Journal of Himalayan Earth Sciences Volume 48, No. 2, 2015 pp.9-18

Architecture of fold-thrust assemblages in the Marwat-Khisor ranges of the outer Himalayan Orogenic Belt of Pakistan

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Abstract

Marwat-Khisor ranges as central division of the Trans-Indus ranges of Pakistan describe an east-west to northeast trending fold-thrust belt. This belt depicts the structural style of the southern deformed fold thrust belt of the outer Himalaya that characterizes the mobile perimeters of the Kohat Plateau and Bannu Basin in the south. The prominent fold-thrust assemblages of the Khisor Range are the Paniala, Saiyiduwali, Mir Ali, and Khisor anticlines with a youngest major Khisor Fore thrust which bordered the Khisor Range in the south. The Marwat Anticline reveals a macro scale single key structure of the Marwat Range. Fold structures of the Marwat-Khisor ranges are generally asymmetric, overturned and exhibit south facing geometry. Construction of balanced structural sections across this belt suggests that the structural style is thin-skinned and mostly comprised of fold-thrust assemblages. These structural elements are kinematically associated to a regional basal decollement located at the base of Jhelum Group rocks. The Marwat Anticline initially developed as low amplitude forced fold and with the course of time displaced over an unexposed fault ramp to form a fault-bend fold. This episode was followed to the south by another thrust ramp from the basal decollement in the Khisor Range forming fault-bend anticlinal folds in the cover sequence. This ramp-flat trajectory from the basal decollement emerged in the form of Khisor Thrust at surface juxtaposing Jhelum Group rocks against the Siwalik Group rocks towards the Punjab Foreland. The Khisor thrust sheet defines the youngest deformation front of the outer Himalayan tectonic wedge in the Trans-Indus ranges.

Keywords: Fold-thrust assemblages; Salt Range; Marwat-Khisor ranges; Outer Himalayan; Orogenic Belt.

1. Introduction

Foreland fold and-thrust belts throughout the world are conspicuous features of the convergent plate tectonic habitat. In North Pakistan the Kohat-Potwar fold and thrust belt along with its associated frontal ranges, which are Salt and Trans-Indus ranges represent the foreland fold-thrust belt of northwestern Himalayas (Fig. 1). The Trans-Indus extension of the Salt Range is composed of Surghar-Shinghar, Marwat-Khisor, Pezu and Manzai ranges which form an "S" shaped double re-entrant and surrounds the Bannu Basin (Fig. 2). These ranges represent the western part of the northwestern Himalayan Foreland Fold and Thrust Belt and formed by progressive south directed decollement-related thrusting of the Indian Plate during the ongoing collision between Indian and Eurasian plates following the convergence of the Kohistan Island Arc (Stocklin, 1974; Stonely, 1974; Molnar and Tapponier, 1975). The Kohistan Island Arc and the Indian Plate connected at the site of Main Mantle Thrust and its lateral equivalents during latest Cretaceous to Early Tertiary time (Yeats and Hussain, 1987; Beck et al., 1995). Tectonics generally shifted southward with time. The external most and latest thrusting has occurred along the frontal thrust system bordering the Trans-Indus ranges (Khan and Opdyke, 1988; Blisniuk and Sonder, 1998). The Marwat-Khisor ranges define an east-west to northeast-southwest trending fold-thrust belt system where deformations and lithospheric fracturing generally evolved southward with time. The Salt Range Thrust that forms the southern margin of the Potwar Plateau apparently continues westward along the southern flank of the Surghar and Marwat-Khisor ranges and is largely covered by alluvium. However, in Western Salt Range near Kalabagh this thrust is exposed and juxtaposes Paleozoic rocks over late Pleistocene conglomerates (Gee, 1989; Ahmad et al., 2003). Two scenarios, which are south directed thrusting and normal faulting, are considered to have been responsible for the tectonic evolution of the Khisor Range. The area along the present day thrust front was affected by synorogenic normal faulting within the foreland basin before thrusting began (Blisniuk and Sonder, 1998). Khisor Thrust is the youngest and active contractional boundary due to which the Khisor Range has been tectonically uplifted and rationally deformed, accommodating shortening in the sedimentary cover sequence above the basal detachment surface. This study focuses on the structural framework of the Marwat-Khisor ranges in order to recognize key structural elements, their local and gross regional patterns, structural style and to construct a consolidated structural model of the area that will help in understanding the structural style of the region for hydrocarbon exploration.

2. Regional setting

The geodynamic processes of sea floor spreading, continental drift and collision tectonics resulted in the formation of a pronounced global feature that is the Himalayas resulting due to the collision of the Indo-Pakistani subcontinent with the Eurasian plate (Molnar and Tapponier, 1975). Four regional fault systems that are Main Karakoram Thrust, Main Mantle Thrust, Main Boundary Thrust and Trans-Indus ranges Thrust subdivide the Pakistani Himalayas into five litho-tectonic terrains, which are characterized by distinctive stratigraphy and physiography. From north to south these gross geological belts are Karakoram block, Kohistan Island Arc, Northern Deformed Fold-Thrust Belt, Southern Deformed Fold-Thrust Belt and Punjab Fore deep (Fig. 2). The northern deformed fold-thrust belt comprises festoon shaped belt of heavily deformed sedimentary, metasedimentary and igneous rocks (Fig. 1). This belt stretches from Kurram area in the west near Afghan border up to the Kashmir Basin in the east. The northern fold and thrust belt is bounded by Main Boundary Thrust separating it from the southern deformed fold and thrust belt. The Kohat Range is located along the southern periphery of this belt and constitutes the hanging wall stratigraphy of the Main Boundary Thrust. The Main Boundary Thrust extends along the front of the northern fold and thrust belt around Hazara-Kashmir Syntaxes. It carries the pre-collision Paleozoic and Mesozoic sedimentary and meta-sedimentary rocks of the Northern Deformed Fold and Thrust Belt in its hanging wall and Post-collision folded Miocene foreland-basin deposits in its footwall Yeats and Hussain (1987) and is comprised of a series of parallel or en-echelon thrust faults (Pivnik and Wells, 1996). The Southern Deformed Fold and Thrust Belt rim the Himalayan mountain belt from Ganges Delta in India up to the South Waziristan Agency in Pakistan (Fig. 1). It is oriented in east-west direction and is underlain by a thick pile of fluvial sediments. This belt was the main depocenter of the synorogenic sediments influx, which started in early Miocene. This fold and thrust belt can be divided into two tectonic provinces, the Potwar Plateau to the east and Kohat Plateau to the west of Indus River, in the Trans-Indus (Fig. 2).

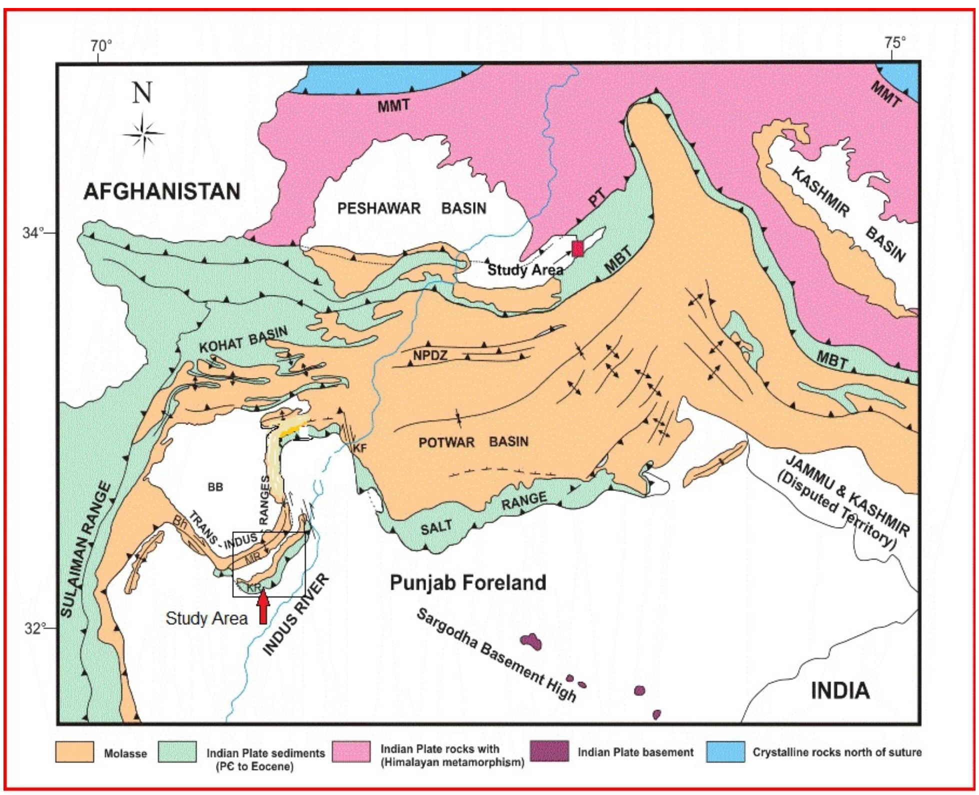

Fig. 1. Map showing major tectonomorphic terrains of North Pakistan. For location see Inset in Figure 2.

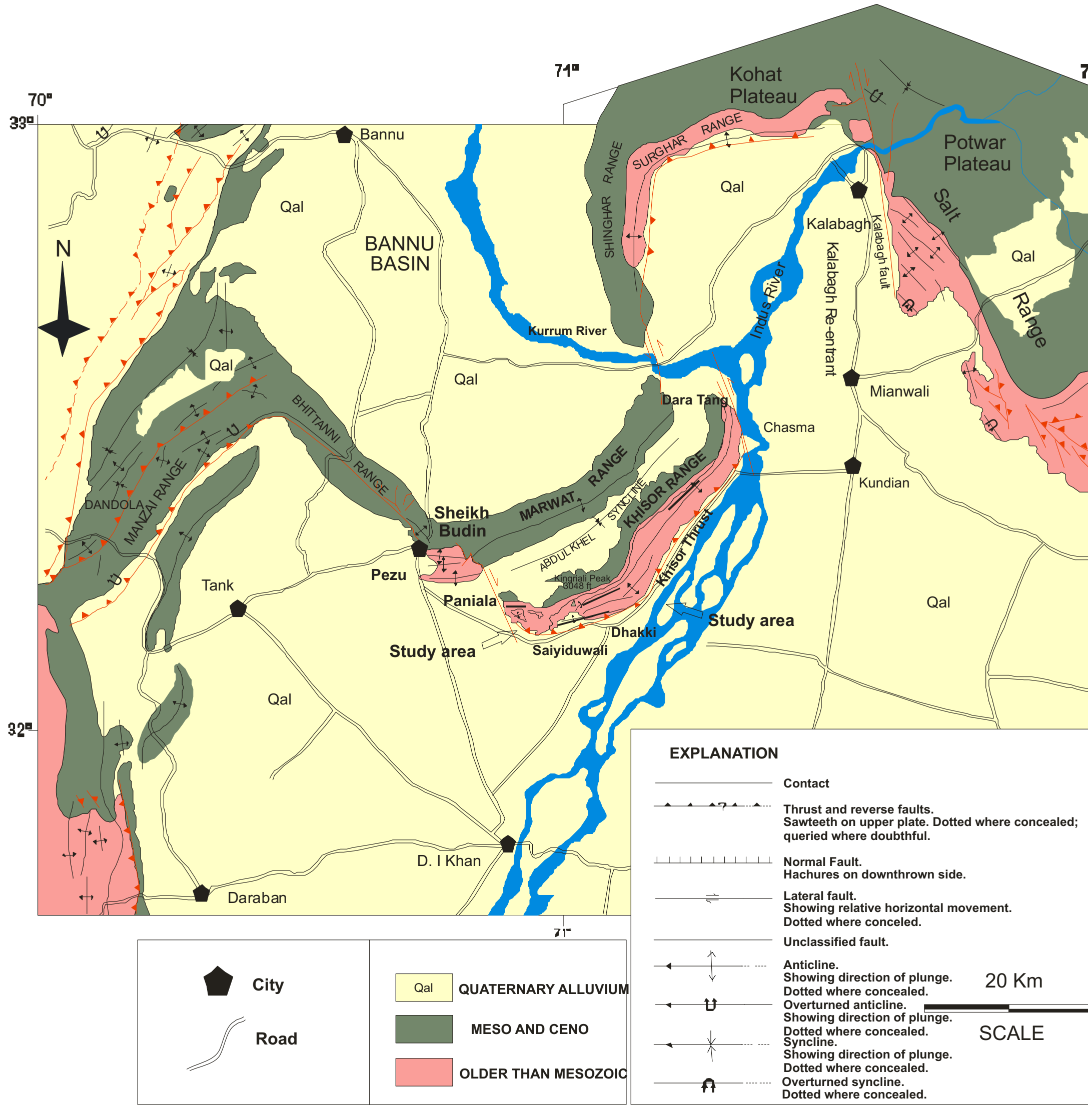

Fig. 2. Generalized geological map of the Trans-Indus ranges shown in inset of Figure 1.

The Potwar Plateau is internally less deformed, fold and thrust belt having a width of approximately 150 Km in north-south direction (Kazmi and Rana, 1982). It is bounded to the south by the Salt Range Thrust and to the north by Hazara/Kalachitta ranges. Most of the deformation is concentrated in the northern part of the plateau, which is called the Northern Potwar Deformed Zone (Leathers, 1987; Baker et al, 1989). The Kohat Plateau is the western most of the Southern Deformed Fold and Thrust Belt and was located far off southwards of the shelf margin at the time of collision and suturing in the north. The area had been influenced by the southward progression of deformation during late Miocene. The Main Boundary Thrust bounds the Kohat Plateau to the north. Towards west, the Kurram Fault (Fig. 1) Juxtaposes highly deformed Mesozoic strata with the Cenozoic sediments of the Kohat Plateau (Ahmad et al., 2004). The southeastern boundary of the Kohat Plateau is marked by the Surghar Range where Mesozoic rocks were emplaced southwards onto the Punjab Foreland in the south. Towards south, the undeformed sediments of Bannu Basin form the southern boundary of the Kohat Plateau (Fig. 2). The Marwat-Khisor ranges lie south of Bannu Basin and form an integral part of the Trans-Indus ranges. These ranges are marked by Khisor frontal thrust system along which Cambrian rocks are thrust over the Punjab Fore deep in the south (Blisniuk and Sonder, 1998).

3. Stratigraphic framework

In the Khisor Range, northwest of Saiyiduwali, an excellent section of Paleozoic and Mesozoic rocks are exposed. The base of stratigraphic succession is occupied by the rocks of Cambrian age that include Khewra Sandstone, Kussak Formation, Jutana Formation and Khisor Formation (Table 1). The Khewra Sandstone consists of purplish-brown, thick-bedded sandstone with coarse clay bands and concretionary layers in the upper part. The overlying Kussak Formation is

Table 1. Generalized stratigraphic sequence of the Marwat-Khisor ranges.

Age		**Group**	**Formation**	**Composite Thickness (m)**
	Tertiary	Siwaliks	Soan	44.00
			Dhok Pathan	166.00
			Nagri	962.00
MES	Triassic	Musa Khel	Kingriali	108.00
			Tredian	46.00
			Mianwali	127.00
PAL	Permian	Zaluch	Chhidru	92.00
			Wargal Ls	156.00
			Amb	60.00
		Nilawahan	Sardhai	42.00
			Warchha	136.00
			Tobra	86.00
	Cambrian	Jhelum	Khisor	172.00
			Jutana	82.00
			Kussak	48.00
			Khewra Ss	64.00+

a sandy and dolomitic unit that is rich in glauconite. The Jutana Formation is predominantly gray, massive dolomite and is overlain by the Khisor Formation that is predominantly gypsiferous marl interbedded with shale along with minor oil-impregnated gypsum and dolomite layers. Overlying the Cambrian rocks is a sequence of Permian rocks that consist of the Nilawahan and Zaluch Group. The base of the Nilawahan Group begins at the Tobra Formation that is a tillitic deposit overlying Warchha Sandstone and contains siltstone and silty shale. The Sardhai Formation consists of carbonaceous, silty shale with minor sandstone bands. Local people have explored the carbonaceous layers for coal. The overlying Zaluch Group consists of mixed sandy and carbonate units in the lower Amb Formation and upper parts of the Chhidru Formation but a thick carbonate cliff-forming unit i.e. Wargal Limestone, is present between these two. Brachiopods, crinoids, bryozoans, corals and other fossils are common in this group. The upper 20 m thick, gray, nodular marly limestone of the Wargal Limestone contains abundant brachiopods and other fossils and underlies the Chhidru Formation. Sandy limestone is common in the upper part of the Chhidru Formation. The contact between the Permian Chhidru Formation and the Triassic Mianwali Formation (Kathwai Member) of the Musa Khel Group is well exposed in the Saiyiduwali area. The basal Kathwai Member of the Mianwali Formation is sandy and dolomitic in the lower part but is glauconitic in the upper part. It is overlain by interbedded limestone and shale with subordinate siltstone of the Mittiwali Member, which is overlain by shale, limestone and the silty and sandy sequence of the Narmia Member. The Tredian Formation overlies the Mianwali Formation, which is silty in the lower part (Landa Member) and thick-bedded sandstone (Khatkiara Member) in the upper part. The Kingriali Formation consists of dolomitic marl and shale, and is unconformably overlain by the Siwalik Group rocks in the Khisor Range. The Musa Khel Group is well exposed in the west and extends up to north of Saiyiduwali but further eastwards it does not make its way to the surface. Jurassic in the west, Triassic in the center and Permian rocks in the east are unconformably overlain by the Nagri, Dhok Pathan and Soan formations, of Siwalik Group. These nonmarine, time-transgressive molasses facies represent the erosional products of southward advancing Himalayan thrust sheets. Marwat Range lies immediately south of the Bannu Basin and outcropping in the form of broad anticline known as Marwat Anticline. It is entirely composed of Siwalik Group rocks (Fig. 3) representing the development of a terrestrial foreland basin that contained generally south-flowing fluvial systems, including the Paleo-Indus River, which were derived from the Himalayas during Pliocene till present. The influence of the advancing orogenic front on the foreland

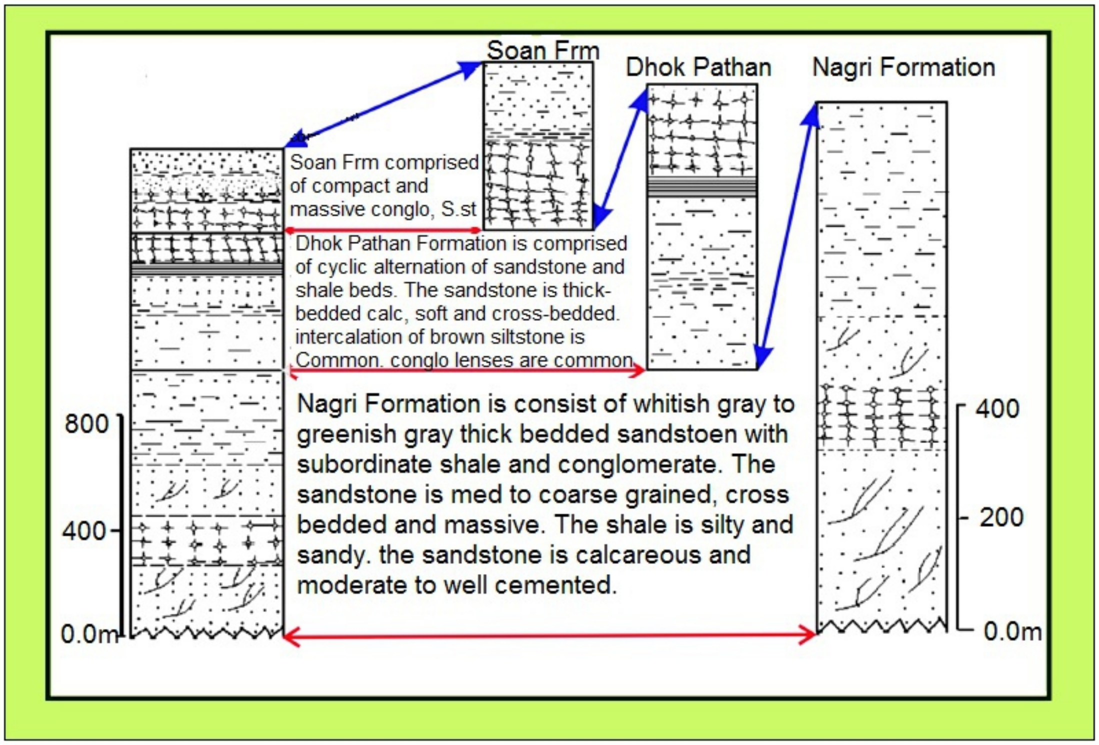

Fig. 3. Generalized stratigraphic sequence of the Marwat-Khisor ranges.

sedimentation becomes more pronounced during the deposition of the Siwalik Group as compared to Rawalpindi Group because the axis of the Siwalik depocenter shifted southward, resulting in the formation of middle/upper Siwaliks in the Marwat-Khisor ranges (Pilgrim, 1926; Fatmi, 1973).

4. Surface structural styles

Key structural elements of the Marwat-Khisor ranges are east-west to northeast trending, parallel to en echelon meso and macro-scale folds and a frontal thrust fault. Folds mapped in the Khisor Range are generally asymmetric, overturned and plunging. Most of the folds and faults define south-vergent structural system. Four macro-scale anticlinal folds are mapped in the area that is Paniala, Saiyiduwali, Khisor and Mir Ali Anticline and one in the Marwat Range named as Marwat Anticline (Fig. 4). Out of the synclinal folds the Abdul Khel syncline is the most prominent and regional scale fold, located between Marwat Range in the north and Khisor Range in the south (Fig. 4).The Paniala Anticline is a prominent structural feature of the western Khisor Range and forms the hanging wall of the Khisor Thrust (Fig. 4). Structural data collected along its limbs indicate that its northern limb is comparatively steeper than its southern limb. Its axis is shallowly northwest plunging and trends in sub-latitudinal fashion. On the basis of attitude data it is interpreted to be slightly asymmetric towards north. The Saiyiduwali Anticline is the largest anticlinal fold mapped along the southern foothills of the Khisor Thrust, located north of Saiyiduwali (Fig. 4). The northern flank of this anticline attains greatest structural relief, where Chhidru Formation occupies the summit of the range. The topographic expression of the Saiyiduwali Anticline is mainly attributed to its back limb, which comprises the rocks of Cambrian to Permian age, whereas its forelimb has been eroded and does not crop out with the exception in the east and west, where both of the anticlinal limbs are found intact. The back limb of the Saiyiduwali Anticline is moderately deformed producing shallow fold structures, well developed in the Musa Khel Group of the Triassic age. The oldest rocks entrapped in the core of Saiyiduwali Anticline belong to Khewra Sandstone. Another important anticlinal fold of the area is the Khisor Anticline which is located northeast of the Saiyiduwali Anticline and is characterized by east west trending fold axis. Both its limbs exhibit identical dip angles having symmetric sectional geometry. Its southern limb comprises the rocks of Chhidru Formation while its northern limb consists of Chhidru Formation overlain by the rocks of Musa Khel Group that is in turn unconformably overlain by Siwalik Group. Khisor Anticline is a regional scale anticlinal fold mapped in the central Khisor Range (Fig. 4). The Khisor Anticline shows highest structural relief compared to other fold structures exposing the Kingriali dolomite in the apex of fold hinge and forms the Kingriali peak where the Khisor Range attain its highest culmination. The Mir Ali anticline is a prominent feature of the eastern Khisor Range. Its axial trend is north-northeast and its extension is more than 20 km (Fig. 4). Its southeastern limb is comprised of the rock of Chhidru Formation whereas its northwestern limb consists of the rocks of Chhidru and Mianwali Formation, unconformably overlain by the Siwalik strata. The topographic expression of the Marwat Range is attributed to a regional anticlinal trend named as Marwat Anticline, bounded by Abdul Khel Syncline in the southeast and Bannu Basin in the northwest. The northern limb of the Marwat Anticline comprises the rocks of Dhok Pathan and Soan Formation whereas the southern limb constitutes the strata of Dhok Pathan Formation only. Nagri Formation of Siwalik Group is entrapped in the core of the anticline. The southern limb of the anticline is dipping to the northwest at moderate to steep angle (500~650) and becomes overturned in

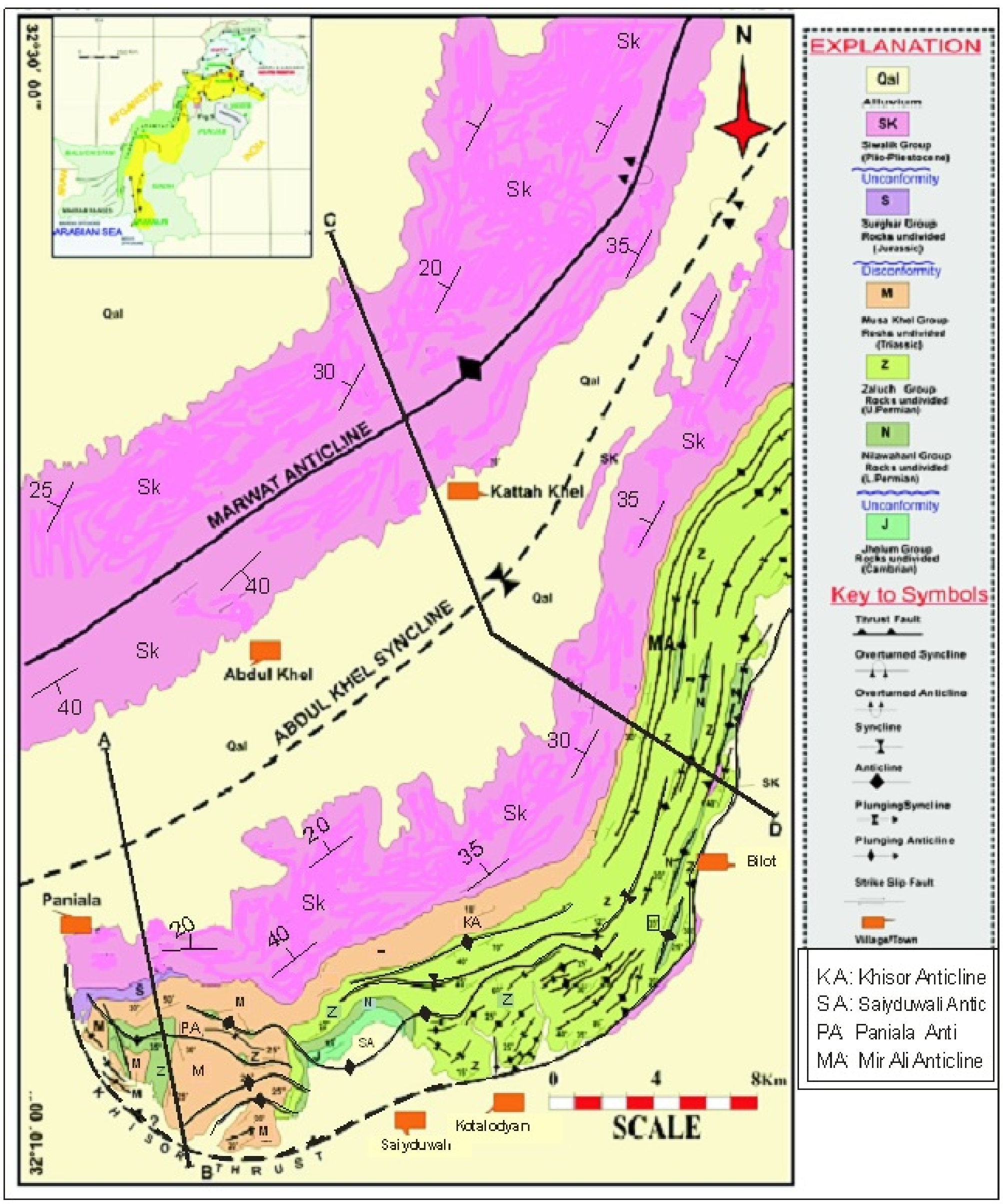

Fig. 4. Geological map of the Marwat-Khisor ranges, Khyber Pakhtunkhwa, Pakistan.

extreme northeast whereas its northern limb gently dips to the northwest (200~450). On the basis of attitude data the Marwat Anticline is considered as an overturned anticlinal fold with south vergence in the east. Abdul Khel Syncline lies between Khisor and Marwat Range, characterized by wide wavelength in the west near Paniala and becomes shorter in wavelength eastwards along its extension. Attitude data collected on the limbs, found that its southeastern limb gently dips to the northwest whereas its northern limb is steeply southeast dipping to overturn towards northwest in the extreme northeast, making the sectional geometry of the Abdul Khel Syncline overturned in the eastern sector of study area (Fig. 4). Emergent faults are non penetrative as compared to folds in the Marwat-Khisor ranges. One regional fault that is Khisor Thrust is partially exposed along the frontal slopes of the entire Khisor Range. It is well exposed northwest of Dhakki, Bilot and Dhupsari village, providing good outcrop exposures. All along the mapped area trace of the Khisor Thrust, the Permian strata constitutes its hanging wall juxtaposed along the Siwalik Group in the footwall. It is dominantly oriented north-northeast and moderately dips towards northwest (Fig. 4). The outcrop characteristics of the fault suggest that it is south verging fore-thrust detached at the base of the Permian rocks.

5. Subsurface structural style

The development of the southern Himalayan frontal thrust system has been previously studied by utilizing the sedimentological record of the Trans-Indus ranges (Blisniuk and Sonder, 1998). Two phases of deformation are suggested for the development of Himalayan frontal thrust system that include an early phase of north dipping normal faulting in the crystalline basement related to lithospheric flexure. This phase of deformation was followed subsequently by the younger south-directed thrust faulting in the cover sequence (Blisniuk and Sonder, 1998). These two major phases of deformation regionally control the surface and subsurface structural style and tectonic history in the area of the present day thrust front. The following factors were considered for the structural interpretation of the Marwat-Khisor ranges: (1) the assessment of major detachment horizon based on the geometric techniques utilizing kink plane bisecting angles; (2) the projection of surface structures to depth in a couple of interpretive cross-sections, using structural styles that are compatible with the surface attitude data; (3) the along-trend variations of the structures.

6. Location of the major decollement

The Trans-Indus and Salt Range of northwest Pakistan represent the mobile perimeter of the Kohat-Potwar fold and thrust belt and is frequently distinguished by décollement thrust-fold assemblages Thrusting along with associated folding is definitely the key method of accommodating shortening within these orogenic belts. The latest most thrusting has occurred along the frontal thrust system in the Salt Range to the east and the Trans-Indus ranges to the west (Blisniuk and Sonder, 1998). Beneath the Potwar plateau and the frontal Salt Range, Precambrian Salt Range Formation forms a laterally extensive basal décollement at the basement-sediment interface. As a result the structural style is mainly thin-skinned and the basement is convex upward with a gentle dip towards north. Similar basement geometry has been interpreted for the basement underneath Eastern Kohat Plateau and Bannu Basin (McDougall and Hussain, 1991, Parwez, 1992). Along the Khisor Range foothills the basal detachment is interpreted to be located below the Jhelum Group, as no salt exists throughout the extension of the Khisor Range (Fig. 4).

7. Structural transects

Two widely spaced structural transects of the Marwat-Khisor ranges along line AB and CD of figures 5 and 6 were constructed through the Paniala, Saiyiduwali and Marwat Anticline for the better understanding of the subsurface behavior of rocks and to understand the kinematics of folding and faulting. It was also aimed to recognize the along trend structural variations in the outcropping rocks. The salient structural features are shown in transects and are discussed in detail as under:

7.1. Structural transect along line AB

Structural transect along line AB (Fig. 4) is located east of Paniala village and depicts the subsurface geometry of the western Khisor Range (Fig. 5). The Paniala Anticline appears as a north facing, asymmetric anticline exposing the Permian rocks in its core. The anticline is characterized by approximately 4 km width in the north-south direction. Dip of the northern limb (forelimb) of the anticline is steep to vertical whereas its southern limb (back limb) dips gently to moderately, towards south. The cross-sectional line is approximately parallel to the north south oriented tectonic transport direction as inferred from the trends of the various structures mapped in the area. The southern limb of Paniala Anticline is marked by an open synclinal structure in the Musa Khel Group and collectively defines the hanging wall strata of the south-vergent Khisor Thrust in the south. Surface structural data along the northern limb of the anticline reveals that its steepening is related to the presence of a blind back thrust that tips at a depth of one kilometer. Projection of fold geometries to depth and well data encountered during Marwat Well-1 indicates that a regional basal detachment underlie the section at the base of Jhelum Group at a maximum depth of 3.5 kilometers below sea level. Frontal ramping from décollement thrusting was the initial response to the onset of compressional deformation and the Paniala Anticline formed as a fault-bend-fold above the Khisor Thrust. It was followed by a north verging ramp from the basal décollement that is believed to be responsible for the change of vergence of the Paniala Anticline, offset of the early course of Khisor Thrust and the formation of a non-outcropping deep seated anticlinal fold. The geometry of this non-outcropping anticline is that of a fault-propagating fold and is in structural contrast with that of the Paniala Anticline. On the northern flank of the Paniala Anticline the Siwalik Group unconformably overlie the Jurassic rocks of Datta and Shinawari Formation suggesting that deformation and uplift of the Paniala Anticline is post Plio-Pleistocene.

7.2. Structural transect along line CD

The transect CD is oriented north-northwest in Marwat Range and bends in the centre of the Abdul Khel Syncline to become northwest across the Khisor Range (Fig. 5). From north to south along the section line the Marwat Anticline depicts high side anticlinal closure geometry related to a major ramp from basal décollement (Fig. 6). The dip of its back limb shows the dip of the underlying ramp, whereas its forelimb is steeply south dipping and is related to the tip line of the fault where movement on the fault is seized below the forelimb of the anticline. South of Marwat Anticline lies the Abdul Khel Syncline that is believed to be a flat-syncline between two successive ramps. Along this transect the southernmost part of the range front is occupied by the Nilawahan and Zaluch Group that preserve small-scale fold train of synclines and anticlines, characterized by very short wavelengths (Figs. 5 and 6). Along this transect, deformation is mostly concentrated in the frontal margin of the Khisor Range that makes the hanging wall strata of the Khisor Thrust. The Khisor Thrust appears as south facing and emplaces Permian rocks of the Zaluch Group over the Siwalik Group strata in the southern frontier of the Khisor Range. North of the Khisor Thrust a small-scale thrust fault emerges at surface. This fault is named as Dhupsari Thrust juxtaposing Amb Formation in its hanging wall against the Nagri Formation in footwall (Fig. 6). The Dhupsari Thrust is south verging fore thrust and is believed to be a splay fault that emerged from the shallow level flat underneath the Khisor Range in order to accommodate shortening within the hanging wall sequence of Khisor Thrust. The intervening folds between the thrust faults and Abdul Khel Syncline are open to moderately tight and asymmetrical, having short wavelengths. Structural style depicted along transect clearly indicates that this part of the Marwat-Khisor ranges has developed as a south directed fold-thrust system, detached from the regional basal décollement. The mapped faults along the section line mostly observe stair case trajectory and the deformational style observed along the section is comparable in style to the AB transect.

8. Conclusions

Geological mapping in the study area indicates that thin-skinned deformed fold-thrust assemblages dominate the structural style of the Marwat-Khisor ranges. The key structural elements of these ranges are defined by east-west to northeast trending anticline-syncline pairs that are generally asymmetric and dominantly southeast vergent. Structural analysis of the structural geometries and the construction of balanced structural transects indicate that the study area is underlain by a regional basal detachment located at the base of Jhelum Group of Cambrian age. The basal décollement is dipping northwards by 2-3°. Structural geometries of the fold assemblages suggest that most of the prominent anticlines have been evolved as fault-propagation folds, being the consequence of the compressional deformation related to south progression of Himalayan deformation. The deformation event in the region postdates the deposition of late Miocene to Pleistocene Siwaliks indicating that the age of compressional deformation is post-Pleistocene.

Acknowledgments

This paper has been extracted from the PhD thesis of Iftikhar Alam, supervised by Prof. Dr. Sajjad Ahmad, UoP, after evaluation by Prof. Dr. Allen J. Dennis, University of South Carolina, Aiken, SC 29801-6309, Prof. Dr. Kevin R. Pogue, Whitman College, Washington USA and Prof. Dr. Riaz Ahmad Sheikh. The author is highly appreciated and extremely acknowledged the suggestions and comments made by these reviewers. All their suggestions have been incorporated in the thesis and it the end improved the quality of the manuscript.

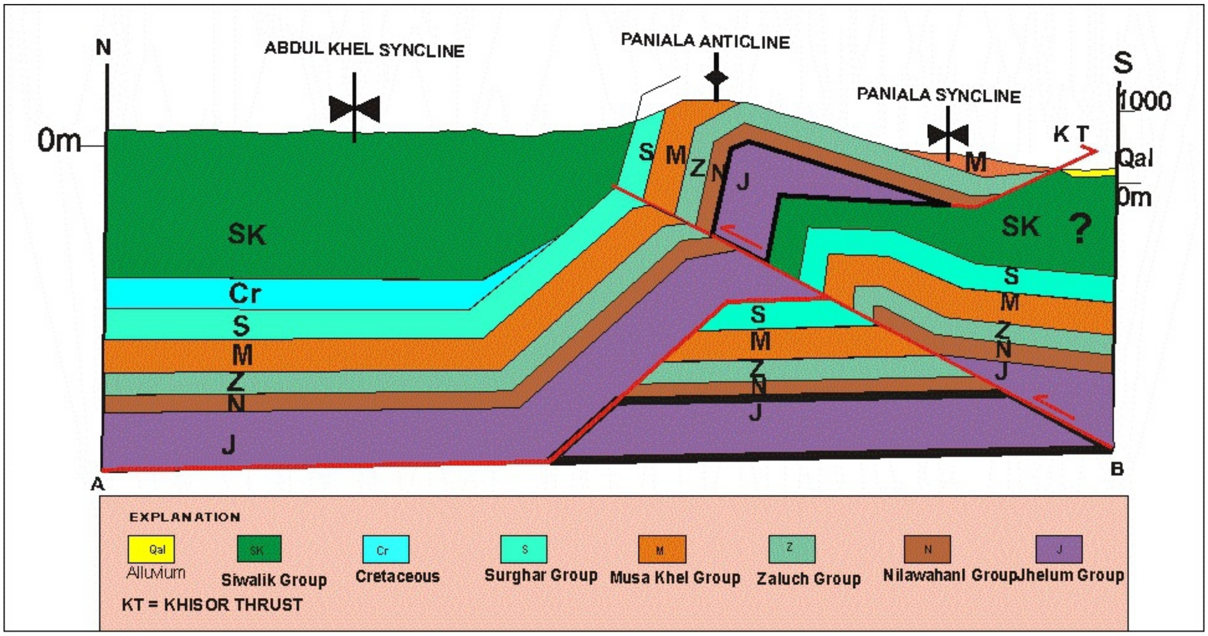

Fig. 5. Structural transect along line AB of Figure 4.

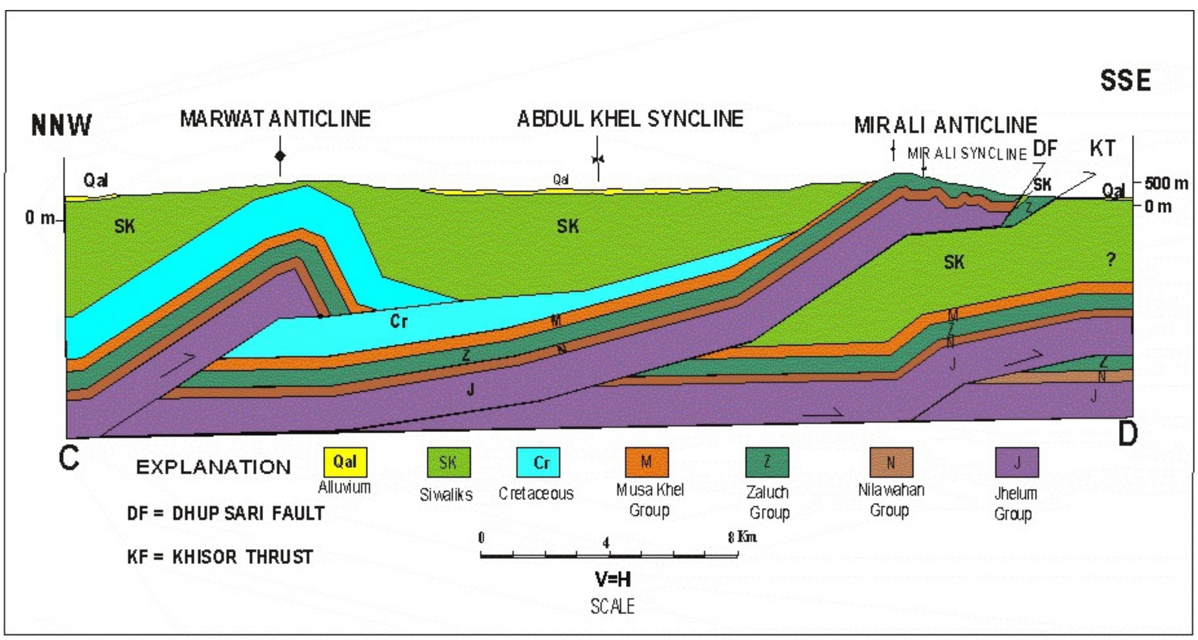

Fig. 6. Structural transect along line CD of Figure 4.

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