Pakistan Journal of Hydrocarbon Research
Vol. 21, (June 2011),p.33-40, 02 Tables, 07 Figs.

Structural Geology and Hydrocarbon Prospects of the Khairi-Murat Area, Potwar Sub-basin, Pakistan.

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ABSTRACT

The Khairi Murat area is the northeastern part of Potwar sub-basin. It is marked by the marine to the transitional sequence of Chharat Group (Margalla Hill Limestone, Chorgali Formation and Kuldana Formation) and the molasse sequence of the Rawalpindi Group and Siwalik Group. These sediments are folded and faulted along with the underlying Eocambrian to Eocene sediments of Indian Plate as a result of Late Tertiary tectonic collision. Structurally, the project area is highly folded, faulted and fractured. The major folds of the area trend NE-SW. The major faults in the area are the Khairi Murat reverse fault and Dhurnal back thrust. At the northern limb of Khairi Murat anticline Murree Formation is exposed, which is deformed by intraformational tight to close folds and faults, while the Kamlial Formation is exposed along the Dhurnal back thrust. A structural cross sections are constructed which depicts that the outcropping structures were evolved as the result of north south oriented stresses with south progression.

INTRODUCTION

The Potwar sub-basin is an active tectonic feature of the Himalayas and is a part of foreland fold-and-thrust belt in northern Pakistan (Figure 1). The structural deformation is due to ongoing collision between the Eurasian and Indian plates. Structurally, Potwar sub-basin is bounded by Main Boundary Thrust (MBT) in the north, left lateral Jhelum fault to the east, the Salt Range Thrust to the south and right lateral Kalabagh fault in the west (McDougall and Khan, 1990; Kazmi and Rana, 1982; Figure 2). The rocks of Potwar sub-basin represent the thin-skinned compressional deformation. The cover sequence is deformed on the basal decollement of Salt Range Formation (Lillie et al., 1987). The northern Potwar deformed zone is separated by the Soan River from southern Potwar platform zone.

The Salt Range Thrust is the major thrust of the Potwar sub-basin and brought the older formations upon the late Cenozoic sequence that underlies the alluvium (Figure 2). The Potwar sub-basin is divided into two parts. Towards the south, the Salt Range thrust is located at the leading edge of an emergent thrust sheet. The style of folding is gentle to open with south dipping thrusts. Towards the north, the thrust sheet is imbricated and folded and named as northern Potwar deformed zone (NPDZ) (Jaswal, 1990). The NPDZ is a belt of Neogene deformation extending southward from MBT to Soan syncline (Figure 3).

Location of the Study Area

The study area lies between the Longitude 72 40 E to 72 45 E and Latitude 33 23 N to 33 30 N. The area covers the part of Survey of Pakistan toposheet no. 43-C/11. Physiographically the area is divisible into dissected terraces, hilly range and flat terrain with an average elevation of about 500 m. In study area hilly range is marked by Khairi Murat Hills, which prominently exposed (Figure 3). Eocene rocks form main ridges and escarpments in this area. Dissected terraces mainly occur in the southern part of the area. Field study and bore hole data show that marine and non-marine sedimentary rocks ranging in age from Eocambrian to Pleistocene occur in the area. Holocene sediments extensively overlie these rocks. Eocene to Recent rock units have been faulted and folded into northeast-southwest trending anticlines and synclines. Tectonically the study area lies in the Northern Potwar Deformed Zone (NPDZ) in which structures become complex, close and tight as compared to southern Potwar (Table 1; Jaswal, 1997)..

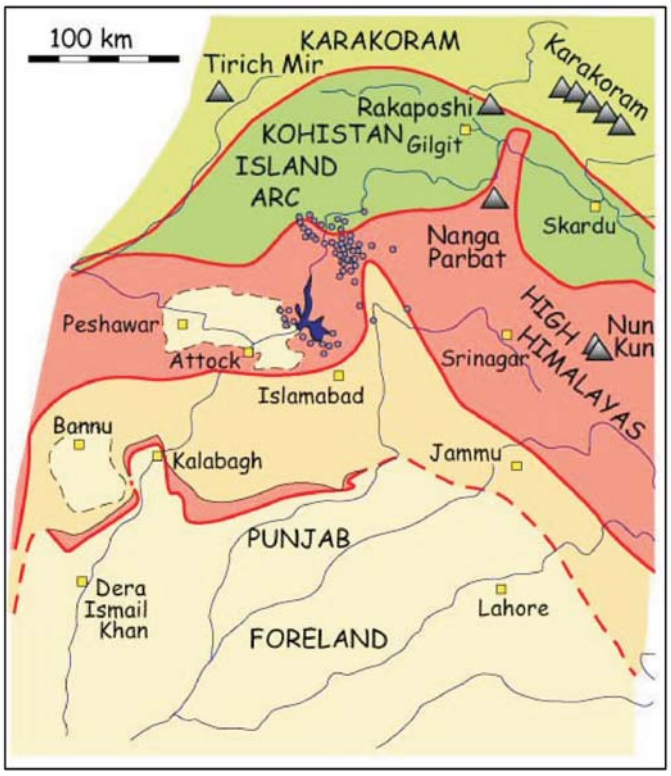

Figure 1 - Simplified tectonic map of the NW Himalayas, showing the main tectonics units (modified Coward from et al, 1987).

Stratigraphyphy

The stratigraphy of the area is well established from outcrops in the Khairi Murat Range and different areas like Ratwal, Tanaza Dam and Dhok Khudadad. The stratigraphy of these formations is discussed with the help of Dhurnal Oil Field bore hole data (Jaswal, 1997), bore hole data of

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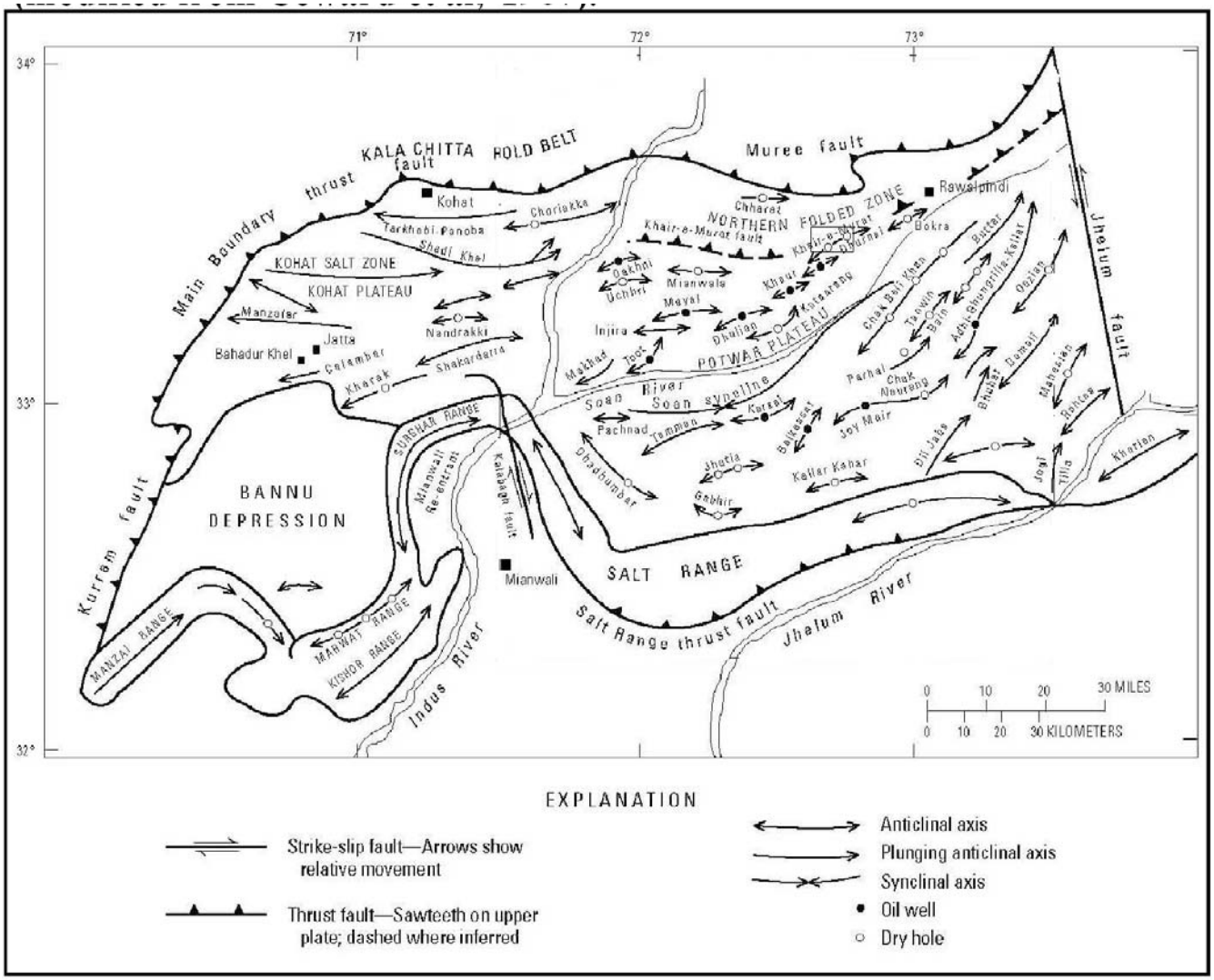

Figure 2 - Structural map of Kohat-Potwar Plateaus, northern Pakistan (after Khan et al, 1986, Gee, 1989). Rectangle shows location of the study area.

Khudadad-01 (after Pakistan Oil Field Limited POL) and field observations (Table 2). The exposed sequences in the study area are differentiated into different lithologic units. The Eocene epoch consists of Margalla Hill Limestone, Chorgali Formation and Kuldana Formation. Carbonates of Margalla Hill Limestone and Chorgali Formation show different types of lithofacies and microfacies. The Margalla Hill Limestone consists of dolomitic, nodular, fossiliferous and fractured packstone to wackestone rock unit. The Chorgali Formation is dominantly consists of limestone and shale (Figure 4). The upper part is mostly shaly while the lower part is sparsely, dolomitized, fossiliferous and also micritic limestone (Shah, 1977). Carbonate deposition was stopped at the end of Early Eocene time due to the increase of orogenic uplift. As a result of this tectonic activity a major unconformity was formed on the top of the early to Middle Eocene carbonate and clastic sediments of Kuldana Formation. Molasse deposits of Rawalpindi and Siwalik Groups represent Miocene to Pleistocene epoch. The Rawalpindi Group comprises Murree and Kamlial Formations. Whereas the Siwalik Group includes the Chinji, Nagri, Dhok Pathan and Soan Formations. The groups as a whole are a body of formations comprising sediments of clastic origin. Holocene sediments include the loessic silt and alluvium (Table 2). This sedimentary sequence contains an exceptionally good record of the geodynamic processes, which were responsible for the extinction, and demise of the Tethys Ocean during Cenozoic Era (Shah, et al 1998).

Structural Analysis of the Study Area

The Khairi Murat area is notheastern part of NPDZ. Structurally the area is highly folded, faulted and fractured. The major F1 folds of the area trend ENE-WSW (Figure 3).

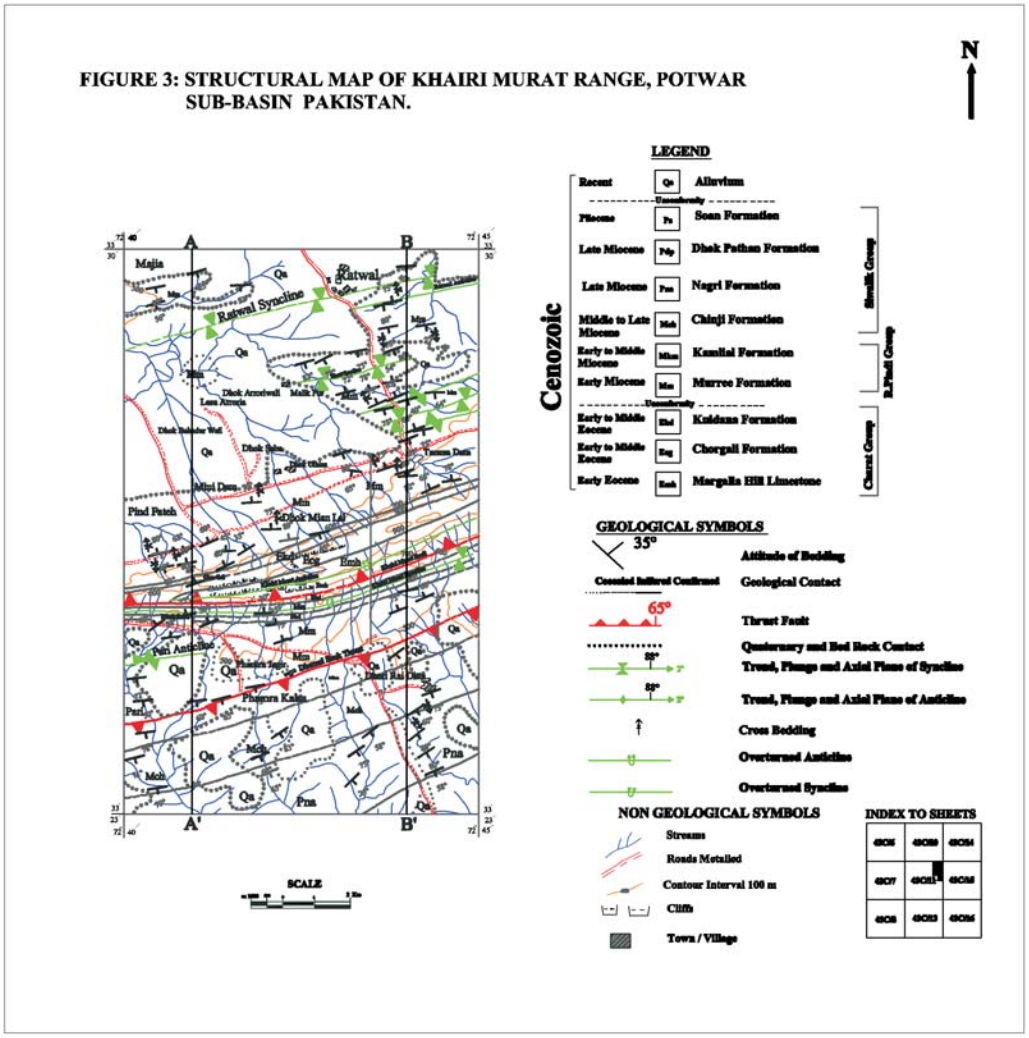

Figure 3 - Structural Map of Khairi MuratRange, Potwar Sub-basin, Pakistan.

Faults

The faulting in the area is mainly southeast directed imbrications and back steepening. The main faults in the area are the Khairi Murat reverse fault and Dhurnal back thrust.

Khairi Murat Fault

The Khairi Murat fault is named after Khairi Murat Range in the northern Potwar. The Kairi Murat fault is a southeast directed reverse fault and lies between the Margalla Hill Limestone and the Kuldana Formation (Figure 3). The dip angle of the fault plane varies from 70°-78°. The surface expression of Khairi Murat fault is prominent due to the thrusting of Early Eocene carbonate (Margalla Hill Limestone) strata over the Kuldana Formation. Along the fault plane shearing and crushing phenomenon is well observed in the field and supported by the presence of fault breccia and gouge along the fault plane.

The Khairi Murat fault has cut the southern limb of Khairi Murat anticline. Toward the north of Khairi Murat Ranges the outcrops of Murree Formation have moderate to steep dips and are deformed into close to tight anticlines and synclines. Farther north, toward Kala Chitta Ranges the northern margin of Potwar sub-basin is marked by MBT along which Eocene carbonates are thrusted southward over the molasse of the Potwar sub-basin (Figure 2).

Dhurnal Back Thrust

The Dhurnal back thrust (DBT) is a passive back thrust at the margin of Potwar foreland sub-basin (Jaswal, 1990). The DBT is a south dipping back thrust. It lies between the Murree Formation and Kamlial Formation. The resistant beds of Kamlial sandstone have tilted upward along the deformation, developing the northern limb of the Soan syncline (Figure 5). The DBT runs almost parallel to the Khairi Murat fault in NE-SW direction. The Kamlial Formation forms the strike ridges

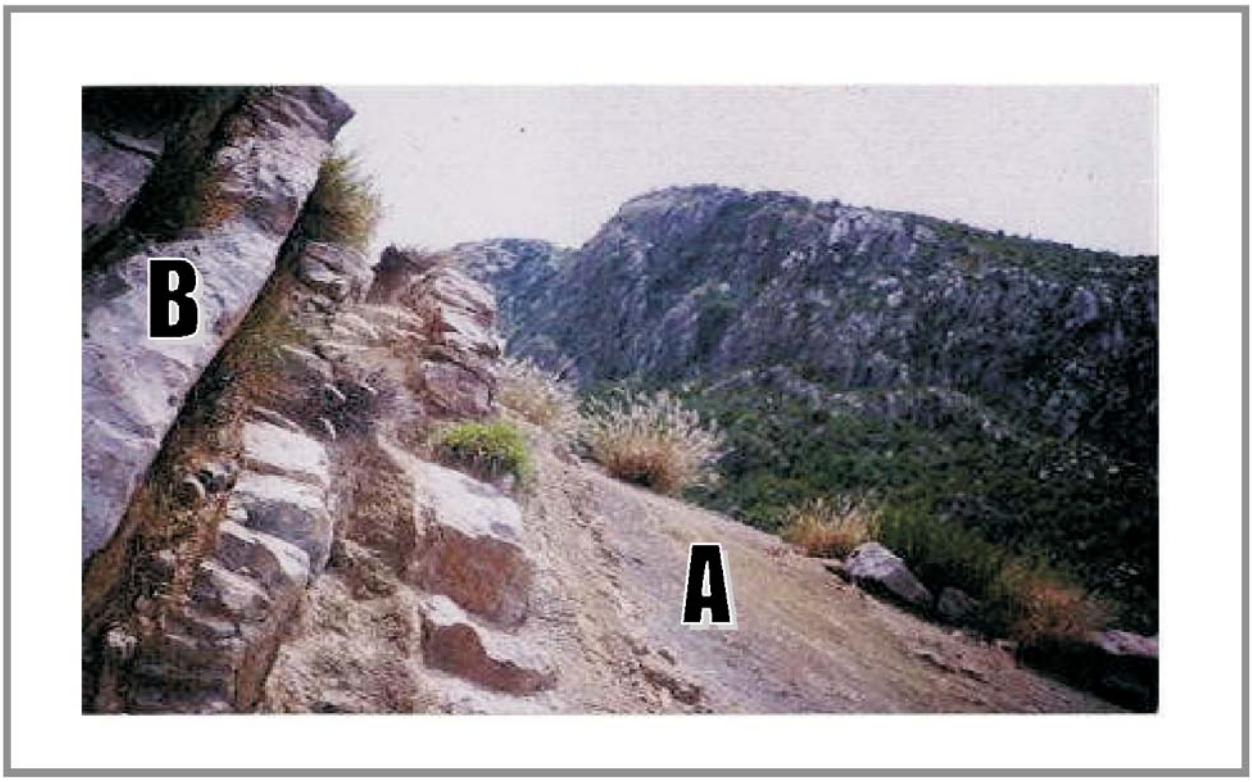

Figure 4 - Chorgali Formation at Chorgali Pass. A). Shale beds, B) Limestone beds along Dhurnal Back thrust near Pari.

Figure 5 - Massive and spheroidal beds of Kamlial Formation exposed along Dhurnal Back thrust near Pari.

Table 1 - Structural Data for F1 Folds of the study area.

Name of Fold	Trend and Plunge	Attitude of Axial Plane	Interlimb Angle	Type of Fold
Khairi Murat Anticline				
(S^8)	25°/76°SW	S76W°/38°NW	6°	Isoclinal
(S^9)	32°/74°SW	S74°W/59°NW	29°	Tight
(S^{10})	20°/65°SW	S65°W/62°NW	26°	Tight
Khairi Murat Syncline				
(S^{11})	1°/84°SW	S84W°/55°NW	40°	Close
(S^{12})	10°/67°SW	N72°E/62°NW	25°	Tight
Soan syncline				
(S^1)	2°/30°NE	N30°E/87°SE	167°	Gentle
(S^2)	3°/52°NE	N52°E/86SE	167°	Gentle
(S^3)	2°/36°NE	N36°E/88°SE	165°	Gentle
(S^4)	2°/34°NE	N34°E/80°SE	172°	Gentle

and the fault runs parallel to the strike of the rock units. The dip of the fault plane varies from 75°SE to 82°SE. The Kamlial Formation and Siwalik Group along the DBT are passively uplifted, tilted and exposed due to the under thrusting of a core wedge. The Khairi Murat fault and DBT form the triangle zone in the north Potwar deformed zone (Siddiqi, 2003).

Folding

In the area synclines and anticlines are present. The main phases of these folds are related with the southward directed thrusting. Folds are parallel, open, and tight and overturned in nature.

Soan Syncline

Soan Syncline is the regional foreland syncline in the central part of Potwar sub-basin. It separates moderately the deformed strata to the south from highly deformed strata to the north. The Soan Synclinorium developed during 2.1-1.9 Ma (Burbank and Raynold, 1986). The Soan Synclinorium is deformed due to the ormation han Feffect of thin-skinned deformation of Salt Range-Potwar thrust sheet above the decollement of Eocambrian evaporates (Kazmi and Jan, 1997). Only the northern limb of Soan Synclineis exposed in the study area. The northern limb of the syncline is relatively steeper than the southern limb dipping southeast. The Chinji Formation, Nagri Formation and Dhok Pathan Formation are exposed along the northern limb of Soan Syncline in the study area. The Soan Syncline is an asymmetrical, northeast plunging and NW vergent gentle fold.

Khairi Murat Anticline

The Khairi Murat anticline is a major F1 fold in the area. It is situated along the Khairi Murat Range. Margalla Hill Limestone is exposed in the core of the anticline while Chorgali, Kuldana and Murree Formations are exposed on the northern limb of the anticline (Figure 6). The southern limb of the anticline is faulted due to the Khairi Murat reverse fault and it run between the Margalla Hill Limestone and Kuldana Formation. The fold axis of the anticline almost runs parallel to the Khairi Murat fault in NE-SW direction. The general trend of both limbs is northeast southwest, dipping in northwest direction showing overturning of anticline. The strike of both limbs varies from N60°E to N85°E. The northern limbs dip from 35o NW to 50° NW. The dips of the southern limb range from 40oNW to 75°NW. The trend and plunge of fold axis varies from 20°/65°SW to 32°/74°SW. The attitude of axial plane ranges from S65°W/62°NW to S76°W/ 38°NW. The interlimb angle of the anticline varies from 6°-29° showing that the fold is isoclinal to tight (Table 1). The structural data shows that the Khairi Murat anticline is a southeast vergent, southwest plunging, over turned anticline (Figure 3).

Khairi Murat Syncline

The Khairi Murat syncline is located between the Pari anticline and Khairi Murat over turned anticline. It extends in east-west direction parallel to the Khairi Murat anticline. Both limbs dipping toward north direction indicating overturning of the syncline. Dip angle varies from 35°NW to 65°NW. The strike of the limbs is between N70°E to N85°E. The trend and plunge of the fold axis varies from 1°/84°SW to 10°/67°SW. The attitude of the axial plane is S84°W/55oNW to S67°W/62°NW. The interlimb angle is 25°-40° (Table 1). On the basis of structural data, the syncline is classified as overturned southeast vergent and close to tight fold (Figure 3).

Intraformational Folds

The northern part of the study area consists of Murree Formation. The rocks have been deformed into several anticlines and synclines (Figure 4). These are the

Table 2 - Generalized stratigraphic sequence of Khairi Murat area based on Dhurnal-3 borehole data (Jaswal et al., 1997), Khudadad-1 borehole data (after POL) and field observations.

AGE			Group	FORMATION	Thickness (Meters)	Description	Environment of Deposition
ERA	PERIOD	EPOCH					
CENOZOIC	Quaternary	Recent		Alluvium		Surficial deposits of sand, silt and clay.	
			..... Unconformity.....				
		Early Pleistocene	Siwalik Group	Soan Formation	500	Conglomerates with sandstone and clay.	Fluvial
	TERTIARY	Middle Pliocene		Dhok Pathan Formation	600	Cyclic deposits of clay and sandstone with igneous and volcanic clasts.	
		Early Pliocene		Nagri Formation	1505	Sandstone with clay, siltstone and conglomerates.	
				Chinji Formation	1030	Clays of reddish brown to brick red.	
		Middle to Late Miocene	Rawalpindi Group	Kamlial Formation	510	Sand stone of grey and greenish grey. Clays of brownish and purple red.	Fluvial
		Early Miocene		Murree Formation	2211	Sandstone of reddish, maroonish and bright red clays.	Fluvial
		Oligocene	..... Unconformity.....				
		Middle Eocene	Chharat Group	Kuldana Formation	70	Shale and marl with sandstone and limestone.	Transitional
		Early Eocene		Chorgali Formation	77	Dolomitic, cherty limestone with subordinate shale.	Supratidal to intertidal
				Margalla Hill Limestone	87	Nodular limestone with subordinate shale.	Shallow marine
		Late Paleocene	Makarwal Group	Patala Formation	168	Dark khaki shale with subordinate grey limestone.	Shallow marine to lagoonal
				Lockhart Limestone	11	Limestone, grey to light grey in color.	Shallow marine
		Early Paleocene		Hangu Formation	13	Sandstone with grey shale.	Marine to continental
Mesozoic			..... Unconformity.....				
PALEOZOIC	Permian	Late	Zaluch Group	Wargal Formation	100	Limestone, sandstone, siltstone and dolomite.	Shallow Marine
				Amb Formation	83	Limestone and dolomite with subordinate sandstone.	Shallow Marine
		Early	Nilawahan Group	Sardhai Formation	116	Bluish grey clay, sandstone, siltstone and shale.	Lacustrine to Shallow Marine
				Warcha Sandstone	110	Coarse-grained sandstone, conglomerate and shale.	Fluvial to Lagoonal
				Dandot Formation	33	Light grey to olive grey and yellowish sandstone.	Shallow Marine
				Tobra Formation	183	Quartzose sandstone with siltstone and shale.	Glacial to Fluvial
	Carboniferous		..... Unconformity.....				
	Devonian						
	Silurian						
	Ordovician						
	Cambrian	Eocamb-rian		Salt Range Formation	1000	Salt, gypsum, marl, clay, dolomite and khewrite.	Restricted marine. (Hyper saline)

intraformational F1 folds. The fold axis runs in east-northeast to west-southwest direction almost parallel to the Khairi Murat fault.

Structural Cross Sections

To interpret the sub-surface structure, structural cross sections along A-A/ and B-B/ has been prepared (Figures 7-a and b). For the construction of cross-sections the stratigraphy, bedding attitude, fold axis and faults are projected on the profile lines (Figure 7). Along these profile lines the following structures have been interpreted.

Khairi Murat Fault

The Khairi Murat fault is the major reverse fault in the study area along which the Margalla Hill Limestone has been thrusted over the Kuldana Formation. The Khairi Murat fault has steep dips at the surface.

Dhurnal back thrust

The Dhurnal back thrust is a south dipping thrust marked between the Murree Formation and the Kamlial Formation.

Soan syncline

Soan syncline is northwest vergent asymmetrical syncline. The northern part of Soan syncline is steeper than the southern limb. The axial plane dips in southeast direction. The development of northern limb of the Soan syncline is related to the Dhurnal back thrust and the southern limb to the Riwat thrust.

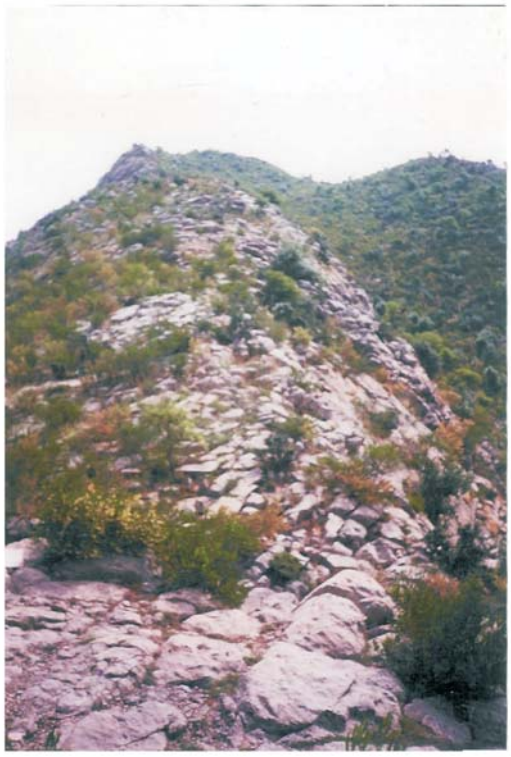

Figure 6 - Fractured and folded Margalla Hill Limestone in the core of Khairi Murat anticline.

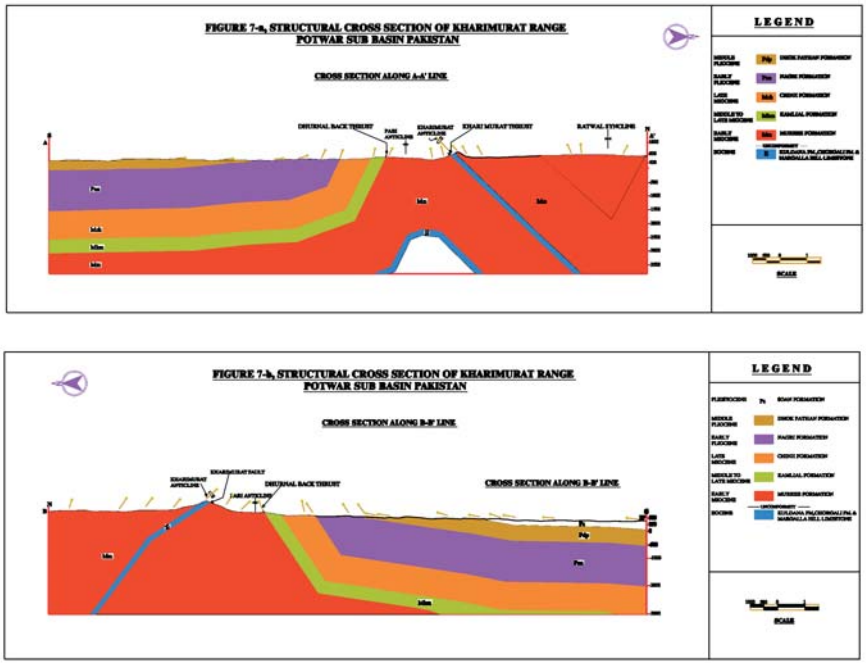

Figure 7 - Structural Cross Section of Khairimurat Range of Potwar Sub-basin, Pakistan.

Conclusion

The Khairi Murat area represents the thn skinned compressional structures. The structurl styles of the area is very complex due to the proximity to the collision zone. The structural style of the northern part of the study area (Khairi Murat Range) differs from the southern part. In the northern part the Eocene carbonates and Miocene Murree and Kamlial Formations are folded, faulted and imbricated. In this area the folds are close to tight, overturned and faulted. Whereas the southern part is less deformed and the structures are asymmetric, northeast plunging, open to gentle folds. Soan syncline is the major fold of the southern part. The Khairi Murat reverse fault and Dhurnal back thrust are two regional faults of the area. The Khairi Murat fault is marked between the Margalla Hill Limestone and Kuldana Formation while Dhurnal back thrust is located between Murree and Kamlial Formations.

The axial plane of Khairi Murat anticline, Khairi Murat syncline and the fault plane of the Khairi Murat fault dip northwest, which indicate that these structures developed due to same deformational event.

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Received June 25, 2012 revised Nov. 12, 2012 and accepted Dec. 25, 2012.