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Bhittani Range, North Pakistan: The Tectonic Evolution and Hydrocarbon Prospectivity - a Geological and Geophysical Approach.

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ABSTRACT

The main topographic expression of the Bhittani Range is credited to the Pezu anticline which is compartmentalized by Pezu Fault into three distinct domains that are northwestern, central and southeastern. The limbs of all the three domains of the Pezu Anticline expose rocks belonging to the Siwaliks of Nagri, Dhok Pathan and Malagan Formations, whereas the Chinji Formation hosts its core. In the northwestern domain of the Pezu anticline, the Pezu Fault occupies the fore limb of the anticline which is asymmetric to the southwest with a prominent plunge to the southeast in the vicinity of Bain Darra. In contrast the Pezu Fault switches to back limb thrust in the central domain of the Pezu anticline which is a three way fold closure bounded by Pezu Fault in the northeast. In the southeastern domain, the Pezu Fault again becomes fore limb bounding fault of the Pezu anticline. The structural genesis of the Bhittani Range is mainly related to the Pezu Fault which has served as a lateral ramp for the southeast propagation of the coherent thrust slab underneath Bannu Basin, characterized by dextral wrenching concomitant with northeast-southwest directed contraction. The structural genesis of the Bhittani Range is well constrained by the available seismic data across the central domain of the Pezu anticline. The proposed geo-seismic model depicts that the Pezu Fault is steeply northeast dipping, southwest verging thrust fault whereas the Pezu anticline is developed on the hanging wall of a blind, southwest facing thrust fault within the Triassic and underlying older rocks which tips underneath its fore limb in the subsurface. Current investigations have revealed that the northwestern and southeastern compartments of the Pezu anticline are more prospective for the oil and gas accumulation as compared to its central compartment.

INTRODUCTION

The Bhittani Range constitutes the western most, along strike continuation of the Trans Indus ranges in the northwest Himalayas. This range follows northwest-southeast structural trend flanking the southwestern margin of the Bannu Basin (Figure 1). Tank Basin (TB) lies to its south, Marwat-Khisor ranges (MR-KR) in the south-southeast whereas the Manzai Range is marking the western boundary of the Bhittani Range (BR).

The Bhittani Range contains northwest-southeast striking topographic high, separating the Tank depression in the south from the Bannu Basin in the northeast. The Pezu and Sheikh Budin anticlines are the major structural elements of this range. The Pezu Anticline is disrupted along its axial trace by a thrust fault, with right-lateral transpressional deformation (Figure 2).

Siwalik sediments are exposed all along the map trace of Pezu Anticline whereas older rocks ranging in age from Permian to Pleistocene are exposed in the Sheikh Budin Hills (SBH), located to its immediate southeast (Figure 2). The surface geology clearly indicates that this area has undergone complex deformation, consisting of fold-thrust assemblages where the structural style is characterized by decollement related thrusting associated with concurrent fault bend/propagation folding within the hanging wall and is high impedance system (Demaison and Huizinga, 1991) related to convergent plate tectonic habitat.

A working petroleum system exists in the area. The maturity of the source rocks in terms of hydrocarbon generation is established by burning gas seepage, found along the Pezu Fault in the central part of the Bhittani Range, near Bain village (Ansari and Siddiqui, 2002). An exploratory well, Pezu-1 was drilled by PPL in 1968-69 in the central valley without any seismic acquisition which penetrated over 600 meters of Siwalik sediments before entering Eocene-Paleocene, Cretaceous and Jurassic sediments in succession. This well was abandoned as a dry hole at 2222 meters depth in the sandstone of Jurassic Datta Formation after drill stem testing of both Cretaceous and Jurassic reservoir rocks. Although water-bearing, Datta sandstone was found to be of reservoir quality.

This paper is an attempt to address the structural geometry of the Bhittani Range as well as its hydrocarbon prospectivity.

PHYSIOGRAPHY AND LOCATION

The Bhittani Range stretches from Pezu town in the southeast whereas in the northwest it merges with the north-south trending Sulaiman Range (Figure 2). The Bhittani Range is having low to moderate relief ranging from 250-300 meters from valley floor in the north and south up to the crestal part of the Pezu Anticline in the vicinity of the Pezu Fault. The Sheikh Budin Hills exhibit comparatively moderate relief, where Jurassic limestone of Samana Suk Formation forming peaks with a maximum altitude of about 1225 meters above the mean sea level. This area is accessible from Peshawar though Indus Highway. A network of tracks and stream cuts exists in the area allowing to study geology in detail.

REGIONAL SETTING

The Pakistani basins have developed their primary structural and stratigraphic features from events associated with plate movements that occurred between latest Cretaceous to the present. Sediments are documented for the Eo-Cambrian onwards. The geodynamic processes resulted in the formation of a pronounced global feature that is the Himalayas surrounding the Indo-Pakistani subcontinent (Figure 1).

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Due to the continent continent collision the geology of the area is dominated by thrust tectonics (Figure 2). A series of peculiar curved mountain ranges, known under various names (arcs, oroclines, syntaxis, and re-entrants) dominate the topography of the northwestern Pakistan. The Trans-Indus ranges comprise four of these curvatures. They are the extreme southern toe of the frontal tectonic unit of the Himalayan thrust belt. The Kohat and Potwar Plateau are interpreted as a thrust sheet for which the Pre-Cambrian Salt Range Formation might provide a surface of decollement.

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 domains (Figure 1), which are characterized by distinctive stratigraphy and physiography. From north to south these geological belts are Karakoram Block, Kohistan Island Arc, Northern Deformed Fold-Thrust Belt, Southern Deformed Fold-Thrust Belt and Punjab Fore deep (Ahmad, et. al.,2005).

The Northern Deformed Fold-Thrust Belt comprises deformed sedimentary, metasedimentary and igneous rocks. This belt stretches from Kurram area in the west near Afghan border up to the Kashmir basin in the east. The Northern Deformed Fold-Thrust Belt is bounded by Main Boundary Thrust separating it from the southern deformed fold and thrust belt (Figures 1 and 2).

The Southern Deformed Fold-Thrust Belt is oriented east-west and switches to north-south along the western border of Pakistan. It is underlain by thick fluvial molasse sediments above early Tertiary and Mesozoic shallow marine sediments. These overly Eo-Cambrian through Paleozoic sediments. The Kohat Plateau is the western most part of the southern deformed fold and thrust belt (Figure 2). The area had been influenced by the southward progression of deformation during late Miocene. The study area is part of the Bannu-Tank basin in the Southern Deformed Fold-Thrust Belt.

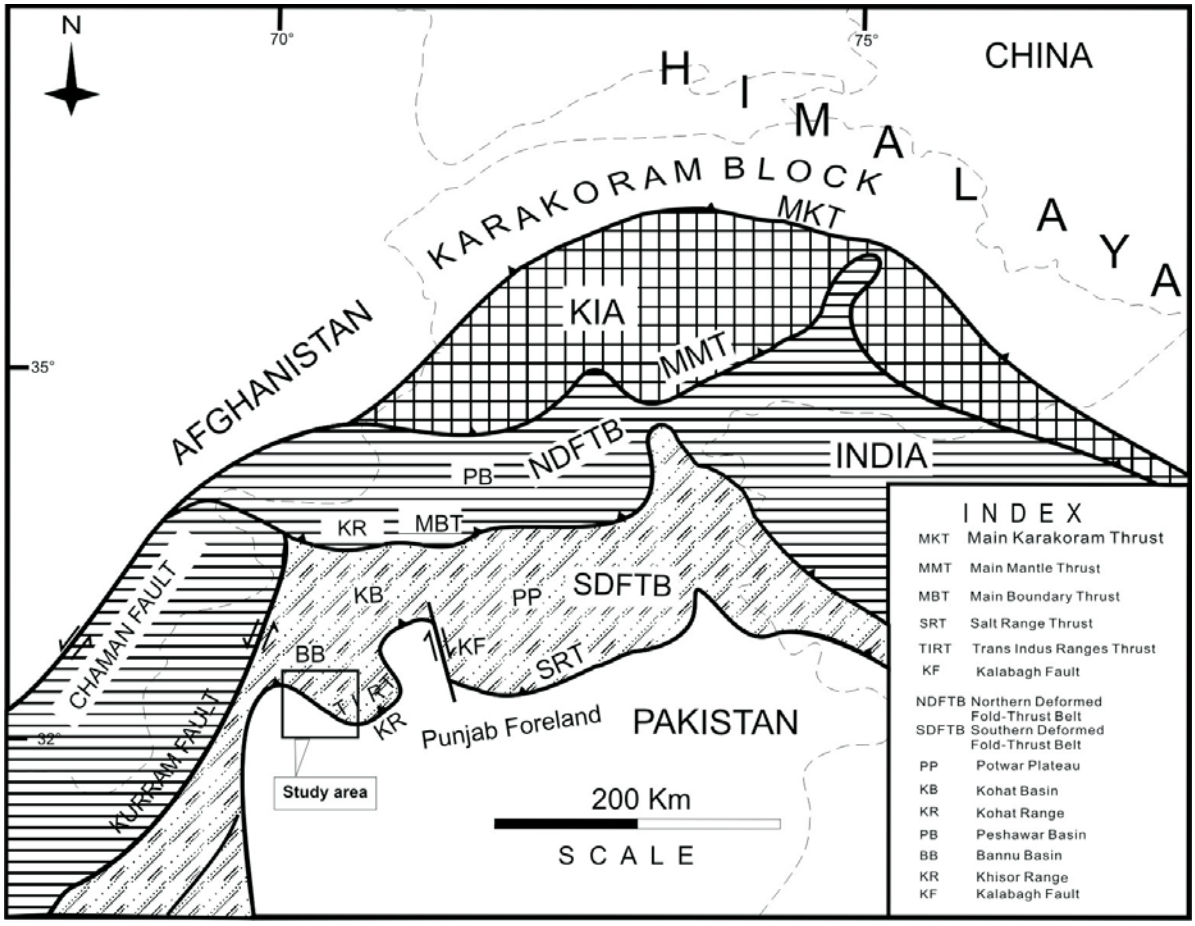

Figure 1 - Tectonic Map of North Pakistan, showing major structural features (Kazmi and Rana,(1982). Inset shows the location of study area.

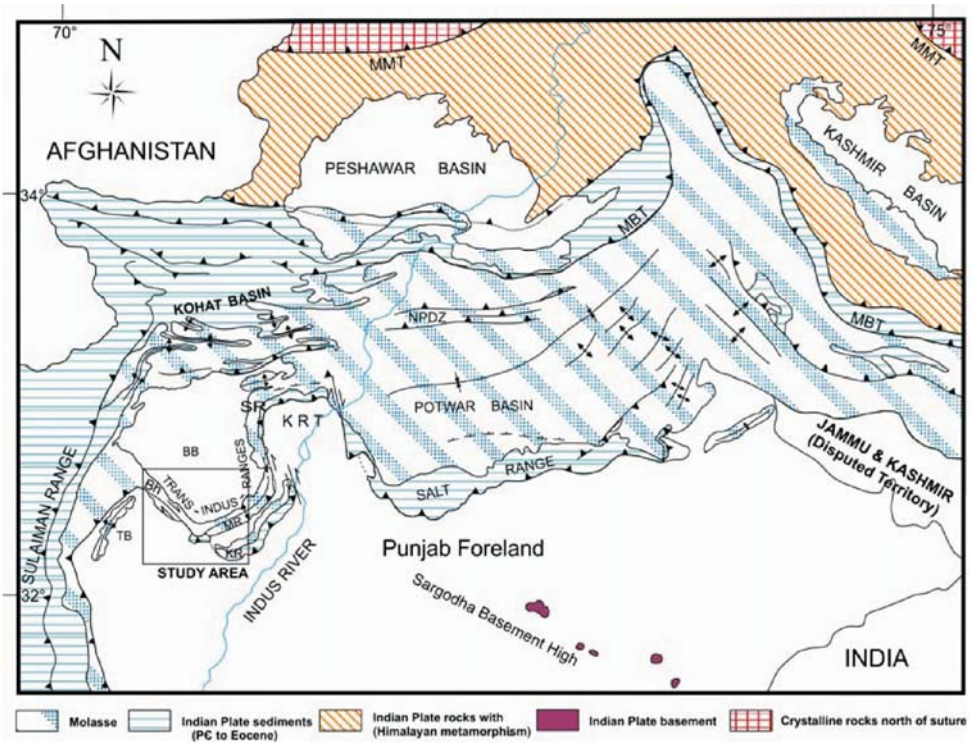

Figure 2 - Generalized geologic map of the NW Himalayan foreland fold and thrust (Kazmi and Rana,(1982). Inset shows the location of study area. MMT: Main Mantle Thrust,MBT: Main Boundarry Thust, NPDZ: Northern Potwar Deformed Zone, KR: Khisor Range, SBH: Sheikh Budin Hills, BB; Bannu Basin, KRT: Kalabagh Reentrant, MR: Marwat Range, BH: Bhittani Range, TB: Tank Basin.

STRATIGRAPHIC SETUP

The Bhittani Range is located near the juncture of the Bannu Basin with northern Sulaiman Range (Figure 2) where rocks ranging in age from Jurassic to Quaternary are exposed. The time equivalent strata belonging to Siwaliks and Pre-Siwalik older rocks in the two ranges bear different nomenclature. Rocks of Paleocene and Eocene age are particularly well developed in the area. A generalized stratigraphic column of the area is given in Figure 3.

The north-south stratigraphic correlation of the Siwalik Group rocks based on outcrop data and stratigraphy encountered at Ramak-1 well in the northeastern part of the Sulaiman Range shows thickness variations of different Siwalik units (Figure 4). Generally thickness of the Siwalik Group increases towards the south taking into consideration the total thickness of the Siwalik strata at Litra Nala (about 3600 meters) in the south and Sheikh Budin Hills (around 2000 meters) towards the north. The upper and lower parts of the Siwalik Group in the area are represented by Malagan Formation and Chitarwata Formation respectively. Both these formations show localized deposition in this part of the Sulaiman Range. The Malagan Formation is only developed in the surrounding of Bain Pass in the Bhittani Range. The Chitarwata Formation shows its development in the Chaudhwan Zam and Ramak-1 well location only and pinches out towards north and south in the Gomal Pass and Litra Nala respectively.

The regional east west stratigraphic well correlation (Figures 5a and b) based on the exploratory wells (Isa Khel-1,Chonai-1,Marwat-1 and Pezu-1) drilled in the Trans-Indus Ranges and Kundian-1 well drilled in the Mianwali re-entrant depicts that Siwalik rocks show their maximum thickness in the Bannu Basin and adjoining area as demonstrated by Isa Khel-1 and Chonai-1 wells and show tapering effects both to the east and west as shown by Kundian-1 and Pezu-1 wells. The Eocene and Paleocene strata was encountered in Pezu-1 (155 M thick) and Chonai-1 (106 M thick) only. It was not encountered in Marwat-1 well. Since the Marwat structure is highly uplifted and possible erosion of Eocene, Paleocene and Cretaceous strata before the deposition of the Siwalik rocks could be one of the reasons for their absence. Further to the east, Eocene and Paleocene strata have not been encountered in Isa Khel-1 and Kundian-1 wells. Thick Cretaceous strata encountered at Pezu-1 well in the west is showing decrease in thickness towards the east. At Chonai-1, thickness of Cretaceous rocks is considerably decreased. Further to the east from Chonai-1, these rocks are not encountered at Marwat-1 well (due to high uplift/erosion of the Marwat Range as mentioned earlier), Isa Khel-1 and Kundian-1 wells. The Jurassic rocks also follow this general eastward truncation trend as shown by their drilling thickness data in the above-mentioned wells. These rocks have shown maximum thickness at Pezu-1 well in the west and then toward the east, Jurassic rocks have shown decrease in their thickness. Subsequently, this thickness has been maintained

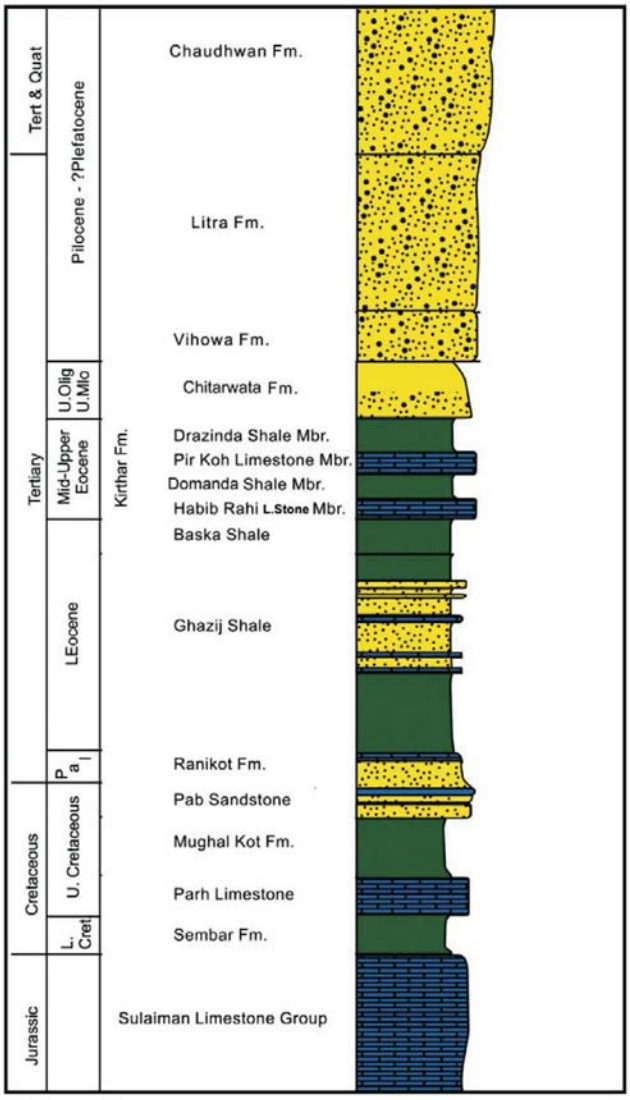

Figure 3 - Generalized Stratigraphy of the Study Area.

between Chonai-1, Marwat-1 and Isa Khel-1 wells. However, further to the east, Jurassic rocks have not been encountered at Kundian-1 well. The Triassic rocks also pinch-out towards the east. Their maximum thickness was encountered at Chonai-1 well and then their thickness has decreased eastward between Marwat-1 and Isa Khel-1 wells as evident from the well correlation (Figure 5a and 5b). Further to the east at Kundian-1 well, Triassic rocks have not been encountered. The Permian strata have also demonstrated eastward pinch-out trend which is clear from their drilled thicknesses at Marwat-1, Isa Khel-1 and Kundian-1 wells. The Cambrian strata are not an exception to this general eastward truncation or decrease in stratigraphic thicknesses. This is evident from their thickness encountered at Isa Khel-1 and Kundian-1 wells.

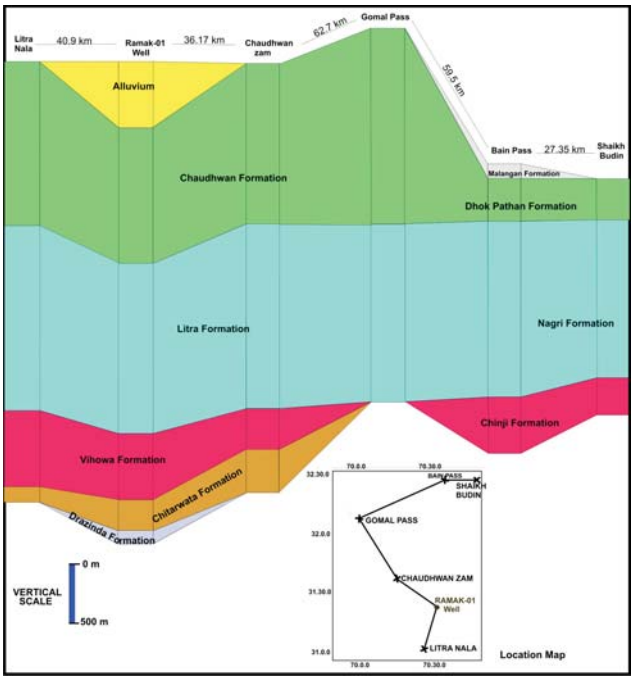

Figure 4 - Correlation of Siwalik Group rocks in the area, modified after Hemphill and Kidwai (1973).

STRUCTURAL GEOMETRY

A detailed geological map of the Bhittani Range and surrounding area has been prepared (Figure 6), showing the trend of the major structures to be oriented northwest-southeast that switches to almost east-west in the Sheikh Budin Hills to the east and southeast of Pezu town. The description of the main structures is given below:

FOLDS AND FAULTS

Folds seem to be the dominant structural grain of the Bhittani Range. These folds are trending northwest to southeast over most parts of the Bhittani Range with a slight swing in the Sheikh Budin Hills (Figure 6). These fold structures are mostly south to southwest facing, indicating the southward progression of tectonic deformation.

Pezu Anticline

The main topographic expression of the Bhittani Range is credited to Pezu Anticline which is compartmentalized by Pezu Fault into three distinct domains that are northwestern, central and southeastern domains (Figure 6). It is bounded to the northeast by Bannu Basin and to the southwest by Tank Basin. The limbs of all the three domains of the Pezu Anticline expose rocks belonging to the Siwaliks of Nagri, Dhok Pathan and Malagan formations whereas the Chinji Formation of Siwalik Group host the core of the anticline (Figure 7). The back limb of the northwestern domain of the Pezu Anticline is

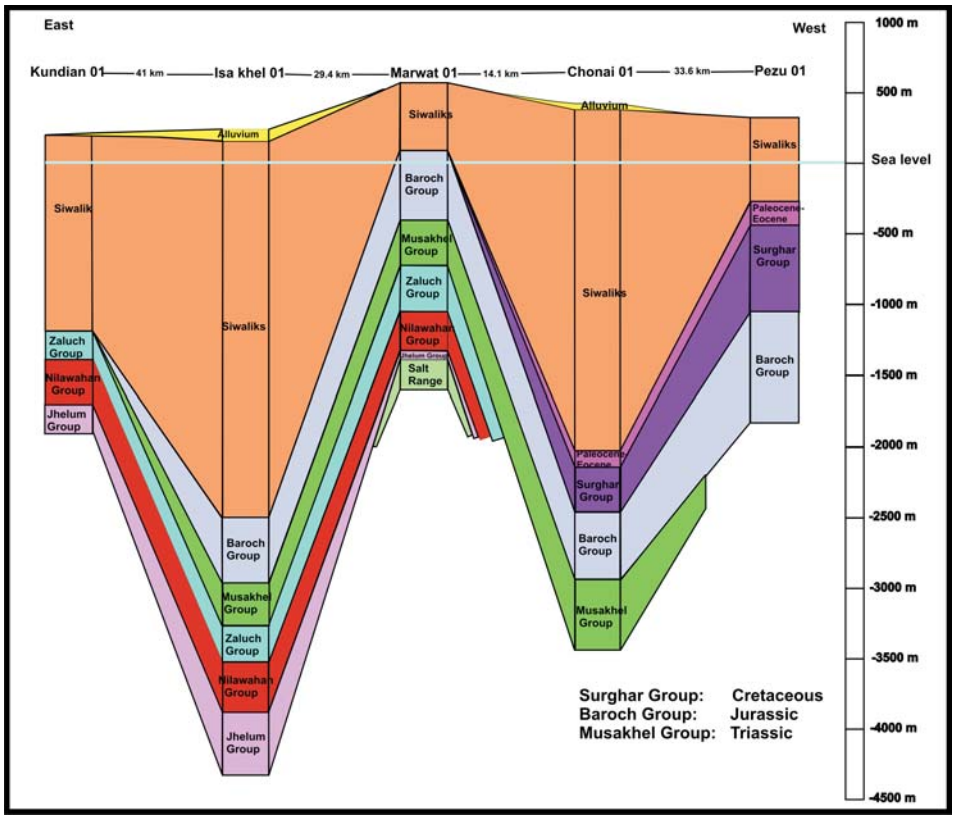

Figure - 5(a) Regional East West Stratigraphic well correlation.

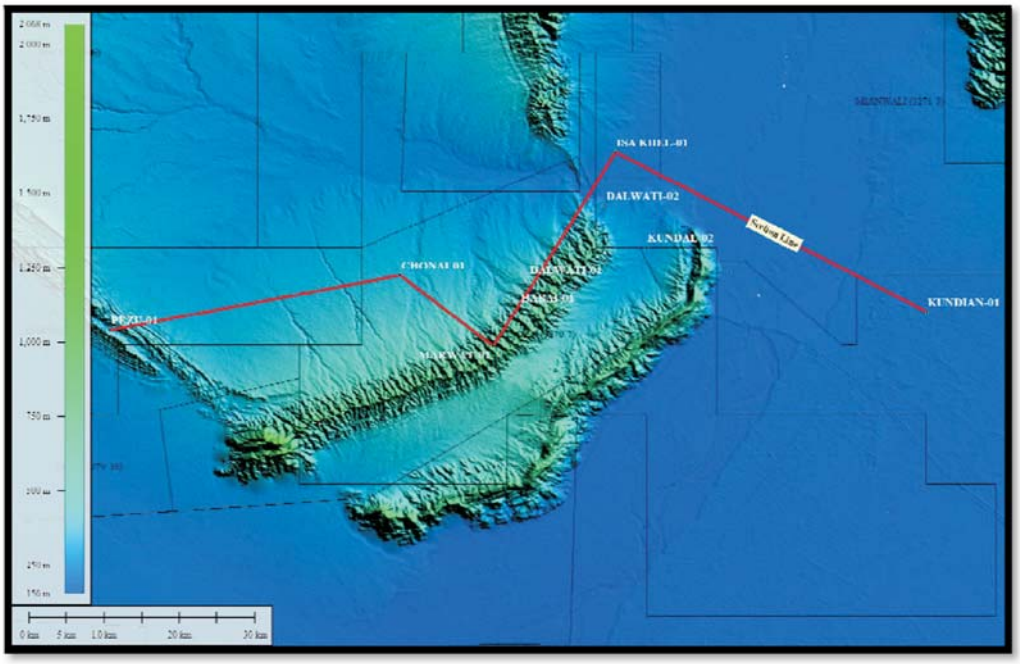

Figure - 5(b) Location map of Regional East West Stratigraphic well correlation.

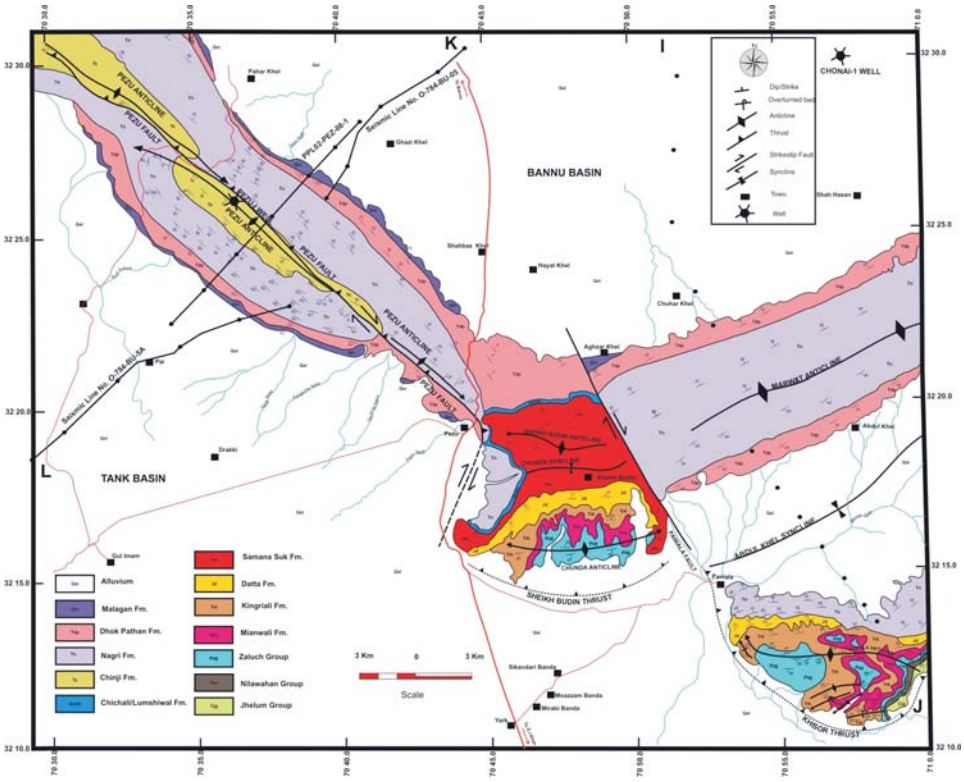

Figure 6 - Geological Map of the Bhittani Range and surrounding area.

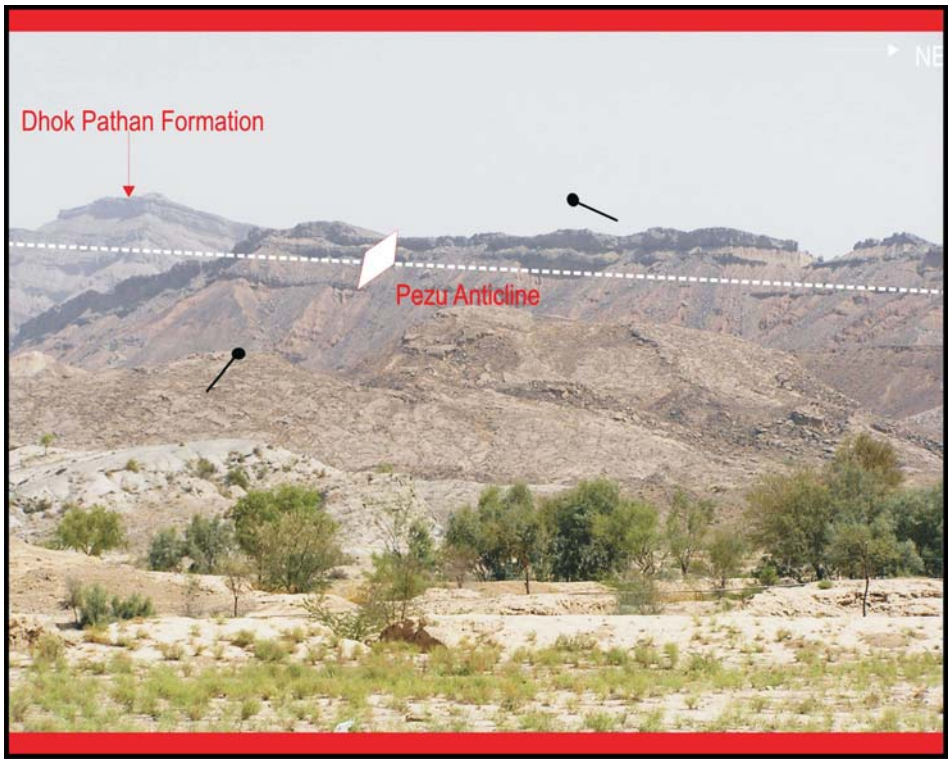

Figure 7 - North looking view of the Pezu Anticline showing back limb dipping towards NE and forelimb towards SW and the sandstone of Dhok Pathan Formation making high ridges.

dipping towards the Bannu Basin in the northeast at moderate angles (28°~46°) whereas its fore limb dips towards the Tank Basin in the southwest with moderate angle (29°~50°) (Figure 8) and is marked by Pezu Fault. The Pezu Anticline in the northwestern domain has a prominent plunge to the southeast in the vicinity of Bain Darra (Figure 6).

The back limb in the central domain of the Pezu Anticline is occupied by Pezu Fault and having dips in the range of 25°~65° whereas the fore limb exhibits low to moderate dips in the range of 13°~60°. The central domain of the Pezu Anticline has a prominent plunge to the northwest near the FC post to the north of Ama Khel village (Figure 6). In the southeastern domain, the back limb of the Pezu Anticline is having dips in the range of 15°~27° whereas the fore limb display dips in the range of around 40° and dissected by Pezu Fault. The southeastern domain of the Pezu Anticline is having a prominent plunge to the southeast (Figure 9). The Pezu Anticline in the Bhittani Range is considered as south verging, slightly asymmetrical anticline.

Pezu Fault

This is the major fault of the Bhittani Range, passing through the crestal part of the Pezu Anticline all along its axial trace resulting in different compartments of the Pezu anticline (Figure 6). It is oriented in northwest to southeast direction and juxtaposes rocks of Chinji Formation in the hanging wall against the rocks of Nagri Formation in the footwall in the northwestern domain of the Pezu Anticline. In the central domain of the Pezu Anticline, Pezu Fault juxtaposes rocks of Chinji Formation in the hanging against the same rocks in the footwall. In the southeastern domain of the Pezu Anticline, Pezu Fault brings rocks of Nagri Formation in the hanging wall against the rocks of Dhok Pathan Formation in the footwall. Its hanging wall is dipping towards the Bannu Basin in the northeast at moderate to steep angle (45°~68°) whereas its footwall is dipping towards the Tank Basin in the southwest with moderate angle (28°~56°). Its map extension along the trend is more than 33 km. Based on its map relationship with the Pezu Anticline, it is believed to be of transpressional nature with dextral movement.

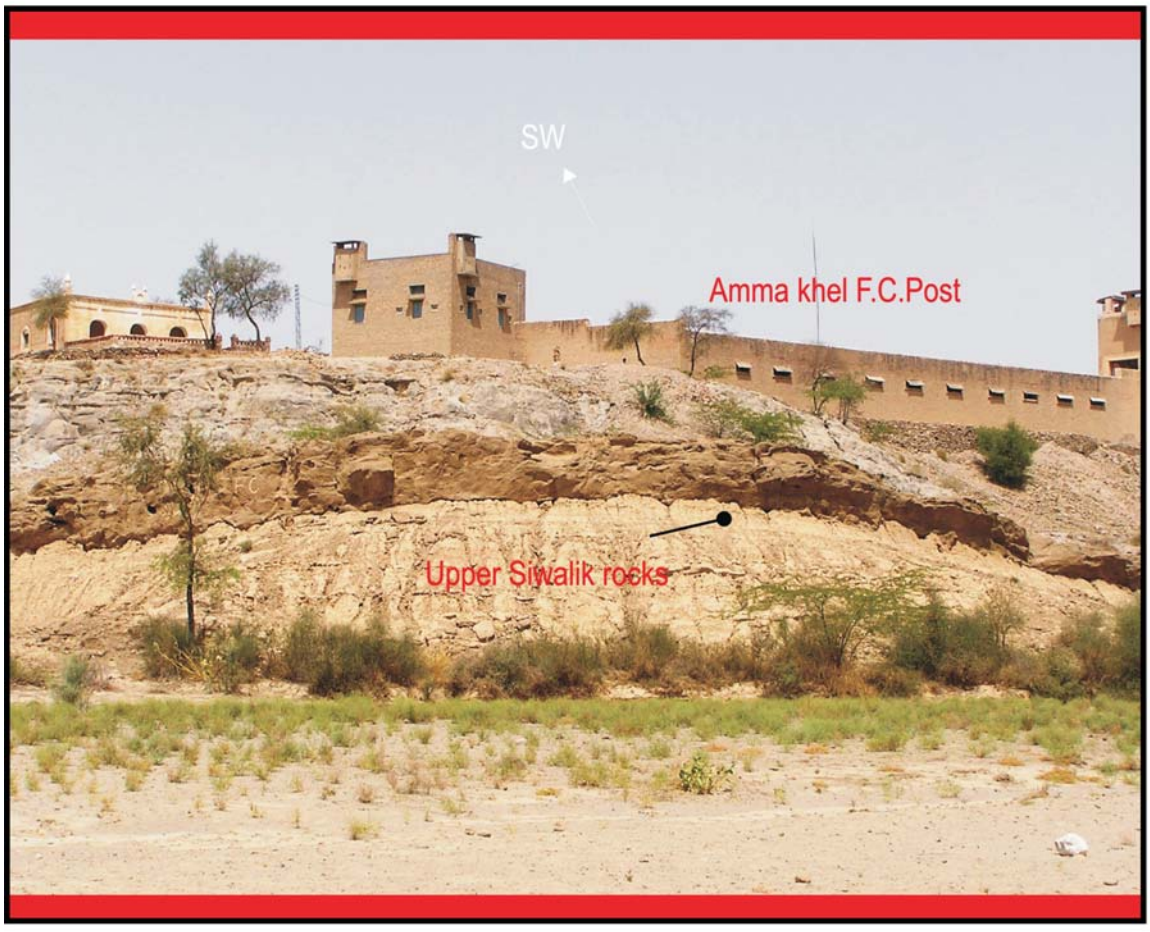

Figure 8 - Southwest looking view of the fore limb of Pezu Anticline with upper Siwalik rocks dipping towards SW in the vicinity of Amma Khel F.C.Post in the Bhittani Range.

Figure 9 - Panoramic view of the backlimb of the Pezu Anticline dipping towards NE, showing Upper Siwalik rocks in the flank and lower Siwalik rocks of Chinji Formation in the core. This mosaic has been prepared with photographs taken north of Pezu in the Bhittani Range.

STRUCTURAL MODEL

Geo-Seismic cross section along line K-L of geological map (Figure 6) has been constructed to illustrate the structural style, kinematics as well as structural geometry of the Bhittani Range utilizing the following database;

a) Surface geological map
b) Three 2D seismic lines with a total length of about 41.5 line km
c) Well data of Pezu-1

The two seismic dip lines O-784-BU-5 and O-784-BU-5A (Figures 10 and 11) were acquired by OGDC in 1978 covering the southwestern and northeastern parts of Bannu Basin and Tank Depression respectively. These lines partially cover flank area of the Bhittani Range as 62 fold data using vibroseis as a source. This data display good quality in shallow as well as in the deeper horizons. Line PPL02-PEZ-8-1 (Figure 12) was acquired as dip line crossing the Bhittani Range in 2002 by Pakistan Petroleum Ltd. (PPL) as 80 fold data, using dynamite as a source. Wideline seismic technique (Ansari and Siddiqui 2002) was applied for the acquisition of this line in order to obtain better quality image in the crestal part of the Bhittani Range, which was not imaged properly by previous surveys due to the scattering effects of the faults associated with steep dips. This line is passing at a distance of about 2 km to the southeast of Pezu-1 well (Figure 6) drilled in the Bhittani Range. The geo-seismic cross-section constructed along line K-L incorporates sub-surface data of the above-mentioned seismic lines and Pezu-1 well. Then the surface geological section has been integrated with the interpreted seismic and well data in order to work out consolidated structural model (Figure 13) for the Bhittani Range.

The structural model along line K-L is oriented from northeast to southwest in the central part of the Bhittani Range. It is roughly parallel to the northeast-southwest oriented tectonic transport direction as inferred from the trends of different structures exposed in the range and almost co-axial with all the three seismic lines used in its construction. The northeastern portion of the section located in the Bannu Basin is characterized by almost flat stratigraphic geometry in the sectional view, validated by seismic line O-784-BU-5 (Figure 10). This line is around 12 km long, covering the northeastern part of the model. A couple of small normal faults have been identified on this seismic line in the southwestern margin of the Bannu Basin where it merges with the Bhittani Range. These faults have resulted in offsetting the Triassic to lower Siwalik Group strata with normal sense of displacement, resulting in a shallow graben.

Further to the southwest, the Bhittani Range is completely covered by seismic line PPL02-PEZ-8-1 (Figure 12), which is about 15 km long. This part of the model is depicting the Pezu Fault to be steeply northeast dipping, southwest verging fault, originating from the basal decollement. It brings the rocks of Chinji Formation in its hanging wall against the same rocks in the footwall to the southwest with less vertical uplift. This fault is cross-cutting through the stratigraphy on the backlimb of the Pezu Anticline. The backlimb of the anticline is dipping towards the Bannu Basin in the northeast at moderate to steep angle (45^{0}~68^{0}) whereas its forelimb dips towards the Tank Basin in the southwest with moderate dip angles (28^{0}~56^{0}) near the surface and steeper dips in the sub-surface, giving it slight asymmetry in sectional view. The Pezu Anticline is a south verging anticline showing moderate uplift as compared to the surrounding low lands. A blind, south facing thrust fault within the Triassic and underlying older rocks tips underneath the fore limb of the Pezu Anticline. At the extreme southwest, lies the Tank Basin, where the forelimb of the Pezu Anticline is dipping to the southwest getting gradually deeper. This has been established on seismic line O-784-BU-5A (Figure 11), which is about 14.5 km long, covering partially forelimb of the Pezu Anticline and extending towards the Tank Basin in the southwest.

DISCUSSION

The Bhittani Range represents significant uplift as compared to the Bannu and Tank basins lying adjacent to its immediate north and south respectively. The Bhittani Range is characterized by northwest-southeast trending fold and fault structures. The trend of these structures suggests southwest directed compressional stresses, resulting into typical fold and thrust belt tectonic regime. The Bhittani Range is believed to have undergone thin-skinned tectonic deformation, related to a regional structural detachment, probably located at the

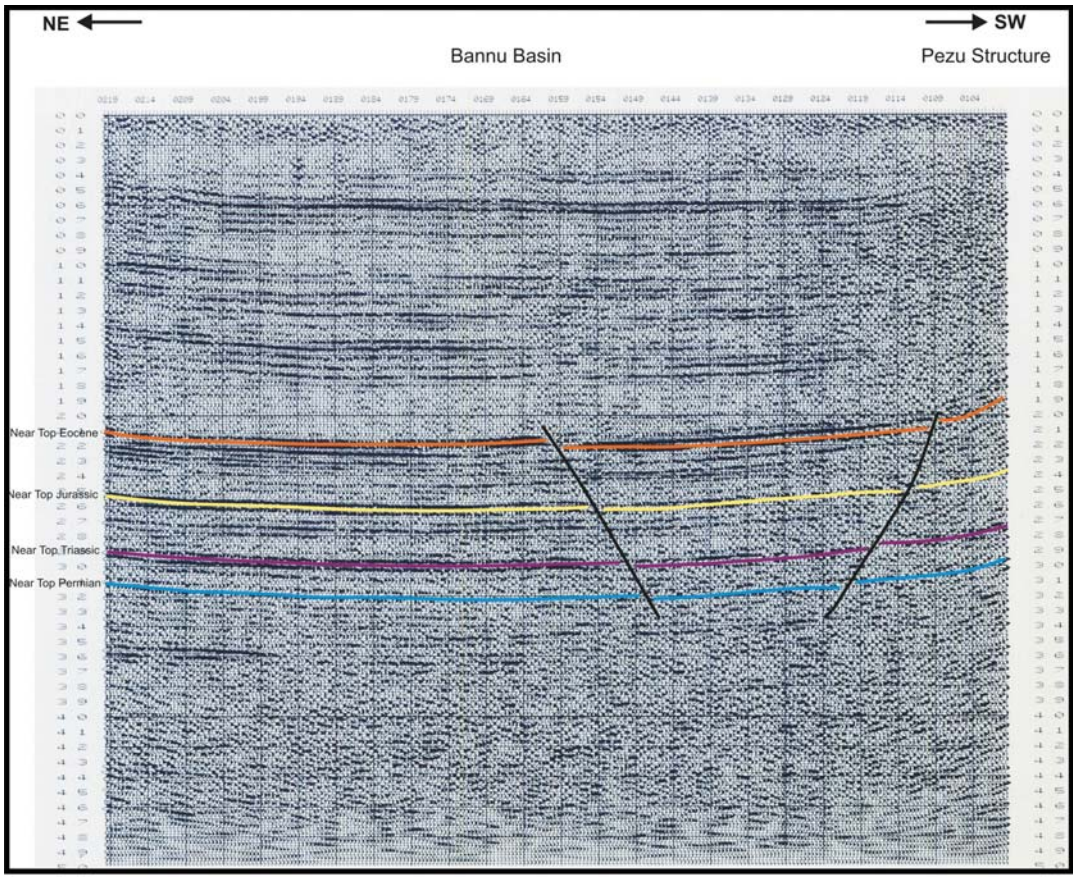

Figure 10 - Interpreted seismic line # O-784-BU-5.

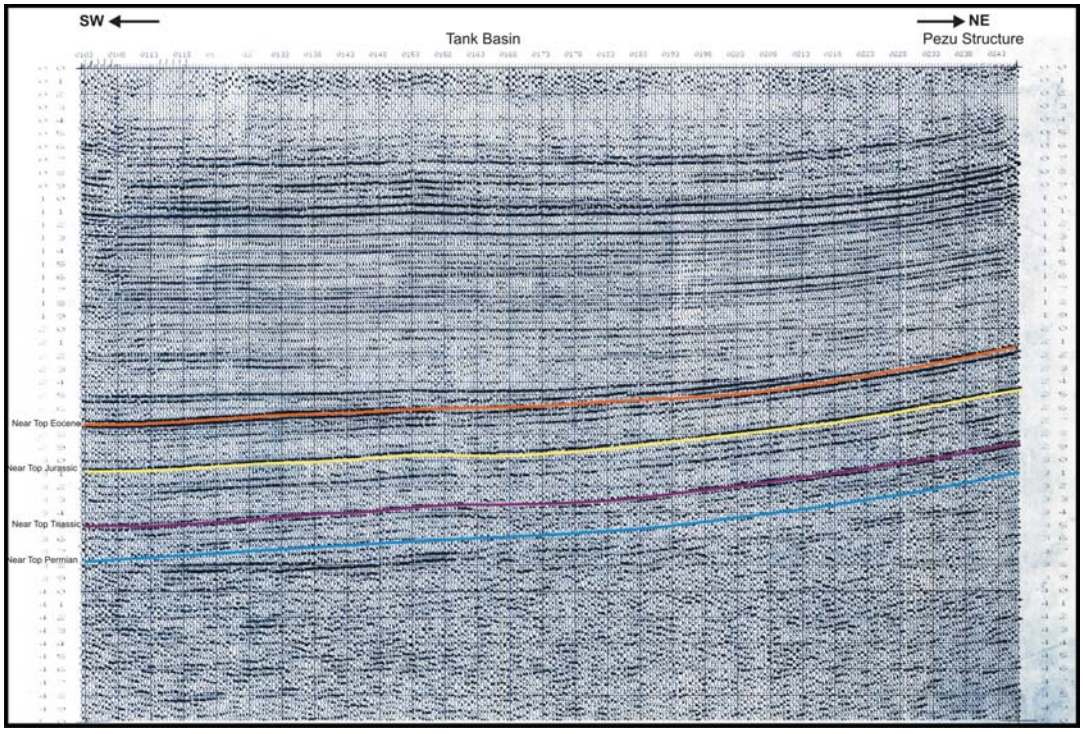

Figure 11 - Interpreted seismic line # O-784-BU-5A.

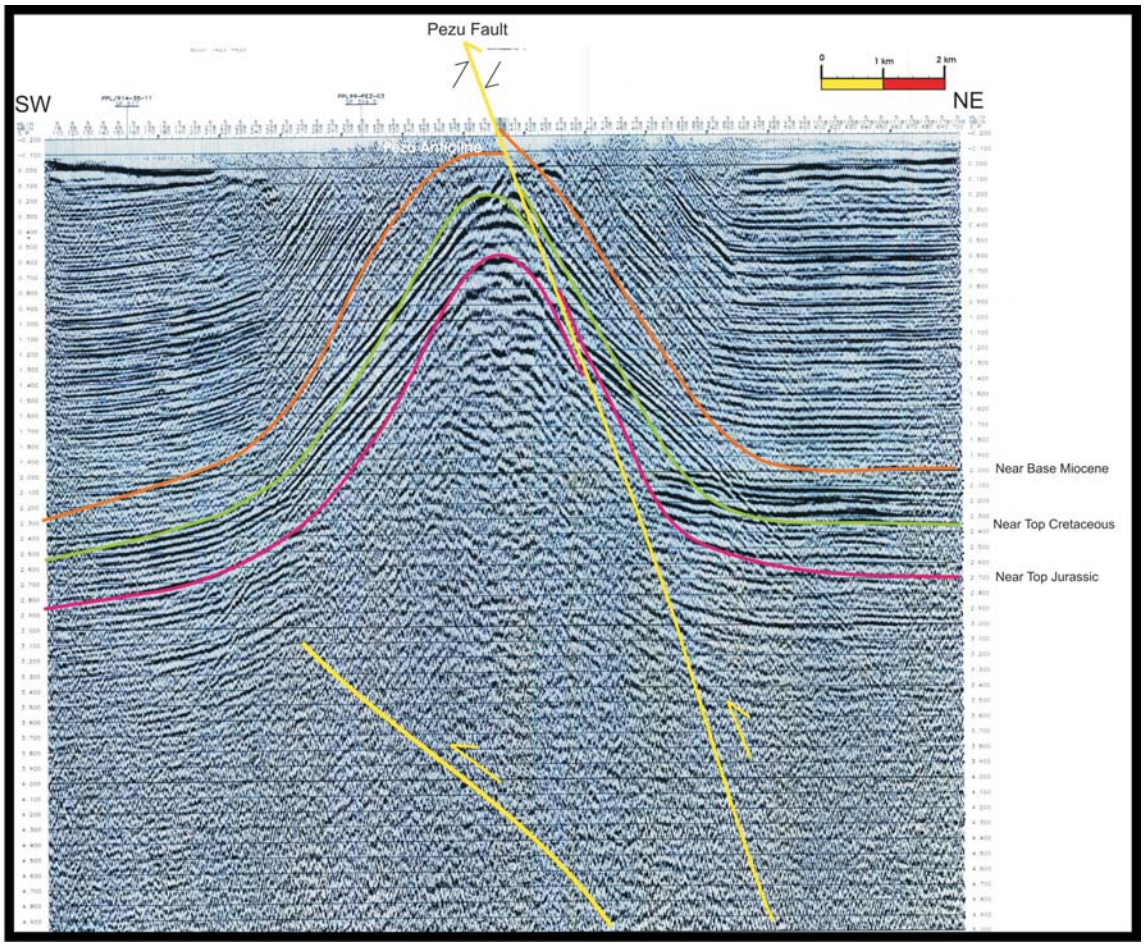

Figure 12 - Interpreted seismic line # PPL02-PEZ-08.

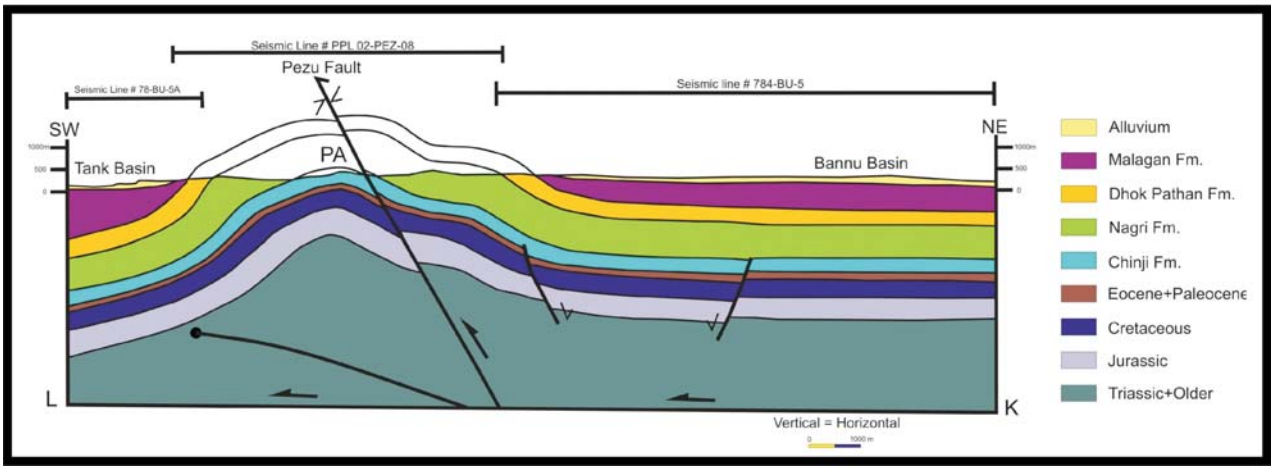

Figure 13 - Geo-Seismic Cross Section along seismic lines # O-784-BU-5, PPL02-PEZ-08 & O-784-BU-5A.

contact between the crystalline basement and Paleozoic sediments. The fold geometry within the Bhittani Range is interpreted as fault-propagation fold, developed in response to the motion along the thrust splays from the regional basal decollement.

The structural genesis of the Bhittani Range is mainly related to the Pezu Fault which has served as a lateral ramp for the southwest propagation of the coherent thrust slab underneath Bannu Basin, characterized by dextral wrenching concomitant with northeast-southwest directed contraction. The proposed geo-seismic model (Figure 13) depicts that the Pezu Fault is a steeply northeast dipping, southwest verging thrust fault whereas the Pezu anticline is developed on the hanging wall of a blind, southwest facing thrust fault within the Triassic and underlying older rocks which tips underneath its fore limb in the subsurface. Current investigations indicate that the northwestern and southeastern compartments of the Pezu anticline are more prospective for the oil and gas accumulation as compared to its central compartment, taking into account their structural geometries.

A working petroleum system exists in the area. The maturity of the source rocks in terms of hydrocarbon generation is established by burning and live gas seep, found along the Pezu Fault in the central part of the Bhittani Range, near Bain village. Another gas seep, known as Manglin gas seep is located near the crestal part of the Pezu Structure in the Bhittani Range about 22 km to the northwest of Bain gas seep. Several potential reservoir horizons are present throughout the stratigraphic sequence in the Trans Indus ranges, ranging in age from Cambrian to Eocene. These mainly include Paleogene shelf carbonates, Cretaceous, Jurassic, Permian and Cambrian sandstones.

REFERENCES

Ahmad, S., Ali, A., and Irfan, M. Khan.,(2005) Imprints of Transtensional Deformation along Kalabagh Fault in the vicinity of Kalabagh Hills, Pakistan. Pakistan Journal of Hydrocarbon Research, vol.15, p. 35-42.

Ansari, A. W and Siddiqui, N. K, (2002) Wideline seismic technique for imaging structurally complex areas A case study. PAPG, ATC 2002, conference proceedings, p.37-45.

Demaison, G. and Huizinga, B.J.1991.Genetic classification of petroleum system, AAPG Bulletin, V.75, No.10, p.1626-1643.

Hemphill, W. R. And Kidwai, A. H., (1973) Stratigraphy of the Bannu and Dera Ismail Khan area, Pakistan. U.S.G.S., Prof. Paper 716-B: 36p.

Kazmi,A.H., and Rana,R.A.,(1982) Tectonic Map of Pakistan, 1:1,000,000. Geological Survey of Pakistan Quetta, Pakistan.

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