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Structural Geology of the Shakar Khel Area, Karak District, Khyber Pakhtunkhwa Pakistan

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Abstract

The study area occupies part of central Kohat Basin marked by the Eocene to Miocene rocks in the fold cores. Folding is the dominant structural grain and consists of tight anticlinal trends exposed at the level of Eocene rocks. The axial trends are generally found to be east west with localized exceptions. A structural transects is constructed which depicts that the outcropping structures were evolved as a result of north south oriented stresses with south progression. The amount of shortening is worked out to be 50% showing high degree of deformation and uplift.

INTRODUCTION

The study area is situated within the central Kohat Plateau that is a well defined compressional structural domain of northern Pakistan. Kohat Plateau is situated in south of Main Boundary Thrust (MBT), bounded in the east by Indus River, having Kurram Thrust in the west and Bannu Basin in its south (Figure1).

Detailed surface mapping and recently acquired subsurface data from the Kohat Plateau of northwestern Pakistan show complex structural styles created by southward directed stresses due to the subduction of Indian plate under the Eurasian Plate (Pivnik, 1993). This creates an overall east-west trending regional structural architecture, with all the folds and faults having their fold axes and fault planes trending within the few degree deviation from due east-west direction. The structural geometry is made even more complex by the later transpressional deformation of the pre-existing compressional related structures (Ahmad, et al. 2004). Kohat Plateau is roughly divided into two structurally distinct regions, a northwestern region (NW) and a southeastern region (SE) (Pivnik, 1993). Structural style in the northwestern Kohat Plateau includes doubly overturned folds, which incorporate a lower Eocene to Pleistocene stratigraphic succession (Pivnik, 1993). Intensely folded stratigraphy in the northwestern region is the relict thrust belt, representing an earlier compressional episode of deformation.

In the southeastern region many folds have had either their southern or northern limb faulted by high angle reverse faults, which flattens near the surface along the lower Eocene shale and evaporite horizon. In the NW region, lower Eocene evaporites and limestones are replaced by thick shales, which served as a fault-flat forming horizon. This is believed to have hindered the surface-ward propagation of fault, leaving detachment folds exposed at the surface. Steeply dipping strata at depths of over 4km, steeply dipping faults that become shallow near the surface forming positive flower structure, large vertical displacement across faults and left-stepping folds suggest transpressional rather than purely compressional deformation. Regions adjacent to Kohat Plateau also contain transpression-related structures, rather than thin-skinned imbricate thrusts. In view of the position of the Kohat Plateau near a major syntaxial bend in the Himalayan orogen, both north-south and east-west convergence played a dominant role in creating structural styles (Figure 1 and 2), and the combination of these two convergence directions influenced the development of transpression related structures during the Plio-Pliestocene time (Pivnik, 1993).

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Study Area

The study area is located about 40kms southwest of Kohat. The community that falls within the study area is of Shakar Khel village. It lies about 20kms west of the Kohat-Bannu Road. Geographically this area lies between 33°, 17'N and 33°, 22'N latitudes, and 71°, 06'E and 71°, 11'E longitudes.

Stratigraphy

In parts of Pakistan the close of Mesozoic Era is marked by a period of emergence. The Tertiary rocks thus have variable lower contact relationships with the older units. This contact varies from an angular unconformity between Paleocene and older units (as old as Jurassic) in parts of the Sulaiman Province and Axial belt to disconformable contact between various Tertiary and older units in Kohat-Potwar Province. In some parts of the lower Indus Basin, Axial belt and Baluchistan Basin, however, the contact between cretaceous and Paleocene is reported to be transitional The Cenozoic rocks were deposited in a broad sea (Figure 2), which gradually narrowed and retreated southward with the passage of time till it came to occupy its present position as the Arabian Sea (Figure 2), (Paracha, 2004).

The rocks of Cenozoic Era exhibit variation in thickness and lithology in different areas. However the Paleocene and Eocene sediments are mainly limestone and calcareous shale, while younger ones are dominantly sandstone, silt and mud. The Quaternary sediments are coarse clastics mainly conglomerates (Alizai, 1988), as against fine clastics of the late Tertiary. Various tectonic elements have played an important role in these variations. These have also affected numerous local unconformities in Pakistan.

Partial emergence towards the end of the Paleocene was followed by submergence in early Eocene when the sea covered major part of Pakistan. Towards the close of early Eocene a short-lived regression took place (Nagappa, 1959), which resulted in the formation of evaporites in the Kohat area and Sulaiman Province. This regression was most effective in Kohat-Potwar province. The regression was followed by the widespread submergence, which effected large areas, including the western Kohat, Lower Indus Basin, Axial Belt and the Baluchistan Basin (Nagappa, 1959).

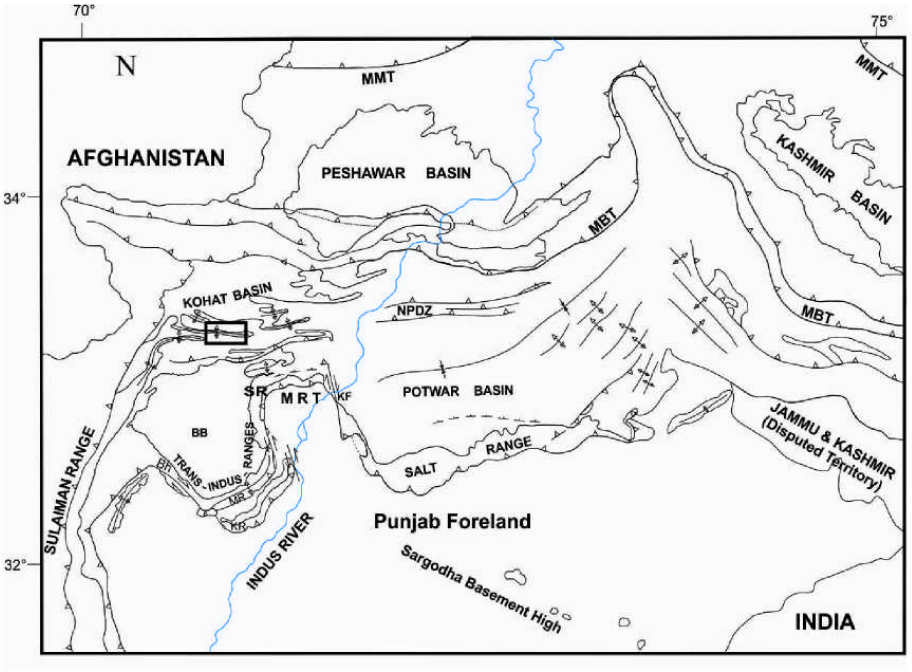

Figure 1- Generalized Geologic Map of the NW Himalayan Foreland Fold and Thrust Belt (moditied after Kazmi and Rana, 1986), Inset shows the location of study area. MMT: Main Mantle Thrus, MBT: Main Boundry Thrust, KF: Kalabagh Fault, NPDZ: Northern Potwar Deformed Zone, KR: Khisor Range, BB: Bannu Basin, KRT: Mianwali Reentrantm, MR: Marwat Rnage, BH: Bhittani Range.

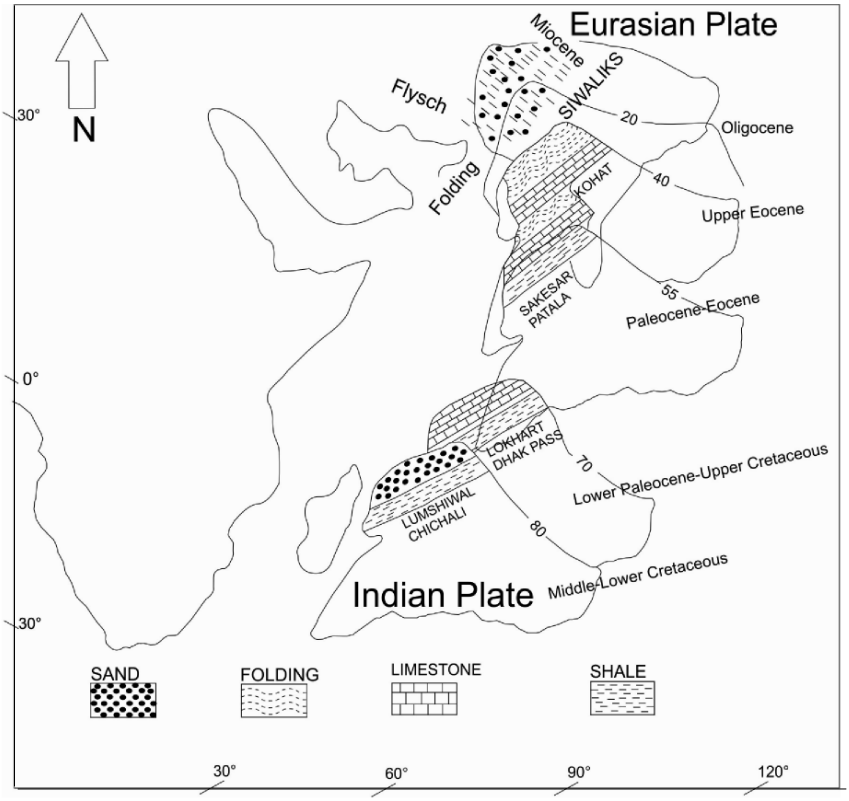

Figure 2- Miocene convergence of Indian Plate into Eurasian Plate with its rotational route, and deposition of different formations in space and time (Paracha, 2004).

The Eocene rocks are limestone and calcareous shale with subordinate sandstone and conglomerate. In some areas, however, the conglomerate becomes important constituent of the sequence. Locally red beds, gypsum, anhydrites, salt, and coal also become significant in the Eocene sediments. Generally the limestone is dominant in the Indus Basin and Axial Belt while shale is dominant in the Baluchistan Basin. During middle and late Eocene times different parts of Pakistan became emergent resulting in unconformities of varying magnitude. The Kohat-Potwar province and major parts of Sulaiman Province were completely emergent during the Oligocene, as Eocene strata are disconformably overlain by Miocene rocks, i.e. Murree Formation of Miocene age disconformably overlying Kohat Formation of Eocene age (Paracha, 2004).

In Miocene time the sea had regressed further west and south, which resulted in fluviatile sedimentation in Kohat-Potwar province. The deposition of Molasse sediments took place during that time.

Stratigraphic well correlation

Amoco Pakistan Exploration Company (APEC) drilled three wells between 1990 and 1993 in the Kohat Plateau: Tolanj-1, Kahi-1 and Sumari-1. The Tolanj-1 well revealed a complex flower type structure, which indicates that it is not a thrust related structure or an evaporite cored anticlinorium and salt was not encountered in the well (Sercombe et al. 1998). Other exploration companies also drilled oil wells during different times, including MOL, Pakistan, Oil and Gas Development Corporation Limited (OGDCL), Pakistan Petroleum Limited (PPL), Pakistan Texas Gulf (PTG) (Figure 3). In the western part of the area, the Kahi-1 well has Panoba Shale (Eocene) exposed. The well was drilled into the Jurassic. East of Kahi-1, Sumari-1 was drilled where the thickness of Paleocene Patala Shale has increased towards the east (Figure 4). NE of the Kohat Plateau Tolanj-01 was drilled where Kohat Formation of Eocene age is exposed. The well shows the repetition of Eocene rocks due to the fault slicing. At southeastern Kohat, Shakardarra-01 was drilled where Pliocene sediments are exposed. At Shakardarra-01 the Cretaceous limestone is absent in the section. Lockhart Limestone (Paleocene) is not encountered in Sumari-1. The Chichali Formation (Cretaceous) is missing in Tolanj-1 (Figure 4). To the SW of Kohat Plateau, the Kundi-X1 well was drilled into Eocene rocks at about 6000 m while in the nearby outcrops of Kohat Plateau, the Eocene is exposed. The thickness of Paleocene-Eocene rocks varies dramatically from east to west (Sercombe et al.1998).

Structural analysis of Shakar Khel area

The main focus of the current paper is to work out the Structural Geology of the region. Thorough field work was conducted aiming to produce a geological map and a cross section by taking surface control and applying it to the subsurface, keeping in view the deformational style of Kohat Plateau.

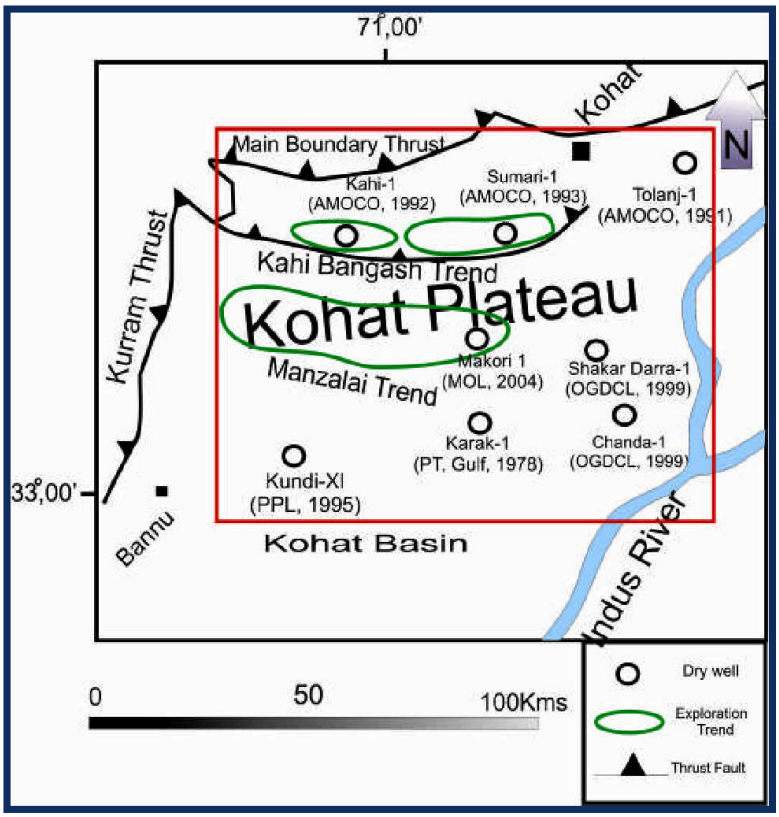

Figure 3 - Locations of wells drilled in different parts of Kohat Plateau (Paracha, 2004).

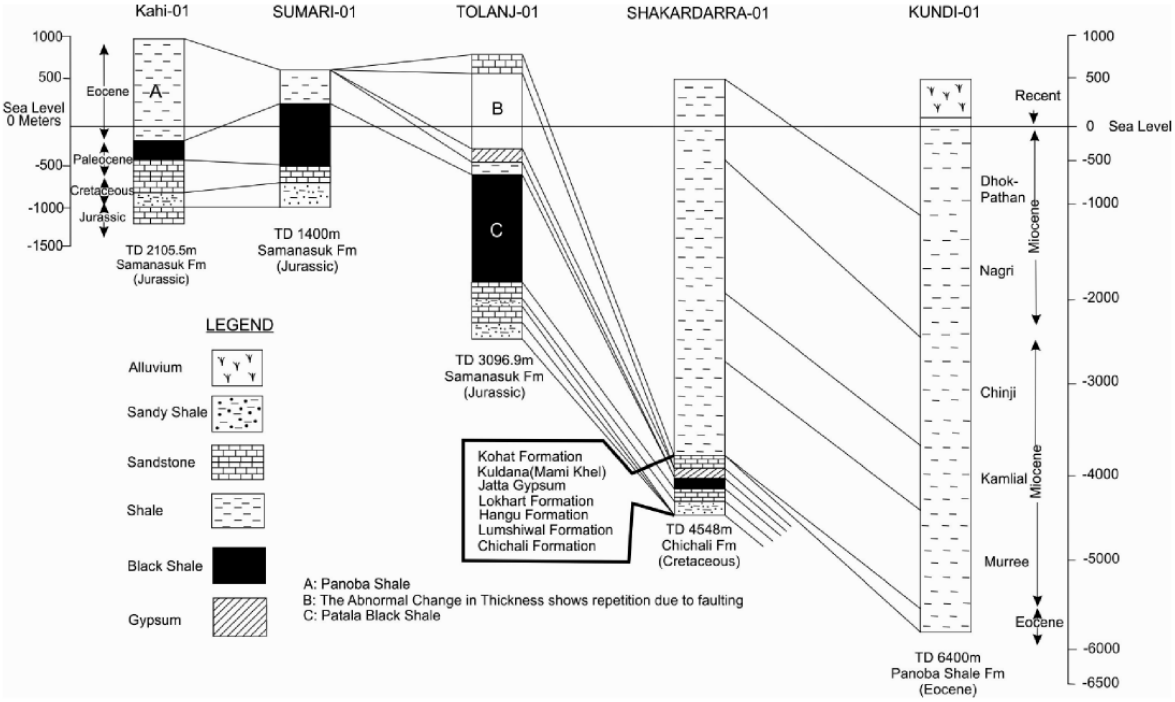

Figure 4 - Generalized stratigraphic well correlation in Kohat Plateau (Paracha, 2004).

Geological map analysis

The Toposheet of 1:50,000 scale was used as base map and different lithological units were marked on it (Figure 5). Topography at Shakar Khel area can be used as major controlling factor for marking the lithologies. All the peaks can blindly be marked as Kohat Formation since it is the most competent of all the stratigraphic units exposed in the area. Murree Formation and Mami Khel Clays which mark the upper and lower contact of Kohat Formation respectively are softer units having conglomerate, clay, shale and sandstone intercalations. Therefore they are subject to erosion and stay in the depressions. Digital Elevation Model of the area was used with Global Mapper, which is the mapping software. This software uses GIS technology for remote sensing and regional interpretations. Along with the digital elevation data, satellite imagery was also used to do the general reconnaissance of the area prior to field visit. The map produced reveals the structural trends and the nature of deformation in the area. The geology in the area can be easily divided into two major structural entities separated by Sangini Syncline (Figure 5). Shakar Khel Anticlinorium rests in the north of Sangini Syncline and acts as a northern structural entity while Shagai Anticline along with its western associates i.e. Chishmai Anticline and Chishmai Syncline (Figure 5) stand as the southern structural entity of the area. Shakar Khel Anticlinorium has two low amplitude anticlinal folds i.e. Jalil Anticline to the north and Azad Anticline to the south which are separated by Anar China Syncline (Figure 5). Azad Anticline exposes Jatta Gypsum of Eocene age in its core at two different locations (Figure 5). Shakar Khel Anticlinorium is an east-west trending structure showing a classical north-south compression (Figure 5) and stretches up to 13Kms in the direction parallel to the trend of the fold. In the study area only the eastern half of Shakar Khel Anticlinorium is mapped and studied which is a 7km stretch while the remaining portion further extends westward and falls outside the area of interest. Sangini Fault lies to the south of the Shakar Khel Anticlinorium. It is basically a back thrust which has juxtaposed Mami Khel Clays against Kohat Formation and caused repetition of Kohat Formation towards south (Figure 5). This fault exploits Jatta Gypsum as a main gliding horizon and emerges at the surface thrusting Mami Khel Clays above Kohat Formation along a listric fault plane (Figure 6). This fault is almost 4kms long in its lateral span (Figure 5). The fault plane trends in East West direction. The Shagai Anticline to the south is also an east-west trending structure exposing Mami Khel Clays in its core (Figure 5). Its southern limb towards west shows a very clear dislocation in the linear ridge of Kohat Formation which can be seen in the map (Figure 5) as well as in the satellite image. This dislocation indicates that there were two episodes of deformation in the area. The first episode was of pure north-south compression due to which Shagai Anticline was formed and it was followed by the second episode of deformation which was dominated by left lateral transpression. It was because of this transpression that the Chishmai Fault is formed. Chishmai Fault trends in north-west south-east direction and have caused the sinisterly displacement of about 800m. In general the study area throughout displays intense deformational geometries but the western portion of the southern entity displays much greater amount of compressional deformation containing tight folds with overturned limbs i.e. Chishmai Anticline, Chishmai Syncline and the remaining portion of Shagai Anticline (Figure 6).

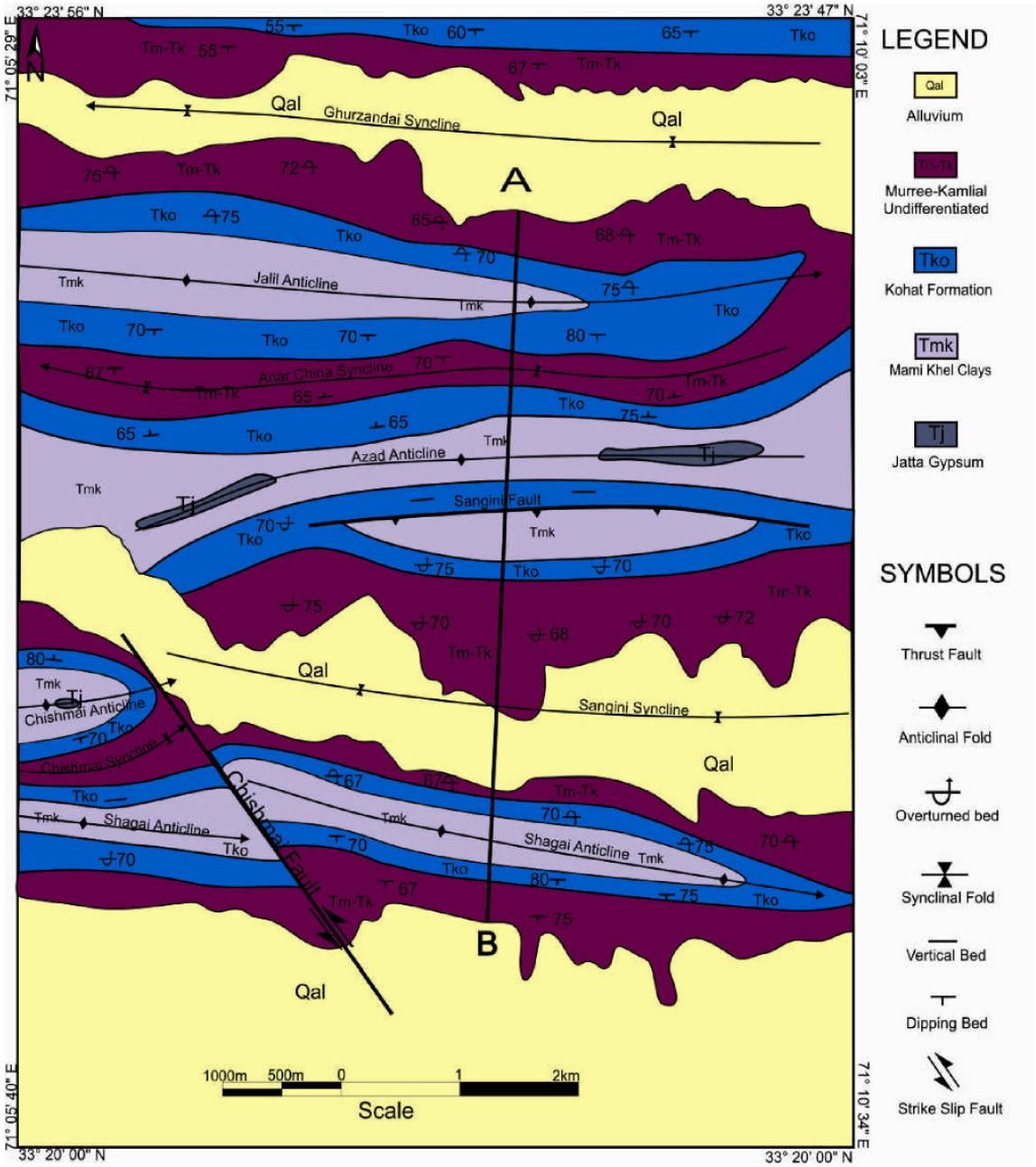

Figure 5 - Geological map of the study area.

Structural transect along section line AB

A structural transect AB is constructed across the structural trends. It is 6km long section covering the subsurface geometries of both the northern and the southern entities (Figure 6). The section profile shows that Kohat Formation stands higher as compared to the other lithological units and makes ridges (Figure 6).

Section AB shows typical deformational style of central Kohat Plateau with tight folding and steep dips (Figure 6). Shakar Khel Anticlinorium displays a very tight compressional folding with both of its limbs overturned (Figure 6). After getting overturned, the southern limb of Shakar Khel Anticlinorium could not resist the intense stresses and thus was faulted in such a way that the stresses from south towards north dominated the regional tectonic stresses which are directed towards south. These northward directed stresses lifted the Kohat Formation from the original depth of about 400m to the surface at 900m creating a new topographic high in the area. The net slip along the fault calculated is about 700m. The fault shows a Z shaped

geometry of the fault plane which is because of the nature of stresses and the lithological units involved in faulting. The lower part of the fault dips toward south which shows that there was room for easy northward glide of the hanging wall horizons over the footwall horizon at this level. The easy glide was due to the softer lithological units i.e. Jatta Gypsum and Mami Khel Clays involved in faulting at that level. Especially Gypsum has the tendency to flow in response to stresses and can absorb huge amount of stresses in getting highly deformed and thus provide good grounds for movements along the direction of dominant stresses. Then the geometry of fault takes a turn and becomes vertical (Figure 6), which reflects that the southward and northward directed stresses are almost equal at that point. This sudden change in the behavior of the movement along the fault can again be related to the lithological units involved in faulting at that particular point. The major lithological unit involved in the vertical zone of the fault is Kohat Formation, which on either sides of the fault plane poses a high resistance to the movement of the hanging wall block (Figure 6). Thus the hanging wall strata being the part of the back thrust glides vertically upward rather than drifting northward against the major stress direction (Figure 6). The geometry of fault takes another turn and dips towards south as it leaves the zone controlled by stiffer strata (Figure 6). This reflects that the northward movement along the fault will continue as the hanging wall strata are completely thrust over the footwall strata. Sangini Anticline which is the part of the southern entity has its northern limb overturned and thus dips southward. This justifies and clarifies the existence of a back thrust i.e. Sangini Fault which is to its further north. The north vergence of the Sangini Anticline reveals that there is a very strong northward force acting on this area which is making the strata glide against the regional tectonic transport direction. It also reveals the fact that there must be some major barrier or resistant structure to the south of the study area which stands in the way of the regional transport direction. The cross section AB in its restored form gives the general idea of the percentage shortening in the area and thus the amount of north-south compression can be roughly calculated from it. Section AB is restored on the bases of bed length balance and Kohat Formation is taken as the basic unit for restoration. The reason for taking Kohat Formation as a reference horizon is because it maintains constant thickness throughout the section (Figure 6). Kohat Formation in the deformed state cross section is accommodated in the 6.5kms section line (Figure 6) which after being restored is straightened to 12.5kms (Figure 7). There is overall 48% shortening along section AB. These figures indicate the amount of stresses which were acting on this area in the past. Kohat Formation which was originally deposited at the depth of 100 to 400 meters (Figure 7) now makes the peaks as high as 1100meters.

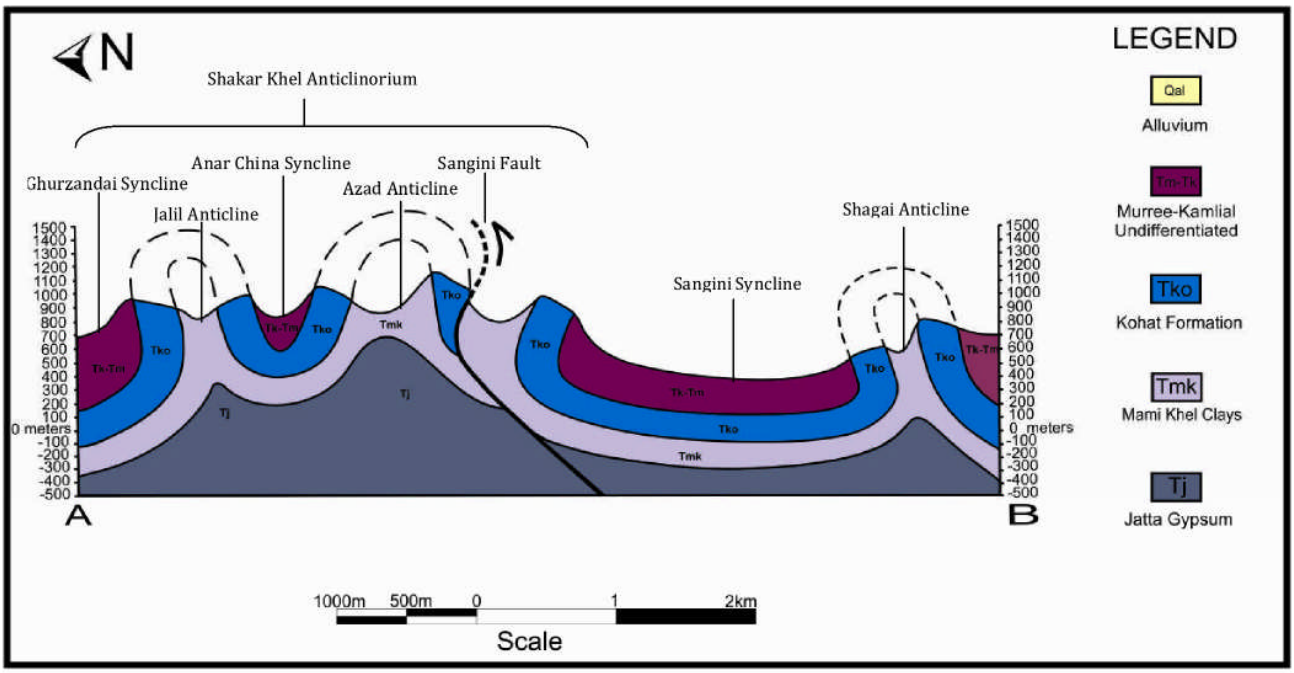

Figure 6 - Cross section along line AB.

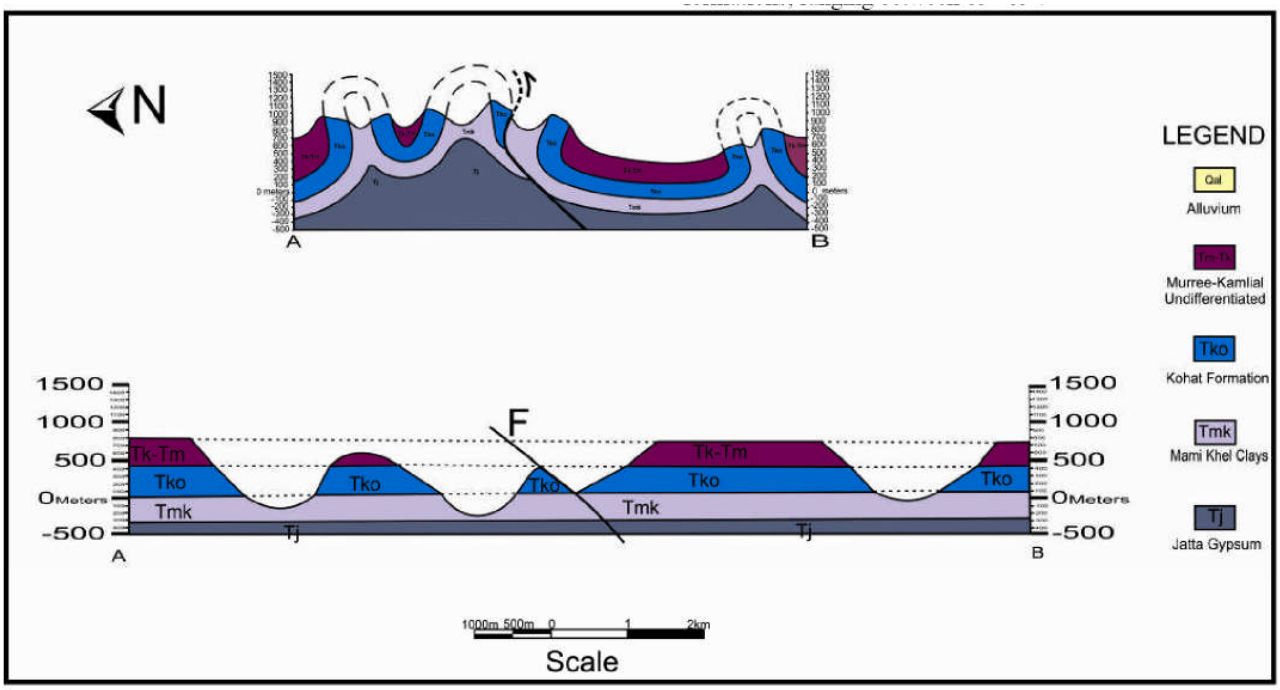

Figure 7 - Restored cross section AB.

Conclusion

The study area is characterized by east west trending folds and a thrust fault that are detached at the level of Jatta Gypsum as the anticlines expose the rocks upto the Jatta level whereas the only fault mapped in the area also exploit Jatta Gypsum. The regional structural trend suggest a north south oriented compressional stresses and the structural geometry is typical of a fold and thrust belt regime. The deformation in the area shows intensive compressional environment. The Shakar Khel Anticlinorium consists of two anticlines separated by a syncline in the centre oriented almost parallel to each other in east-west direction. The southernmost limb of Shakar Khel Anticlinorium i.e. southern limb of Azad Anticline is faulted, which is a Z-shaped fault. The displacement along this fault is almost 700m. The area represents great amount of uplift. In the deformed state cross section the projected elevation of Kohat Formation reaches up to 1500m, which are brought down to the normal level of 300-400m in restored cross-section. The average crustal shortening in the study area is 50.22%, calculated from balanced cross sections. Kohat Formation forms ridges as it is the hardest unit in the Eocene stratigraphic succession. Most of the folds are plunging eastward. The area is highly deformed which is proved by the high angle dips of most of the formations; ranging between 65˚-85˚.

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