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Evaluation of Infra-Cambrian Plays in Punjab Platform

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Abstract: Punjab Platform is the eastern part of the Middle Indus Basin, Pakistan with no surface outcrops. It covers an area of more than 100,000 sq.Km. Exploration activities started in mid 1950s when Shell drilled first exploratory well, Karampur-1 in 1958, which shows an evidence for occurrence of heavy oil in Infracambrian rocks.

In India, a petroleum system has been established after the discovery of Baghewala-1 in 1991 in Infra-Cambrian rocks of Bikaner-Nagaur Basin. In the Bikaner-Naguar Basin, the deepest occurrence of oil is recorded in Infra/Lower Cambrian Jodhpur Sandstone with porosity ranging between 16-25% and oil saturation of 65-80%. The similar type of crude oil has been discovered in the overlying Bilara Dolostone with porosity 07-15%. Thin siltstone layers in Hanseran Evaporite (equivalent to Salt Range Formation) also found to contain heavy oil (Sheikh *et, al.,* 2003). Karampur-1, produced heavy oil from Salt Range Formation is geochemically similar to Baghewala oil.

Geochemical studies, Seismic and well data of Punjab Platform suggest that Infra- Cambrian is the complete petroleum system in the Punjab Platform. It is to be noted that wells drilled in Paleo-highs are dry due to lack of maturity and insufficient depth of burial. Maturity tends to increase with depth and deeper source rocks expected to be present in Punjab Platform. So in future, the wells drilled on Paleo- lows should encounter Infracambrian Formations (Sheikh *et, al.,* 2003).

Keywords: Middle Indus Basin, Pakistan, Bilara Dolostone.

1. INTRODUCTION

No well has explored on the basis of Infra-Cambrian play in Punjab Platform. Only twenty three wells were drilled since 1959 **(Table-1)** in which two wells were reached the target of Infra-Cambrian Formation. However, only one well Bijnot-1 penetrated Infra-Cambrian reservoir with good oil shows. The geological and seismic data suggests that potential of Infra-Cambrian reservoirs may be re-evaluated in the south-eastern part of Punjab Platform particularly in the close proximity discoveries where Infracambrian shows complete petroleum system describes Punjab Platform as the eastern segment of Central Indus Basin where no surface outcrops of sedimentary rocks are present. Tectonically, it is a broad monocline dipping gently towards the Suleiman Depression. Punjab Platform is tectonically the least affected area because of its greater distance from collision zone.

The Punjab Platform extends eastward into India and is called as Bikaner-Nagaur Basin where India has discovered significant quantities of heavy oil in the Infra- Cambrian Evaporite sequence called Hanseran Evaporite and Jodhpur Sandstone equal to Salt Range formation in Pakistan.

2. MATERIAL AND METHODS

Exploration History:

Exploration in the Punjab Platform started when Shell Oil Company drilled Karampur-1 up to the depth of 3034m to the basement and got Heavy asphaltic oil from Infracambrian reservoirs. On the basis of its results, two exploratory wells namely Bahawalpur East-1 and Marot-1 were drilled in this area during 1980 and 1981. Both wells did encounter Infracambrian rocks i.e. Jodhpur and Bilara Formations, but failed to find out hydrocarbons possibility due to lack of closure at the Infracambrian level and poor reservoir quality. So both wells were declared abandoned. So far, only one gas field had been discovered from Salt Range reservoirs whereas two gas fields have been discovered from Triassic reservoirs (Table-1). Heavy oil discovery in Baghewala-1 (1991) in Bikaner–Nagaur Basin, Rajasthan India, from Infracambrian sandstone and carbonates has renewed exploration activity for Infracambrian Play, which was almost abandoned in Pak. ummarized information of wells drilled in Punjab Platform is presented.

In (1991), ONGC drilled a Stratigraphic test well Pugal-1 based on gravity data followed by Baghewala-1, which resulted in the discovery of heavy oil with a estimated oil in place of 94 MMT (628 MM BBL). It is felt that the oil discovery of Baghewala-1 and good oil shows in the wells to the Baghewala-1 discovery, reportedly 5 development wells have been drilled and other exploratory wells like Kalrewala-1,2 and Tavriwala-1 (precise dates of drilling are not known) were drilled and discovered oil in the Infra-Cambrian reservoirs **(Fig. 1).** Exploration activities accelerated again in the area during the early 1990s when POL drilled Ahmedpur East-1 **(Table 1)** in 1992 to explore the Cretaceous reservoirs (Probably Pab Sandstone pinchout). OGDCL drilled Fortabbas-1 and Bijnot-1 during 1994 and 1996 respectively, to explore

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the potential of Infra- Cambrian reservoirs in the basin. Fortabbas-1 was not drilled down to Infra-Cambrian and was plugged and abandoned in the Salt Range Formation at 1651m depth. Bijnot-1 encountered Infracambrian reservoir in a well defined structural closure and there were very good oil shows during drilling but somehow the well was not tested on the basis of log results. In the recent past, OMV drilled Suji-1 in 2000. Suji-1 failed to find Infra-Cambrian reservoirs and drilled some 100m into basement rocks (Sheikh *et, al.,* 2003**). (Table 1).**

Table-1: Summary of wells drilled in Punjab Platform (After Peters *et. al.*, 1995).

S.No	WELLS	OPERATOR	YEAR	KBE(M)	TD(M)	TD FORMATION	STATUS
01	Karampur-01	SHELL	1958	142.33	3034.1	Basement	ABD
02	Bahawalpur East-01	SHELL	1980	135	3024	Basement	ABD
03	Marot-01	SHELL	1981	143	2596	Basement	ABD
04	Bijnot-01	OGDCL	1996	129.4	1914	Basement	ABD
05	Suji-01	OMV	2000	110	2626	Basement	ABD
06	Sarai Sidhu-01	AMOCO	1973	145.26	3279.5	Salt Range	ABD
07	Darbula-01	OGDCL	1989	184	1550	Salt Range	ABD
08	Fort Abbas-01	OGDCL	1994	144	1651	Salt Range	ABD
09	Bahu	OGDCL	2006	145.6	2936	Salt Range	ABD
10	Kamiab-01	AMOCO	1974	163.18	2298.4	Samanasuk	ABD
11	Piranwal-01	OGDCL	1986	143.7	2581	Baghanwala	ABD
12	Tola-01	AMOCO	1974	146	1828.7	Warcha	ABD
13	Panjpir-01	OGDCL	1985	142.3	2120	Tredian	Gas
14	Nandpur-01	OGDCL	1984	141.5	2110	Kingriali	Gas
15	Amir Wali-01	OGDCL	2005	144.7	2049	Kingriali	ABD
16	Ali Sahib-01	OGDCL	2005	142	2052	Kingriali	ABD
17	Jander-01	OGDCL	2005	143	2055	Kingriali	ABD
18	Chak-12-1	OGDCL	2006	135	2130	Kingriali	ABD
19	Bagh X-01	OGDCL	2006	148.57	1398	Kingriali	ABD
20	Ahmedpur-01	POL	1992	114.6	2634	Datta/Shinwari	ABD
21	Jiwanwala-01	OGDCL	1999	131.4	2100	Shinwari	ABD
22	Budhuana-01	AMOCO	1974	153.7	1279.5	Samanasuk	ABD
23	Saro-01	OGDCL	1992	166.7	1040	Samanasuk	ABD
24	Baghewala-1	OIL	1991			Basement	OIL
25	Pugal-1	OIL	1960			Salt Range	ABD

The discovery of non-biodegraded- sulfur rich heavy oil (API 17.6) from Baghewala-1 (Fig. 1) in 1991 in multiple zones of the Lower Paleozoic sequences were the first record of oil in the Bikaner-Nagaur Basin. The reported reserves are 94 MMT (628 MM BBL). Subsequently 3 wells have been nearby in Pakistan with no commercial success. It is felt that the oil discovery of Baghewala-1and good oil shows in the wells Bijnot-1 and Karampur-1 are quite encouraging and indicate an underexplored new exploration play in the southern part of Punjab Platform. Heavy oil of Karampur-1 from Salt Range Formation is geochemically similar to Baghewala oil. This study shows our understanding of the distribution of the Jodhpur and Bilara reservoir rocks of Infra-Cambrian age on the basis of well and seismic data from Pakistan and India (Sheikh *et al.,* 2003).

Geological Setting:

Punjab Platform dips westward into the Sulaiman Foredeep. The Sargodha High makes the north-eastern boundary, while is bounded by Jaisalmer-Mari-Kandhkot High in the south. Towards east, it extends into Bikaner-Nagaur Basin of India **(Fig. 1).**

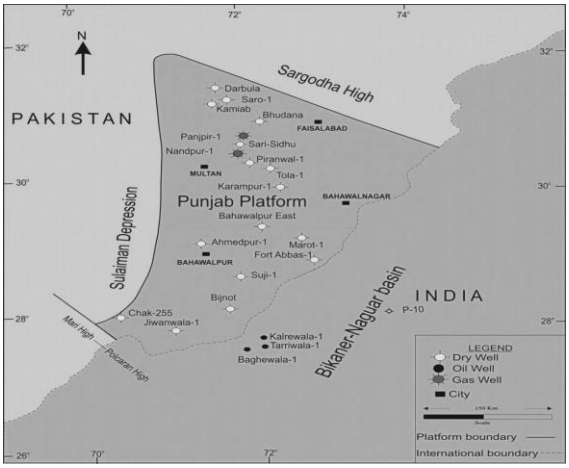

Fig.1: Map showing Punjab Platform and Bikaner-Nagaur Basin with well locations

Punjab Platform, the geological study of area is based on seismic, well logging and drilling information. Punjab Platform is covered with thick alluvium deposits of clay, silt and sand layers. The sub-surface geology of Punjab Platform consists of rocks from Pre-Cambrian to recent age.

Stratigraphy:

Geologists have correlated the Infra-Cambrian stratigraphy on the Punjab Platform with the Bikaner-Nagaur Basin of India by integrating the existing geological and geophysical data including wells of Pakistan with India (Fig.1) in order to understand the Infra-Cambrian stratigraphy and its hydrocarbon prospects.

Subsurface geological data indicate the Precambrian basement rocks are comprised of granites, unfossiliferous metasediments and metavolcanics. The oldest rocks encountered in Punjab Platform through drilling are of Infracambrian Salt Range Formation. Pre - Himalayan orogenic movements have resulted in prolonged uplifts/sea regression causing unconformities. As a result, several salt cored anticline structures are expected in the southern portion of this monocline (Kadri, 1995 and Humayun *et al.,* 1991). Only the scattered outcrops of Precambrian shield rocks are present in Sargodha, Kirana, Shahkot and Sangla Hill area (Shabih *et al.,* 2005). The generalized Stratigraphic sequence in Bikaner-Nagaur Basin, India **(Table-2)** is based at outcrops and from the wells drilled in India and Pakistan.

Infra-Cambrian:

The oldest Infracambrian sediments overlying the basement are Jodhpur Formation of Bikaner-Nagaur basin of India (Sheikh *et al.,* 2003), consists of sandstone, siltstone, shale, claystone, and dolomitic limestone.

Table-2: Stratigraphic Succession in Bikaner-Nagaur Basin (modified after Gupta and Bulgauda).

AGE		SUCCESSION ESTABLISHED BY THE GSI	SUCCESSION ENCOUNTERED IN OIL WELLS
QUAT.	Pleistocene-Recent	Alluvium	Alluvium
TERTIARY	Eocene	Marh	Marh
	Paleocene	Palana	Palana
MESOZOIC	Cretaceous		Parh equivalent
	Jurassic		Lathe equivalent
	Permo. Triassic	Badhaura	Badhaura
PALEOZOIC	Cambrian	Upper Carbonate	Upper Carbonate
		Nagaur	Nagaur
	Infra-Cambrian	Hanseran	Hanseran
		Bilara	Bilara
		Jodhpur	Jodhpur
	Pre-Cambrian		Milani Suite

followed by Bilara Formation comprising of dolomite and limestone. The Jodhpur and Bilara Formations are both exposed in the western part of Bikaner-Nagaur basin of India and extend towards north and northwest into Salt Range including Kirana area (Sargodha Hills) and have been drilled in Bijnot-1 and Bahawalpur East-1 wells of Punjab Platform and Baghewala-1 of Bikaner-Nagaur Basin (Sheikh *et al., 2003*) **(Fig. 2).**

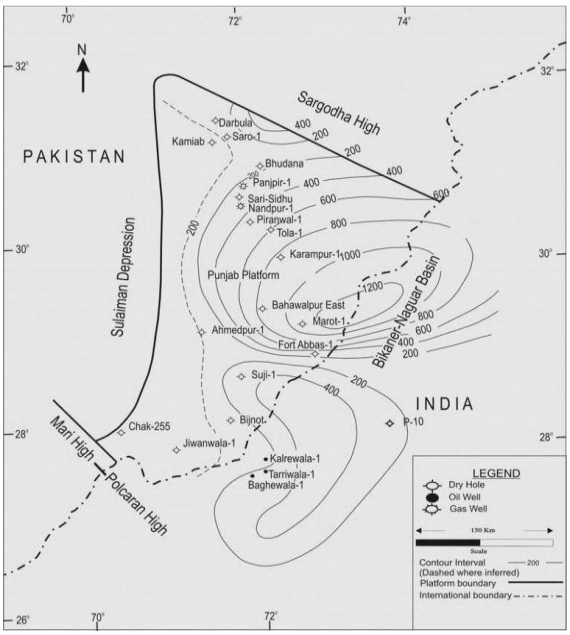

Fig.2: Isopach Map of Infracambrian

Geology and Tectonics:

The rifting of Indian Plate as part of Gondwanaland super-continent started in Late Proterozoic time. which resulted in the deposition of Infra-Cambrian sediments over the Pre-Cambrian basement. The Indo-Pakistan plate has experienced various tectonic events during Proterozoic including several episodes of volcanism associated with rifting. The rift associated faults are visible on seismic profile of Bikaner-Nagaur basin and Punjab Platform. The offset of basement rooted normal faults in Bikaner-Nagaur basin is quite pronounce. General trend of the horst and graben appears to be north-south whereas shelf-slope-basin stretched from east to west. Drilling results suggests that over the basement rocks of Paleozoic to Cenozoic is present **(Fig. 3,4).**

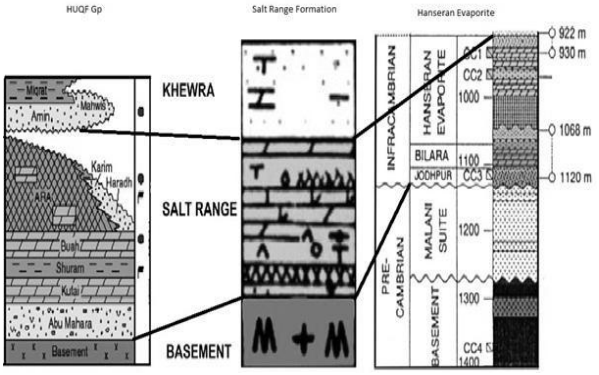

Fig.3: Regional Stratigraphic Correlation

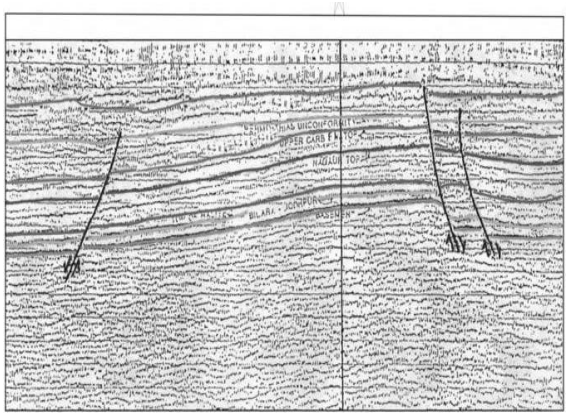

Fig. 4: Seismic section through well BGW-01 showing Rift associated features of Infra-Cambrian time (Reinterpreted after Gupta and Bulgauda 1994).

Basement received sedimentation during Infracambrian by marine transgression, which resulted in deposit of shallow marine siliciclastics in the shallow shelf through fluvial influx .The deposition of carbonates t took place at the shallow and broad shelf. During cyclic sea level change, evaporites were deposited including massive rock salt. Subsidence,

possibly due to reactivation of the basement faults provided additional accommodation space in the grabens, which is considered being preferential site for siliciclastics deposition (Paliwal, 1992). This added accommodation space is interpreted to be the reasons for considerable sediments thickness at Punjab Platform. Punjab Platform owing to its distant location to the site of major tectonic event remained mostly undisturbed. However, minor tectonic events appear to have re-modified the preexisting structures. Salt and evaporites may have also participated in the structuring. In Punjab Platform, the second rift phase is not much visible due to the dragging effect of Infra-Cambrian strata.

Petroleum System:

Infra-Cambrian rocks exhibits complete petroleum system. The producing fields (Nandpur and Panjpir) in the north-west indicate the presence of a valid petroleum system in the area.

Source Rocks:

The geochemical studies demonstrated that Infra-Cambrian shales are potential source rocks in the Punjab Platform. The Infra-Cambrian salt range formation has adequate organic richness but its distribution is not thick wide enough and suffers **(Fig.5).**

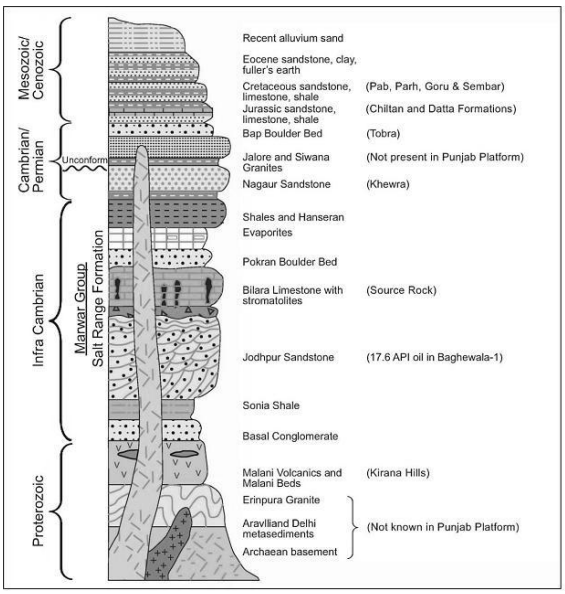

Fig.5: Lithostratigraphic column of the Aravalli Range (Rajasthan, India), where entire section from Proterozoic to quaternary are exposed at various localities. These sections helped to identify the diverse Lithostratigraphic distribution of Infracambrian in Punjab Platform. Modified after (Pareek 1981, 1983Paliwal 1992 and Peters *et al.*, 1995).

Karampur well the oil was discovered, but it was too viscous to produce. In contrast with Bikaner-Nagaur basin in India, significant reserves of oil have been discovered in the Baghewala area close to the border with Pakistan. On Pakistani side commercial accumulation of gas at Panjpir and Nandpur were discovered. The gas has high Nitrogen and Carbon dioxide contents. Geochemical studies indicate that Infra-Cambrian / Cambrian are the principal source rocks in the area. It has been postulated that significant amount of hydrocarbon could be generated, if these are buried to a sufficient depth.

Infracambrian:

A large number of oil and gas fields, including the giant ones, have been discovered in the Infracambrian of the Siberian Platform and Oman (Bois *et. al.*, 1982 and Hunt, 1979). This emphasizes the suitability of more extensive hydrocarbon exploration in the Infracambrian of the Punjab Platform.

In eastern Salt Range, Infracambrian is extensively rich in Total Organic Carbon (TOC) up to 30% with yield capacity of more than 20% rock weight. Infracambrian oil from Oman has strong resemblance and considered comparable source type as found in the heavy oil of Karampur-1 and oil seepage of Salgi Nala, Salt Range, Punjab (Ahmed and Alam, 1999 and Peters *et. al.*, 1995) **(Fig. 6).**

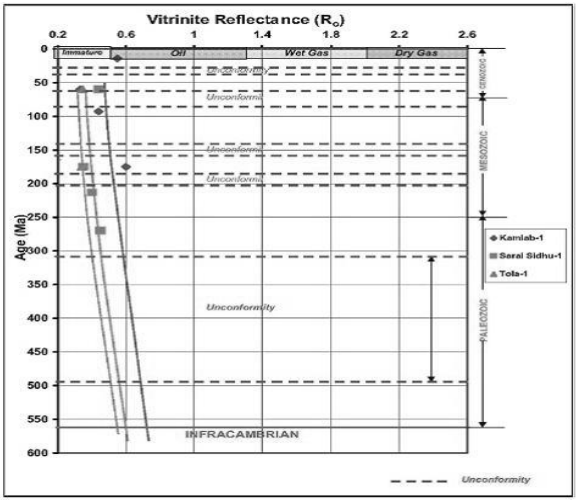

Fig.6: Plot showing Vitrinite reflectance (VR) vs. Geological Time scale. Three wells data of Kamiab-1, Sarai Sidhu-1 and Tola-1 have been used for determining the possible thermal maturity in Infracambrian. The trend shows that Infracambrian falls within oil generation window (For well locations, refer Fig.1).

Bilara Formation:

Heavy oil (probably immature) has been found in Baghewala, Bijnot and Kalrewala wells of Bikaner-Nagaur basin of India. The result of geochemical studies indicates that the source of oil is the dolomite of Bilara from lack of maturity due to insufficient depth of burial. However it is possible and even likely that these rocks might have attained adequate maturity in Paleo lows. In

Formation. These fancies also extend into Punjab Platform (Sheikh *et al.,* 2003) and have been deposited in structural lows (graben areas), where they may survive as potential source rock under optimum thermal conditions.

Jodhpur Sandstone:

Baghewala-1, heavy oil was discovered in Bikaner-Nagaur basin in Rajasthan, India from Infracambrian Jodhpur sandstone (Peters *et al.,* 1995). analysis of the oil suggest that charge of the oil primarily sourced from Infracambrian source. The heavy oil is non-biodegraded sulfur rich oil (API 17.6) and age diagnostic biomarker supports the presence of source potential in Infracambrian and provides a basis for consideration that chances for finding mature source will be higher in Punjab Platform area due to increasing depth (Hasney *et al.,*).

Salt Range Formation:

Two types of source facies in Salt Range Formation have been identified. The upper part contains lenticular bodies of high-grade oil shales whereas low-grade oil shales are present in the middle part, which is laterally more consistent, but their thickness varies from few centimeters to few meters (Ahmed and Alam, 1999). Most of the maturity data indicate marginal mature source (GEOCHEM, 1989; I.E.D.S., 1995, OMV, 2000, and Pakistan Petroleum Limited, 2005).

Karampur-1 heavy oil from Salt Range Formation interpreted to be geochemically similar with Indian oil (Peters *et. al.,* 1995). It also suggests the occurrence of potential Infracambrian source, which falls in early oil window. We have collected the Vitrinite Reflectance (VR) data of Kamiab-1, Sarai Sidhu-1 and Tola-1 and plotted the VR data against the geological timescale in order to infer the expected deeper thermal maturity at Infracambrian level (Fig. 6). (GEOCHEM, 1989). This plot shows that Infracambrian has been in early oil generation window.

Source rock studies carried out by Shell Oil (PSPD) indicate that shales of Salt Range Formation qualify as source rock in Karampur-1 and Bahawalpur East-1. In Bijnot-1, the shales are poor in organic richness (TOC: 0.20%). However, in Fort Abbas-1, it has poor to marginal organic richness (TOC: 0.43–0.60%). The results of geochemical analysis of OGDCL are given in **(Table-3)**.

Maturity Modeling:

Maturity tends to increase with depth anddeeper source rocks expected to be present in Punjab Platform. However, wells failure analysis suggests.

Table-3 Stratigraphic Succession in Bikaner-Nagaur Basin (modified after Gupta and Bulgauda).

S.No	WELLS	TOC(%)	S1	S2	GP(Kg/t)	HI	Tmax(°C)
1	Bijnot-1	0.10-1.38	0.18-0.96	0.41-5.12	0.62-6.08	37-632	429-530
2	Fortabbas-1	0.10-1.15	0.41-8.02	1.51-5.81	9.82-11.62	256-505	434-435
3	Bahawalpur East-1	0.44-0.88	0.02-0.83	0.02-4.12	0.04-4.95	3-468	435-441
4	Marrot-1	0.07-1.33	0.03-1.00	0.03-1.34	0.06-1.84	0-185	411-447

Source rock parameters of Salt Range Formation (OGDCL).

that lack of favorable mature source rocks are the major reason of failures. (Hasany, *et al,* 2012).

Summary of Geochemical parameters:

Total organic Carbon(TOC) %	0.1-0.5 =Poor	0.5-1.0 =Fair	1.0-2.0 =Good	2.0-4.0 =V.Good
Generation Potential GP(Kg/t)	<2 =Marginal	2-6 = Moderate	>6 =Good	
Hydrogen Index HI	<300 =TypeIII	300-700 =typeII	>700 =TypeI	
Tmax(°C)	<430 =Immature	430-435 =early mature	435-465 =mature	

Geo-history analysis:

The burial history curve of Fort Abbas Well-01 **(Fig. 7)** shows the geo-history of rock units encountered in Fort Abbas Well-01. It can be seen that the oil shales of Salt Range Formation falls within oil window; however, these shales have poor to marginal organic richness (TOC 0.43-0.60). As the well is dry probably due to insufficient organic matter (HDIP Report 2007).

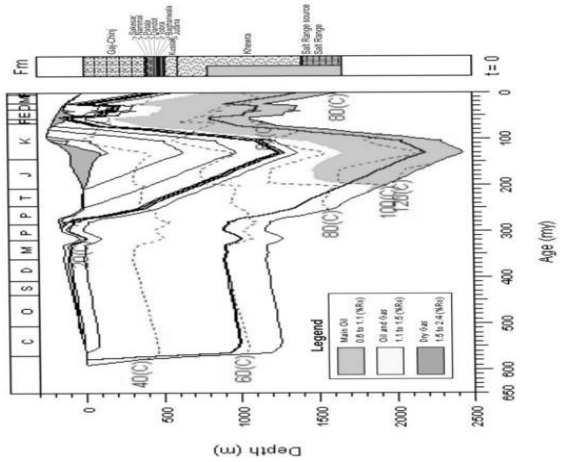

Fig. 7: Burial History Diagram Of Fort Abbas Well01. Plot Show Paleobathery, Isotherm And Depth And Time Of Oil Generation

3. RESULTS AND DUISCUSSION

Reservoir Rocks:

Several reservoir horizons have been identified in the region. Good reservoir quality sand exists in Infra-Cambrian and reported to be as oil reservoir in Baghewala Well-01 in Rajasthan state of India. Infra-Cambrian have high porosity carbonates

and Sandstones in Marot-01 and Bahawalpur East Well-01. To the south across the border of India **(Table 4),** heavy crude has been discovered at Baghewala Well-01 in Jodhpur Sandstone at the base of Infra-Cambrian Salt Range formation overlain by Shale and Dolomite having good source potential sealed by salt and anhydrites. The structure is Basement controlled feature. The discovery of Hydrocarbon in Baghewala suggests that Punjab Platform structures formed over Basement high should be looked for as source, seal and reservoir are likely to be present below Salt layers.

Reservoir	Kalrewala-1	Baghewala-1	Bahawalpur East-1	Marot-1	Bijnot-1
Gross(m)	0	32	30	30	19
Net(m)	--	11	8	13	8
N/G(%)	--	34	30	40	40
Porosity(%)	--	19-25	6-14	14-17	3-16

Table-4: Reservoir characteristics of Jodhpur Sandstone

Infracambrian:

Six Stratigraphic units in the Infracambrian are recognized (Paliwal, 1992, Pareek, 1981, Pareek, 1983, Peters *et. al.,* 1995). Oil production has been reported from Bilara Carbonate and Jodhpur Sandstone in Baghewala-1 (Peters *et. al.,* 1995).

We have adopted the Stratigraphic distribution of the Infracambrian as proposed by B.S. Paliwal (1992). Four out of six Infracambrian units have been identified in Infracambrian in Punjab Platform. These are Sonia Shale, Jodhpur Sandstone, Bilara Carbonates and Hanseran Evaporites.

4. CONCLUSIONS

The study indicates that tectonics, structural styles and stratigraphy of Bikaner-Nagaur basin of India are similar to Punjab Platform of Middle Indus basin, Pakistan. Therefore it is considered that the two basins are of the same geological age.

Geology and tectonic setup of Punjab Platform and Bikaner-Nagaur basin suggests a northeast-southwest directed extensional regime, caused due to Infra-Cambrian rifting.

The deposition of Jodhpur, Bilara and Salt Range Formations seem to have been controlled by features related to extensional tectonics, which resulted in the development of hydrocarbon traps associated with normal faults, on lap structure pattern and drop folds.

Geochemical analysis of well samples indicate that shales of Jodhpur, Salt Range, and Carbonates of Bilara, formations contain adequate organic carbon content but generally suffer from lack of maturity in the eastern part of Punjab Platform due to inadequate overburden.

Sandstones of Jodhpur, and carbonates of Bilara, formations show good to excellent reservoir characteristic in most part of Punjab Platform.

Discovery of heavy oil in Jodhpur, Bilara, Hanseran and upper carbonate formations at Baghewala, Tavriwala, Kalrewala structure of Bikaner-Nagaur basin of India, oil shows recorded in Salt Range Formation in Bijnot, bitumen in Salt Range Formation at Karampur, pieces of asphalt in lower and middle portion of Salt Range Formation at Fort Abbas, fluorescence in upper carbonate formation at Suji indicate an active petroleum system in the region.

Tectonic, structural and depositional history indicate that the Infra-Cambrian formations may act as effective source rock in the structural lows (Graben areas) and western part of Punjab Platform due to high thermal maturity related to increased overburden.

Recommendations:

The review of Seismic and well data of Punjab Platform and Bikaner Basin Suggests that wells drilled on Paleo-highs are dry mainly due to failure in finding Infra-Cambrian reservoirs. These well located on Paleo-lows did encounter Infracambrian Formations. This confirms the existence of Paleo-high during deposition of Infracambrian sediments. It should be noted that so far the exploration efforts in the area have been concentrated on exploring conventional structural plays, whereas, the depositional history of the area and the objective reservoirs as indicated by the seismic data evidence suggest that there is far greater possibility of finding Stratigraphic rather than structural plays in the area. Therefore, our future exploration efforts need to be focused in this direction.

The geological and seismic data demand that Infra-Cambrian reservoirs potential may be re-evaluated in the south-eastern part of Punjab platform particularly in the close proximity of Indian discoveries where source rock is believed to be of a localized nature.

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