Hydrocarbon Potential of Marwat and Khisor Trans Indus Ranges, Northwest Pakistan*

Mudassar Khan[1], Moin Khan[1], and Ali Raza[1]

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[1]Pakistan Petroleum Limited, Karachi, Sindh, Pakistan (k_moin@ppl.com.pk)

Abstract

Fold and thrust belts throughout the world are the most significant areas for hydrocarbon exploration and exploitation. These fold and thrust belts, which have globally been explored for hydrocarbons for over a century now with mixed results, have become even more challenging frontiers for hydrocarbon exploration because of the steeply increasing exploration cost and risk. Although acquisition of 3D seismic data has contributed much to the understanding of complex geometries in the fold-thrust belts in the subsurface, challenges still exist for exploration geoscientists. The Himalayan foreland fold and thrust belt of Pakistan includes the Kohat foreland fold-and-thrust belt along with its associated frontal ranges to the west of the Indus River that include Surghar-Shinghar, Marwat-Khisor, Bhittani and Manzai Trans-Indus ranges, Northern Sulaiman Range and the D.I. Khan Plain in the south. This compressional structural domain has yielded several significant discoveries of oil and gas, albeit more than a dozen dry wells. The Marwat and Khisor ranges remain devoid of any commercial discovery, though the first exploration well (Kundal-1) drilled in the subcontinent in 1866 (only 7 years after the birth of modern oil industry in Pennsylvania), was located near the most prolific oil seepage of the region in the foothills of Khisor Range. Critical review of the available literature and geological field work in the Marwat-Khisor Range depicts that all the ingredients of a working petroleum system exist in the area. The petroleum system of the area is characterized by multiple reservoirs and sealing horizons that are likely to be charged by multiple source rocks. Surface structural style shows that en-echelon anticlinal closures developed within the hanging walls of major faults could provide primary traps for hydrocarbons. In addition, sub-thrust plays as well as stratigraphic traps (formed as a result of eastward truncation of various horizons) may also provide potential drillable prospects. The presence of a regional hydrocarbon kitchen is well supported by the stratigraphic record, whereas the oil and gas discoveries along with oil/gas seepages in the surrounding fold belts provide clear indication of the optimum timing of hydrocarbons generation, migration and entrapment in the area. The key to success is correctly deciphering the subsurface geometries and eventually precisely locating the trap culminations.

Introduction

The Marwat-Khisor ranges define an east-west to northeast-southwest trending fold-thrust belt system, located in central part of Trans Indus ranges. The stratigraphic fabric comprises a Cambrian to Eocene platform succession, unconformably overlain by a thick pile of fluviatile molasse deposits.

The Marwat Range is an anticlinal feature largely covered by the Pliocene-Pleistocene Siwalik Group rocks. The Khisor Range that lies south of the Marwat Range exposes Cambrian to Triassic rocks which are unconformably overlain by the Pliocene-Pleistocene Siwalik Group rocks. The structural style of the Khisor Range includes parallel to en-echelon fold trends, detached at the base of Jhelum Group rocks of Cambrian age. The stratigraphic succession and structural styles observed within the Trans Indus ranges offer a complete petroleum system comprised of multiple source, reservoir, seal rocks and traps, both structural as well as stratigraphic, for the accumulation of hydrocarbons.

The area needs to be thoroughly investigated by seismic data to correctly decipher the subsurface geometries and eventually precisely locating the trap culminations. There is a strong possibility of the existence of a sub-thrust play in the footwall of the Khisor Frontal Thrust, which also needs validation through seismic.

Regional Tectonic Framework

Pakistan contains the northwestern boundary of the Indian lithospheric plate (Figure 1). Pakistani basins have acquired their primary structural and stratigraphic features from events associated with plate dynamics that occurred since Precambrian to present. The Indo-Pakistani Plate was located in the Southern Hemisphere between the African, Antarctic and Australian plates and comprised of part of southern Gondwana from Permian through Middle Jurassic time (Wandrey, 2004). The under-thrusting of the Indo-Pakistani Plate beneath the Eurasian Plate resulted in compressional thin-skinned tectonic features since Eocene to present on the northern and northwestern fringes of the Indo-Pakistani Plate (Figure 2). The continued under-thrusting produced the spectacular mountain ranges of the Himalayas and a chain of foreland fold-and-thrust belts as thick sheets of sediments thrust over the Indian Craton (Kemal, 1992). Trans-Indus ranges constitute the mobile flank of the Kohat and Potwar fold and thrust belt and is mostly characterized by decollement thrust-fold assemblages. Most of the recent thrusting is believed to have occurred along the frontal thrust system in the Salt Range to the east and in the Trans-Indus ranges to the west (Blisniuk et al., 1998). Trans-Indus ranges represent the leading deformational front of the Kohat fold and thrust belt and Bannu Basin in North Pakistan (Ahmad et al., 2005). It has been interpreted that the major thrusting along the Salt Range front started at ~ 2.5 Ma (Burbank and Raynolds, 1988; Burbank and Beck, 1989a) and along the Trans-Indus ranges major convergence it started at ~ 1 Ma (Khan et al., 1988; Pivnik and Khan, 1996; Blisniuk and Sonder, 1998). In northern Pakistan, the frontal thrust system has accommodated about $\geq$ 20 km of shortening in Salt Range (Lillie et al., 1987; Baker et al., 1988) and ~10 km of shortening in the Trans-Indus ranges (Blisniuk, 1996).

Exploration Histroy

Petroleum interest in the area was first generated by the Kundal oil seep at the northern edge of the Khisor Range. One of the first exploration well (Kundal-1), drilled in the subcontinent in 1866, was located near the Kundal oil seepage. Exploration activities in the area were extended to the 19th century wherein few wells were drilled in early decades on surface geology only. Later drilling activities continue with poor seismic data quality, which is also one of the main reasons for disappointing results.

Petroleum Plays

The petroleum system of the area is characterized by multiple source and reservoirs along with associated seal horizons (Figure 3). Geochemical data, oil to source correlation studies and lithological characteristics of some rocks suggest that there are multiple potential source rock horizons with varying levels of maturity in the area. Presence of an active oil seep also provides clear indication of the optimum timing of hydrocarbons generation, migration and entrapment in the area. Existence of a regional hydrocarbon kitchen is well supported by the stratigraphic record.

Wireline log data of surrounding wells, along with field observations, confirm the existence of numerous good quality reservoirs throughout the stratigraphic sequence. The main reservoirs range in age from Cambrian to Cretaceous. These mainly include shallow marine/deltaic clastics of Mesozoic and Paleozoic formations showing a wide range of thickness and facies variation and at times truncations of the entire formation towards the east.

The thin-skinned deformed fold-thrust assemblages dominate the structural style of the Marwat-Khisor ranges, defined by east-west to northeast trending anticline-syncline pairs that are generally asymmetric and dominantly southeast verging (Figure 4). These are parallel to en echelon meso- and macro-scale folds. The area is underlain by a regional basal detachment located at the base of Jhelum Group of Cambrian age. 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. A NW-SE trending Sargodha High is also located SE of the Block which represents a foreland bulge formed from Late Eocene onwards. During Late Eocene-Oligocene, its uplift resulted in the erosion of Early Tertiary to Late Permian sediments in the area. Therefore, sediments of Early Eocene to Precambrian gradually truncate below the Base Miocene unconformity (Figure 5). This makes the area attractive for structural stratigraphic plays.

Conclusions

- An active oil seep from Early Cretaceous source rock indicates a working petroleum system.
- Numerous potential source rocks exist in kitchen in immediate vicinity.

- Multiple good quality reservoirs are present.

- Most of the wells were drilled decades back based on surface geology with lack of good quality seismic data, hence the region still considered unexplored.

- Proper imaging of the subsurface by seismic will help delineate the geometry of elements for both structural and stratigraphic traps the may exist in the area.

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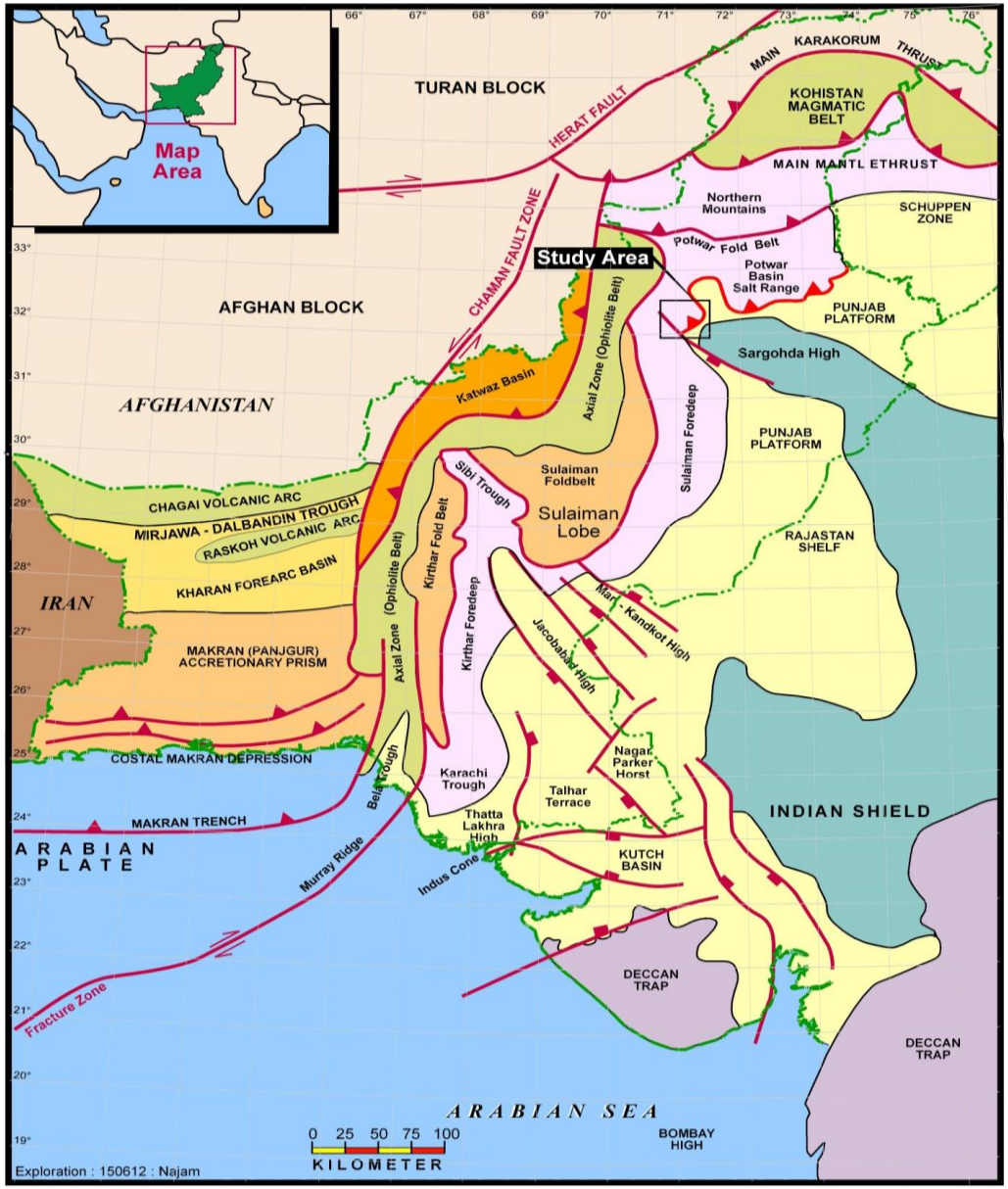

Figure 1. Generalized tectonic map of Pakistan showing location of the study area.

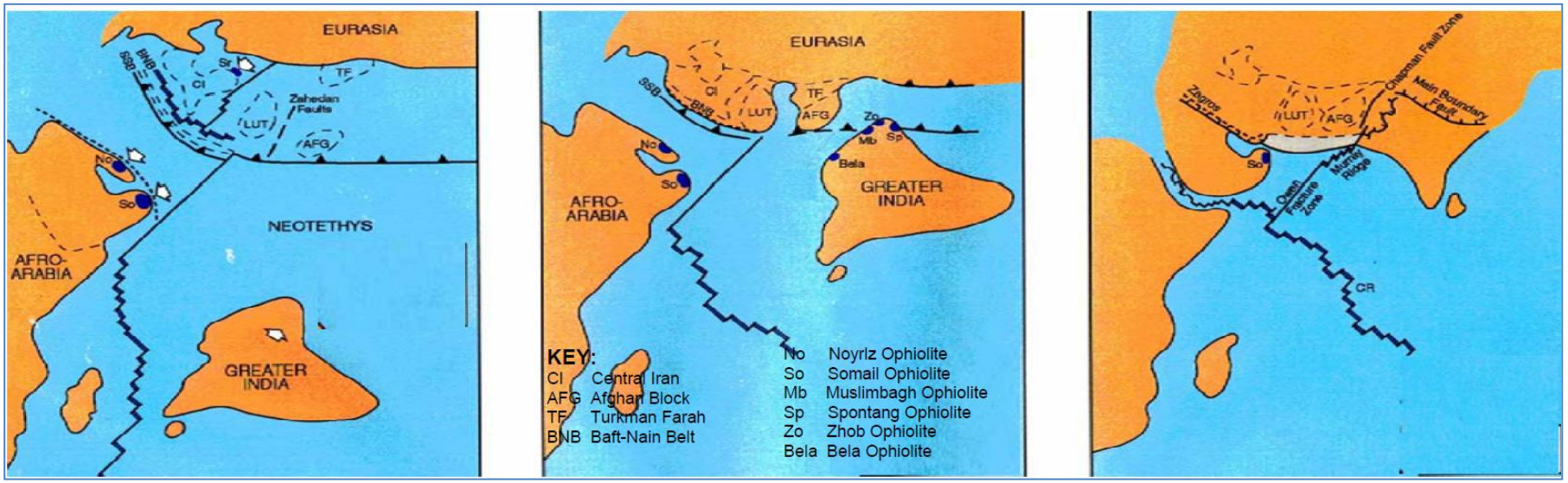

Figure 2. Plate Tectonics – at 70 my, 55 my and 3 my (after Scotese et al., 1988; Scotese, 1997).

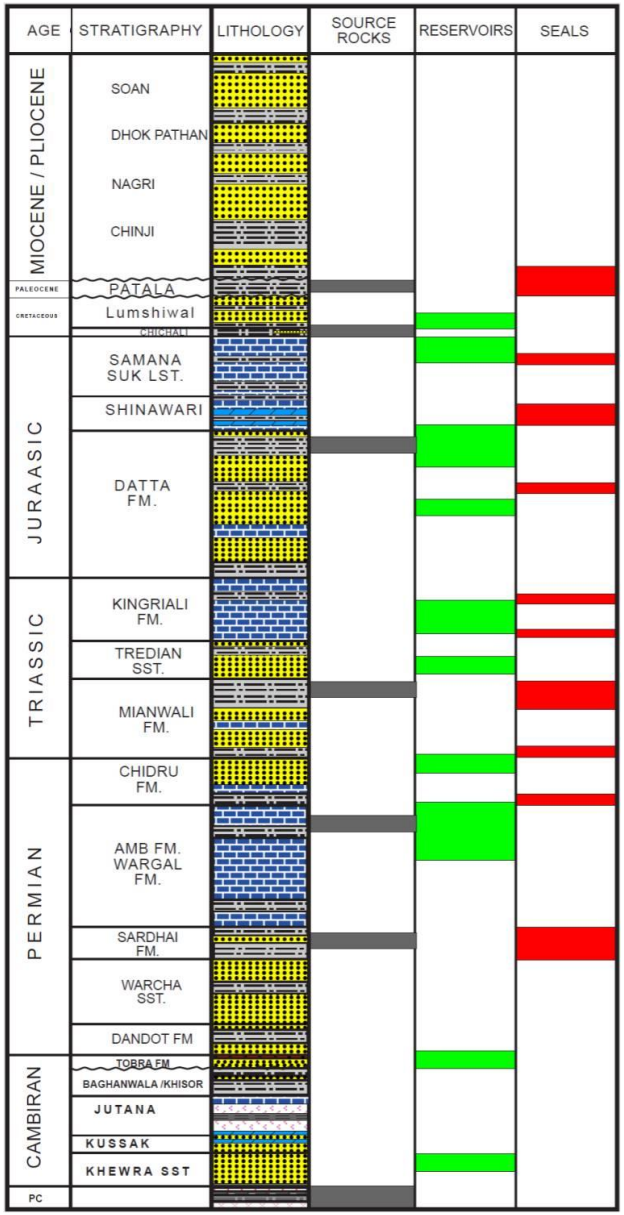

Figure 3. Generalized stratigraphy of the study area.

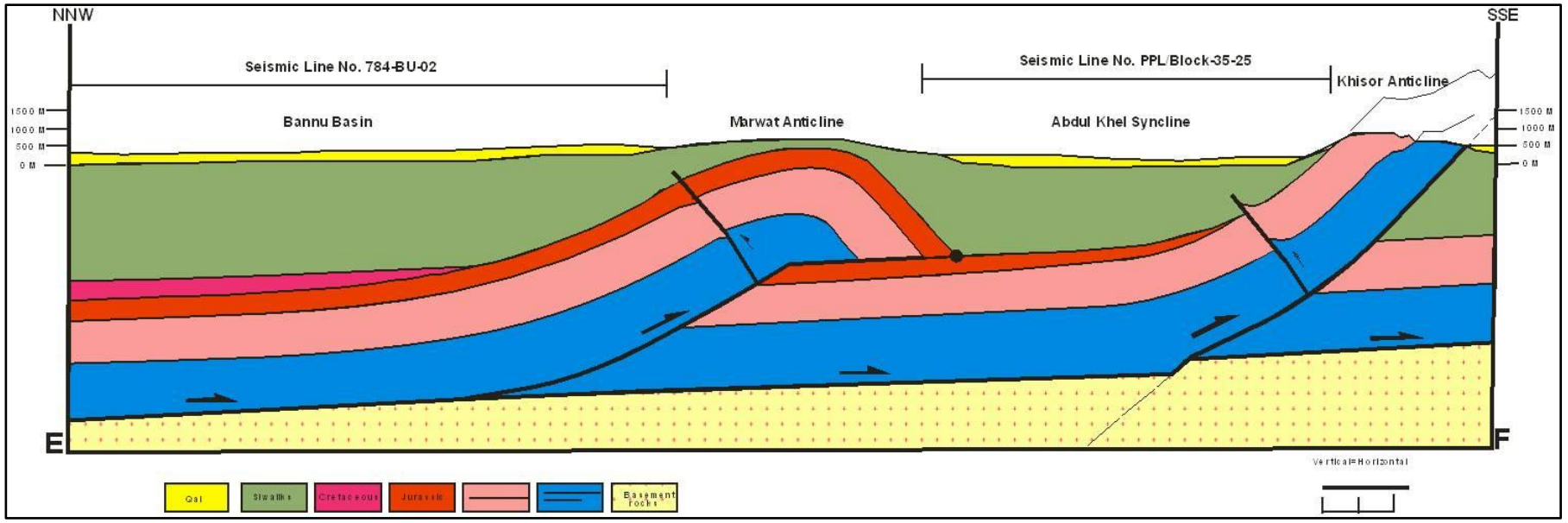

Figure 4. NW-SE schematic cross-section through the Marwat-Khisor ranges.

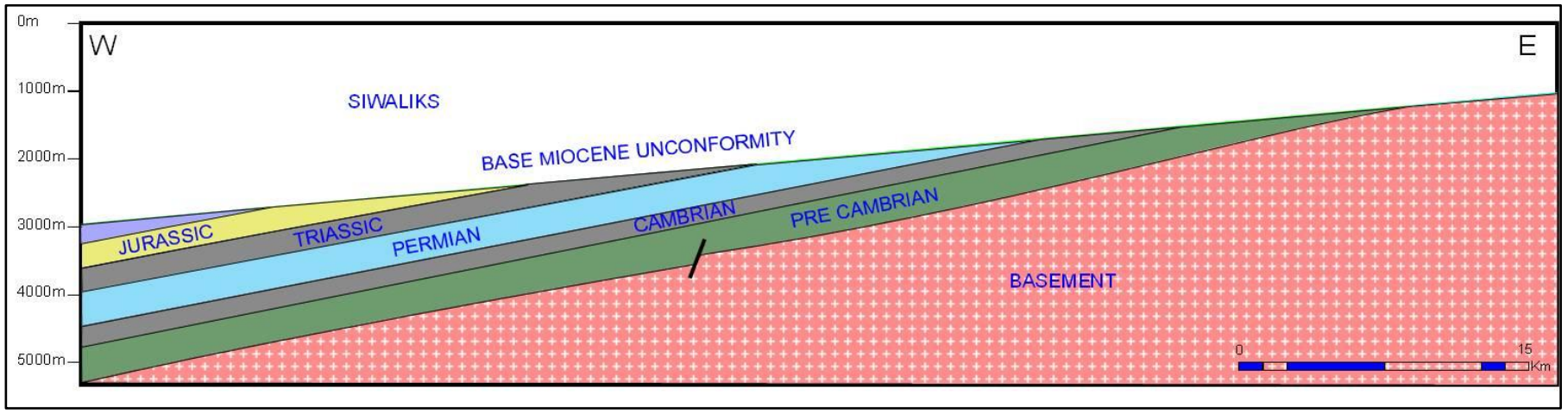

Figure 5. Schematic section showing truncations of different formations below the Base Miocene unconformity.