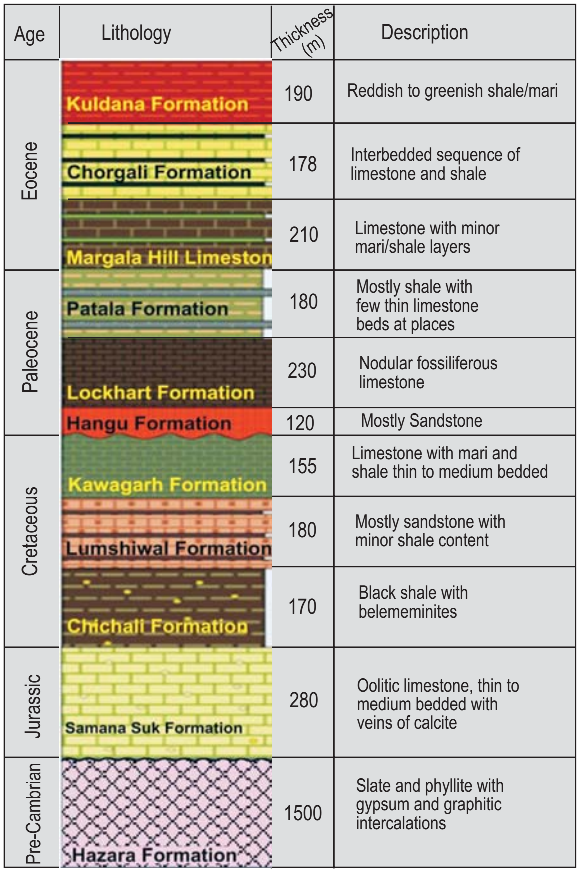

Fig. 2. Generalized stratigraphic column of the study area.

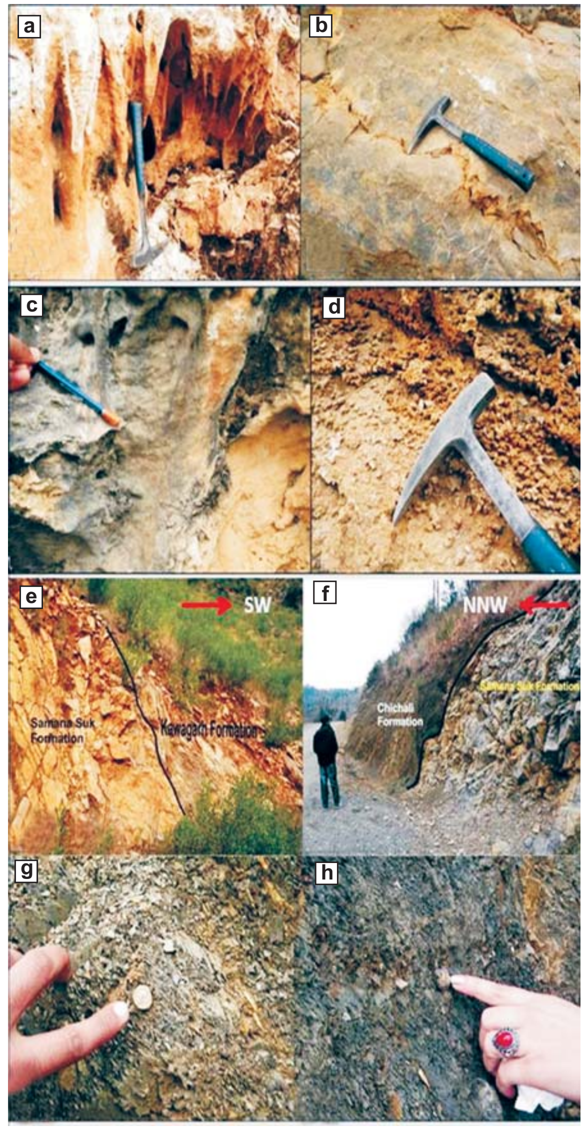

Plate no 1. Field illustration of Samamana suk. (**a**) Stalactites, (**b**) Stylolites, (**c**) Caliche, (**d**) Corals, (**e**) Contrimable contact of Samana Suk and Kawagarh, (**f**) Faulted contact of Samana Suk and Chichali, (**g**) Belemnites in Chichali formation, (**h**) Iron nadules

intense straining area (Rahim *et al*., 2018). This formation has conformable contacts with Chichali formation and Kawagarh formation. Lithologically, the Kawagarh formation is thin to sublithographic thick bedded limestone with well exposed grey olive to grey light marls and thin beds of carbonaceous shale at some locations. The marly portion is cleaved having light grey colour on weathered surface (Plate. 2 B). Limestone is sandy with light grey colour having broken shell fragments of brachiopods (Plate. 2 C). The upper disconformable contact is with Paleocene Hangu formation which is and lower confirmable contact is with Cretaceous Lumshiwal formation (Rahim *et al*., 2018) (Plate. 2 D). Hangu Formation is thin to medium bedded, coarse grained yellowish to greyish yellow, highly deformed glauconitic sandstone with intercalation of Shale at places (Plate. 2 E). Laterite bed has been observed in the Lumshiwal formation. The lateritic facies are red to maroon in shade, while they give rusty to brownish colour on weathered surface. It overlies Kawagarh formation unconformably, while its upper contact is with the Lockhart formation (Shah *et al*., 2004). (Plate. 2 F). Lockhart formation is nodular, hard and medium to thick bedded, massive and light grey in colour. It gives rotten smell, while freshly broken. Patches of blackish grey carbonaceous matter are also present here (Malkani *et al*., 2016). This formation along Jabbri road is having an-echelon gash veins of calcite (Plate. 2 G). The limestone is highly fossiliferous dominated by shell fragments (Sameeni *et al*., 2009 and 2013). The lower contact Lokhart formation is confirmable with Hangu formation and upper contact

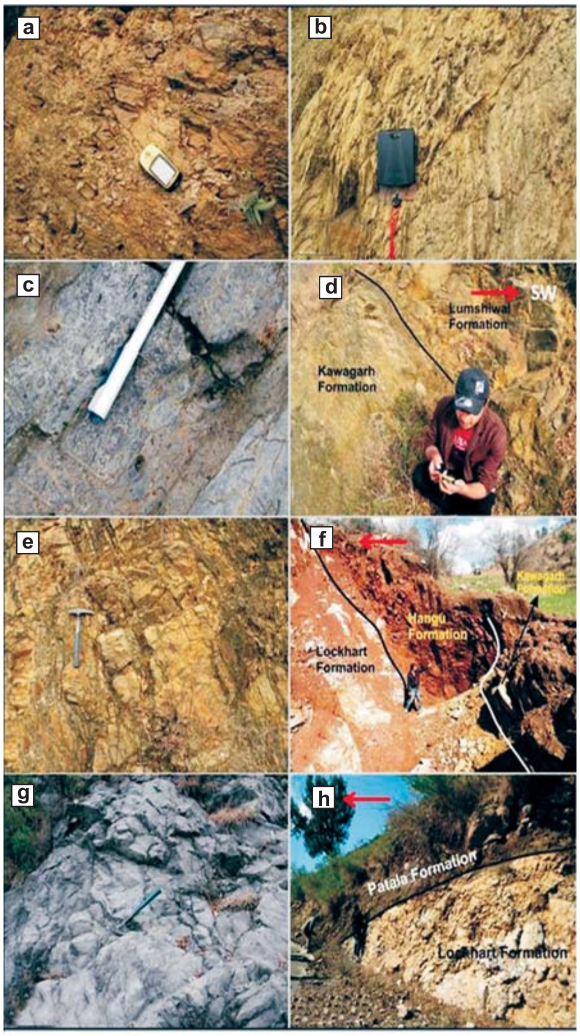

Plate no. 2. (**a**) Lumshiwal formation, (**b**) Marl Kawagarh, (**c**) Barchiopod shell fragments in Kawagarh, (**d**) Contrimable contact of Kawagarh and Lumshiwal, (**e**) Sandstone of Hangu, (**f**) Kawagarh- Hangu and Lockhart Contart, (**g**) Naduler formation, (**h**) Lockart-Patala contact.

is with younger Patala formation (Khan *et al*., 2018; Umar *et al*., 2015) (Fig. 3; Plate. 2 H). The Patala formation along the Rupper-Jabbri road is mainly shale with occasional interbeds of limestone and intercalation of marl (Plate. 3 A). The shales are greenish to brownish green on outcrops. The shale is fissile to splintery and the limestone is light grey containing small forams, mollusks by Haque (1956). Both lower and upper contact are conformable with Lockhart limestone and Margalla-hill limestone (Plate. 3 B).

Margalla hill limestone with interbedded marl and shale is present along Jabbri-Pir-Sohawa road. Limestone is nodular, fine to medium grained, dark grey in colour (Plate. 3 C). The dominant fossils of Margalla hill

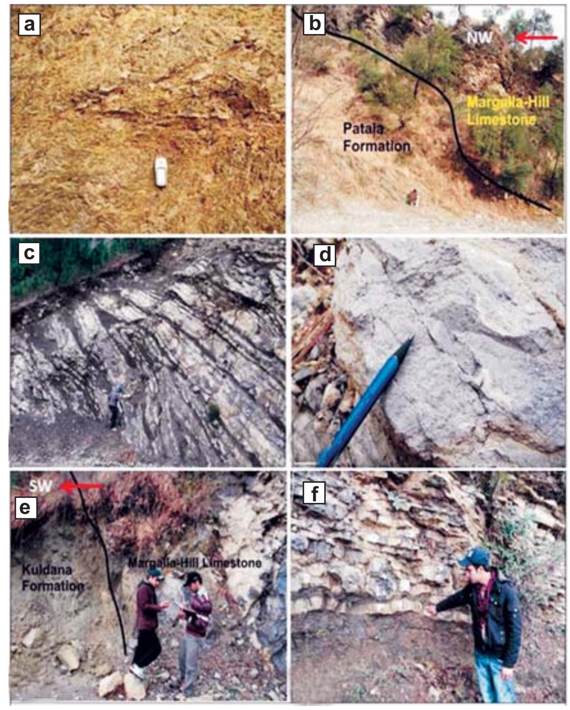

Plate no. 3 (**a**) Greenish Patala Shale, (**b**) Patala-Margalla contact, (**c**) Deformed Margalla formation, (**d**) Nummmulites of Margala, (**e**) Margala-Kuldana contact, (**f**) Chorgali formation.

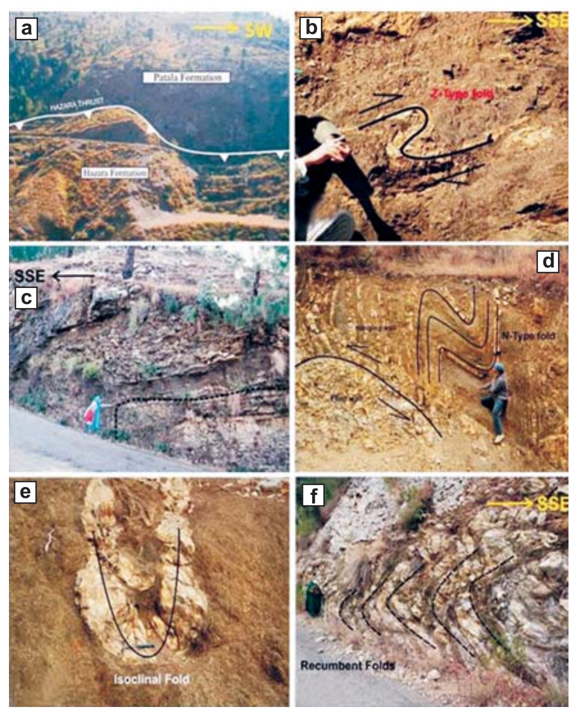

Plate no. 4 Field based structural illustration, (**a**) Hazara thurst, (**b**) Z_type fold in hanging wall Chichali formation of Hero thrust, (**c**) Asymmetrical fold in hanging wall sequences of Sangoda thrust, (**d**) N-type fold and thrust in Lumshiwal formation, (**e**) fold of Chorgali formation, (**f**) Recumbent folding associated with fault line.

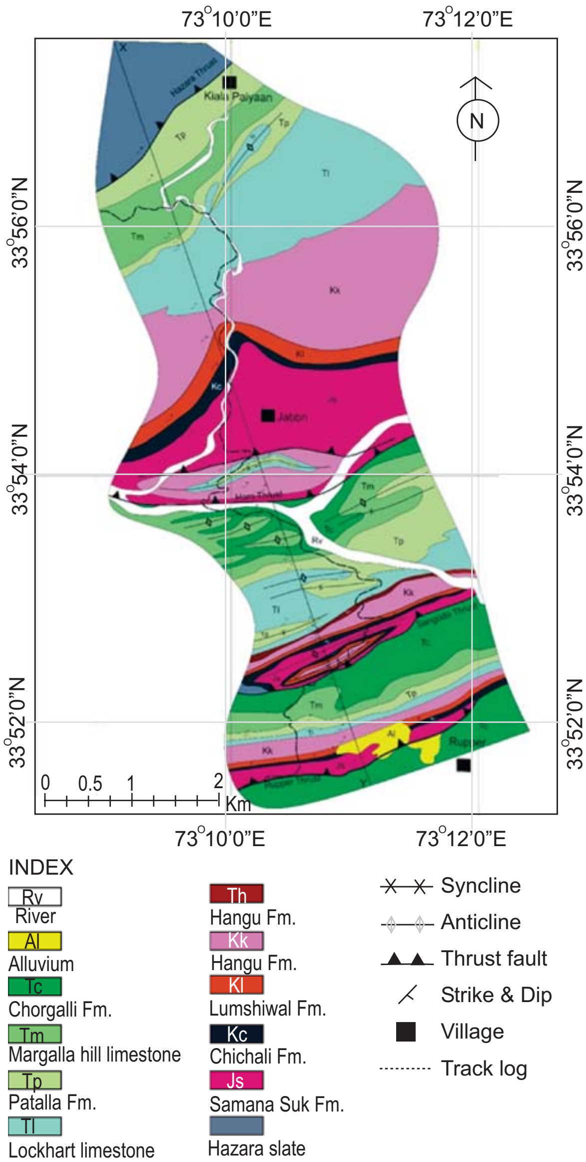

Fig. 3. Geological map of the study area.

limestone are Nummulities (Ullah *et al*., 2017; Swati *et al*., 2013) (Plate. 3 D). Both contacts are conformable, lower one with Patala formation and upper one with Chorgali formation. At some locations, the formation has faulted contact with Kuldana formation (Plate. 3 E). Chorgali formation is light grey colour, medium to thin bedded limestone. This limy portion contains calcite veins with greenish grey calcareous shale (Plate. 3 F). Chorgali formation has conformable contacts with underlying Margalla-Hill limestone and with overlying Kuldana formation (Munir *et al*., 2005). Kuldana formation is reddish to greenish shale and marl with occasional limestone bodies. White gypsum veins are present in reddish color of shale. Kuldana formation has a confirmable Lower contact with Chorgali formation while its upper contact is not exposed (Afzal, 2009).

Structural system of the project area. The project area is highly deformed due to close association with MBT in south and Hazara thrust in north. The related shortening has produced several large thrust fault splays along with large and small-scale folds of several generations (Akhtar *et al*., 2019). Moving from north to south, the prominent thrust faults observed are given below (Fig. 3)

Hazara thrust. Hazara thrust is situated in the northern most part of the study area characterized by the presence of Pre-cambrian Hazara formation thrusting over the Jurassic Samana Suk formation (Qasim *et al*., 2015; Zahid *et al*., 2009) but in this specific area, the Hazara formation thrusted over Paleocene Patala formation. due to severe thrusting. Thus, this thrust is characterized by Cambrian Hazara formation in its hanging wall and Paleocene Patala formation in the footwall (Fig. 3) having east-west orientation with dip ranging from 51º to 58º (Plate. 4 A).

Haro thrust. Haro thrust is present in south of major Hazara thrust and marked by thrusting of Jurassic Samana-Suk formation over the eocene Chorgali formation. The Haro thrust is roughly east west oriented with a dip range from 58º to 64º. This thrust extensively deformed its hanging wall sequences as SSE oriented Z-shape folds can been seen in hanging wall strata of Chichali formation in. (Plate. 4 B).

Sangoda. *Thrust.* The Sangoda thrust is present to the south of Haro thrust, characterized by the thrusting of Jurassic Samana Suk formation over the eocene Chorgali formation. Like Haro thrust, the hanging wall of this thrust is characterized by Samana Suk formation, while the footwall contains the Chorgali formation. This Thrust is east-west oriented with bends and undulations and its dip is ranging from 52º to 60º. Small scale asymmetric folding is well developed in the hanging wall of the Sangoda thrust which suggests south-south-east displacement on the Sangoda thrust (Plate. 4 C).

Rupper. *Thrust.* The rupper thrust occurs to the further south of Sangoda thrust. Along this thrust, the Jurassic Samana Suk formation thrusted over the eocene Chorgali formation. Like Haro and Sangoda thrusts, the hanging wall of this thrust is characterized by the older Samana Suk formation while the footwall is dominated by the younger Chorgali formation. This thrust is also east-west oriented with undulations and its dip is ranging up to 82º.

Geological mapping and cross section. To demonstrate the surface and sub-surface geometrical setting of the exposed structural features, a geological cross-section 'XY' on the geological map has been generated (Fig. 4).

The different structural features explicit in this cross-section are described below.

Cross-section and balanced section. The structural transect along the section line 'XY' (Fig. 4) is north-west oriented and is normal to the general exposed structural trend observed in the area of investigation. The formations present in the study area are usually north-east oriented. On traverse from X to Y, the hanging wall of the Hazara thrust is present along which the pre-cambrian Hazara formation is thrusted over the Paleocene Patala formation. An anticline is present within the Patala formation which is followed by a syncline within the Margalla-hill limestone in the core. Another broader anticline is appeared exposing the older strata of Lockhart formation followed by Kawagarh, Lumshiwal, Chichali and the oldest Samana Suk formations. The older Samana Suk formation are exposed here due to erosion of the surface younger strata. This broader anticline is acting as a hanging wall of thrust in which the Jurassic Samana Suk formation thrusted over the Kawagarh formation. This thrust is followed by folds forming a small-scale anticline and syncline and occupy the hanging wall of the Haro thrust. Along Haro thrust; The Jurassic Samana Suk is thrusted over the Chorgali formation. Southeast of Haro thrust, a couple of tight anticline-syncline is present in the younger strata's which is followed by a broader anticline exposes Chichali and Samana-Suk formations in their core due to its extensive erosion. These folds occupy the footwall of Haro thrust as well as acting as hanging wall of the Sangoda thrust. At Sangoda thrust the Samana-Suk formation is thrust over the Chorgali formation. Further south of the Sangoda thrust, another thrust system i.e. the Rupper thrust is present. The hanging wall of the Rupper thrust possesses the Jurassic Samana Suk formation which lies over the Eocene Chorgali formation along the contact.

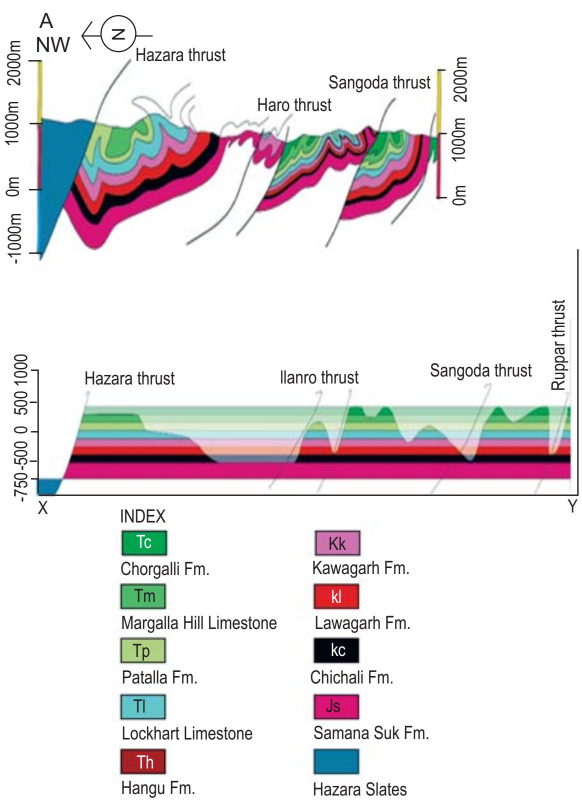

Fig. 4: (a). Geological Cross-section along line 'XY' of the geological map, (**b**) Balanced section of the section.

The study area is highly deformed due to the presence of major thrust systems. These geological structures show the south vergence of the area. Although at some places some features like few plunging folds, and local faults indicates the north vergence which is probably due to back thrusting in the hanging wall of main boundary thrust (MBT). The stereographic plot of these Geological structures mainly folds axes as plotted on Georient software show three folding events and varying plunging directions. The folds orientations suggest transpressional deformation rather than pure compression (Fig. 5).

The section has been be restored along the deformed section XY to find out shortening along the section (Fig. 4B). The restored section is about 15 km which is about 2.5 km longer then deformed 12.5 km. Overall the section recorded about 16.6% shortening along all the thrusts in the sections. Individually, each fault shows different amount of shortening. Along Haro thrust, there is about 1 km shortening as the restored section is 6.7 km as compared to 5.7 km deformed section. This shows about 14.9% shortening along Haro thrust. The second splay of Haro thrust shows about 400 meters shortening as section shortened from restored 1.2 km to deformed

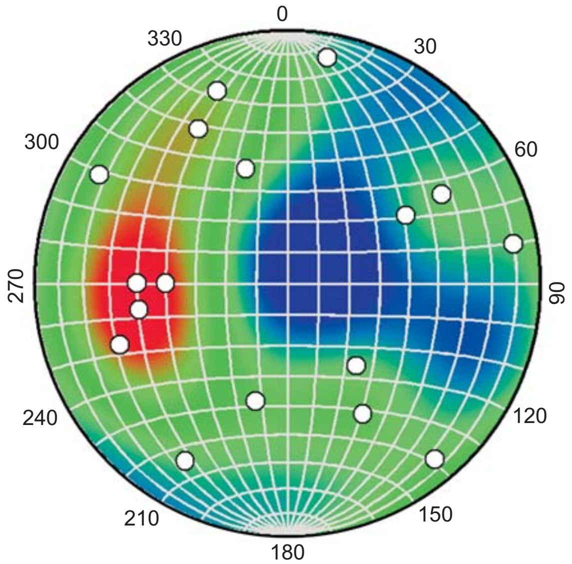

Fig. 5. Equal area plot of the hinge lines of the folds observed using Stereonet software.

0.8 km with 33% deformational shortening. Along the southeastern Sangodha thrust, there is small deformation about 500 meter shortening along 3.9 km restored section to 3.4 km deformed section showing about 12.9% shortening. Ruppar thrust, shows about 390 meters of shortening from restored 3.95 km section to 3.56 km deformed section recorded 13.2% shortening. The maximum shortening is recorded along splay-1 of Haro thrust which is 1 km, while intense shortening is recorded along splay-2 of Haro thrust which is about 33%.

Stereographic plot of fold axes of mesoscopic folds. In Fig 5, the closely spaced axes in red color near the western half of the stereonet indicate that mesoscopic folds are plunging between the range of 240º and 290º. There are scattered fold axes which are plunging towards south or north. The overall green and red patch shows that most of the folds are plunging towards west and this is yet another indicator of east-west compressional forces. The fold axes plotted on north and south of the stereonet shows the presence of east–west compression in study area. Based on stereographic plot, it is ultimately concluded that transpressional forces prevailed in the study area rather than pure north-south compression (Fig. 5).

Plunging orientation of different folds. During this study, a total of twenty-seven (27) folds were studied in which eighteen (18) were considered for the

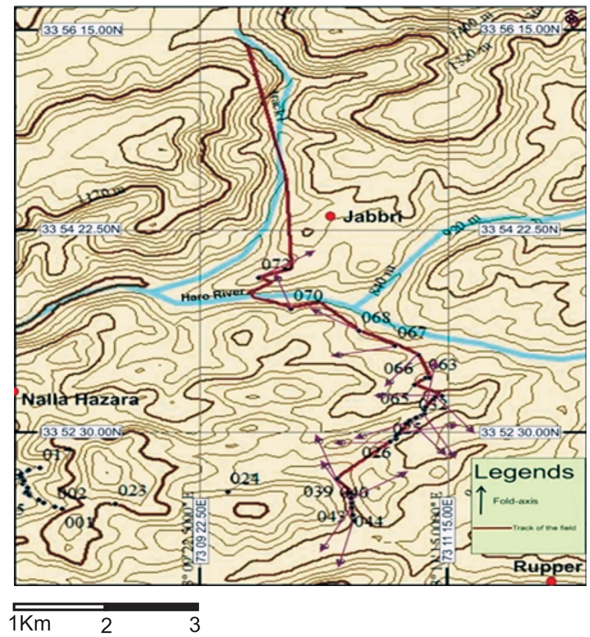

Fig. 6. Contour map of the study area showing different folds orientations.

delineation of the major stresses' direction. Five (5) folds are plunging in southwest quadrant, four (4) folds plunging in northeast quadrant; another four (4) folds are plunging in northwest and four (4) folds are plunging in southeast quadrant. One (1) fold is plunging in perfect western direction. Again, these plunging orientations simply clarifies that this area has experienced transpressional forces rather than pure north- south compression. Due to which the folds axes are plunging in all possible directions i-e north, south, east and west (Fig. 6). Therefore, it can be predicted that this area has faced north west or southeast compression followed by southwest or northeast compression.

Conclusion

The structurally complex area contain Pre-cambrian to Eocene litho-stratigraphic units .The stratigraphy of the area is Pre-cambrian Hazara formation; Jurassic Samana Suk formation;, Cretaceous Chichali, Lumshiwal and Kawagarh formations, Paleocene Hangu, Lockhart and Patala formations, and Eocene Margalla hill limestone, Chorgali and Kuldana formations. The southeast Hazara, being very close to the MBT (to the north of MBT) has undergone intense deformation. The study area is comprised of the following thrust systems traversing from south to north i.e. Rupper thrust, Sangoda thrust, Haro thrust and Hazara thrust. The NE-SW oriented folds dominate the structural fabric of the area and thrust assemblages due to the NW-SE compressional stresses. The hinge lines of most of the folds in the study area are characterized by the northeast-southwest orientation, which also concludes that the area is subjected to northwest-southeast compressional stresses. All the major thrust system shows an alignment with main boundary thrust (MBT) except for few small scales north verging thrust. This shows that these local thrust systems are regional splay setting of MBT and the north verging thrust support the back thrust effects of MBT in the area. This back-thrusting effects increases to toward MBT in southern portion of the study area which evidence of translational deformation is present. The general trend of the hinge lines of meso and macro-scale folds within the Hazara Slates and overlying younger strata is NE-SW, which is indicate NW-SW stress direction. Our study reveals that Hazara Thrust sheet plays a vital role in the structural evolution of the study area.

Conflict of Interest. The authors declare no conflict of interest.

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