



Distribution and Hydrocarbon Potential of Datta Sands in Upper Indus Basin, Pakistan

S. N. A. ZAIDI⁺⁺, I. A. BROHI*, K. RAMZAN**, N. AHMED**, F. MEHMOOD, A.U. BROHI*

Oil and Gas Development Company Limited, Islamabad

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Abstract Datta sands are producing oil and gas on commercial scale. It has collectively produced more than 1500 million barrels of oil from Toot, Meyal and Dhulian fields. In Pezu, Chonai and Marwat wells, porosity range from 17-30%. The discoveries of Chanda and Mela wells in the sandstone of Datta formation in Kohat sub-basin have made it more important. The formation is widely distributed in western part of the Salt Range and in Surghar, Shinghar, Shaikh Budin Hills in the Marwat Range and western Khisor Range. These delta front facies bear very good reservoir characteristics in thick sandstone beds that are cleaned and quartose. The formation also extends in Kala-Chitta, Hazara and Samana Ranges.

The Jurassic sands provide good porosities in the area. The matrix porosity of Datta formation in Potwar ranges from 5% to 18%. Geochemical studies conducted by HDIP and OGDCL on well samples indicate that Datta formation of Jurassic age contain adequate amount of organic matter in some wells. The area contains overturned faulted anticlines, popup structures, or fault block traps. The structures in the area are considered to be formed by the combination of compressional tectonics and salt movement due to which reverse faults and thrusting are common.

Keywords: Oil and Gas Surghar, Shinghar, Shaikh Budin Hills Datta Nala in Surghar Range.

1. INTRODUCTION

Upper Indus basin is generally considered northern part of the Indus basin, comprising of the northern part of Sargodha High and some part of Punjab Platform and Potwar Kohat area. The basin has become more important after the discoveries of Hydrocarbons in the Potwar and Kohat sub-basin.

discovery was made in late 1800's when first well was drilled and Khaur oil field was discovered in 1915 at Khaur, district Attock, Punjab by Attock Oil Company. Since then Potwar is the main source of hydrocarbons and number of wells of crude oils and condensate are explored in the Potwar Basin (Fig 1). The Datta Formation is only present in the western and north-western parts of Potwar (Table 1).

Potwar Basin is one of the oldest area explored for petroleum in the world while first commercial oil

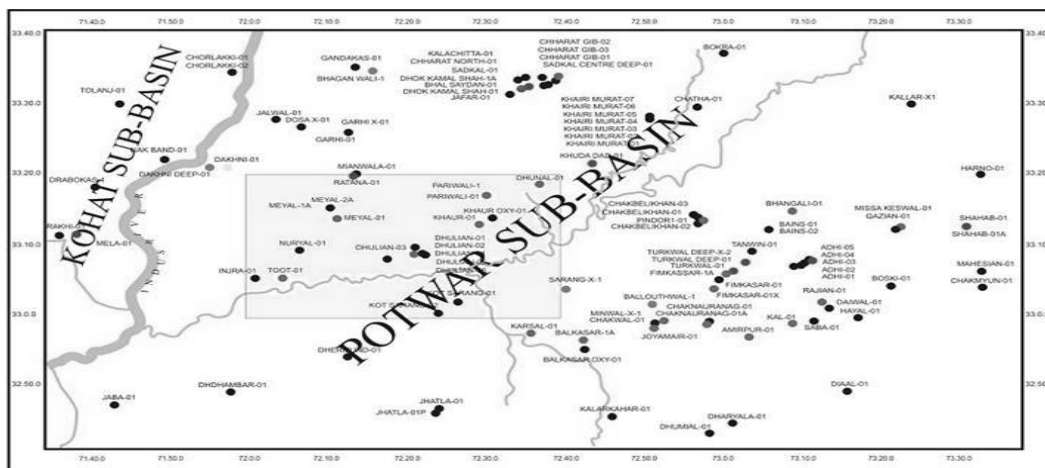


Fig. 1: Well location map, inside showing the study area.

⁺⁺ Corresponding author, E-mail: N-zaidi4@hotmail.com, +92-3218585368

*Department. of Geology, University of Sindh, Jamshoro Sindh.

**Hydrocarbon Development Institute of Pakistan, Islamabad.

Table 1: Summary of wells drilled in study area.

S. No	WELL NAME	OPERATER	YEAR	T.D(m)	FORMATION @ T.D	STATUS
01	Kot Sarang-01	O.G.D.C.L	1968	4524	Wargal	Abandoned
02	Dhulian-06	P.O.L	1937	2749	Rani Kot	Oil
03	Khaur-01	P.O.L	1915	1407	Sakessar	Oil
04	Pariwali-01	Occidental of Pakistan	1986	5793	Sardhai	Oil/Gas
05	Dhurnal-01	Occidental of Pakistan	1984	4461	Datta	Oil
06	Toot-01	O.G.D.C.L	1968	4863	Datta	Oil
07	Nuryal-01	O.G.D.C.L	1971	5235	Datta	Abandoned
08	Meyal-01	P.O.L	1968	4155	Sakessar	Oil/Gas
09	Ratana-01	Occidental of Pakistan	1989	5713	Datta	Gas/Cond.
10	Injra-01	OGDCL	1987	4739	Datta	Non-Commercial

In the Upper Indus basin, the Datta sandstone is producing in Toot, Meyal, and Dhulian oil fields, with thick exposures occurring at Sheikh Budin Hills in the Marwat Range. These delta front facies bear very good reservoir characteristics in thick sandstone beds that are clean and quartzose.

This reservoir is present in the Meyal, Dhulian, and Toot, Dhadambar, and Dharmund wells and absent in the Kotsarang, Karasal, Jhatla, Sarang wells. Stratigraphic traps can be sought along this N-NW to S-SE trend (Oil and Gas Journal, 2000). In producing fields like Toot, the depositional environment of individual sand packages within the overall pay zones is very interesting. Variations in crude suggest that many different oil saturation lenses exist within layers 1-4 with proven oil columns, tight to porous sandstone, continuous in some cases and lenticular in others, deposited in a delta on the edge of an arid area. The Datta formation of Early Jurassic age is of continental origin and is widely developed in the Western Salt Range/Potwar Plateau, Kohat and Khisor Range. It is comprised of variegated sandstone, shale, siltstone, and mudstone, with occasional layers of ferruginous glass sand and fireclay.

The geological division between Kohat and Potwar is done naturally by river Indus, the East and west of river represent the Potwar and Kohat Basins respectively. The geological structure of the Potwar Basin is one of the most complex structures of the world which is the result of the Tertiary Himalayan Collision between Eurasian and Indian plates. This intense tectonic activity has affected Eastern Potwar, the most compared to Western Potwar. The study area is represented by Yellow color.

2. EXPLORATION HISTORY

Petroleum Exploration history of the Potwar Basin starts when commercial quantities of oil were discovered in 1915 at Khaur, district Attock, Punjab by the predecessor of Attock Oil Company (AOC). As a result of the combined efforts of AOC and Burma Oil Company (BOC), Dhulian (1936), Joya Mair (1944), Balkassar (1946) and Toot (1968). During this period Pakistan Oil Limited (POL) discovered oil at Meyal (1968). Oil fields were discovered in the Potwar area establishing the oil potential of Potwar region. Occidental reported the most prolific discovery at Dhurnal-1 in Potwar region in 1984. The discovery of condensate/gas and oil at Dakhni (1983 and Dhurnal 1984) provided new leads to the hydrocarbon potential of Northern Potwar regions. Oxy discovered oil at Bhangali and Pindori during 1989-1990 in their Soan Concession. Pindori-1 during recompletion blows out and the well had to be abandoned but Pindori-2, 3, 4, 5A and 6 are producing. OGDC discovered heavy crude at Chak Naurang (1986), rested old Qazian Structure and found oil at Missa Keswal-1 (1990). Oil was also discovered by OGDC in Potwar at Sadkal (1991) near Fatehjang, Rajian (1993) and Kal (1995) near Chakwal. Other significant discoveries were made by POL at Pariwali-1 (sidetrack in 1986) and Turkwal-1 (sidetrack in 1997) wells in Ahmadal and Central Potwar Concessions.

OGDCL make a break through when oil was discovered for the first time in Kohat region at Chanda (former Shakardara Structure) from Datta Formation of Early Jurassic. As a matter of fact, this was first ever hydrocarbon discovery in KPK province which was followed by another discovery namely Manzalai (2002) and Makori (2005) by MOL of Hungary making Kohat

plateau, new focus area for exploration. The discovery of Mela oil/gas (2006) by OGDCL, which were reinforced the belief of many Geologist that this region can host large hydrocarbon reserves with upside touching tens of trillion cubic feet of gas.

3. GEOLOGICAL SETTING

Upper Indus basin is generally considered northern part of the Indus basin, comprising of the northern part of Sargodha High and some part of Punjab Platform and Potwar-Kohat area. The Potwar Basin is located on a portion of the Indian Plate which was structurally deformed during the Indo-Eurasian collision and by the overthrust of the Himalayas to the North and NW. Overthrusting has resulted in intense deformation and the juxtaposition of strata of widely varying ages (e.g. Precambrian and Tertiary) in close proximity. Precambrian rocks are exposed in the Salt Range at the southern margin of the basin. Before the onset of plate collision in the Eocene, the Precambrian interval was not buried sufficiently deeply for OM maturation to occur and much of the Precambrian to Paleocene succession has remained thermally immature to the present day (Khan *et al.*, 1986; Grelaud *et al.*, 2002). However, in local areas, abnormally high formation pressures resulting from regional compression and compaction disequilibrium, together with deep burial by overburden rocks, have led to the generation and expulsion of hydrocarbons from pre-Eocene source rocks (Law *et al.*, Grelaud *et al.*,2002).

4. STRATIGRAPHY

Stratigraphy of the area described here belongs to the drilled wells in the study area and its vicinity. Pliocene to Precambrian age rocks has been penetrated by wells with major unconformities at various levels (Fig. 2).

The Datta Formation is mainly of continental origin and is composed of shales and non-marine sandstones with paralic intervals. It has both reservoir and source rock potential (Fig. 3).

Stratigraphic Correlation of Dhermund-01, Kotsarang-01, Dhullian-43 and Khaur-oxy-01 shows that Datta Formation is pinching out from South- west to North- east in the study area (Fig. 4).

Tectonic Setup of Potwar Basin:

The Main Boundary Thrust (MBT) marks its northern boundary with Parachinar-Kala Chitta Fold Belt. The sinistral Jhelum Fault is the boundary separating the Potwar Plateau and the Salt Range from the Hazara-Kashmir Syntaxis to the east.

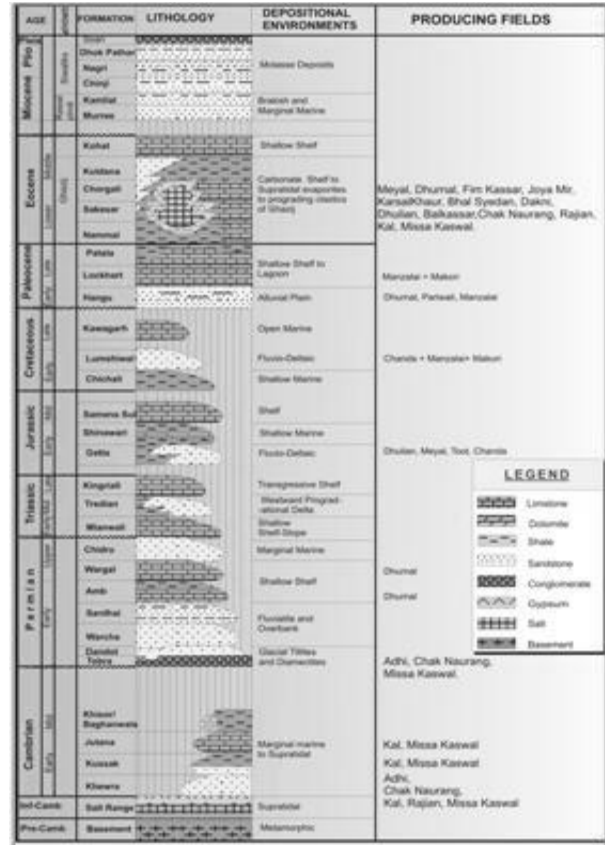


Fig. 2: Generalized Stratigraphic Column of Potwar Basin.

AGE/EPOCH		LITHOLOGY	FORMATION		
NEOGENE	Pliocene	[Lithology symbol]	Nagri Chirji		
	Miocene Oligocene	[Lithology symbol]	Kamli Murree Kohat		
		unconformity			
PALEOGENE	Eocene	[Lithology symbol]	Mamikhel Chorgali # Sakesar # Nammal #		
	Paleocene	[Lithology symbol]	Patala* # Lockhart* # Hangu* #		
Mesozoic & late Permian unconformity					
JURASSIC		[Lithology symbol]	Datta		
PERMIAN	Early Permian	[Lithology symbol]	Chhadr Wargal Amb Sardhai Warcha Dandot Tobra#		
		unconformity			
		Cambrian TO PRE-CAMBRIAN	Cambrian Infra Cambrian	[Lithology symbol]	Baghanwala Jutana Kussak # Khewra* #
				[Lithology symbol]	Salt Range*
				[Lithology symbol]	
[Lithology symbol]					

Fig. 3: Stratigraphic column for the Potwar Basin. #: source rocks; * reservoir rocks (modified from OGDCL 1996;

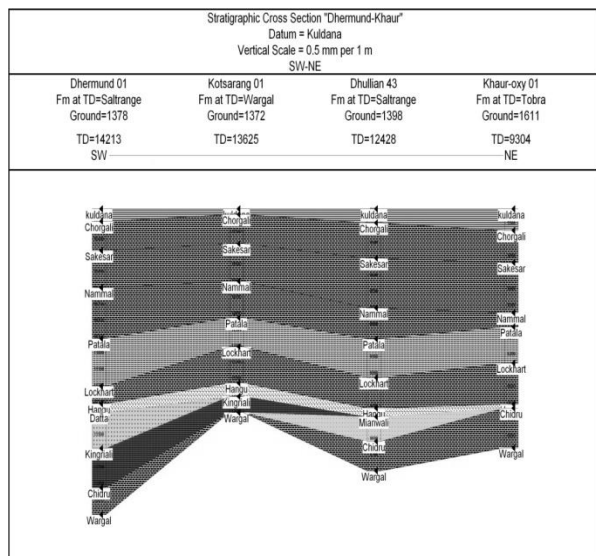


Fig.4: Stratigraphic Correlation B/W Toot 11 and Kot Sarang.

The Salt Range Thrust (the Main Frontal Thrust; the limit of significant deformation associated with the Himalayan Orogeny) marks the southern boundary of the Salt Range against the relatively undeformed rocks of the Punjab Sub-basin. The dextral Kalabagh Fault marks its boundary to the west.

The Upper Indus Basin, carved out by various tectonic elements, is constituted by Kohat-Potwar fore-deep, Salt Range horst and platform region north of Sargodha high. The basin is asymmetrically elongated in NE-SW direction. The southern limits of the basin are demarcated by Sargodha High and its westward extensions south of Marwat Range. The Kala Chitta and Margala Hills mark its northern boundary, while in the east it is bounded by the Jhelum fault Zone (HDIP-IPR, 1995). (Fig. 5)

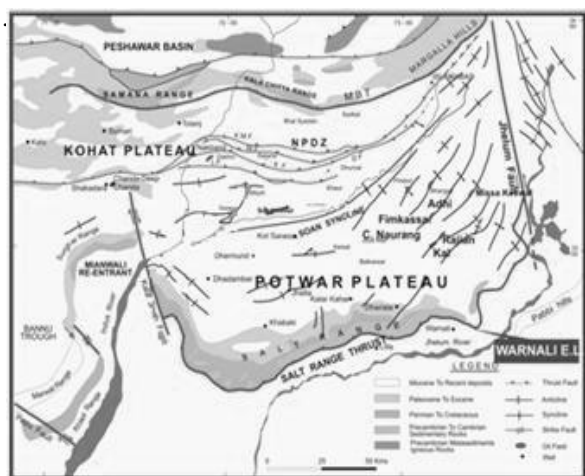


Fig. 5: Tectonic Map of Kohat Potwar Basin

The northern boundary of the basin is characterized by the Eocene to Jurassic succession along a south directed over-thrust fault, known as Main Boundary Thrust (MBT). This important tectonic line is the surface expression of the Himalayan collision zone. Several oil seeps are known along its length.

The tectonic development of the basin as an oil province is mainly Post-Tertiary. However, Pre-Tertiary tectonic events provided basis for initial basinal architecture and controlled the migration fairway up to the traps for accumulation of hydrocarbons.

The Potwar depression contains a sufficient thickness of sediments ranging from Precambrian to Pleistocene age. Many existing fields are producing oil and gas from the Cambrian, Permian, Jurassic, Paleocene, Eocene and Miocene rocks.

Structure:

Structuration in Potwar Plateau started during Late Miocene (~10 Ma), by initiation of Main Boundary Thrust (MBT). Soan Syncline is the dividing boundary between structural styles on either side. The deformation is characterised by relatively simple fold and thrust structures in the south of Soan Syncline while complex and duplicate structures in the north.

The timing of deformation decreases from MBT (~ 11.6 Ma) to Salt Range Thrust (~ 1.6 Ma). The youngest deformation in the northern limb of Soan Syncline is dated as 2.1 Ma. The producing structures south of Syncline have been interpreted to develop between 3.4 and 2 Ma. Thus the timing of hydrocarbon entrapment in the area is Upper Pliocene.

Structurally, the area can be divided into two zones with Soan syncline as the dividing line.

- 1) North Potwar Deformed Zone.
- 2) Southern Potwar Zone.

Our area of concerned is North Potwar Deformed Zone. The structures in the Potwar depression are formed due to compressional tectonics as a result of Indian Plate beneath the Eurasian Plate. In the North Potwar Deformed Zone (NPDZ), structures are complex being close to the Main Boundary Thrust (MBT). They are generally oriented in a sub latitudinal fashion, mainly following the trend of the major faults like Kheri-Murat and Kanet faults (Fig. 5). The anticline structures are isoclinal and overturned to the south (HDIP-IPR, 1995).

The NPDZ contains several oil fields like Dhurnal, Dakhni, Toot, Meyal, Sadkal, BhalSyedan and

Dhulian. In the northeastern and central parts of Southern Potwar Zone, are some discoveries like Missa Keswal, Rajian, Chak Naurang and Adhi, whereas its western part remains undiscovered despite of the several surface oil seepages (HDIP-IPR, 1995).

Three structures, Kot Sarang, Nuryal and Sarang-X-1 have been drilled in the study area. Kot Sarang is NE-SW trending very gentle anticline although has very small vertical closure (35 ms) and aerial extent but it could be confirmed on the seismic (Fig-6).

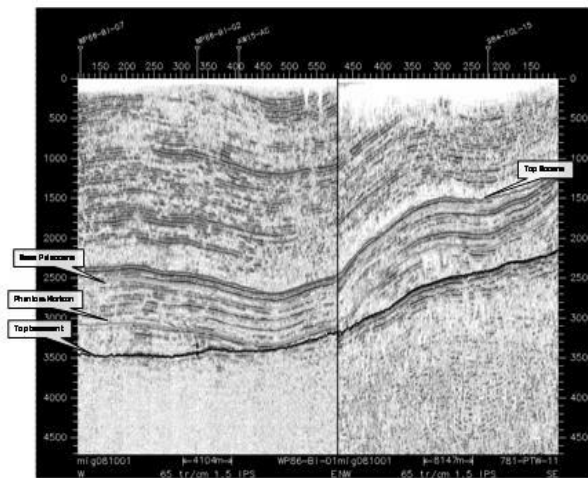


Fig. 6: Strike line along axis of Kot Sarang structure.

Petroleum Geology:

The Upper Indus Basin is an oil productive province, with 21 known oil and gas fields and with oil and gas reservoir horizons developed at a number of Stratigraphic levels ranging in age from Infra-Cambrian to Miocene (HDIP-IPR, 1995).

5. SOURCE ROCK

Datta Formation:

The Lower Jurassic (Datta Formation) also has shale intervals with reported 1.0 % TOC. From the Amoco's interpretation the Shinwari and Datta formation contain gas-prone Kerogen.

The Geochemical analysis by G and R Labs of OGDCL of the drill cuttings from shale horizons within Datta Formation in Chanda deep #1, show fair to very good TOC (0.7 – 2.4 wt. %) with fair to good genetic potential (1.17- 8.86 mg HC/g rock). Shale is generally mature. Kerogen are generally of type III but type II are also present (G and R Lab. Note No. 385).

Datta Formation has TOC ranges from (0.27 to 0.8 wt. %), with HI up to 151(Toot-1& Dhermund-1).

Tmax data > 460 shows Datta formation is gas mature in the wells.

Samples of Datta Formation from Meyal field contained substantial amounts of OM (Organic Matter). TOC (1.0 to 7.5 wt. %). Rock-Eval data included an S1 of 0.5 to 5, and an S2 of 4 to 33mg HC/g rock. The total genetic potential (GP) of the Datta Formation showed good potential for hydrocarbon generation (average S1+S2 of 10). The Datta Formation mainly contained Type II oil prone OM. (HI 250 to 500 mg HC/g TOC).

Tmax values were in the range of 424 to 436 °C. The average Tmax of 430 °C indicated marginally mature OM. The PI (0.1-0.2) indicated that the sediments were at the beginning of the oil window (Fazeelat *et al.*). Shale in Datta Formation in Chanda deep #1, show fair to very good TOC (0.7 – 2.4 wt. %) with fair to good genetic potential (1.17 – 8.86 mg HC/g rock). Shale is generally mature. Kerogen is generally of type III but type II Kerogen is also present (G & R Lab Note No.385).

Maturity:

Potwar region, which has been the traditional oil producing area of Pakistan, has the average geothermal gradient of the order of 2 °C / 100 meters. Hence the general range of oil window is between 2750 – 5200 meters. The reason for its being such a prolific basin is the ideal coexistence of source, reservoir and trap within a favorable geothermal regime. In all of the oil producing structures, both source and reservoir lie within oil window.

Thermal maturity ranges from Vitrinite reflectance (VR) 0.70 to 0.86% for the Jurassic Datta Formation in Toot-6 and Dhulian-44, but as high as 1.43% in Meyal-10 (Porth *et al.*).

Datta Formation of Early Jurassic age has TOC ranges from 0.27% to 0.8% with HI up to 151 (Toot-1 & Dhurnal-1). Tmax data >460 shows Datta formation is gas mature in the wells.

Hydrocarbon Migration/ Entrapment:

Migration of the hydrocarbon in Potwar thrust related belt is reverse faults. It was observed that nearly all of the oil bearing structures are fault bounded and uplifted through these faults. The commonly used term for such traps or structure is "Pop-Up"; source rock underneath the pop ups gets mature and expels oil and migrated upward through the neatly created avenues along the fault planes. Structures other than pop up are not found to be oil bearing. Khaur, Dhulian, Dhurnal, Balkassar, Meyal and Adhi fields are all Pop-up structures (Hasney *et al.*).

6. RESERVOIR ROCK

Datta Formation:

In Potwar depression, the main Mesozoic oil (and solution gas) producer is the Early Jurassic Datta Formation. The Datta sandstones are oil-bearing in the oil fields of Toot, Meyal and Dhulian. Some oil and gas was also tested in Nuryal-1 (Porth *et al.*);).

Oil and gas discoveries (Dakhni, Chanda, Mela, Manzalai, & Makori) in the vicinity confirm the genesis of hydrocarbon in the area.

Porosity values range from 12% to 15% in Chanda wells. It is expected to be the main target horizon in the wells drilled in Kohat Plateau.

Datta sandstone of Jurassic age is the main producing reservoir in Toot Field. Porosity of the reservoir horizons in the formation ranges from 4.7% to 13.4%. Its average porosity is 5.75%.

The Jurassic continental clastic (Datta Formation) is a prominent reservoir in the western part of the Foredeep where the matrix porosity of the formation ranges from 5% to 18% (HDIP-IPR, 1995).

It is producing oil and gas at Dhulian, Toot, Meyal and Ratana fields in the western Potwar. In Toot well -01, the Porosity is 9%, Permeability is 74 mD (milli Darcy), reservoir thickness is 25m and produced 1554 Barrels of oil per day. In Dhulian field, the Porosity is 8.5%, Permeability ranges from 1.2 to 869 mD, and reservoir thickness is 40m and produced 2744 barrels of oil per day.

Cap Rocks:

Seal to the Datta sandstone reservoir of Jurassic age is provided by intraformational shales or by overlying laterite bed situated at the base.

In the Kohat-Potwar fold and thrust belt, almost all the hydrocarbon producing structures are either fault bounded or compartmentalized by high angle thrust faults, resulting in the juxtaposition of older rocks against the overlying younger molasse sediments. This kind of Stratigraphic relationship provides a good and effective lateral seal in most of the cases.

Play Types:

Principal play types in the Kohat-Potwar Basin are anticlinal structures, which are invariably faulted, mostly salt cored and at places asymmetrical to overturn. In addition, pop-up structures, fault-blocks and triangle zones traps have also been encountered.

Trapping Mechanism:

Both structural and Stratigraphic traps are possible in the Kohat-Potwar. Eastern Potwar represents thrust and salt cored anticlines and local pop-ups. Northern Potwar represents Passive Roof Duplex geometry, where thrust anticlines are the potential targets. Further north in the North Potwar Deformed Zone, imbricated antiformal stacks are the main targets. The Kohat area has experienced very complex deformation style due to the development of multiple detachment levels, and compression as well as strike slips motion. The area is represented by antiformal stack and possibly flower structures, thrust anticlines and pop-up, fault propagating folds etc.

Type of Possible Traps:

The possibility of structural cum Stratigraphic trapping of Datta at south- western plunge of Kot Sarang structure is in the study area (**Fig-7**).

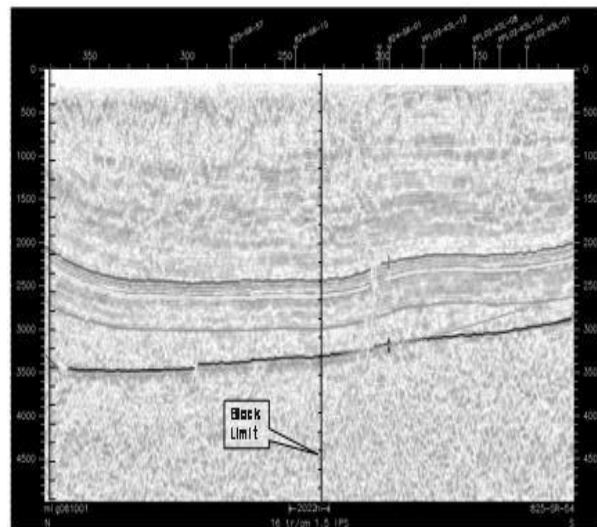


Fig. 7: Showing the Plunge of Kot Sarang structure cum Stratigraphic trapping for Datta may possible at this Plunge.

Structural Traps:

Structural traps in the Potwar Basin include faulted anticlines, pop-up and fault blocks.

The overall structural trend is east to west or northeast to southwest. The majority of the large surface anticlines is bounded by the thrust or reverse faults. Few large thrusts are exposed on surface such as Khairi-Murat Riwayat fault otherwise all the key anticline bounded thrust faults are blind thrust which never emerged on surface. These blind thrust played role in the formation of the anticlines; many of them are petroleum bearing (E and P Geology 2011).

Stratigraphic Traps:

Few fields are associated with Stratigraphic trap as well. Dhulian oilfield, where oil in Jurassic Datta sandstone is stratigraphically trapped (Fig. 7).

7. CONCLUSIONS

1. Reservoir rocks are present.
2. Seals are present
3. Petroleum charge is available.
4. All wells drilled are either produced or have hydrocarbon shows.
5. Producing fields are present in the neighbourhood i.e. in Kohat sub-basin.
6. The identified structures are drilled.
7. There is possibility of Stratigraphic truncation play formed by Datta below base tertiary unconformity on the south-western plunge of Kot Sarang which is inside the study area.

8. RECOMMENDATIONS

As Datta Formation are proven petroleum prospects in upper Indus basin especially in Western Potwar. In Dhulian field, main targets were Ranikot and Lockhart Formations, deeper drilled wells to Datta Formation may give more prospects because Datta is proven reservoir in the area. Although in Khaur field Sakesser was main target it may deeper to Datta as

targeted reservoir may give more prospects. While in Pariwali and Meyal fields no reservoir test have been taken for Datta Formation. So it is suggested that if Datta Formation is considered as reservoir for above fields may enhanced reserves.

It is suggested that identified structures will drilled up to Datta Formation as targeted reservoir around the production fields of Western Potwar.

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