Pakistan Journal of Hydrocarbon Research
Vol. 16, (June 2006), p.23-35, 7 Figs.

Structural Transect of the Western Kohat Fold and Thrust Belt between Hangu and Basia Khel, N.W.F.P., Pakistan.

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ABSTRACT

A structural transect of about 66km length has been constructed along the western Kohat Fold and Thrust Belt in order to understand the structural variations within the outcropping rocks. Along the transect from Hangu in the north to Kurma in the south, the belt is dominated by thin-skinned structures that includes south verging thrust faults, disharmonic shale-cored anticlines, shale-withdrawal synclines and pop-downs. The thin-skinned structures gives way to thick-skinned structures south of Kurma and is confined to a 12 km wide zone named as Zarwam Wrench Zone. This zone is defined by three, sub vertical wrench faults that involves crystalline basement as well. The genesis of these wrench faults is related to the westward under thrusting of Kohat Fold and Thrust Belt underneath the Sulaiman and Samana range along the transpressional boundary known as Kurrrum Fault. Orientation of both large and small-scale structures, within the Western Kohat Fold and Thrust Belt, indicate that it has undergone an earlier phase of compressional deformation over its major part, superimposed by a later phase of transpressional deformation in the south along Zarwam Wrench Zone.

INTRODUCTION

The mountain belt of North Pakistan lies at the western end of the main Himalayan chain in the apex of a major oroclinal deflection in structural trend from east west to north south. The Kohat Fold and Thrust Belt lie in this apex, about 100Km southwards of the main part of the western Himalayan foothills (Figure 1). The geographic boundaries of the Kohat Fold and Thrust Belt are marked by Kohat Range in the north and northeast, Indus River in the east, Surghar Range in the southeast, Bannu Basin in the south and Samana Range in the northwest (Figure 2).

The sedimentary record of Himalayan convergence in northwestern Pakistan is well preserved in the Kohat Foreland Fold and Thrust belt, which constitutes western part of the deformed foreland fold and thrust belt of northern Pakistan (Pivnik & Wells, 1996). The Kohat Fold and Thrust belt comprises Paleocene to Eocene sedimentary rocks in a complex assemblage of limestone, shale, evaporites, sandstone and conglomerates succeeded by an unconformity, which is overlain by Miocene terrestrial, synorogenic foreland basin deposits.

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Significant contribution owes to (Meissner et al., 1974 & 1975) regarding the geology of the Kohat Foreland Basin. They conducted detailed geological investigations and prepared a geological map at a scale of 1:250,000, including the lithostratigraphic boundaries and structural details. Wells (1984) worked out the depositional environments of the Cenozoic rocks of Kohat Foreland in detail. McDougal & Hussain (1991) prepared a balanced cross section through the eastern Kohat Foreland and Surghar Range to describe the fold and thrust propagation beneath the Kohat Plateau. Abbasi & McElroy (1991) outlined a structural model for the Kohat Foreland basin utilizing north-dipping, low-angle imbricate thrust faults underneath a passive roof thrust. An alternate interpretation of the Kohat Foreland basin suggests that it is a complex, hybrid terrain consisting of strike-slip and compressional features (Pivnik, 1992; Pivnik & Sercombe 1993; Sercombe et al., 1994 a & b). They suggested that the majority of early Cenozoic rocks exposed in the Kohat Foreland basin crop out in the core of anticlines and forms detachment folds and pressure ridges above complex, positive flower structures that represents considerable amount of north to south shortening.

Until this study several regional and local scale cross sections have been constructed across the eastern and central Kohat Fold and Thrust Belt but no regional cross section has been constructed for the western segment of the belt. This study presents a 66 Km long section to help in understanding the tectonic evolution of an active foreland fold and thrust belt having evaporites and shale horizons at a shallow level. It will also help to work out the processes involved in the development of variable structural suits within the Eocene and Miocene carapace of Kohat Fold and Thrust belt and whether these share an extensive and common detachment at the base of Eocene or related to a basal detachment at deeper level.

GEOLOGICAL SETTING

The Kohat Fold and Thrust belt became part of the terrigeneous Indo-Gangetic foreland basin by early Miocene and is represented by sedimentary rocks, ranging in age from Paleocene to Pliocene. The oldest rocks exposed in the area belong to Paleocene and consist of limestone and shale (Figure 3). These rocks were deposited in a restricted fore deep marine environment due to the loading of the Indian plate margin and represent the first record of the Himalayan convergence (Pivnik & Wells, 1996). This sequence is conformably overlain by a complex assemblage of shale, carbonate, evaporite and clastic rocks, which was deposited in a restricted marine basin and represents a tectonically isolated portion of the Tethys Sea situated between

Figure 1- Tectonomorphic map of Pakistan, showing the location of Kohat Foreland Basin (Modified after Kazmi & Rana, 1982).

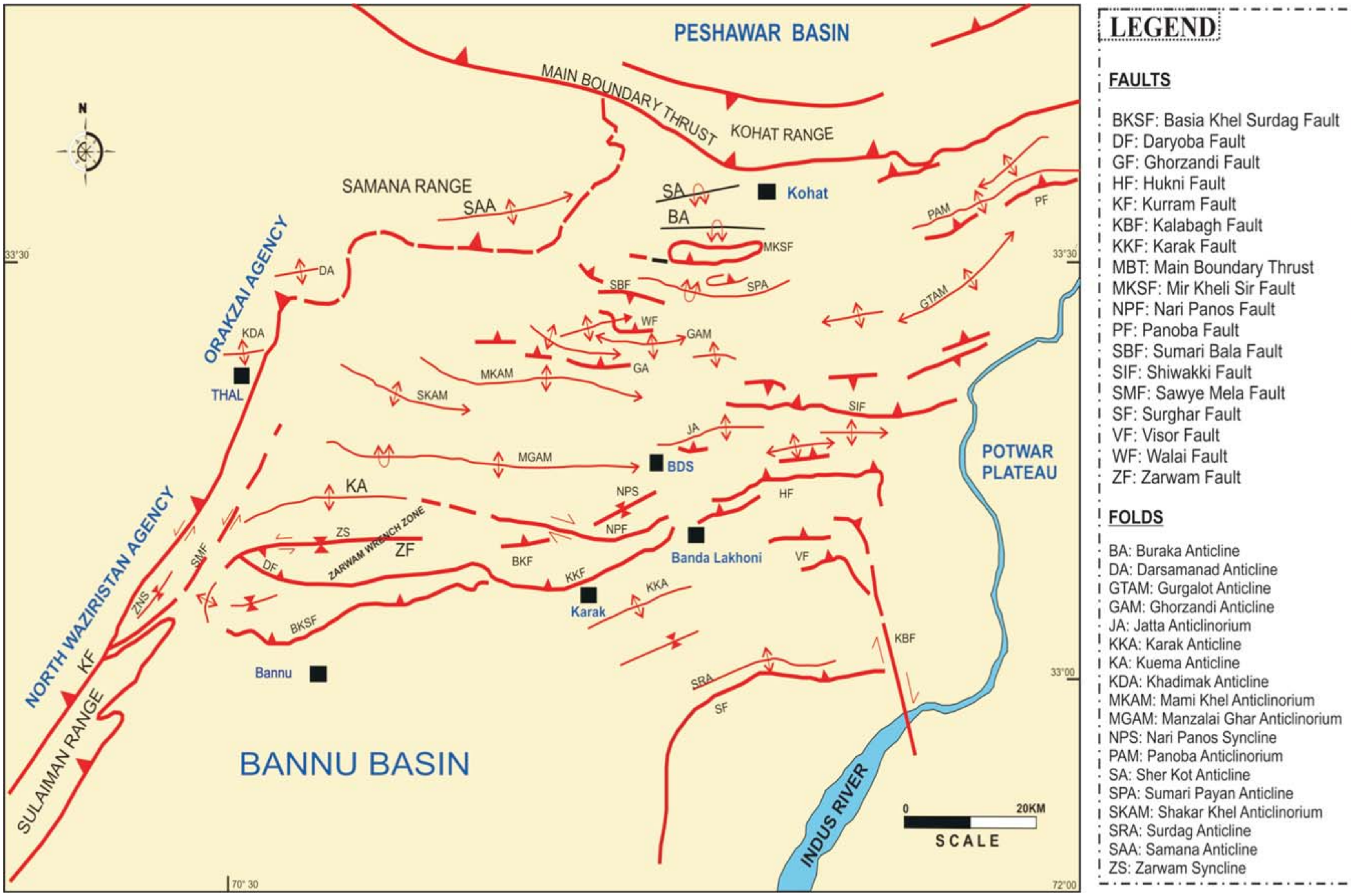

Figure 2- Structural Map of Kohat Plateau, modified after Pivnik and Secrcombe,1993.

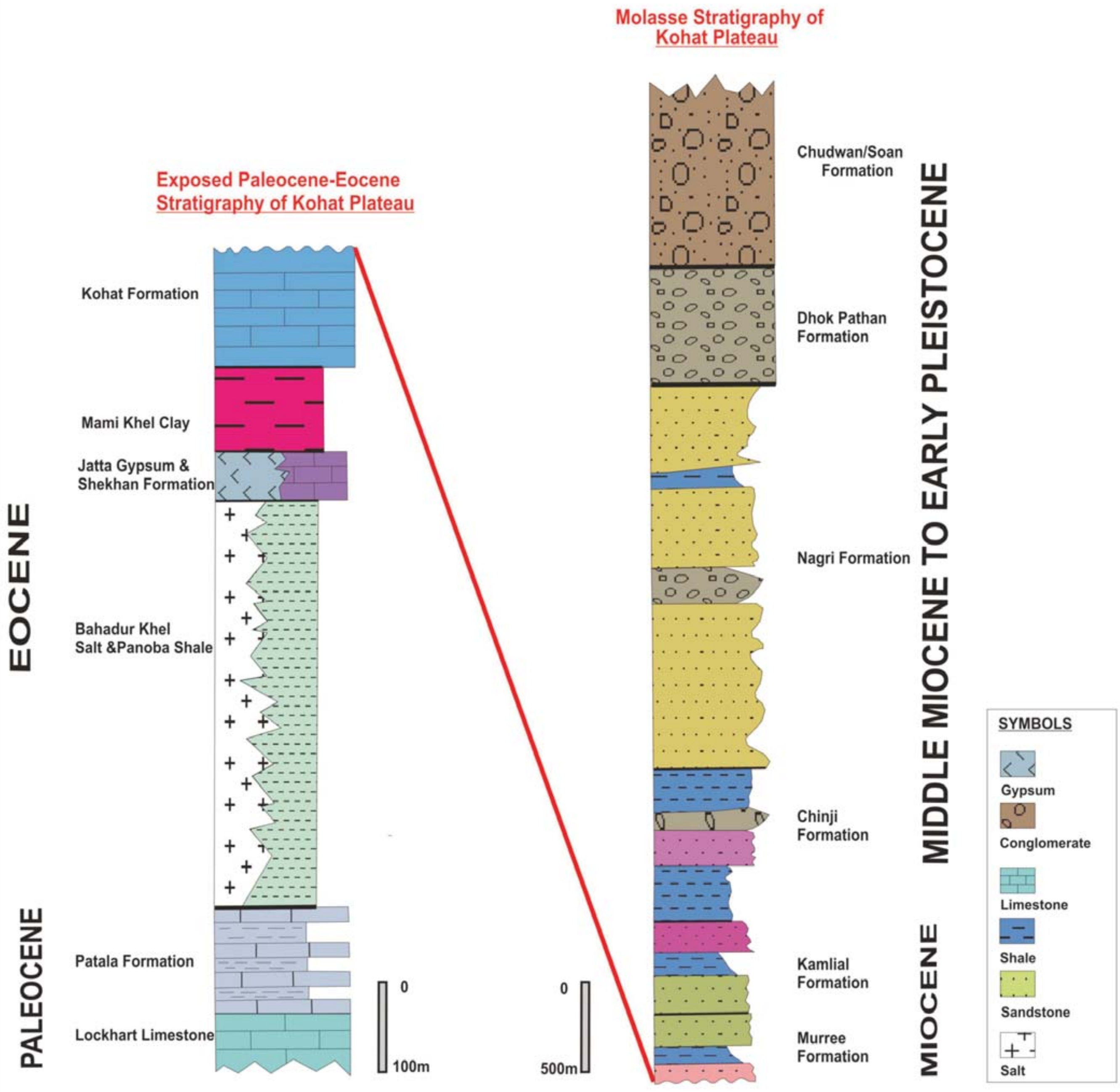

Figure 3- Composite Lithostratigraphics column of the Kohat Foreland Basin.

northwestern Indian continental margin and the southern Asian margin (Pivnik & Wells, 1996). The Eocene sequence is in turn unconformably overlain by a thick succession of Miocene to modern molasse sediments of Murree and Siwalik Group. The molasse interval of sedimentation is lithologically represented by sandstone, shale and conglomerate and is the product of Himalayan exhumation.

The northern margin of the Kohat Foreland Basin is marked by Kohat Range trending east west and is composed of Jurassic to Paleocene carbonate, sandstone and shale having a total stratigraphic thickness of 1300 meters. Towards west of the basin, a series of en-echelon anticlinal trends such as Khadimak, Darsamand and Samana Anticline (Samana Range) mark its geographic and stratigraphic boundary with Orakzai Agency (Figure 2). These structures expose about 1000 meters thick succession of Jurassic to Paleocene rocks comprising limestone, shale and sandstone.

The Surghar Range is located towards southeast of Kohat Foreland Basin and represents it's leading deformational front. It exposes about 1100 meters thick Triassic to Eocene rocks including carbonates, sandstone and shale. This sequence is unconformably overlain by a thick succession of middle Miocene to Pleistocene rocks of Siwalik Group. Towards southwest, the flat lying Bannu Basin, which is covered by recent sediments, borders the belt. The western boundary of the Kohat Fold and Thrust Belt has a faulted contact with the north-south trending Sulaiman Range, which is a complex assemblage of sedimentary successions of Mesozoic to recent age.

STRUCTURAL SETTING

The Pakistani Himalayas can broadly be subdivided into five tectono-stratigraphic terrains, delineated by regional fault boundaries (Figure 1). From north to south these are as under:

Karakorum Block
------- Main Karakorum Thrust (MKT) -------
Kohistan Island Arc
------- Main Mantle Thrust (MMT) -------
Northwestern Deformed Fold and Thrust Belt
------- Main Boundary Thrust (MBT) -------
Southern Deformed Fold and Thrust Belt
------- Salt Range Thrust (SRT) and Trans
Indus Ranges Thrust (TIRT) -------
Punjab Plain

The Kohat Foreland Basin lies in the southern deformed fold and thrust belt and had been influenced by the southward progression of deformation during late Miocene. The Kohat Foreland Basin is bounded to the north by the MBT, which brings highly deformed Mesozoic rocks of Kohat Range over the Eocene-Miocene sediments of Kohat Foreland Basin (Yeats & Hussain, 1987).

According to Iqbal & Baig (2007) the nature of MBT is not clear in Pakistan along the hill ranges. However, there is little doubt about the existence of a frontal thrust system boarding the hill ranges and separating the Northern Deformed Fold Thrust Belt from the Southern Deformed Fold Thrust Belt. The usage of the word MBT is still retained in this paper based on the fact that it is the most commonly used name for the frontal thrust system along the hill ranges in Pakistan.

Towards west, the Kurram Fault juxtaposes highly deformed Mesozoic rocks of Samana, Darsamand, Thal and North Waziristan Agency with the Eocene to Miocene sediments of the Kohat Plateau. The Kurram Fault is believed to be a left lateral transpressive boundary. The southeastern boundary of the Kohat Plateau is the Surghar Range with Mesozoic rocks emplaced southwards onto the Indo-Gangetic foredeep in the south. Toward south, the undeformed sediments of Bannu Basin form the southern boundary of the plateau.

SURFACE GEOLOGY

The western Kohat Fold and Thrust belt, based on the structural style can be divided into a northern and southern domain of the latitude of Kurma Anticline (Figure 4). The surface geology in the northern domain of the latitude of Kurma Anticline is covered by east-west trending anticlines with associated small-scale folds e.g. Chaparai, Walai, Mami Khel, Shakar Khel and Manzalai Ghar (Figure 4). These anticlines are commonly very wide, with approximate widths ranging from 2 to 5 kilometers. Generally both limbs of these anticlines are overturned and expose the base of the Eocene rocks in their core (Figure 4). Between these anticlines, broad synclinal structures are also mapped with their limbs overturned. The Rawalpindi and Siwalik Group rocks cored these synclinal structures (Figure 4). In addition, several thrust faults are mapped in the region as well. From north to south these faults include Walai Fault, along which the Mami Khel Clay is thrust over the Kohat Formation in the footwall. It is oriented east-west and is steeply north dipping (Figure 4). The Ghorzandi Fault marks the southern limb of the Ghorzandi Anticline and is steeply north dipping. It has an east-west orientation and emplaces the rocks of Jatta Gypsum over the Rawalpindi Group towards south. The Shakkar Khel Fault dissects the southern limb of Shakkar Khel Anticline, along which the base of Eocene sequence is thrust over the Rawalpindi Group in the footwall (Figure 4). A pair of south-verging fore thrusts are mapped along the southern flank of Dallan Syncline and emplaces Panoba Shale in its hanging wall above the Kohat Formation in the footwall (Figure 4).

The southern domain is further distinguishable into a western and eastern domain east and west of the longitude of Latambar. West of the longitude of Latamber, the Kurma Anticline marks the northern limits of this domain and is found to be roughly oriented east west with Panoba Shale in its core (Figure 4). At the surface, both of its limbs are steeply overturned. South of Kurma Anticline, the Zarwam Syncline exposes the Upper Siwalik Group rocks in its core. It is east west oriented and is the largest fold structure within the entire Kohat Foreland Basin. Its limbs are characterized by steep dips, which progressively become gentle towards its core. Parallel to its axial trend, it is offset by an east west trending strike-slip Zarwam Fault (Figure 4). This fault is vertical to sub vertical with sheared conglomerate at its surface exposure (Figure 5 & 6). At places horizontal slicks have been observed along the fault plane. The southern limb of Zarwam Syncline is also dissected by another regional scale fault named as

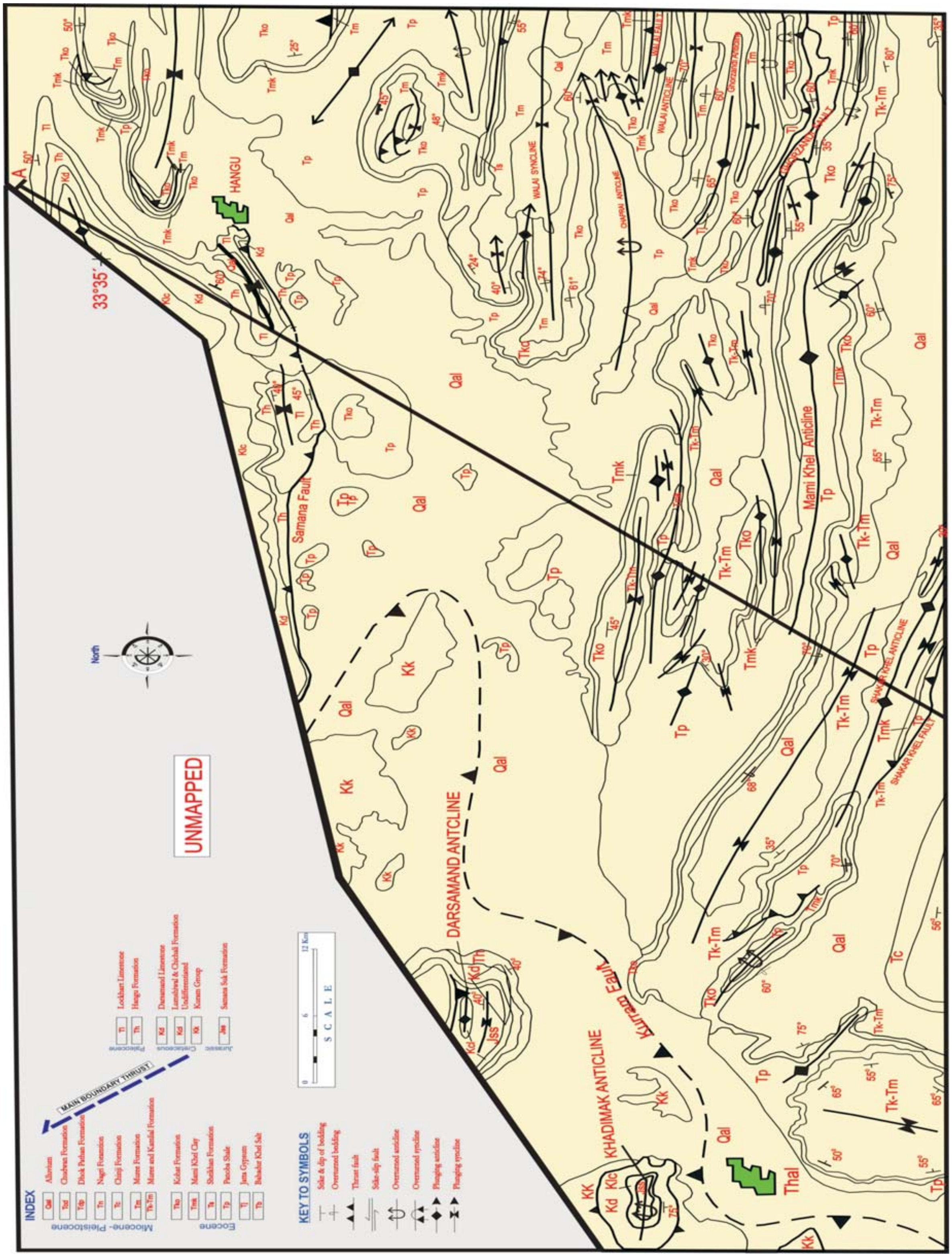

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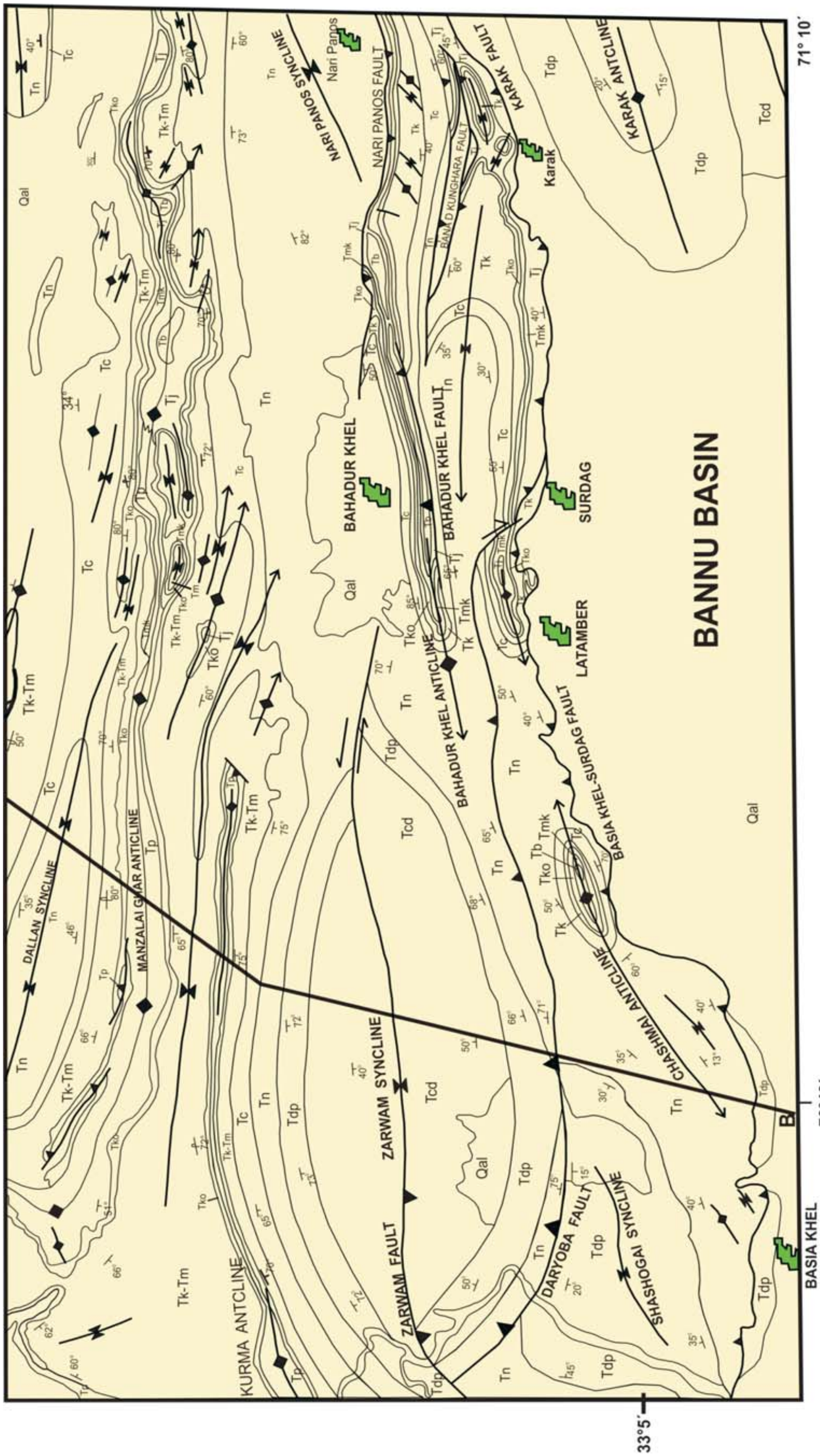
Figure 4- Geological map of the western Kohat Plateau, north-west Himalayas, N.W.F.P., Pakistan.



Continuation of Figure 4.

Daryoba Fault. It is east west oriented and joins the Zarwam Fault in the west and Karak Fault in the east (Figure 4). At the surface, the fault is steeply north dipping and brings the rocks of Nagri Formation in the north over the flat lying rocks of the Dhok Pathan Formation (Figure 4). Another prominent feature of the region is the Shashogai Syncline, which lies south of Daryoba Fault and has curvilinear axial trend. Its limbs are characterized by low dip angles and expose the Dhok Pathan Formation in its core. The southern limb of this syncline incorporates several en-echelon fold structures (Figure 4). The Basia Khel-Surdag Fault demarcates the southern limb of Shashogai Syncline in the west and the southern limb of Latamber anticline in the east. The Basia Khel-Surdag Fault is east west trending and is gently north dipping fore thrust (Figure 4).

Imbricate thrust splays contained along anticlinal limbs dominate the structural geometry east of the longitude of Latamber. The important structural features of the region include the Nari-Panos Fault in the north (Figure 4). At surface the Nari-Panos Fault is moderately south-dipping back thrust and brings the Jatta Gypsum over the Nagri Formaton in the footwall (Figure 4). The Banda Kunghara Fault lies south of the Nari-Panos Fault and is steeply south-dipping back thrust (Figure 4). It brings the Jatta Gypsum in the hanging wall over the Chinji Formation in the footwall. To the south of Banda Kunghara Fault lies the north-dipping Karak Fault. It has moderate dip angles and emplaces the rocks of Jatta Gypsum over the Chinji Formation in the south (Figure 4). The Karak Fault represents the southern most extension of the evaporite facies exposed at surface within the Kohat foreland Basin.

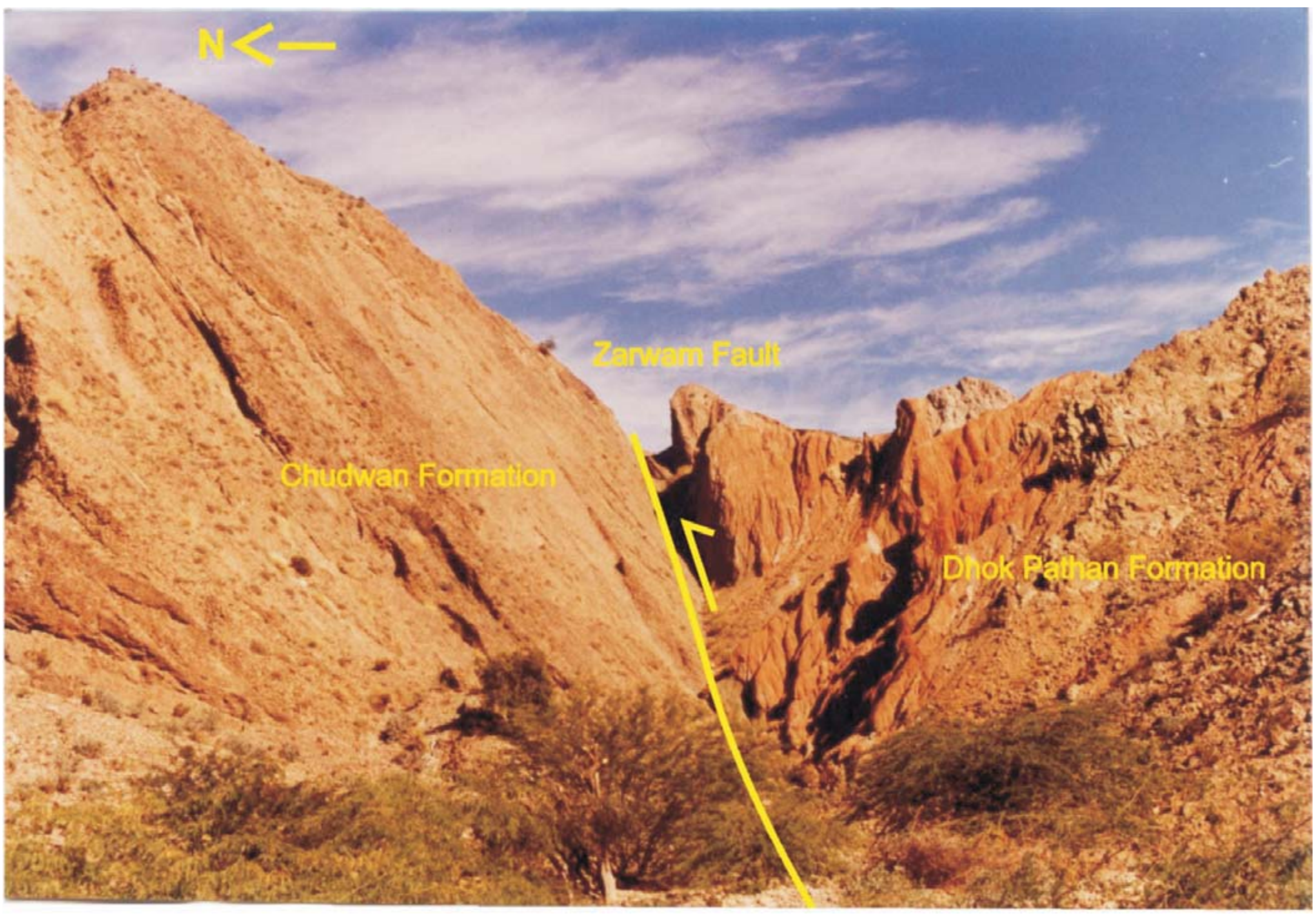


Figure 5- East looking view of Zarwam Fault exposed along Bannu-Zarwam road, characterised by steep dip angle.

Figure 6- Sheared clasts of conglomerate that belongs to Chudwan Formation exposed along Zarwam Fault east of Zarwam village.

STRUCTURAL TRANSECT OF THE WESTERN KOHAT FOLD AND THRUST BELT

The structural styles of the Western Kohat Fold and Thrust Belt will be summarized by describing a transect between Hangu and Basia Khel. The location of the transect has been choosen so as to cross all significant structures of the region and depict the overall structural geometry of the region (Figure 4). The surface geology along the structural transect is constructed from new field mapping and the subsurface information are obtained from seismic line No. YACP-09A of the AMOCO, Pakistan, obtained in 1992. Based on structural geometries the structural transect is divisible into a northern thin-skinned deformed fold and thrust belt and a southern thick-skinned deformed zone (Figure 7).

THIN-SKINNED DEFORMED FOLD AND THRUST BELT

Imprints of thin-skinned deformation are well developed along the western Kohat Fold and Thrust Belt from Hangu in the north up to the latitude of Kurma Anticline in the south (Figure 7). From north to south the Samana Anticline of the Samana Range is a fault-propagating fold related to the uplift along the Samana Fault. The Samana Fault appears to be a regional fault detached from the sediment-basement interface**.** The Eocene carapace of the Kohat Foreland Basin that lies south of the Samana Anticline exhibit disharmonic folds of varing amplitudes (Figure 7). As the Panoba Shale occupies the base of the Eocene, its plastic nature has resulted in thickening of the anticlinal cores giving rise to shale-cored anticlines and shale-withdrawal synclines. Nearly all the folds are south facing as seen along the transect though most of these folds becomes doubly overturned towards east along their map exposures and exhibits fan geometries. The structures within the non-outcropping Mesozoic-Paleozoic succession beneath the Eocene cover are interpreted to be dominated by a series of north-dipping blind, listric thrust faults. These faults exhibit curved fault plane geometries and share a common basal decollement at the sediments-basement interface. Most of these faults appear to be blind and tip out at the base of Eocene succession. This structural style is persistent up to the Shakar Khel Fault in the south. The Shakar Khel Fault is a deep rooted, south verging fore thrust that truncates the forelimb of Shakar Khel Anticline. South of the Shakar Khel Fault, the Dalan Pop-Down appears on the transect. This structure is bounded by a couple of opposite verging, blind back and fore thrusts that are related to deformation associated with regional basal decollement. The southern bounding fault of the Dalan Pop-Down is a north vergent backthrust that tips out at the level of Panoba Shale along the northern limb of the Manzalai Ghar Anticlinorium. The thin-skinned deformation vanishes as it reaches the Kurma Anticline, which lies at the boundary of transition from thin to thick-skinned deformation.

THICK-SKINNED DEFORMED ZONE

The thick-skinned style of deformation along the structural transect is confined to a 12 Km wide zone bounded by Kurma Anticline in the north and Daryoba Fault in the south. (Figure 7). Kurma Anticline is interpreted as a tight anticlinal structure cored by a steeply south-dipping fault. The apparent displacement along the underlying fault appears as normal in sense. South of the Kurma Anticline, the northern limb of Zarwam Syncline is steeply south-dipping and a vertical to sub-vertical fault namely Zarwan Fault offsets its core. Daryoba Fault truncates the southern limb of Zarwam Syncline, which is steeply north dipping reverse fault. The zone between Kurma Anticline and Daryoba Fault seems to be deformed by thick-skinned deformation style that involves the basement as well. South of Daryoba Fault, the deformation style switches to thin-skinned mode and the Shashogai Syncline seems to be a flat-syncline sitting on top of the Basia Khel-Surdag Fault, which itself is a north-dipping fore thrust emplaced over the Bannu Basin (Figure 7).

ANALYSIS

The map data, combined with subsurface interpretations of the exposed structures depicts that the geometry of western Kohat Fold and Thrust Belt is a combination of thin and thick-skinned deformed style. The thin-skinned deformation is related to a regional structural detachment, located at the contact between the crystalline basement and Paleozoic to Pliocene sediments. Projection of fold geometries within the Eocene rocks requires a decoupling surface at the base of Eocene sequence. The sectional geometries of the surficial folds indicate that these are detachment folds developed in response to the accommodation of shortening associated with the listric thrust splays cutting up section from the basal detachment. The subsurface fold geometries present within the Paleozoic Mesozoic rocks are interpreted as fault propagation folds developed in response to the motion along the listric thrust splays from the basal detachment. The rheological contrast between the base of Eocene succession and the non outcropping Mesozoic-Paleozoic sequence has played an important role in determining the contrasting structural styles within the exposed and subsurface rocks. It is believed that the presence of a thick sequence of shale and evaporites at the base of Eocene has defined the zone of strain partitioning between surface and subsurface structures where the subsurface structural system is migrating southwards in response to the Himalayan deformation. The Paleozoic to Mesozoic rocks are deformed by low angle listric thrust splays and give rise to fault propagation folds within the overlying rocks. At the base of Eocene the faults tip out and the overlying Eocene sequence is disharmonically folded along with the plastic flow of shale into the anticlinal cores and withdrawal from synclinal cores.

The thick-skinned deformation is displayed in the zone south of the latitude of the Kurma Anticline. All the faults in this zone are vertical to sub-vertical at the surface and are mostly non-parallel to bedding. The vertical to sub-vertical dips of the faults is an indication of the lateral motion along Daryoba and Zarwam Fault. The projection of the limbs of Zarwam Syncline and Kurma Anticline leads to the inference of a blind normal fault beneath Kurma Anticline. The sense of displacement in cross section for this fault has an apparent normal sense of motion along which the northern limb of Zarwam Syncline is down thrown. However, in a region subjected to contractile deformation, normal sense of displacement is kinematically beyond question. The sense of displacement along Daryoba Fault at deeper level seems to be normal in the sense that changes to reverse sense at shallow level indicating significant lateral motion along it. Based on these observations it is inferred that the area between Daryoba

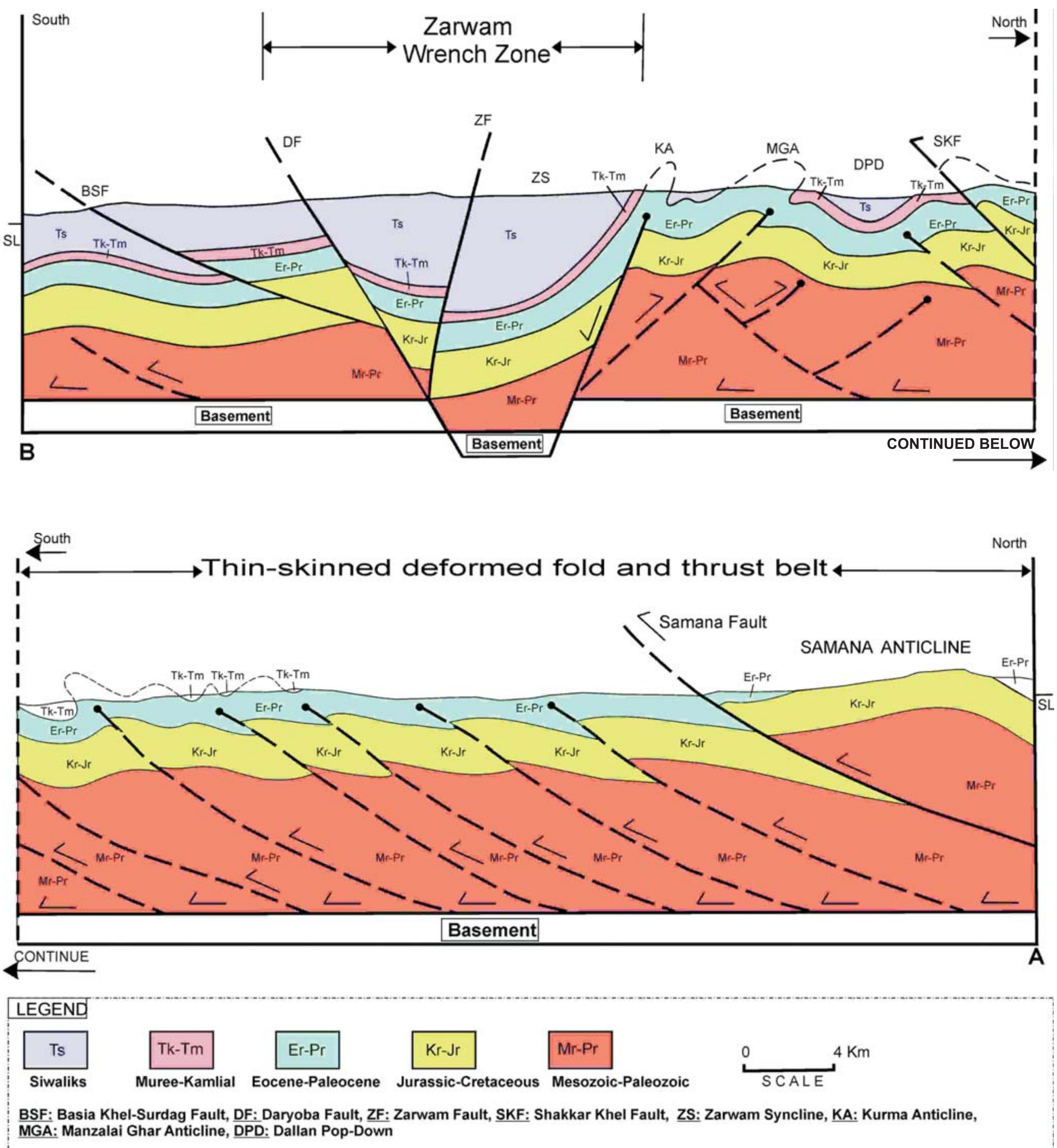


Figure 7- Structural transect across the western Kohat Plateau along line AB of figure 4.

Fault and Kurma Anticline has undergone strike-slip adjustments that involves the basement as well. The involvement of basement rock is inferred from the projection of the limbs of Zarwam Syncline into the subsurface. To place in the stratigraphic sequence below the Zarwam Syncline, it would require a deeper detachment level compared to the north and south of Zarwam Syncline. The concept of strike-slip movement is also supported by the fact that the limbs of Zarwam syncline offset in a lateral manner along Zarwam Fault (Figure 4). The geometric intersection of the faults within the Zarwam Wrench Zone and the area south and north of it suggest that the strike-slip faulting is a later activity superimposed upon the earlier contractile deformation.

The Potwar Foreland basin is the eastward geographic extension of the Kohat Foreland basin, which is separated by the Indus River tributary (Figure 2). The Potwar Foreland basin is a well documented thin-skinned fold and thrust belt underlain by a regional decollement at the contact between the Eocambrian evaporites and crystalline basement (Seeber and Armbruster, 1979; Jaume and Lillie, 1988). The south propagation of deformation along the regional basal decollement is greatly facilitated by the presence of evaporite horizon, which as a consequence emerges at the surface along the Salt Range Thrust (SRT). The Eocambrian-Cenozoic succession is emplaced over the Punjab foreland along the SRT in the south (Lillie et al., 1987). Based on the deformation style, the Potwar Foreland basin can be subdivided into the northern and southern Potwar Basin. Much of the southern Potwar Basin is internally less deformed and has been pushed 20 kilometers southwards as a coherent block with the thrust sheet being gently folded. In comparison, most of the deformation is concentrated in the northern Potwar Basin called as the Northern Potwar Deformed Zone (NPDZ). The NPDZ is a belt of Neogene deformation extending south of the MBT up to the northern limb of Soan Syncline (Jaswal et al., 1997). It is severely folded and faulted and consists of compressed faulted folds, which are separated by wider synclines and have undergone 555 kilometers of shortening between the MBT and the northern limb of Soan Syncline (Baker et al., 1988). The presence of salt underneath the northern Potwar Basin has long being suspected and the distribution of salt underneath the Potwar Basin could be a well controlling factor for the contrasting structural behavior in the north and south of the basin.

The present account of the structures within the Kohat Foreland basin and its comparison with that of the Potwar Foreland basin suggests that the NPDZ is a true structural analogue of the Northern Kohat Foreland basin. The NPDZ and Kohat Foreland basin bears close similarities that include tight anticlinal trends separated by broad synclines, blind to partially emergent thrust faults giving rise to characteristic foreland structures such as pop ups and down. These structural similarities could be ascribed to the similar sort of rheologies at the basal decollement underneath the Kohat Foreland basin and the NPDZ. It is inferred that the basal decollement underneath the Kohat Foreland basin lacks salt horizon, which is the case underneath the NPDZ. Furthermore, structural trends in the NPDZ are consistent with that of the Northern Kohat Foreland basin suggesting a structural analogy.

DISCUSSION AND COCLUSIONS

Two contrasting models have explained previous account of the structural genesis of the outcropping rocks in the Kohat Foreland Basin. One of these models depicts that the structures within the exposed rocks are part of a passive roof thrust that is translating northwards in a thin-skinned fashion. This passive roof thrust is underlain by an active wedge of south-directed thrust slices of Pre-Tertiary stratigraphy that form a passive roof duplex (McDougal & Hussain, 1991; Abbasi & McElroy, 1991). If the outcropping strata within the Kohat Foreland Basin is regarded as a Passive roof sequence then it must be characterized by a) hinterland-facing isoclinal folds, b) overstep sequence of foreland-dipping passive back thrusts and, c) foreland ward-dipping monoclinal range front (Bank & Warburton,1986). In fact none of the above mentioned structures are found in the western Kohat Foreland to support the idea of passive roof thrusting. Majority of the folds mapped in the region display fan geometries. Though back thrusts are mapped in the area but are genetically related to the south-facing fore thrusts without any overstepping. The Surghar Range, which represents the leading front of the Kohat Plateau, is a weakly to strongly emergent thrust (Ahmad et al., 2003). It is interpreted that the northern domain of the Western Kohat Fold and Thrust Belt is dominantly a south verging structural system and the deformation is related to a single regional basal decollement. The second model suggests that the structural evolution of the Kohat Foreland Basin has been greatly influenced by strike-slip faulting related to thick-skinned deformation. These strike-slip faults are not recognizable at the surface but are deep-rooted in the basement and expose themselves as anticlinal trends in the Eocene cover (Pivnik & Sercombe, 1993; Sercombe et al., 1994 (a) & (b) & Sercombe et al., 1998). However, the present structural data in the western Kohat Fold and Thrust Belt over its major proportion do not coincide with this interpretation. If the anticlinal trends at the surface are rooted by basement related strike-slip faults, it is surprising that not at a single locality evidence of lateral off set are found. Further, the northern domain of the western Kohat Fold and Thrust Belt entirely lacks any of the characteristic features related to strike-slip faulting such as transtensional and transpressional bends, en-echelon array of faults and folds (Sercombe et al., 1998). However the structural account of the southern domain of the western Kohat Fold and Thrust Belt is consistent with the second model with some exceptions. This distinctive structural domain is named as the Zarwam Wrench Zone (ZWZ) and can easily be differentiated from the other widespread compressional features distributed throughout the plateau. The ZWZ typify strike-slip deformational features that include steep dips along the faults, stratigraphic mismatch across the faults, horizontal slicks along the fault surfaces and stepped arrangement of small-scale folds. The older compressional structures mapped in the ZWZ are influenced due to the motion along younger strike-slip faults. Despite the fact, that the entire Kohat Plateau shares almost similar rheologies and tectonic environments, the southern domain of Kohat Fold and Thrust Belt behave differently. It is suggested that the genesis of the strike-slip faulting in the ZWZ is related to the westward under thrusting of the Southern Kohat Plateau rocks underneath the

Sulaiman and Samana Ranges in the west along the transpressional boundary called as Kurram Fault (Pivnik & Sercombe, 1993). The transpressional deformation associated with the Kurram Fault has been transmitted to the ZWZ and the strike-slip faults of the ZWZ are believed to be REIDEL shears associated with the major principle displacement zone that is the Kurram Fault.

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PJHR

Received Jan. 10, 2007, revised Aug. 25, 2007 and accepted Sep.15, 2007. First the paper was presented in Annual Technical Conference of PAPG & SPE held in Islamabad, Pakistan, Oct. 8-9, 2004 and published in its proceedings. Now the paper is being published after subjecting it to refereeing process outlined by Higher Education Commission, Islamabad, Pakistan.