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Hydrocarbon Prospects Of Punjab Platform Pakistan, With Special Reference To Bikaner-Nagaur Basin Of India

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ABSTRACT

The present study describes the petroleum geology and prospects of Punjab Platform on the basis of new play concepts utilizing geological, geophysical, geochemical, petrophysical and other relevant geoscientific data of both Punjab Platform and adjoining Bikaner-Nagaur basin of India. The synthesis of data indicates that Punjab Platform has tectonic, structural and sedimentary setting conducive to the generation and accumulation of hydrocarbons in Infra-Cambrian to Tertiary sedimentary succession in various parts of the study area.

The main oil producing Infra-Cambrian reservoir facies of Jodhpur sand and Bilara dolomite, of the Indian side of the platform, also extend into Punjab Platform and have been drilled in a few wells. Sandstones of Jodhpur, Khewra, Kussak, Baghanwala, Warcha, Amb, Datta, Shinawari, Lumshiwal/Lower Goru, Ranikot/Hangu and carbonates of Bilara, Samana Suk/Chiltan and Laki/Sakesar/Chorgali formations of Infra-Cambrian to Eocene age show marginal to very good porosity in Punjab Platform.

Geochemical studies conducted by HDIP on well samples indicate that shales of Salt Range, Amb, Datta, Chichali, Mughalkot, Ranikot and carbonates of Samanasuk, Parh and Dunghan formations ranging from Infra-Cambrian to Paleocene age contain adequate amount of organic matter in some wells.

Deposition of Jodhpur, Bilara and Salt Range formations is controlled by extensional tectonics, which resulted in the development of hydrocarbon traps associated with normal faults, onlap structures and drop folds.Other hydrocarbon traps are salt pushed anticlines formed from Infra-Cambrian to Eocene, normal fault blocks from Cambrian to Mesozoic and truncated Permian, Triassic, Jurassic and Cretaceous strata against Tertiary unconformity.

INTRODUCTION

The Punjab Platform is a westward dipping monocline covered by alluvium and is situated at the eastern segment of the central portion of Indus Basin, Pakistan. It is bounded by Sargodha high in the north, Mari High in the south and merges into Sulaiman depression in the west, towards east it extends into Bikaner-Nagaur Basin of India (Figure 1). Despite its large sedimentary area of approximately 69,000 sq km, the exploration activities were marginal with more than 24 wells drilled so far, which resulted in the discovery of three small gas fields in carbonates of Samana Suk Formation and sandstone of Lumshiwal Formation of Jurassic and Cretaceous age respectively at Nandpur, Panjpir and Bahu structures (Figure 2). However, the discovery of heavy oil (probably immature) at different stratigraphic levels in Infra-Cambrian-Cambrian age at Baghewala, Tavriwala and Kalrewala structures in Bikaner-Nagaur Basin of India near the Pakistan border (Figure 2) opened a new exploration play on Punjab Platform. Hence the present study is conducted to formulate and furnish information about regional tectonics, structural styles, source, reservoir and trap mechanism and to re-evaluate not only the hydrocarbon potentials of Infra-Cambrian-Cambrian formations but also the younger stratigraphic successions on Punjab Platform. The following publications and reports helped in developing the concept and conclusion of this study.

Hydrocarbon Development Institute of Pakistan (HDIP), Islamabad, Pakistan.

Dickinson (1953), Bakr and Jackson (1964), Shah (1977), Steckler and Watts (1978), Klootwijk and Peiree (1979), Powell (1979), Sclater and Christie (1980), Falvey and Middleton (1981), Schmoker and Halley (1982), Pareek (1981), Balli (1983), Searle et al., (1983), Bond and Kominz (1984), Patriat and Achache (1984), Baldwin and Butler (1985), Khan and Raza (1986), Dykstra (1987), Gupta et al., (1988), Malik et al., (1988), Soulsby and Kemal (1988), Bannert et al., (1989) Raza et al. (1989), Allen and Allen (1990), Duncan (1990), Lowell (1990), Porth and Raza (1990), Raza and Ahmed (1990), Raza et al., (1990), Ahmed and Ahmad (1991), Eickhoff and Alam (1991), Einsele (1991), Kemal et al., (1991), Gouze and Coudrain-Ribstein (1993), Waples and Kamata (1993), Ahmed et al., (1994), Duddy et al., (1994), Gupta and Bulgauda (1994), Sheikh et al., (2003), NELP-III, (2002). Karampur-1 (1959), Darbula (1970), Sarai-Sidhu (1973) Tola-1 (1974), Bhudana (1975), Kamiab (1975), Marot-1 (1981), Bahawalpur East (1981), Panjpir-1 (1986), Nandpur-2 (1986), Bijnot-1 (1998), Ahmedpur-1 (1992), Piranwala-1 (1993), Fort Abbas-1 (1994), Chak-255-1 (2000), Jiwanwala-1 (2000), Suji-1 (2000).

STRATIGRAPHY

In the past it was considered that Salt Range Formation is the oldest Infra-Cambrian unit overlying the basement. The wells drilled in Bikaner-Nagaur Basin reveal that the Salt Range Formation is underlain by Bilara Formation followed by Jodhpur Formation which overlies the basement (Gupta and Bulgauda, 1994, Sheikh et al., 2003). The correlation of well data of Punjab Platform and Bikaner-Nagaur indicate that these formations extend towards north and northwest into Punjab Platform including Kirana Hills (Sargodha high) (Sheikh et al., 2003). Accordingly the stratigraphy of Punjab Platform has been modified by incorporating the mentioned formations.

The stratigraphic succession established on the basis of drilling shows that the region contains mainly marine Paleozoic-Cenozoic rocks of clastic and carbonate origin and Neogene fluviatile sediments and are characterized by a number of unconformities.

Up to Early Late Triassic the stratigraphy of Punjab Platform is similar to that of Potwar sub-basin. From Late

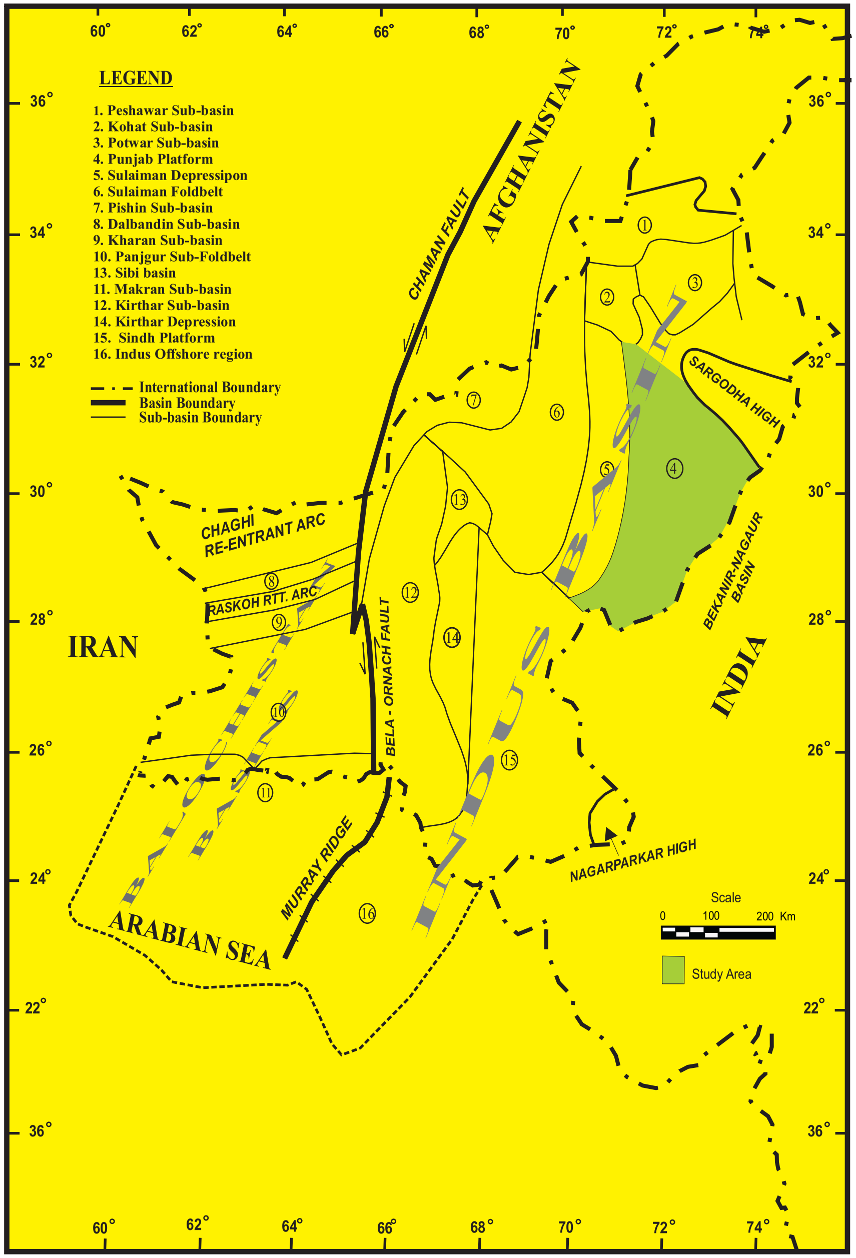


Figure 1 - Sedimentary Basin of Pakistan (Modified after Ahmed et al., 1994).

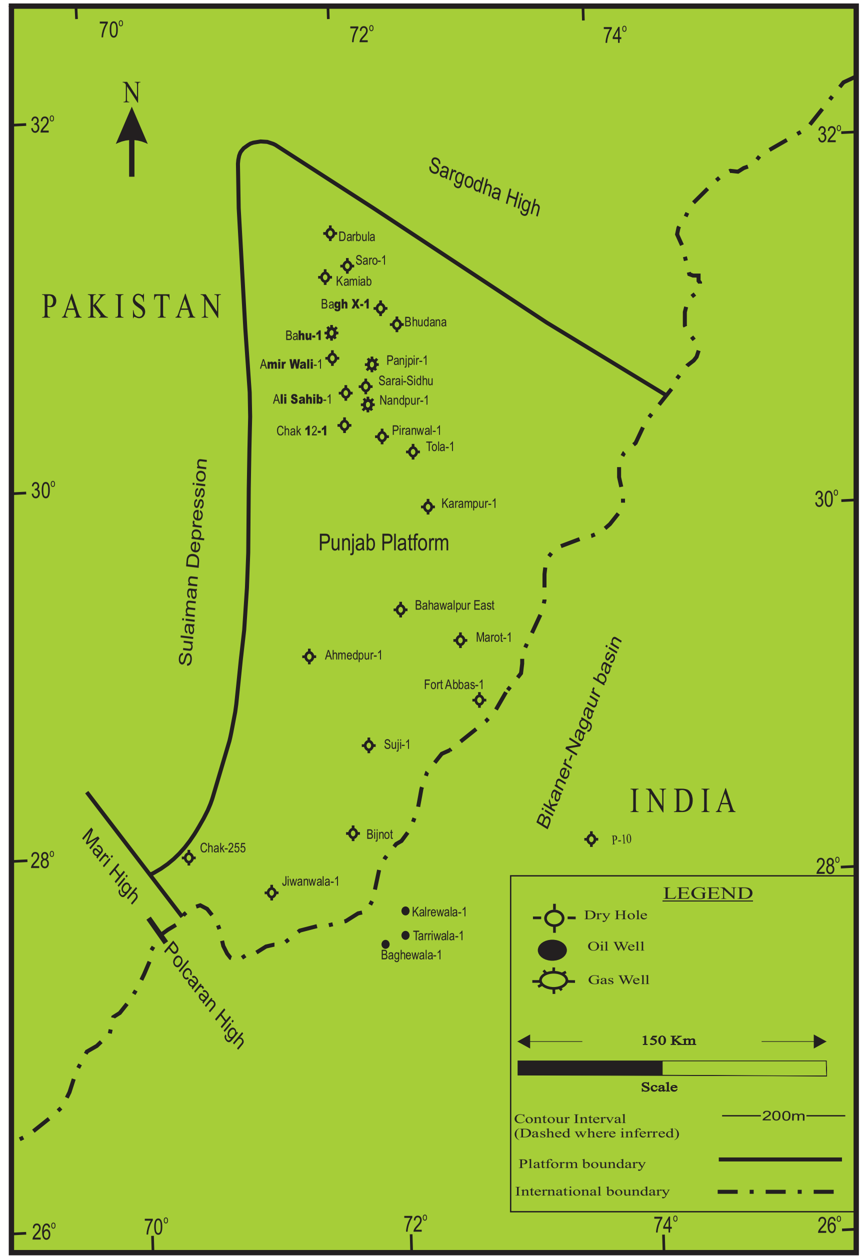


Figure 2 - Map showing Punjab Platform and Bikaner-Nagaur Basin with well Locations.

Triassic onwards the stratigraphy of the southern part is compareable to sindh plateform and the northern part has the same stratigraphic succession as Potwar (Figure 1).

The stratigraphic succession of Punjab Platform and Bikaner-Nagaur Basin is given in Tables 1 and 2 and their thickness and distribution is shown in Figures 3 to 11.

TECTONICS

The rifting of Indian Plate as part of Gondwanaland super-continent started in Late Proterozoic time (Kemal et al., 1991), which resulted in the deposition of Infra-Cambrian sediments over the Pre-Cambrian basement. 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 pronounced (Figure 12). Whereas in Punjab Platform the normal faults show minor displacement (Figure 13). After a long hiatus of about 250m.y Gondwanaland was once again subjected to rifting during Permo-Triassic time (Searle et al., 1983). This rift event is also visible on seismic profile of both Bikaner-Nagaur Basin and Punjab Platform (Figures 12 and 13). In Bikaner-Nagaur Basin the second phase of rifting can be explained by the small displacement of Permo-Triassic strata as compared to the large displacement of basement. In Punjab Platform the second rift phase is not very visible due to the dragging effect of Infra-Cambrian strata. The rifting of India from Africa and Madagascar probably started in Cretaceous time (Kemal et al., 1991). The evidence of rifting can be seen on the seismic profile of Punjab Platform where the reflectors of Cretaceous strata have been displaced along a system of normal faults (Figure 14). The northwards drift of Indian Plate started during Early Companian time Powell, 1979, Klootwijk and Peiree, 1979, Duncan, 1990), which continued till the continent to continent collision of Indian Plate with the Eurasian mass in the Late Eocene (Patriat and Achache, 1984). Subsequently, the Indian continental mass subducted under the Eurasian Plate. The process of subduction is still ongoing . In the west the collision of the Indian plate with the Eurasian plate is oblique along left-lateral Bela-Ornach-Chaman fault zone, which marks the western boundary of the Indian plate with the Eurasian plate and separates the two major sedimentary basins of Pakistan namely Indus Basin in the east and Balochistan Basin in the west (Figure 1).

STRUCTURAL STYLES AND HYDROCARBON TRAPS

Due to varied geodynamic conditions of, rifting, drifting, collision and under thrusting of the Indian Plate through geologic time, variable structural patterns have been developed in Punjab Platform and Bikaner-Nagaur Basin and are discussed as under.

Rift Associated Structural Patterns

Traps associated with normal faults developed as a result of Infra-Cambrian to Mesozoic rift episode in both Bikaner-Nagaur basin and Punjab Platform have been drilled at several locations such as Bijnot (Figure 15), Jiwanwala (Figure 16) and Bhagewala (Figure 12). The structural highs and lows developed as a consequence of Infra-Cambrian to Mesozoic rift event can be seen on regional scale in Punjab Platform and show an overall increase in depth towards west (Figures 17,18,19,20 and 21).

Paleogeographic and Salt-induced Structures

Seismic lines (Figure 13 and 22) show paleogeographic and salt-pushed structures at various stratigraphic levels on Punjab Plateform.

Stratigraphic Traps

The study of sub-surface data in Bikaner-Nagaur Basin and Punjab Platform indicates that the deposition of Jodhpur and Bilara formation of the Infra-Cambrian is controlled by paleo-highs formed as a result of Infra-Cambrian rifting. Figure 23, shows onlap of Jodhpur and Bilara formations encountered in Bijnot and Baghewala wells over paleo-high of Kaberwala structure forming stratigraphic traps. The stratigraphic traps may also be formed by the truncated Permian, Triassic, Jurassic and Cretaceous strata against Tertiary unconformity (Figures 18,19,20 and 21).

SOURCE ROCKS AND HYDROCARBON OCCURRENCE

INFRA-CAMBRIAN

Bilara Formation:

Heavy oil (probably immature) has been found in Baghewala, Tariwala and Kalrewala wells of Bikaner-Nagaur Basin of India (Figure 2). The result of geochemical studies indicate that the source of oil are the dolomite of Bilara Formation (Gupta and Sheikh). These facies also extend into Punjab Platform (Sheikh et al., 2003) and have been deposited in structural lows (graben areas), where according to our interpretation they may survive as potential source rock under optimum thermal conditions.

Salt Range Formation

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. The results of geochemical analysis of HDIP show moderate organic carbon content (TOC: 1.27-1.58%) with other geochemical parameters indicative of good source potential for hydrocarbon generation in Karampur-1 well. However in Bahawalpur East-1 the formation shows poor organic richness (TOC: 0.44%). In Bijnot-1 the shales are poor in organic richness (TOC: 0.20%). Whereas, in Fort Abbas-1, it has poor to marginal organic richness (TOC: 0.43-0.60%).

PERMIAN

Amb Formation

The result of geochemical analysis by PSPD indicates that shale of Amb Formation qualify as source rock in Sari-Sidhu well.

The results of geo chemical analysis conducted by HDIP on samples from Jurassic and Eocene strata as follow:

JURASSIC

Datta Formation

In Ahmedpur-1 the shales of Datta Formation indicate poor

Table 1 - Stratigraphy of Punjab Platform.

AGE			STRATIGRAPHY	
ERA	PERIOD	EPOCH	NORTHERN PART	SOUTHERN PART
CENOZOIC	Quaternary		Siwaliks	Siwaliks
CENOZOIC	TERTIARY	Pleistocene		
CENOZOIC	TERTIARY	Pliocene		
CENOZOIC	TERTIARY	Miocene		
CENOZOIC	TERTIARY	Oligocene		
CENOZOIC	TERTIARY	Eocene – late		Kirthar
CENOZOIC	TERTIARY	Eocene – Middle	Chorgali Sakesar Nammal	Laki/Ghazij
CENOZOIC	TERTIARY	Eocene – Early		
CENOZOIC	TERTIARY	Paleocene	Patala Lockhart Hangu	Dungan Ranikot
MESOZOIC	CRETACEOUS	late		Pab Mughalkot Parh
MESOZOIC	CRETACEOUS	Middle		Goru: Upper Goru
MESOZOIC	CRETACEOUS	Early	Lumshiwal Chichali	Goru: Lower Goru Sembar
MESOZOIC	JURASSIC	late	Samana Suk	Chiltan
MESOZOIC	JURASSIC	Middle	Shaniwari	Shirinab
MESOZOIC	JURASSIC	Early	Datta	
MESOZOIC	TRIASSIC	late	Kingriali	Wulgai Kingriali
MESOZOIC	TRIASSIC	Middle	Tredian	Tredian
MESOZOIC	TRIASSIC	Early	Mianwali	Mianwali
PALEOZOIC	PERMIAN	late	Chhidru	Chhidru
PALEOZOIC	PERMIAN	Middle	Wargal Amb	Wargal Amb
PALEOZOIC	PERMIAN	Early	Sardhai Warcha Dandot Tobra	Sardhai Warcha Dandot Tobra
PALEOZOIC	ORDOVICIAN-CARBONIFEROUS			
PALEOZOIC	CAMBRIAN	late		
PALEOZOIC	CAMBRIAN	Middle	Baghanwala Jutana	Baghanwala Jutana
PALEOZOIC	CAMBRIAN	Early	Kussak Khewra	Kussak Khewra
INFRA-CAMBRIAN			Salt Range Bilara Jodhpur	Salt Range Bilara Jodhpur
PRE-CAMBRIAN			Kirana	Kirana

Table 2 - Stratigraphic Succession in Bikaner-Nagaur Basin (modified after Gupta and Bulgauda, 1994).

ERA	Period Epoch	Succession Established by the GSI	Succession Encountered in Oil Wells
CENOZOIC	Quatnary Pleistocene-Recent	Alluvium(Sandstone)	Alluvium(Sandstone)
CENOZOIC	Eocene	Marth (Ferruginous sandstone and clay)	Marth (Ferruginous sandstone and clay)
CENOZOIC	Paleocene	Polana (Shale, sandstone and limestone)	Polana (Shale, sandstone and limestone)
MESOZOIC	Cretaceous		Parh equivalent (Claystone and sandstone)
MESOZOIC	Jurassic		Lathe Equivalent (Claystone, sandstone and coal)
MESOZOIC	Pemo-Triasssic	Badhaura (Conglomerates and claystone)	Badhaura (Conglomerates and claystone)
PALEOZOIC	Cambrian	Upper Carbonate (Dolostone, Limestone and claystone	Upper Carbonate (Dolostone, Limestone and claystone
PALEOZOIC	Cambrian	Nagaur (Siltstone, claystone and sandstone)	Nagaur (Siltstone, claystone and sandstone)
PALEOZOIC	Cambrian	Hanseran (Siltstone, Claystone and sandstone)	Hanseran (Siltstone, Claystone and sandstone)
PALEOZOIC	Infra-Cambrian	Bilara (Dolomite)	Bilara (Dolomite)
PALEOZOIC	Infra-Cambrian	Jodhpur (Sandstone, siltstone and clay)	Jodhpur (Sandstone, siltstone and clay)
Pre-Cambrian			Milani Suite

Figure 3 - Isopach Map of Infra-Cambrian.

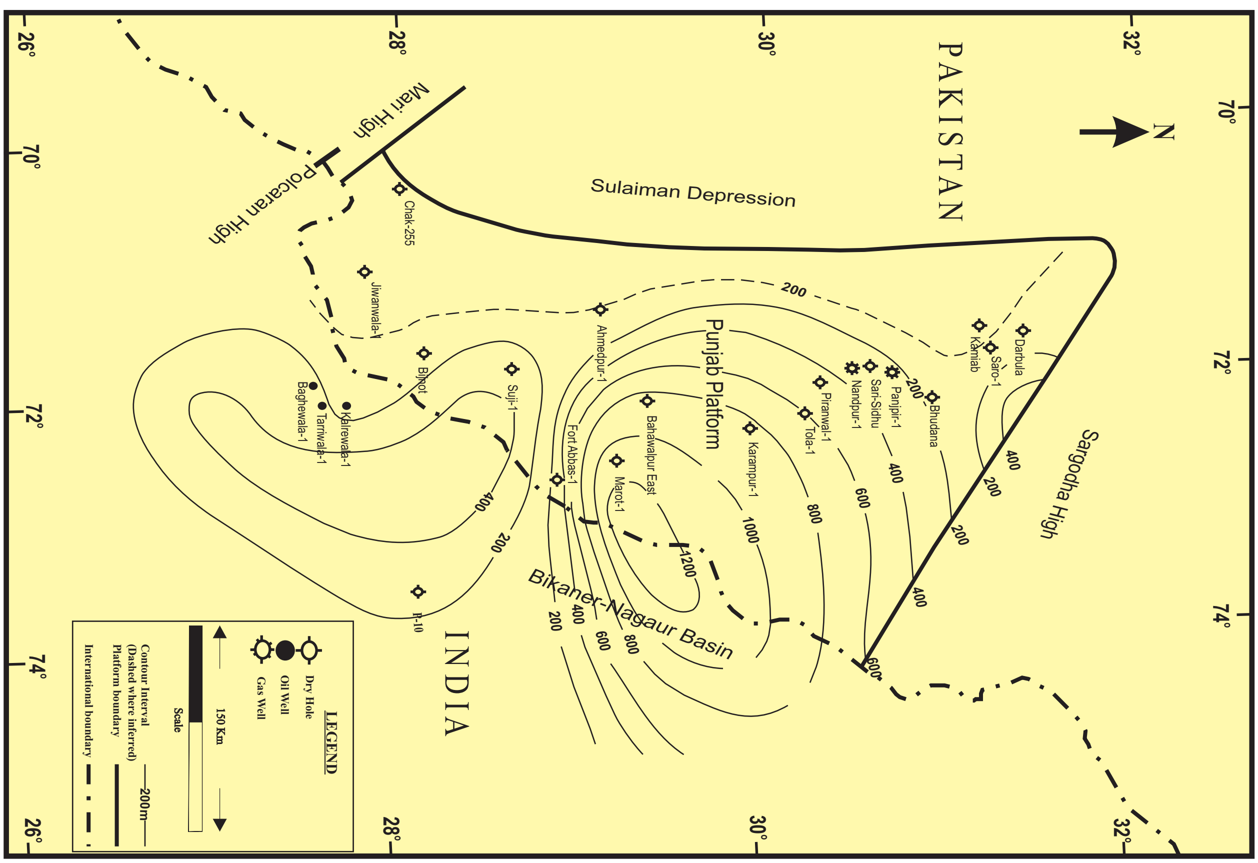
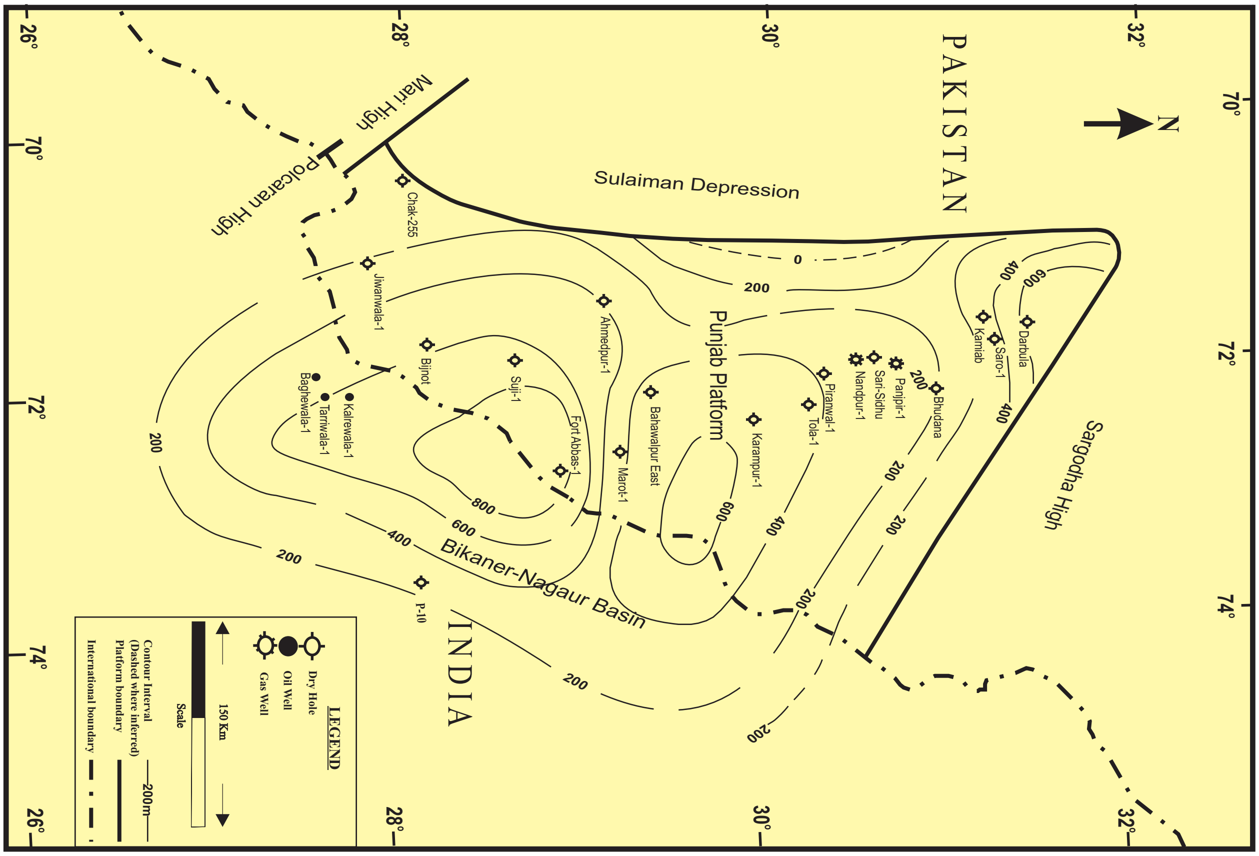


Figure 4 - Isopach Map of Cambrian.



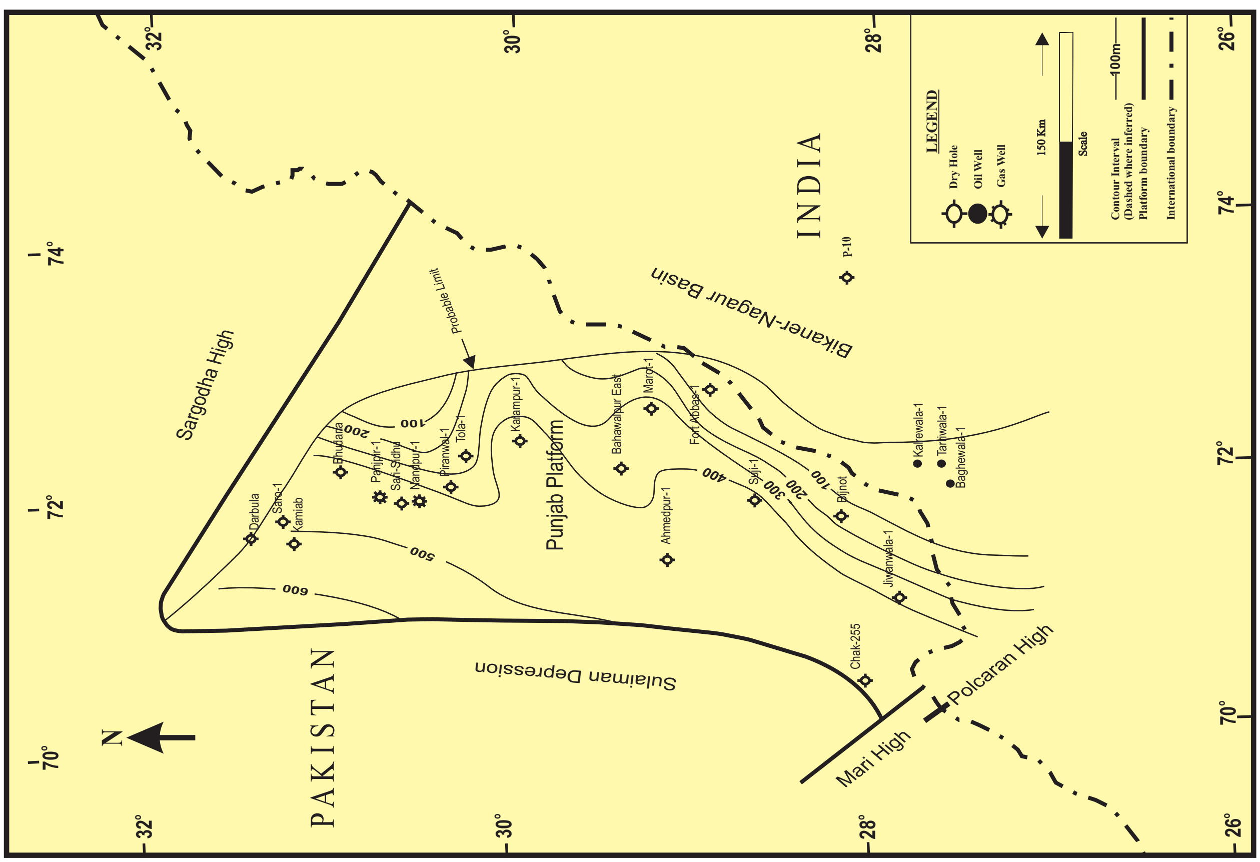


Figure 5 - Isopach Map of Permian.

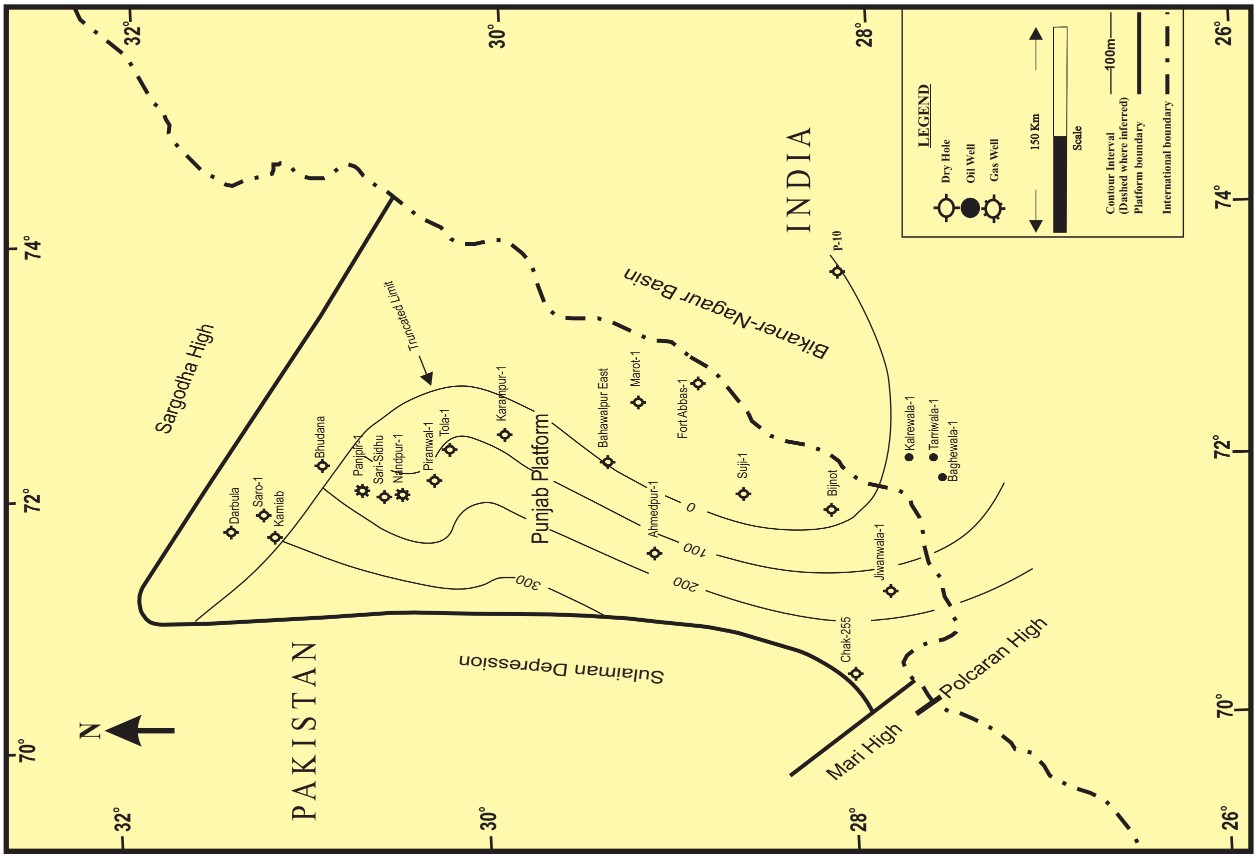


Figure 6 - Isopach Map of Triassic.

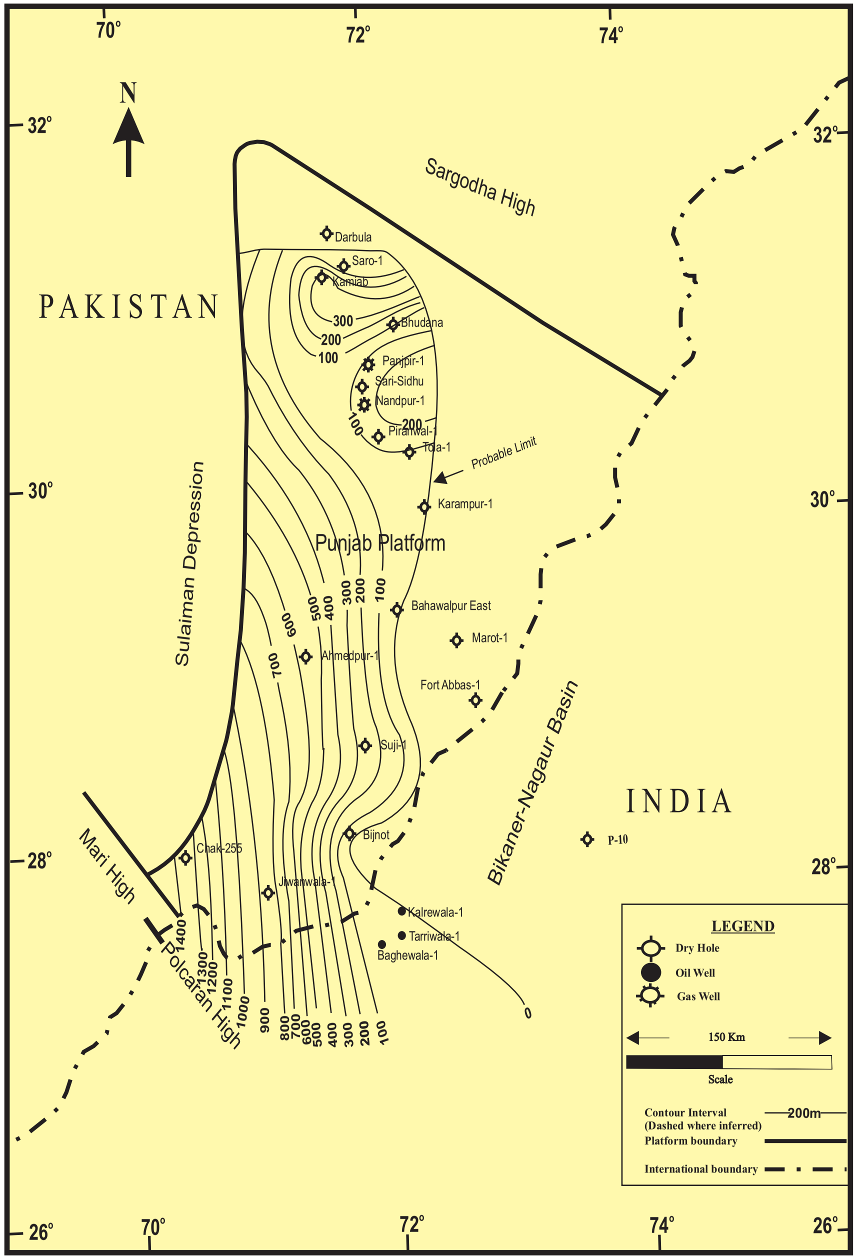


Figure 8 - Isopach Map of Cretaceous.

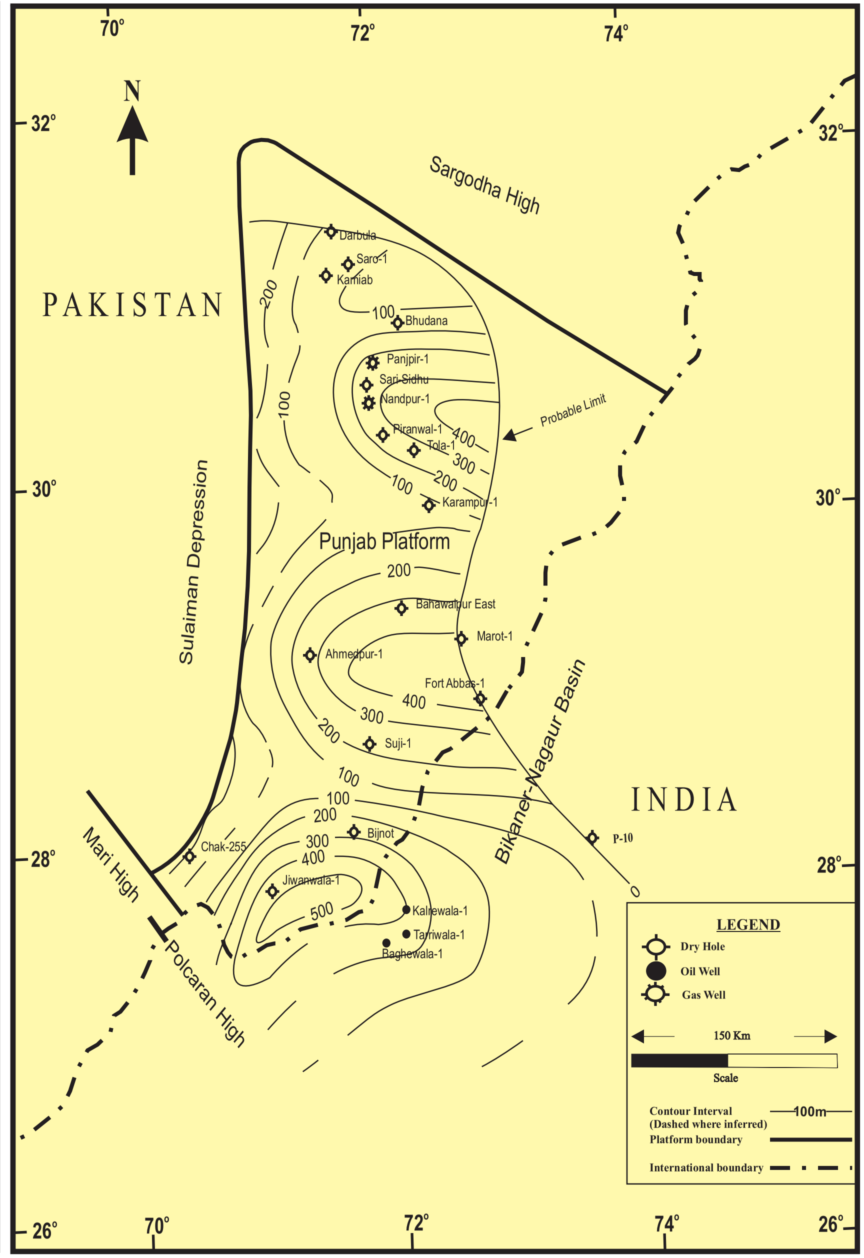


Figure 7 - Isopach Map of Jurassic.

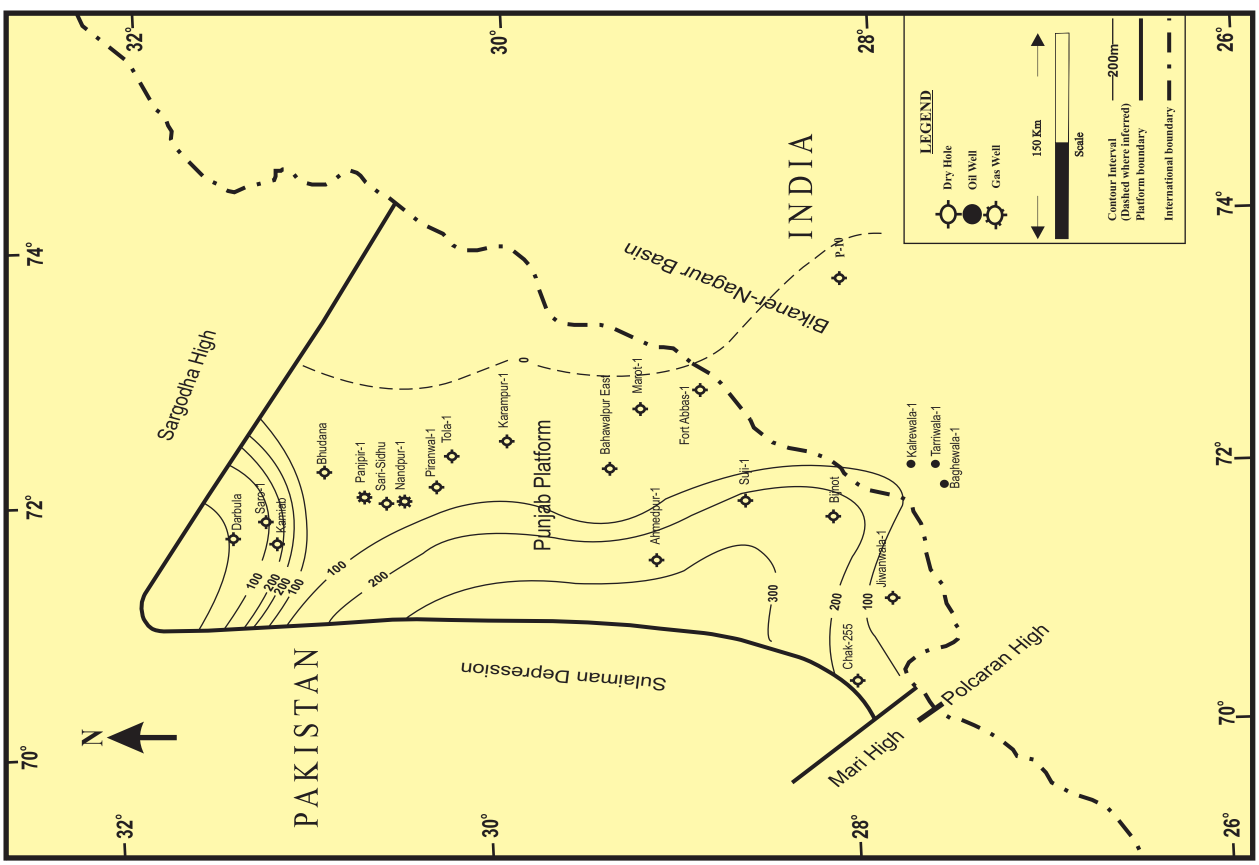


Figure 9 - Isopach Map of Paleocene.

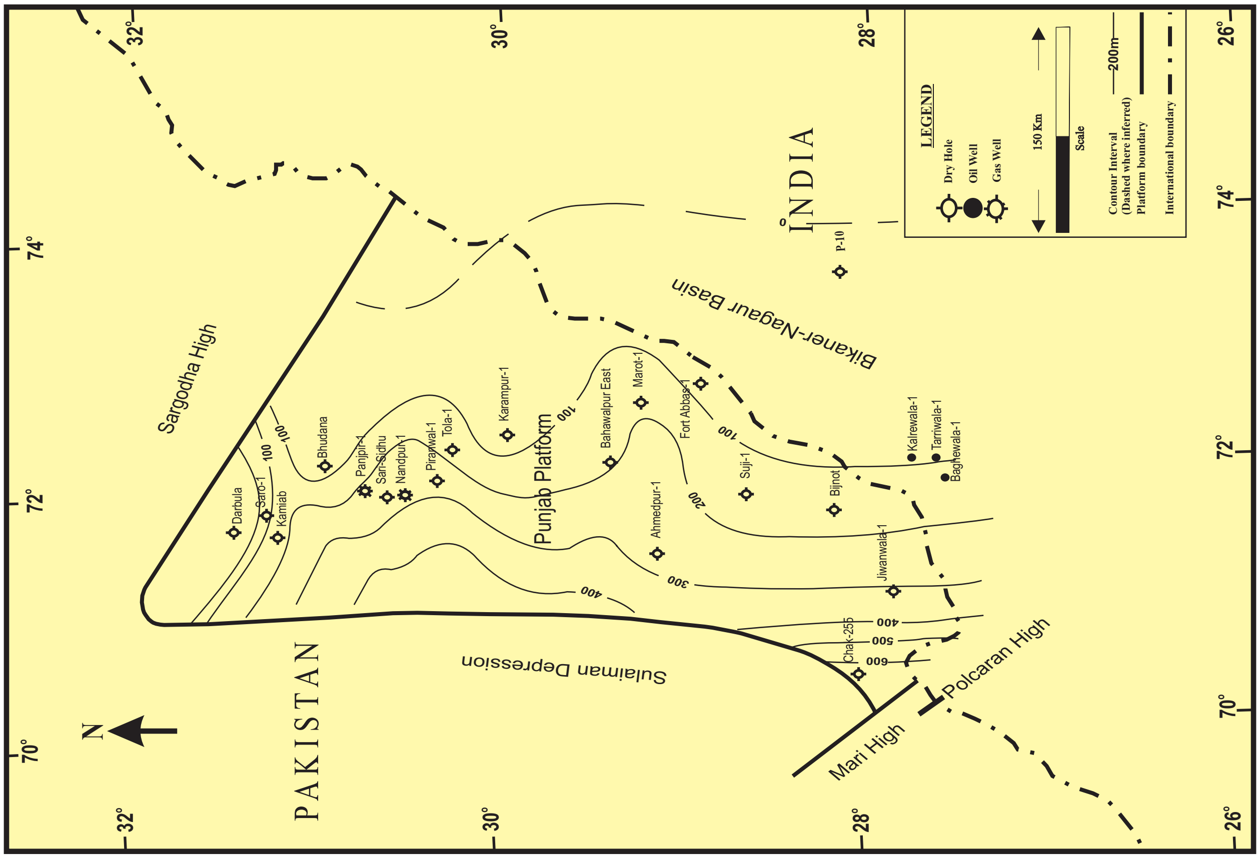


Figure 10 - Isopach Map of Eocene.

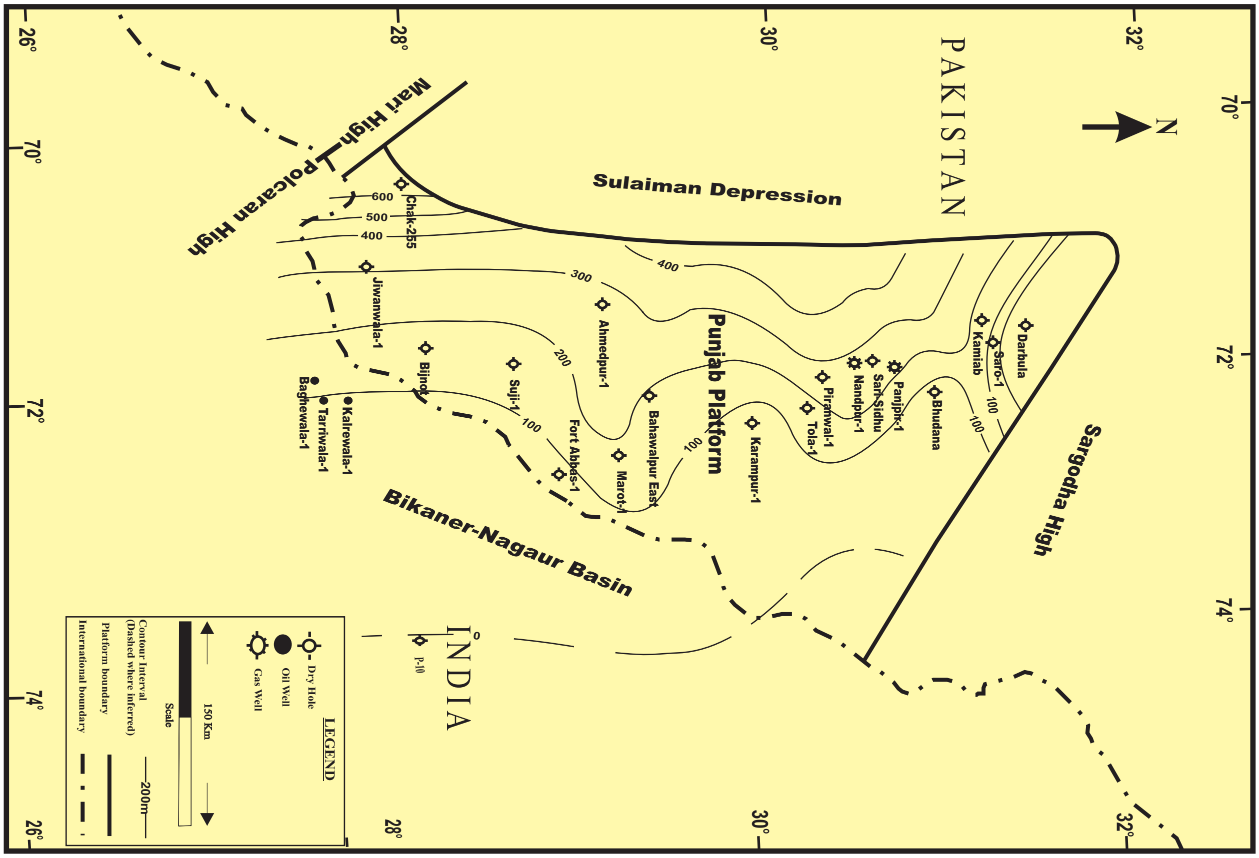


Figure 11 - Isopach Map of Siwaliks-Recent.

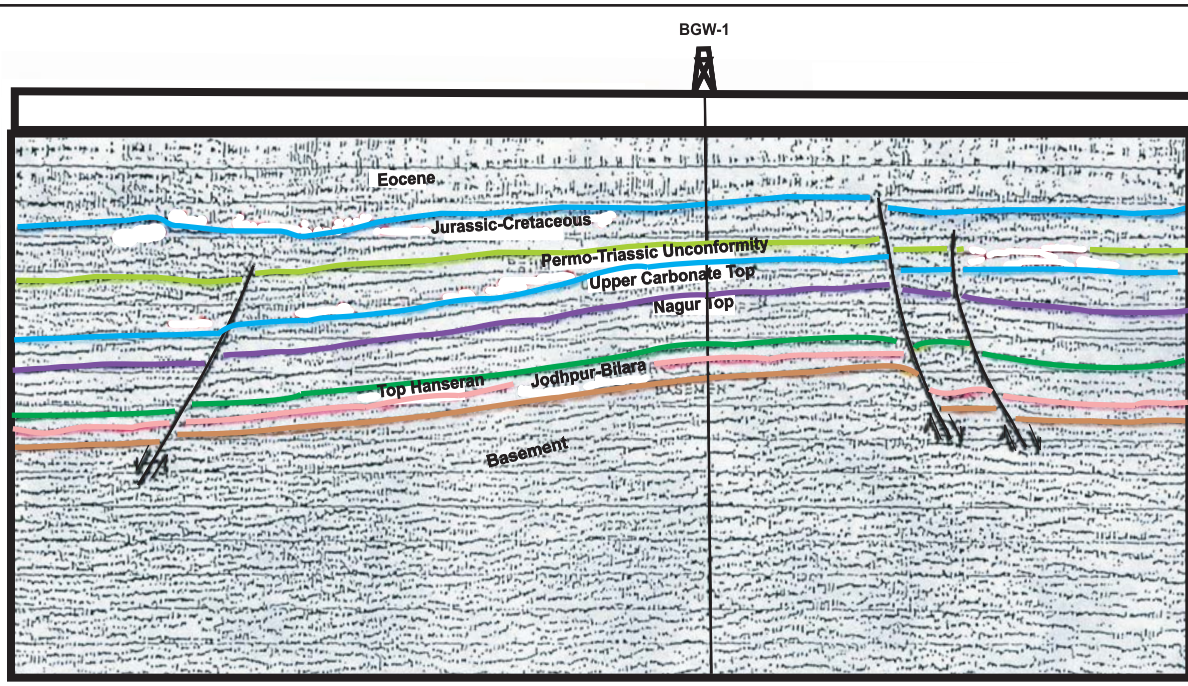


Figure 12 - Seismic section through well Baghewala-1 showing Rift associated Features of Infra-Cambrian and Permian time (Reinterpreted after Gupta and Bulguada 1994).

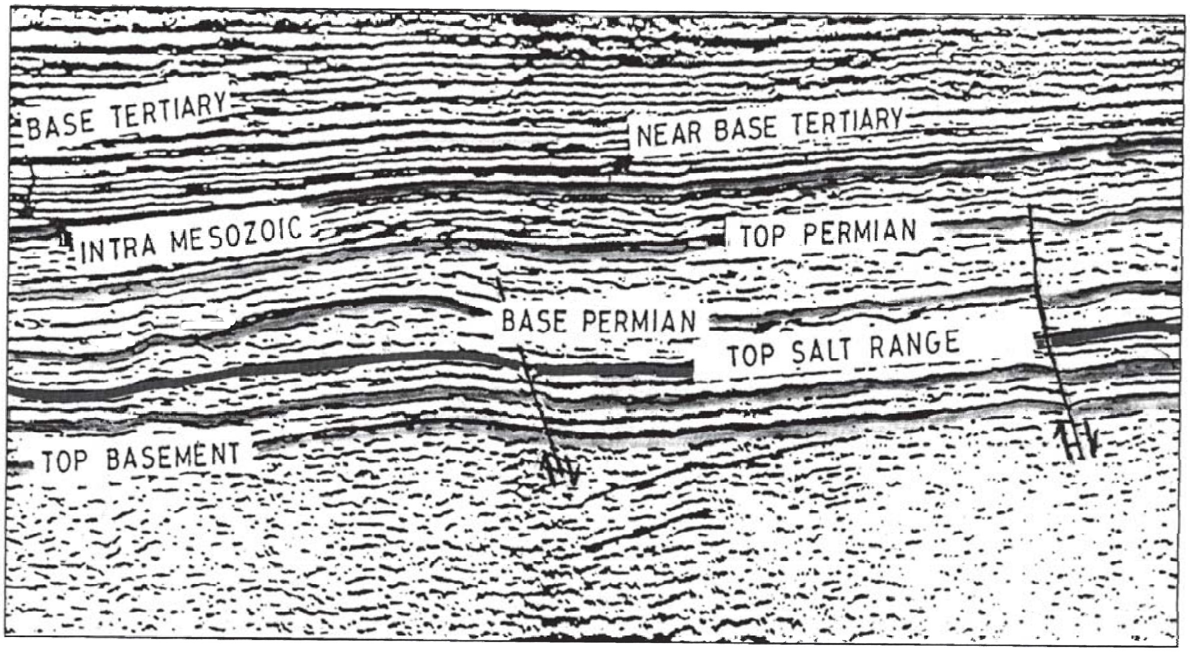


Figure 13 - Profile along Line 8 showing Paleogeographic Structure in Punjab Platform and evidence of Infra-Cambrian and Permian Rifting (Reinterpretted after Raza et al, 1989)

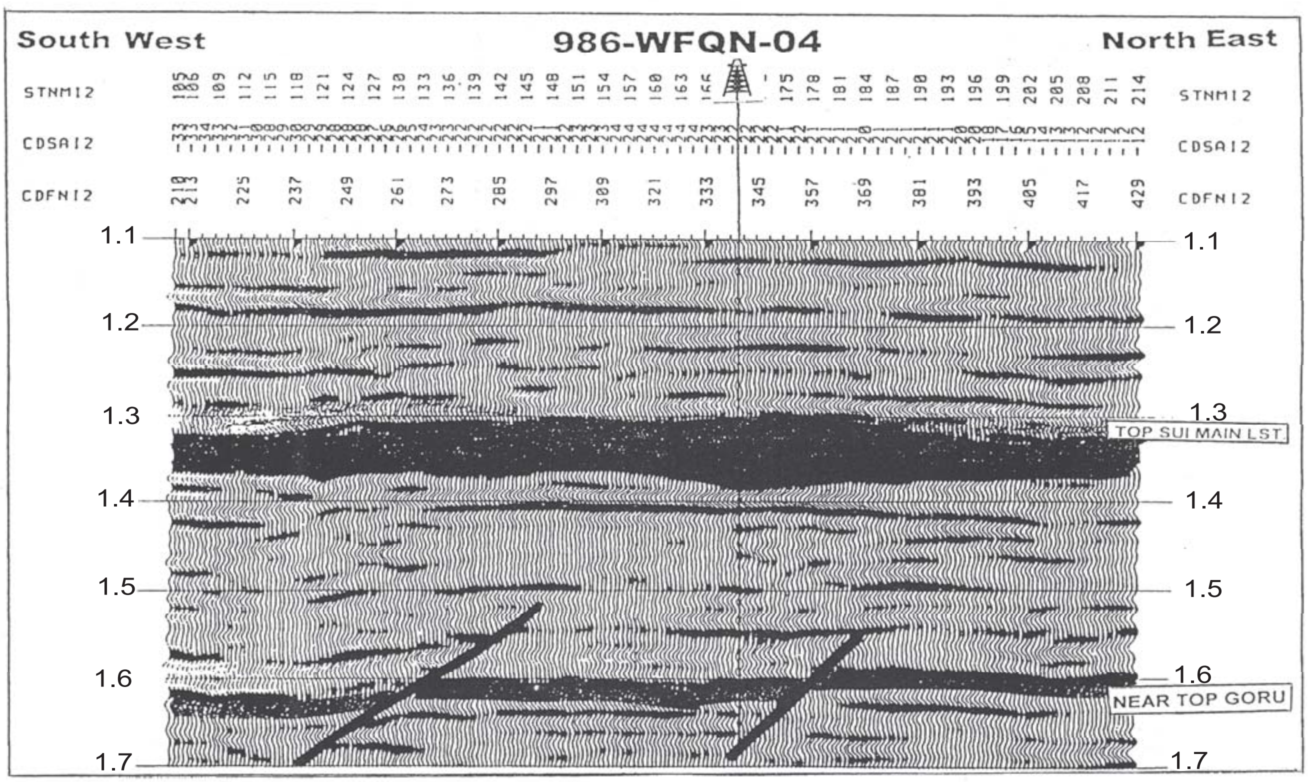


Figure 14 - Chak 255 No.1 Seismic Line 986-WFQN-04 showing Rift Features of Cretaceous Age.

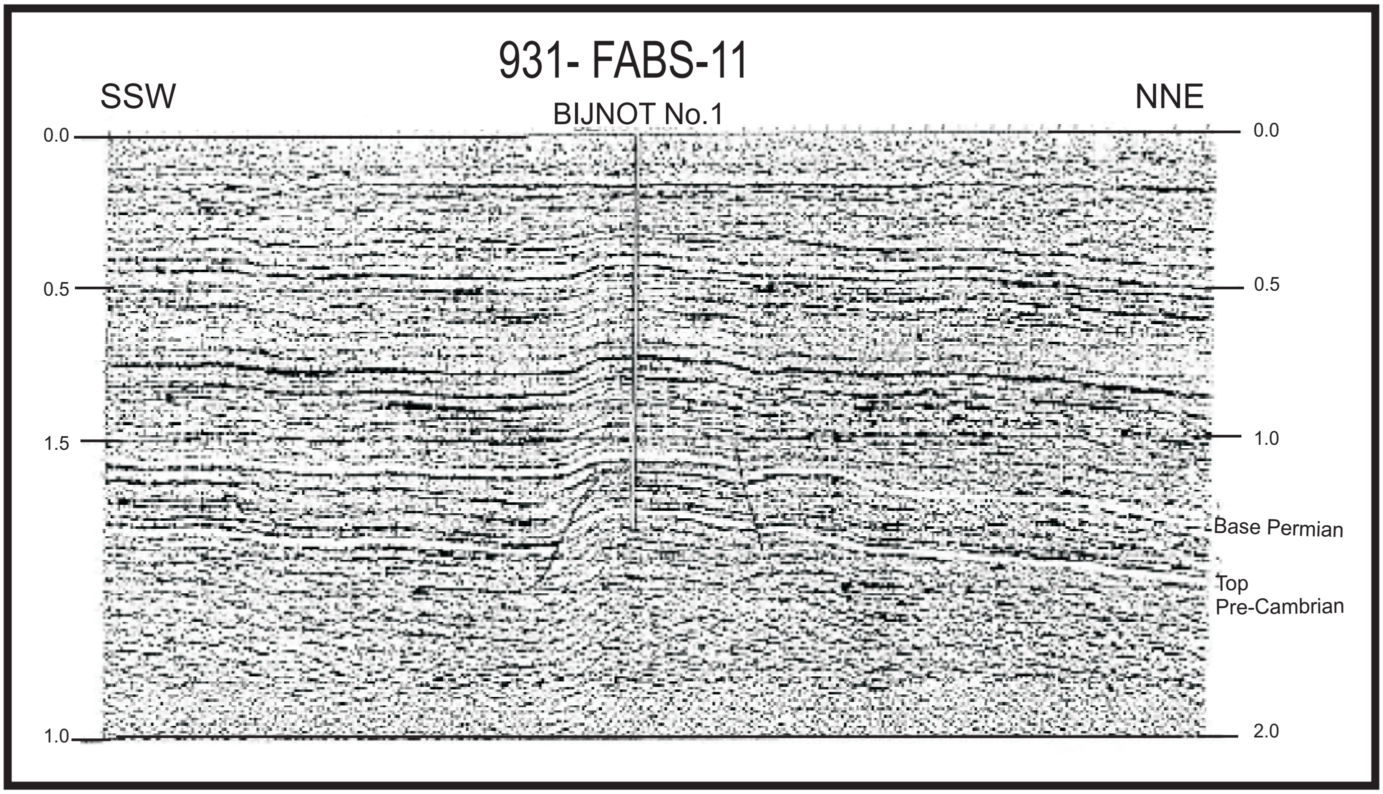


Figure 15 - Bijnot No. 1 Seismic Line 931-FABS-11 showing the development of Structural High as a consequence of Infra-Cambrian and Permian Rift Phase.

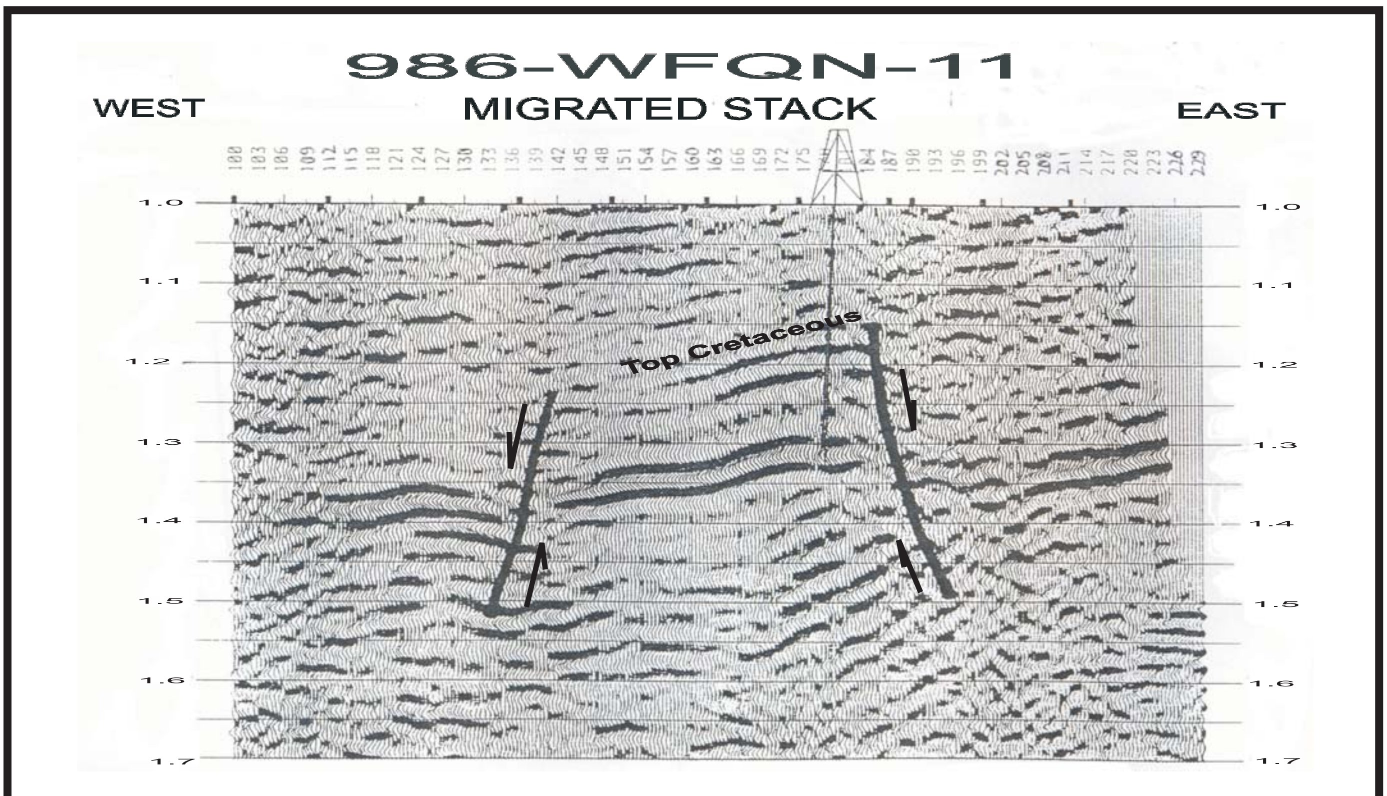


Figure 16 - Jiwanwala No. 1 Seismic Line 986-WFQN-11 showing the Development and Structural High as a result of Infra-Cambrian to Cretaceous Rifting.

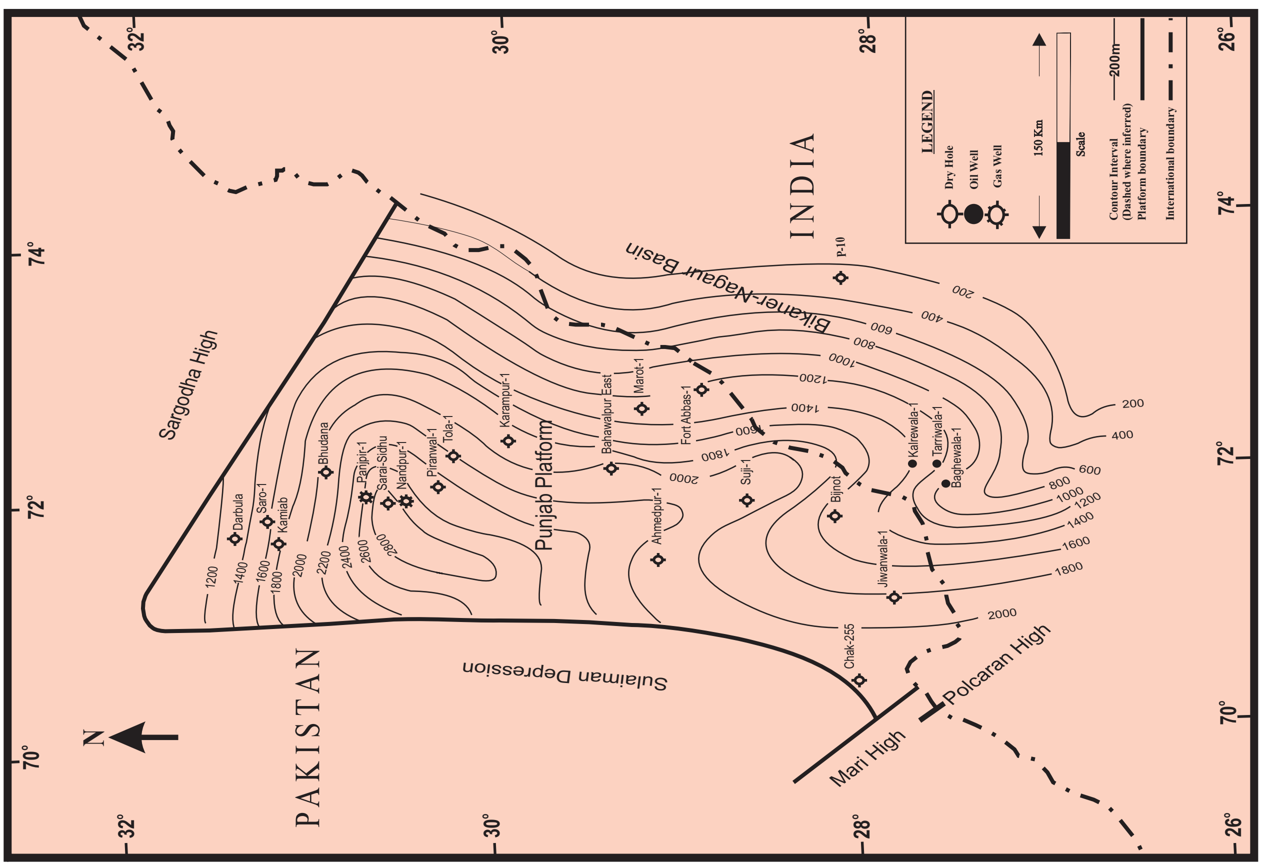


Figure 17- Structure Contour Map - Base Cambrian.

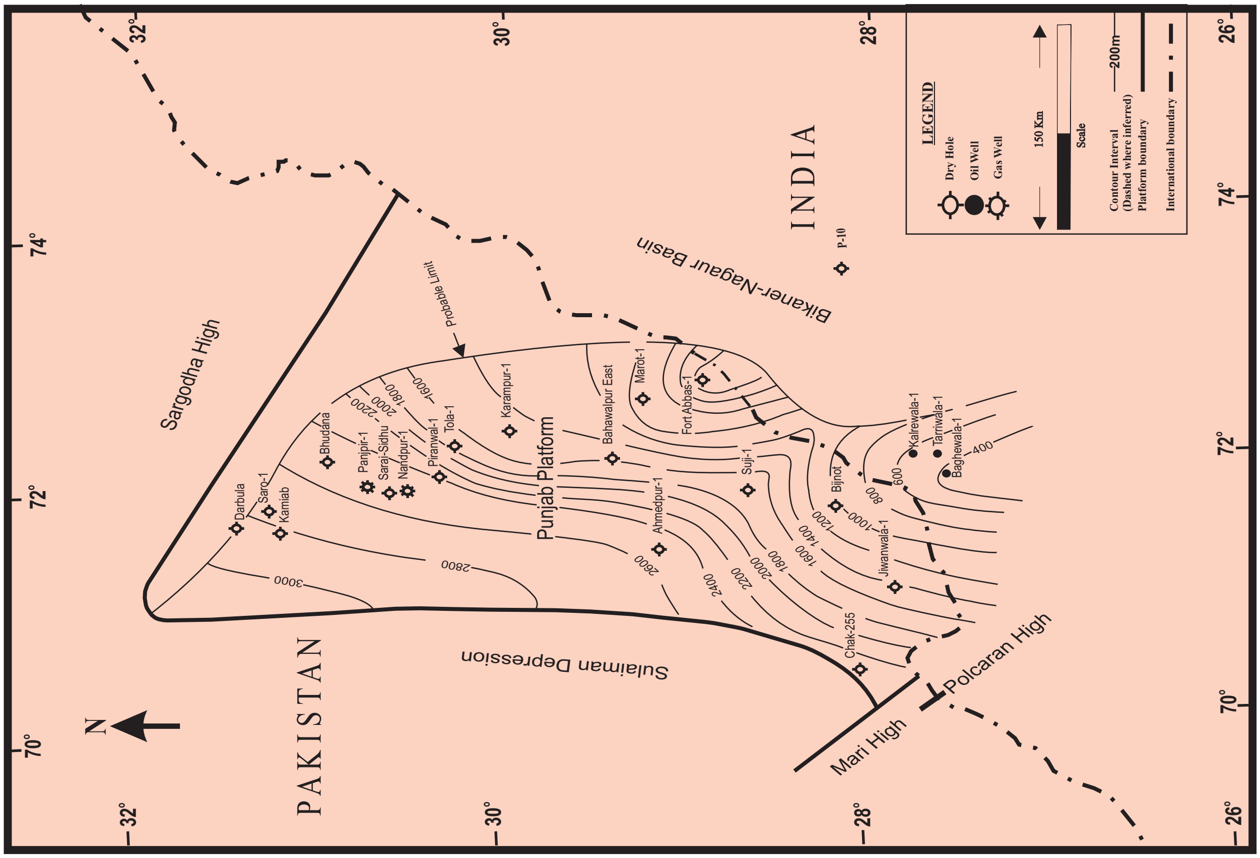


Figure 18- Structure Contour Map - Base Permian.

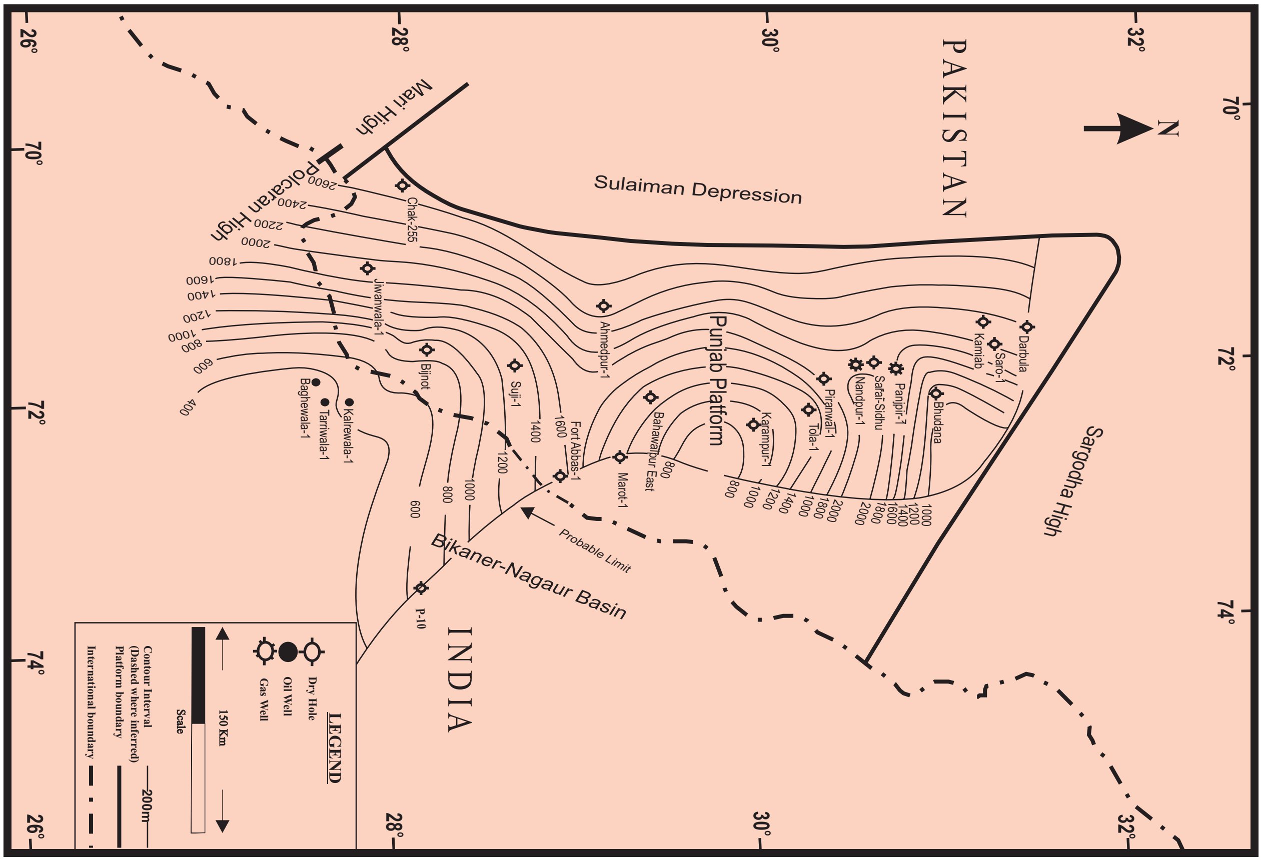


Figure 20 - Structure Contour Map - Base Jurassic.

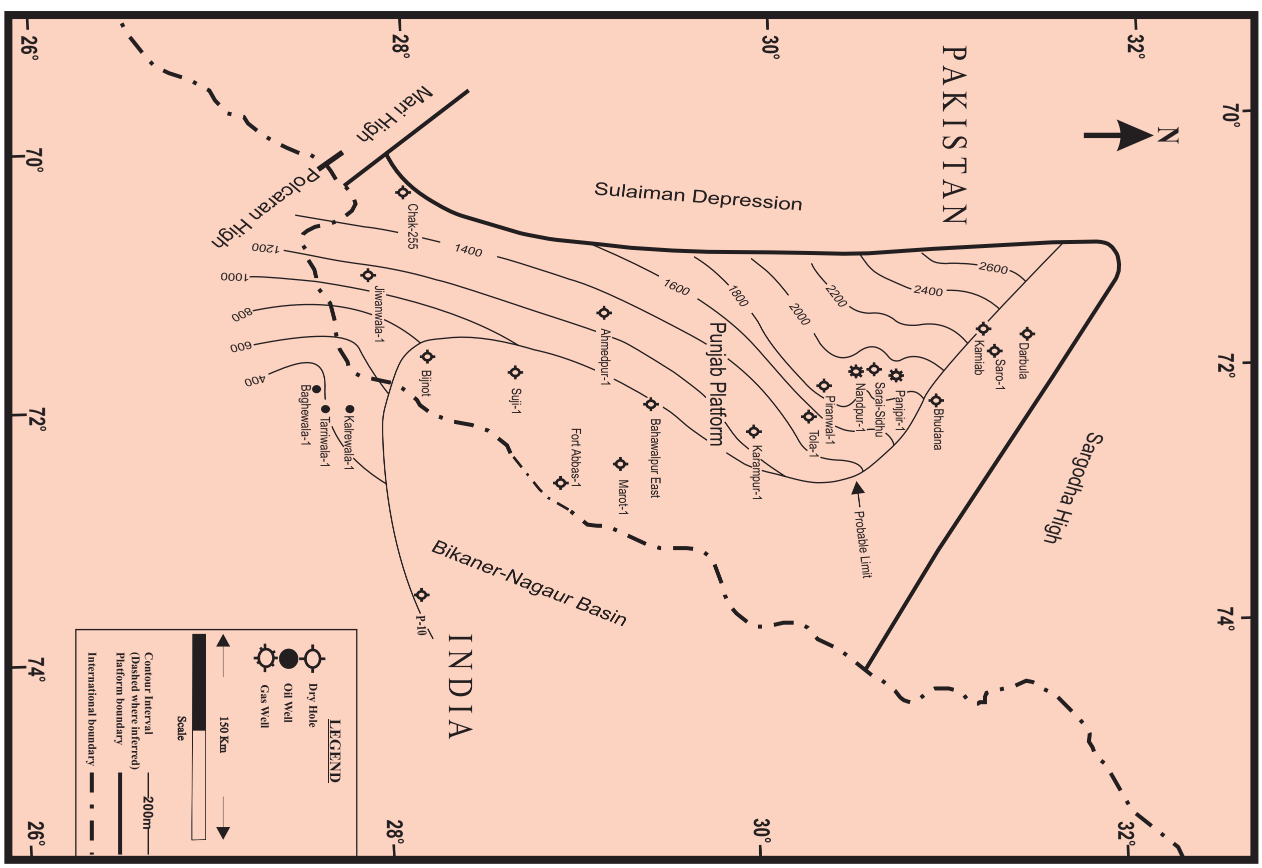


Figure 19- Structure Contour Map - Base Triassic.

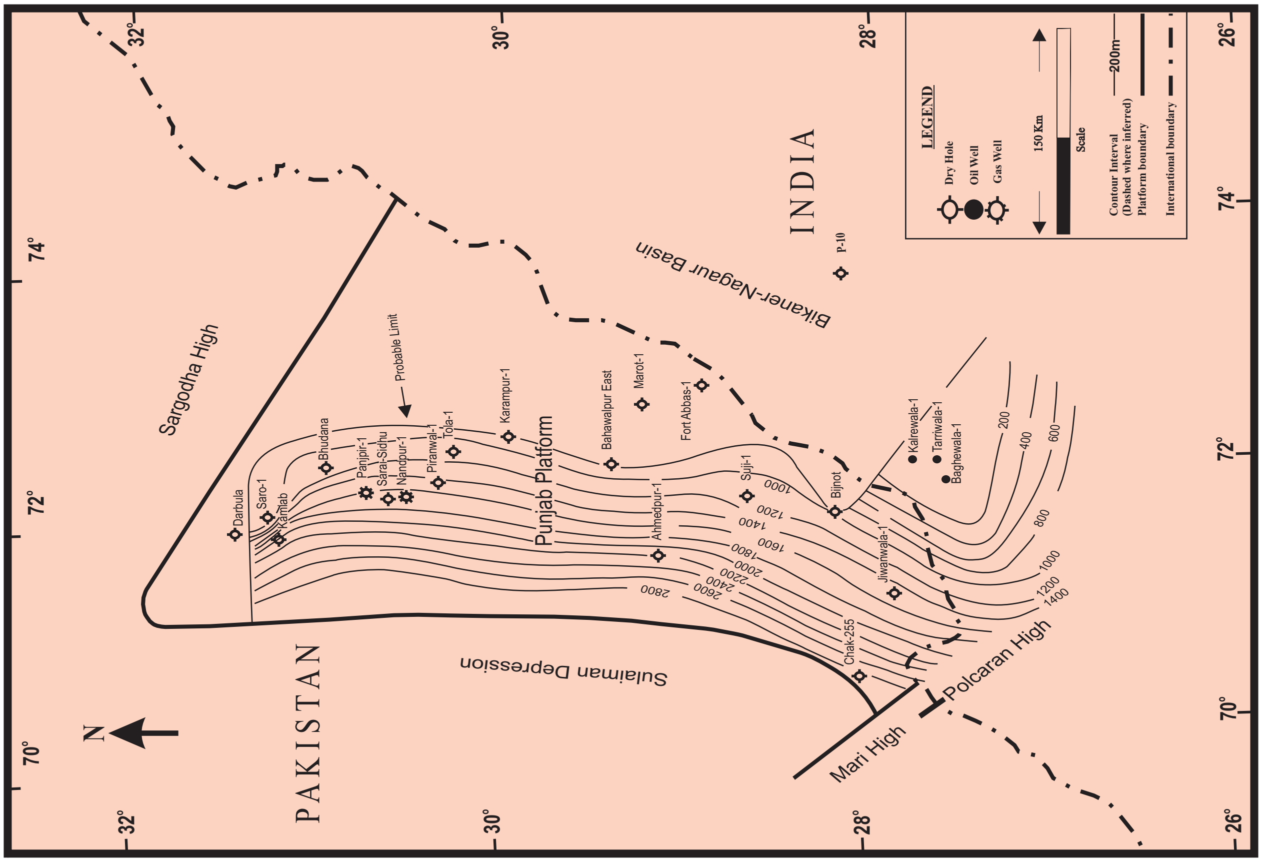


Figure 21 - Structure Contour Map - Base Cretaceous.

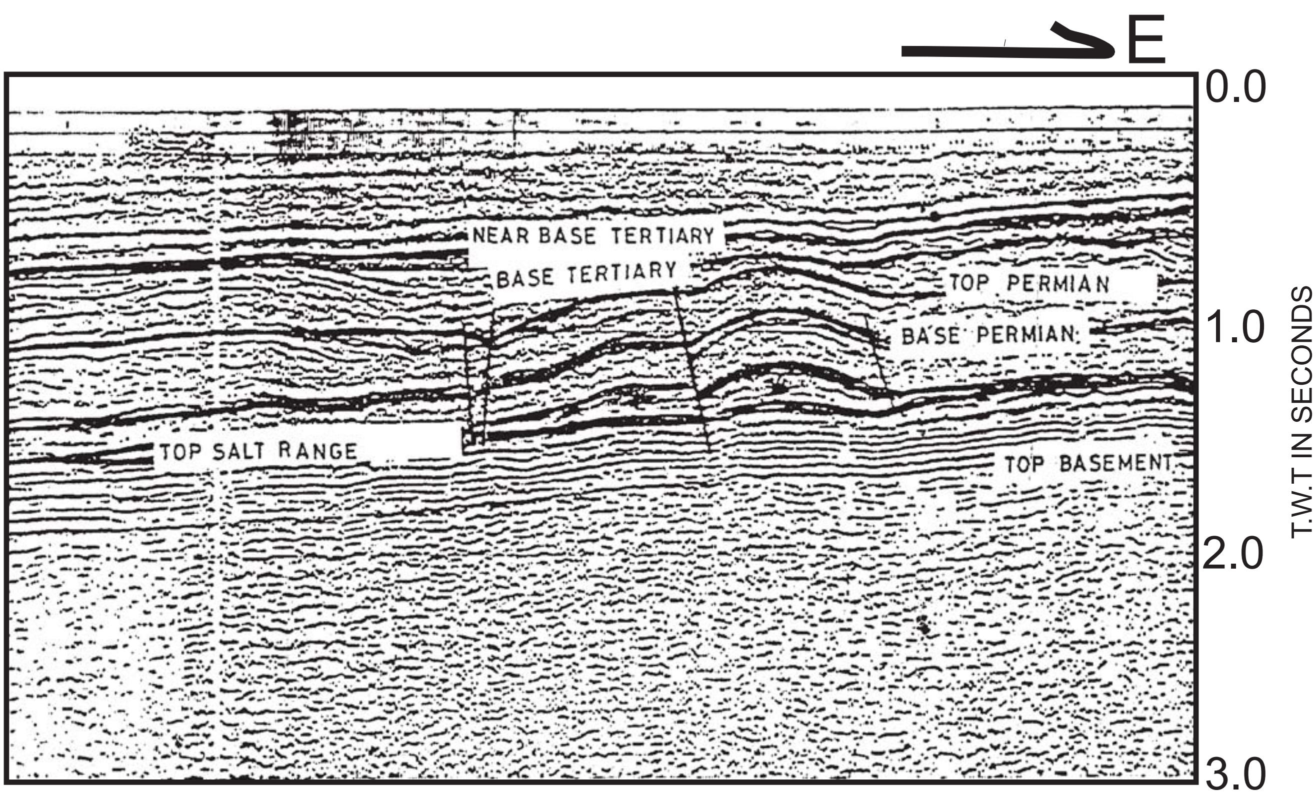


Figure 22: Seismic line No. 7 showing Salt-Induced Structures in Punjab Platform(Raza et al., 1989).

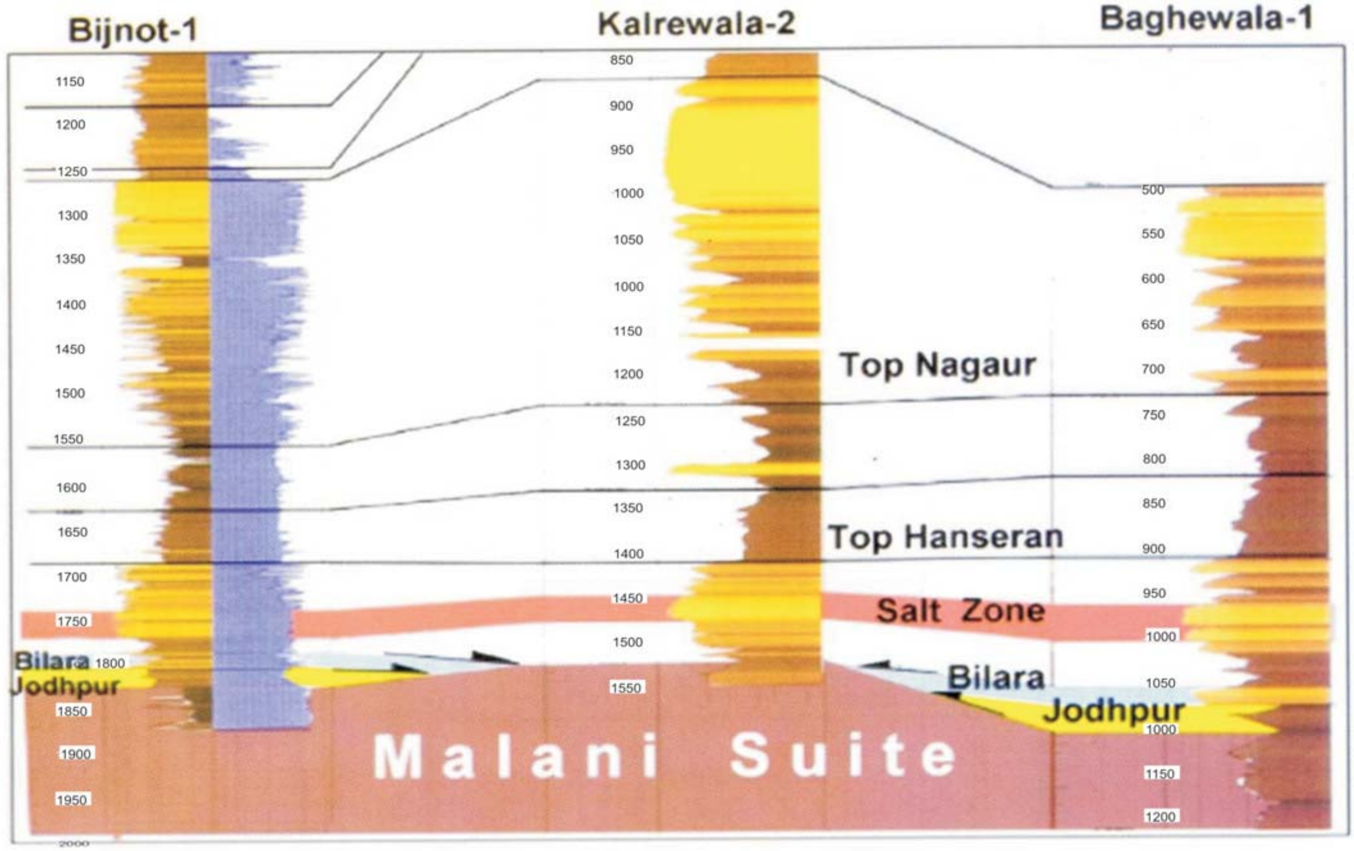


Figure 23 - Showing the Jodhpur and Bilara formations penetrated in the Bijnot-1 well drilled on Punjab Platform and Baghewala-1 of Bikaner-Nagaur Basin, India with correlation of wells indicating onlaps of Infra-Cambrian Formation on Paleo-High of Kalrewala-2 well (after Sheikh et al, 2003).

organic richness and the source rock potential for liquid hydrocarbons.

Samana Suk Formation

In Ahmedpur-1 the Samana Suk Formation shows organic richness poor to fair organic richness (TOC: 0.22- 0.80) and has limited gas potential.

In Panjpir-1 the carbonates of Samana Suk show marginal to fair organic carbon content (TOC: 0.53 -1.59%). The genetic potential indicates limited gas potential (Gp: 1.40-1.54 kg/t).Samana Suk has poor to marginal organic richness (TOC: 0.48- 0.68%) with limited gas potential (Gp < 1 kg/t) in Nandpur-1.

CRETACEOUS

Chichali Formation:

Shales of Chichali Formation show fair organic richness in Panjpir-1 (TOC: 1.30-2.00%) and fair hydrocarbon generation potential.

Lumshiwal Formation:

Geochemical analysis of shale samples show very poor organic carbon content in Nandpur-1 (TOC: 0.25- 0.42%).

Parh Formation:

The geochemical analysis of the samples show poor to fair organic richness (TOC: 0.24-0.90%) in Ahmedpur-1. This formation may have some potential for gas generation (GP 1.4 Kg/t).

Mughal Kot Formation:

In Ahmedpur-1 the formation shows poor to marginal organic richness (TOC: 0.37-0.64%). Pyrolysis study indicates no source potential for liquid hydrocarbons (GP < 1Kg/t).

PALEOCENE

Ranikot Formation:

Shales of Ranikot Formation show poor to fair organic richness (TOC: 0.33-1.00%) in Ahmedpur-1 with limited gas potential (Gp < 1 kg/t).

Dunghan Formation:

The formation shows poor to fair organic carbon content in Ahmadpur well (TOC: 0.38-1-12%). The genetic potential indicates no source potential for hydrocarbon generation (Gp: <1 Kg/t).

EOCENE

Ghazij and Kirthar Formations:
The analysis of samples from Ahmedpur well-1 shows that the Ghazij Formation has poor organic richness (TOC: 0.13-0.25%) while Kirthar Formation also shows poor values (TOC: 0.09-0.24).

MATURITY MODELING

Data from three wells (Fort Abbas-1, Nandpur-2 and Ahmedpur -1) have been incorporated to carry out the maturity modeling of the Punjab platform. In this study geological time scale has been used to define the events (such as deposits, hiatuses or unconformities).

Tectonic subsidence analysis (back-stripping)
One of the objectives of subsidence analysis is to extract the true “tectonic subsidence” component through time, indicating the plain movement of the basement after the removal of the effects of sediment/water load and eustatic sea level fluctuations (Allen and Allen, 1990; Steckler and Walts, 1978; Sclater and Christie, 1980; Bond and Kominz, 1984). Tectonic subsidence may be the result of several interacting geodynamic processes, such as:

- Flexural bending due to loads away from analyzed location
- Thermal contraction or uplift
- Delayed compaction of sediments
- Faulting

Burial history at three locations
Burial history of the three above noted wells, as shown in Figures 24, 25 and 26, is based on stratigraphy (chronostratigraphic time scale, depth and thickness) and lithology, encountered or predicted at individual well locations. Lithologies obtained from the lithology logs were specified as percentages of sand, silt, shale and limestone etc. Compaction was calculated automatically by the computer programme using the equation of Falvey and Middleton (1981). Petrophysical parameters necessary for calculating compaction, porosity, thermal conductivity etc. were provided by the computer programme on the basis of lithology specified for each rock unit which is present today or was deposited but subsequently eroded away. The precise lithologies of eroded rock units, of course, are never known. In this study lithologies of eroded sections have been estimated from data on rocks present in nearby wells or outcrops, and also taking into consideration the different facies and modes of deposition.

Figure 24 shows the burial history of the rock units encountered at Ahmedpur-1 well. Shirinab/Datta Formation was the deepest rock unit, which was encountered during drilling at this location. Deposition of the sediments of Shirinab Formation started 210 million years ago, whereas deposition of the younger encountered sediments (i.e. Chinji-Gaj) culminated somewhere during Quaternary. The figure shows that Shirinab/Datta, Chiltan/Samana Suk (Jurassic) and Sembar/Chichali (Cretaceous) formations fall within the oil window. However, the geochemical studies conducted by HDIP indicate that Shirinab and Sembar formations have poor source potential (TOC 0.2 and 0.4 respectively). The Chiltan Formation shows fair organic richness (TOC 0.76-0.80) but the pyrolysis study does not indicate potential for liquid hydrocarbon. The well is dry probably due to insufficient organic content and pyrolysis values.

Figure 25 shows the geo-history of rock units encountered in Fort Abbas-01 well. 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.

Figure 26 displays the geo-history of Nandpur gas field that is situated in Punjab Platform. The oldest formation penetrated in the well is Kingriali Formation of Triassic age. It is quite clear from the diagram that none of the expected potential source rocks reached to the stage of hydrocarbon generation due to quite low temperature and comparatively shallow depth. The presence of gas is either due to lateral migration from the kitchen area, probably located in the Sulaiman Depression in the west or from deeper source through fault conduit.

RESERVOIR ROCKS

Several reservoir intervals including productive ones have been identified on Punjab Platform.

INFRACAMBRIAN

Jodhpur Formation:
The fluvial and shallow marine sandstones of Jodhpur Formation are the proven reservoir rocks in Baghewala-1 and Tariwala-1 wells of Bikaner-Nagaur Basin of India (Figure 27). In Baghewala well, the Jodhpur sandstone exhibits porosity ranges of 19-25%. These reservoir facies extend towards the north and northwest into Salt Range including Kirana area (Sargodha Hills) and have been reported in Bijnot-1, Marot-1 and Bahawalpur East 1 wells of Punjab Platform with porosity ranges of 14-17% and 6-14% in Marot and Bahawalpur wells respectively (Sheikh et al., 2003). The average porosity trend indicates good to excellent porosity from central to the eastern part of the study area (Figure 27).

Bilara Formation:
The dolomites of Bilara Formation are the proven reservoirs in Baghewala-1, Kalrewala-2 and Tarriwala-1 wells of Bikaner-Nagaur Basin of India (Sheikh et al., 2003). The carbonates of Bilara Formation have been deposited in coastal marine environment and more especially in supratidal to inter-tidal environment which supports the development of secondary porosity. The porosity of Bilara dolomite ranges from 7-15% in Baghewala-1, 0-12 % in Bijnot-1, 3-24% in Bahawalpur East 1 and 8-14% in Marot-1 (Sheikh et al., 2003).

The distribution pattern of average porosity indicates good reservoir characteristic on Punjab Platform with an increase in average porosity towards west (Figure 28).

Salt Range Formation
Two bitumen-bearing zones were encountered in the dolomite section in Karampur-1. Heavy oil has also been reported from cherty dolomite at Kalar Kahar and Dulmial wells of Potwar sub-basin (Sheikh et al., 2003). The formation has an average porosity of 10% in Bijnot-1, 8% in Fort Abbas-

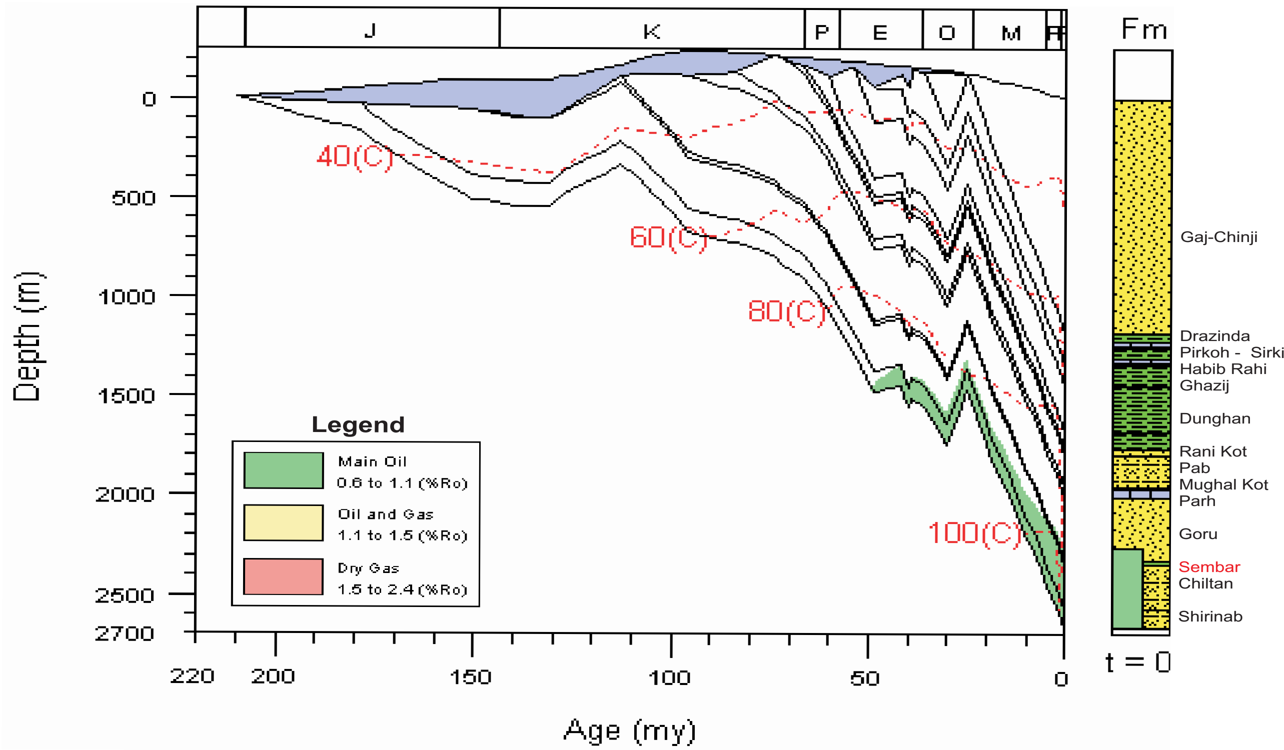


Figure 24 - Burial history diagram of Ahmedpur-01 well. Plot also shows paleobathymetry, isotherms and depth and time of oil generation.

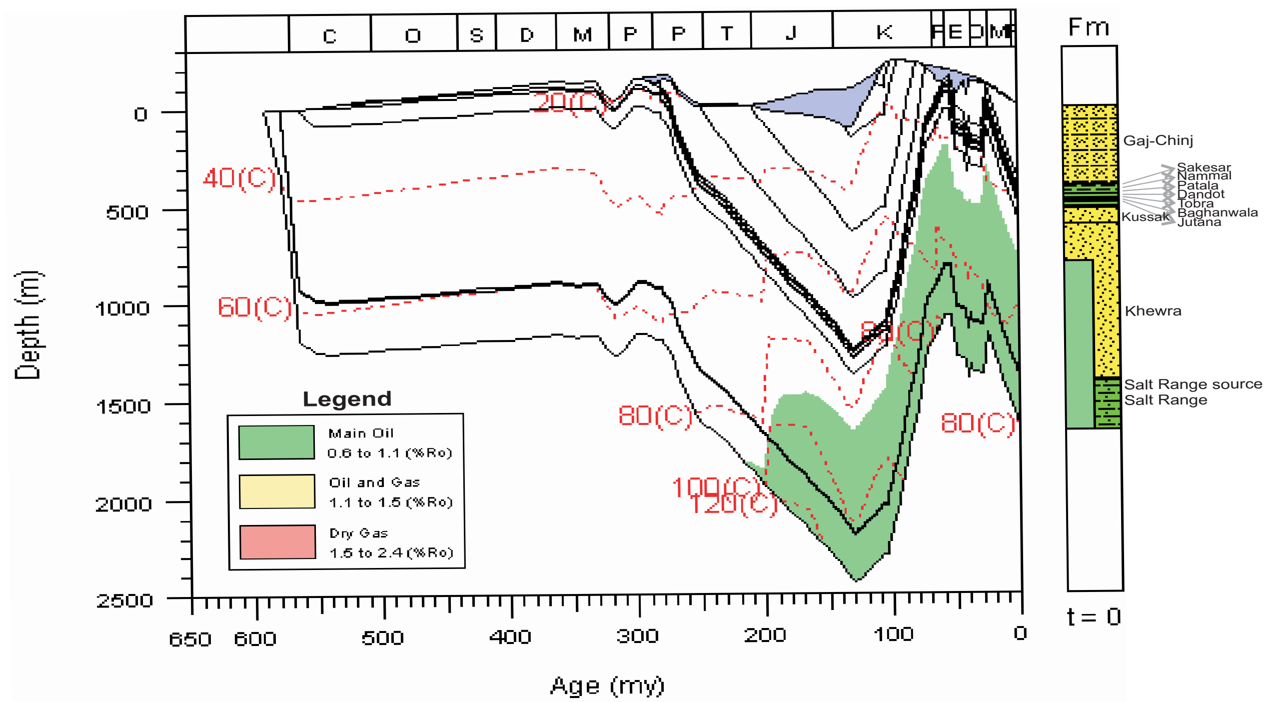


Figure 25 - Burial history diagram of Fort Abbas-01 well. Plot also shows paleobathemetry, Isotherms and depth and time of oil generation.

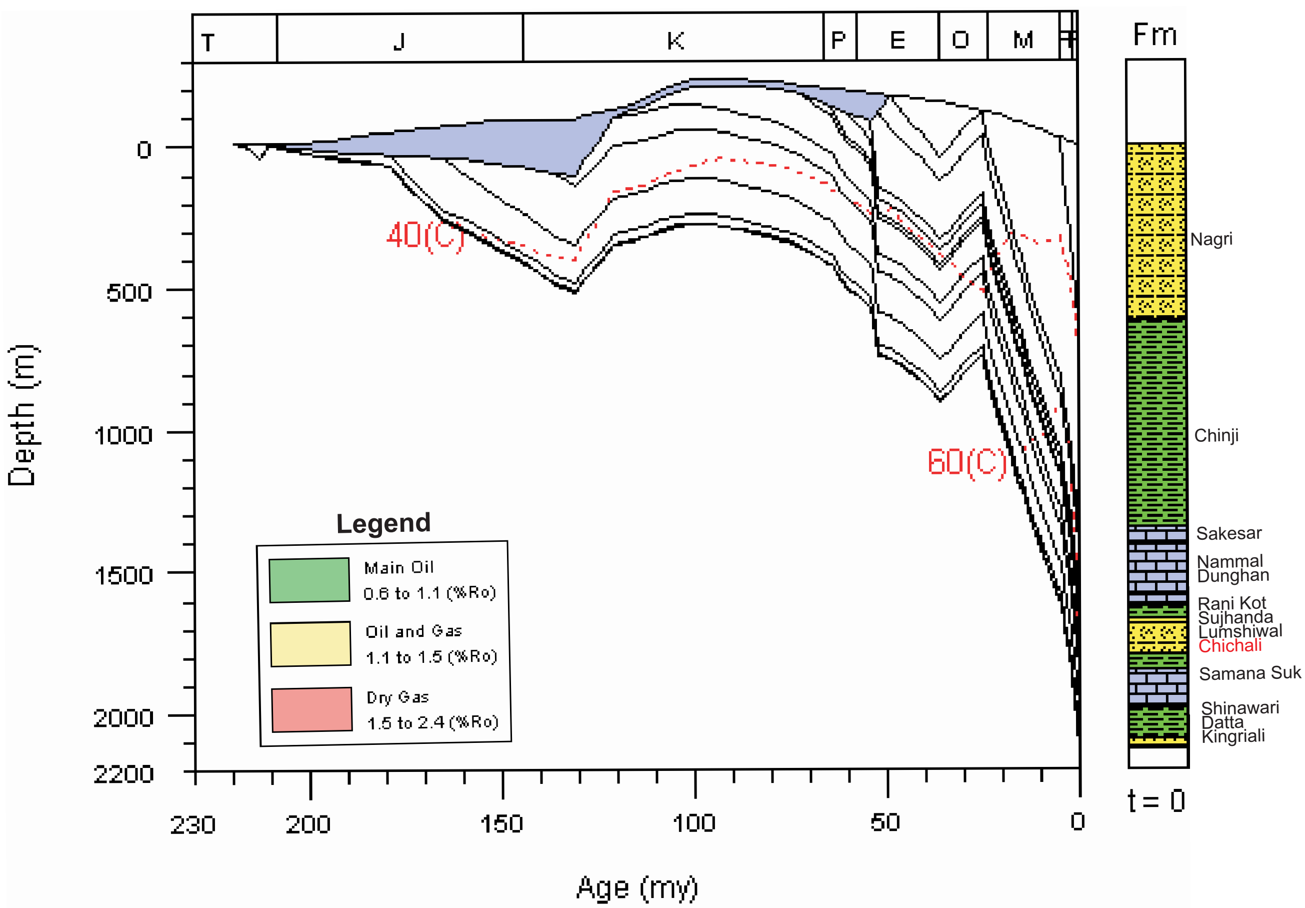


Figure 26 - Burial history diagram of Nandpur-02 well. Plot also shows paleobathymetry and isotherms with no oil and gas generation.

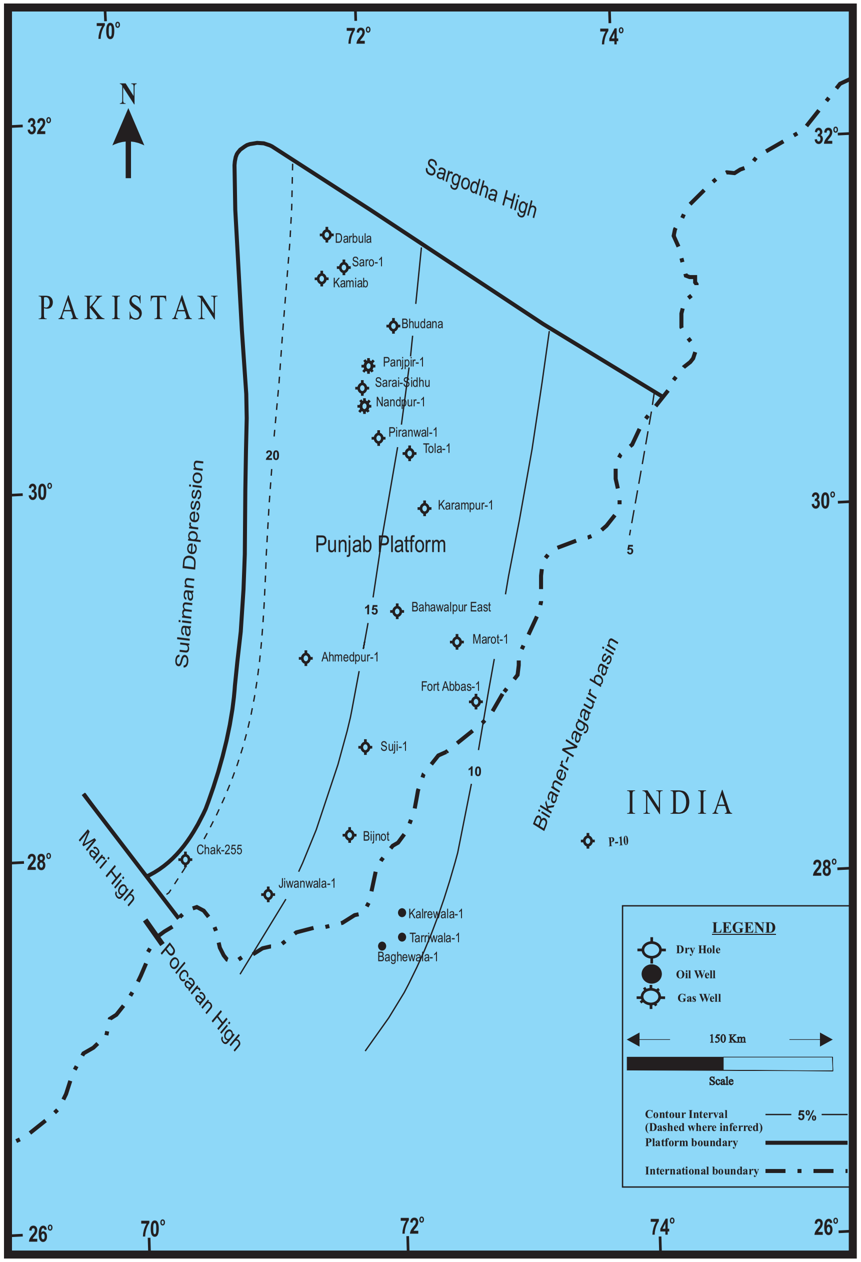


Figure 28 - Average Porosity Map of Bilara Formation.

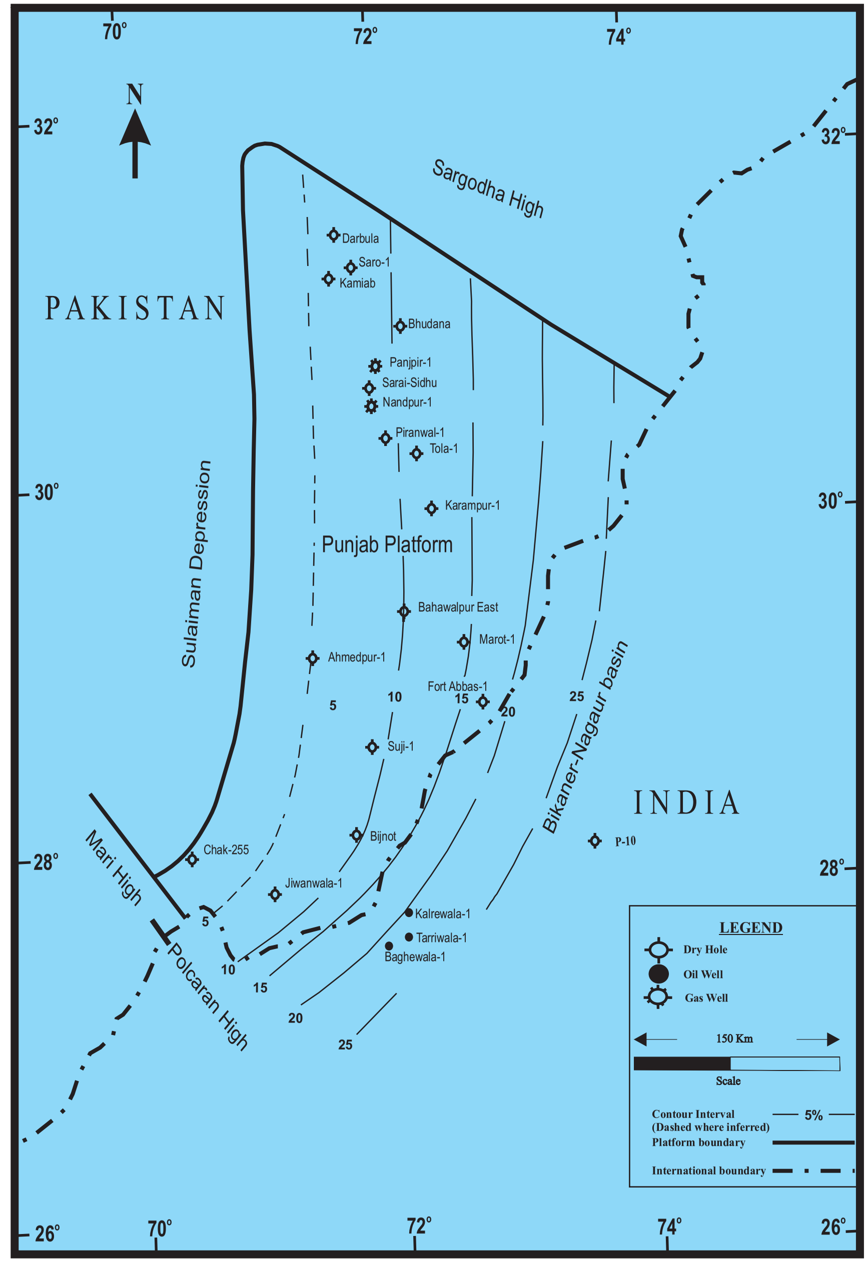


Figure 27 - Average Porosity Map of Jodhpur Formation.

1, 5% in Ahmedpur-1, 5% in Bahawalpur East-1 and 10% in Karampur-1. The average porosity trend shows good porosity towards north and southeastern part of Punjab Platform (Figure 29).

Cambrian

Khewra Formation:

The Formation is well developed in Punjab Platform. The sandstone of Khewra Formation is the producing reservoir in Adhi field of eastern Potwar. In Punjab Platform, the sandstone has an average porosity of 15% in Bijnot-1, 14% in Fort Abbas-1, 10% in Suji-1 and 6% in Bahawalpur East-1. The sandstones have good average porosity range in the northern, eastern and southern part (Figure 30).

Kussak Formation:

The sandstones of Kussak Formation have 13% average porosity in Fort Abbas-1, 23% in Bahawalpur East-1 and 4% in Bijnot-1. It has more than 20% average porosity in the eastern part which decreases westwards (Figure 31).

Baghanwala Formation:

In Punjab Platform, the formation has an average porosity of 12% in Bahawalpur East-1 well. The speculative trend of average porosity shows an increase in porosity towards east (Figure 32).

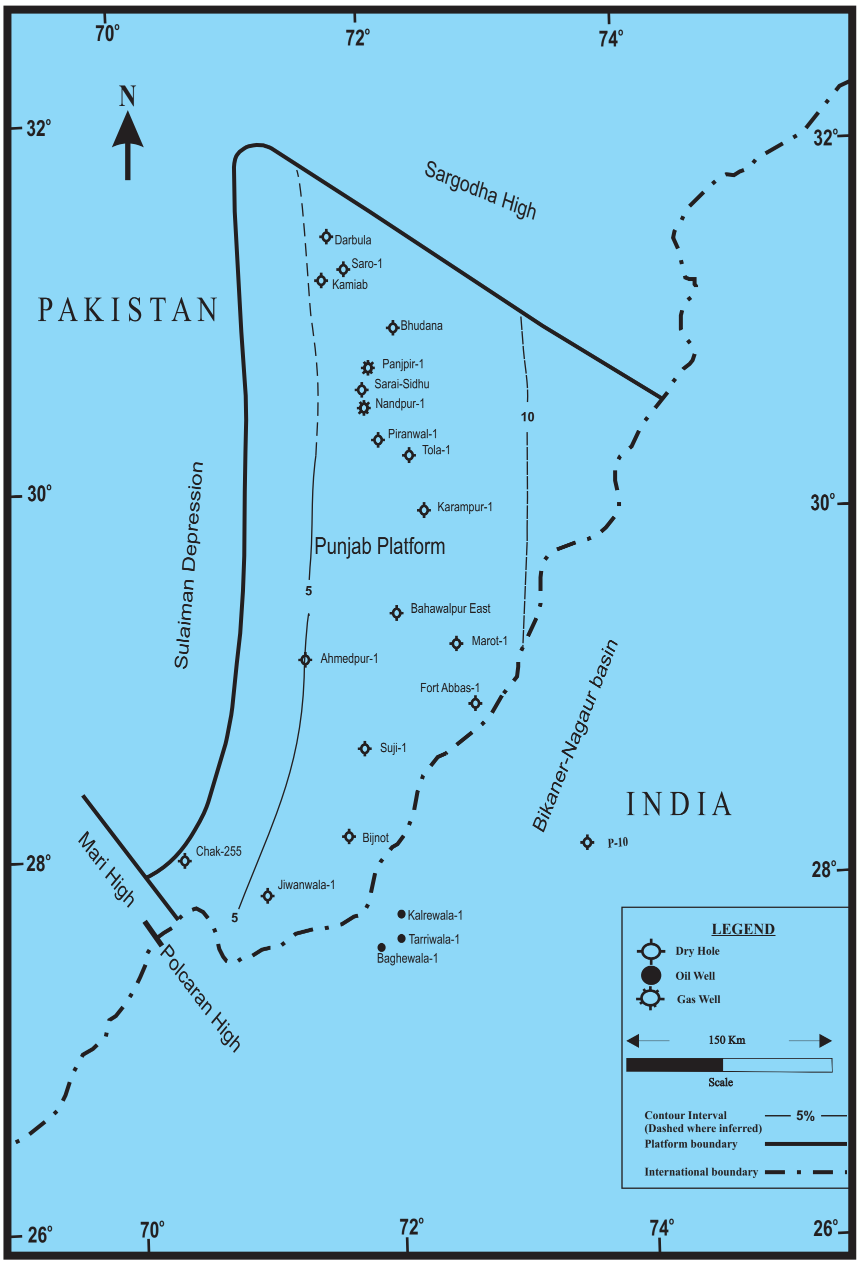


Figure 29 - Average Porosity Map of Salt Range Formation.

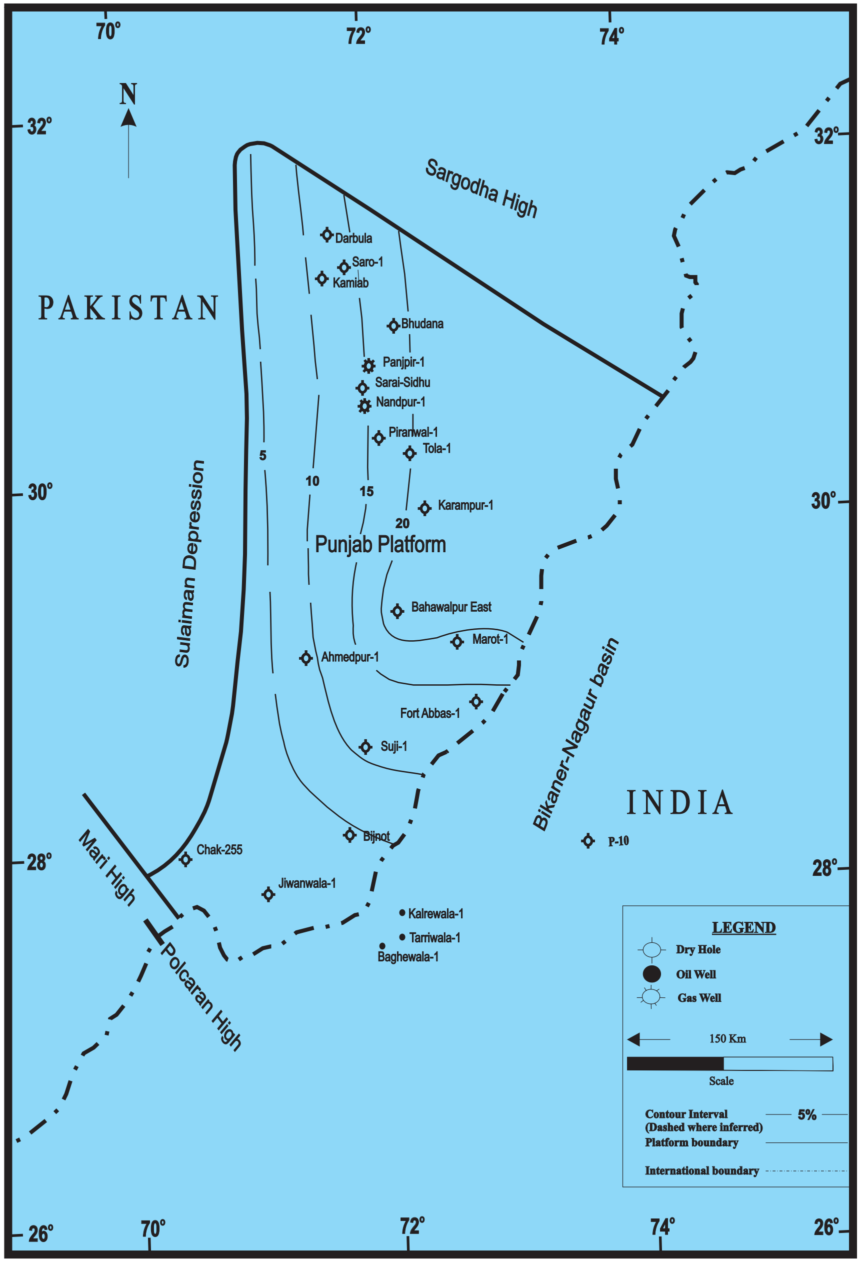


Figure 31 - Average Porosity Map of Kussak Formation.

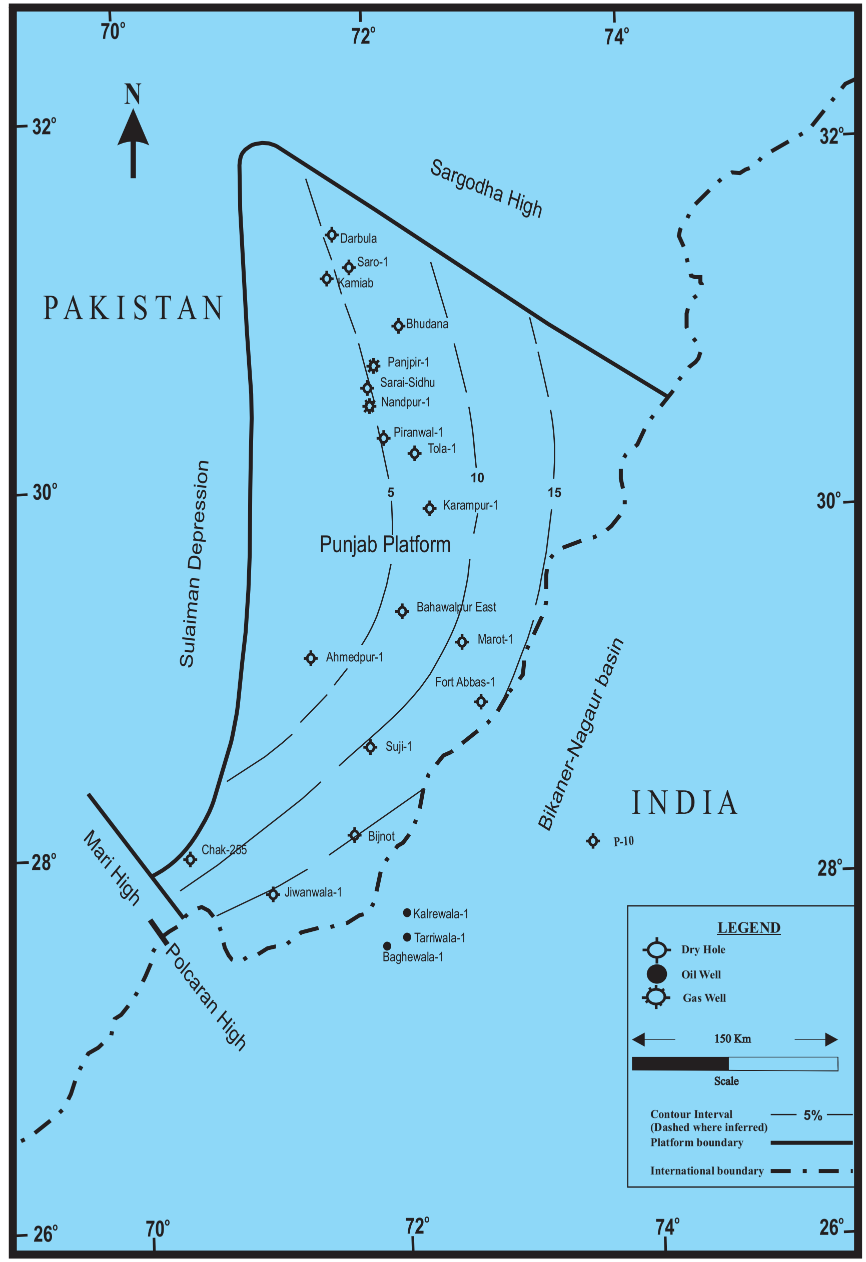


Figure 30 - Average Porosity Map of Khewra Formation.

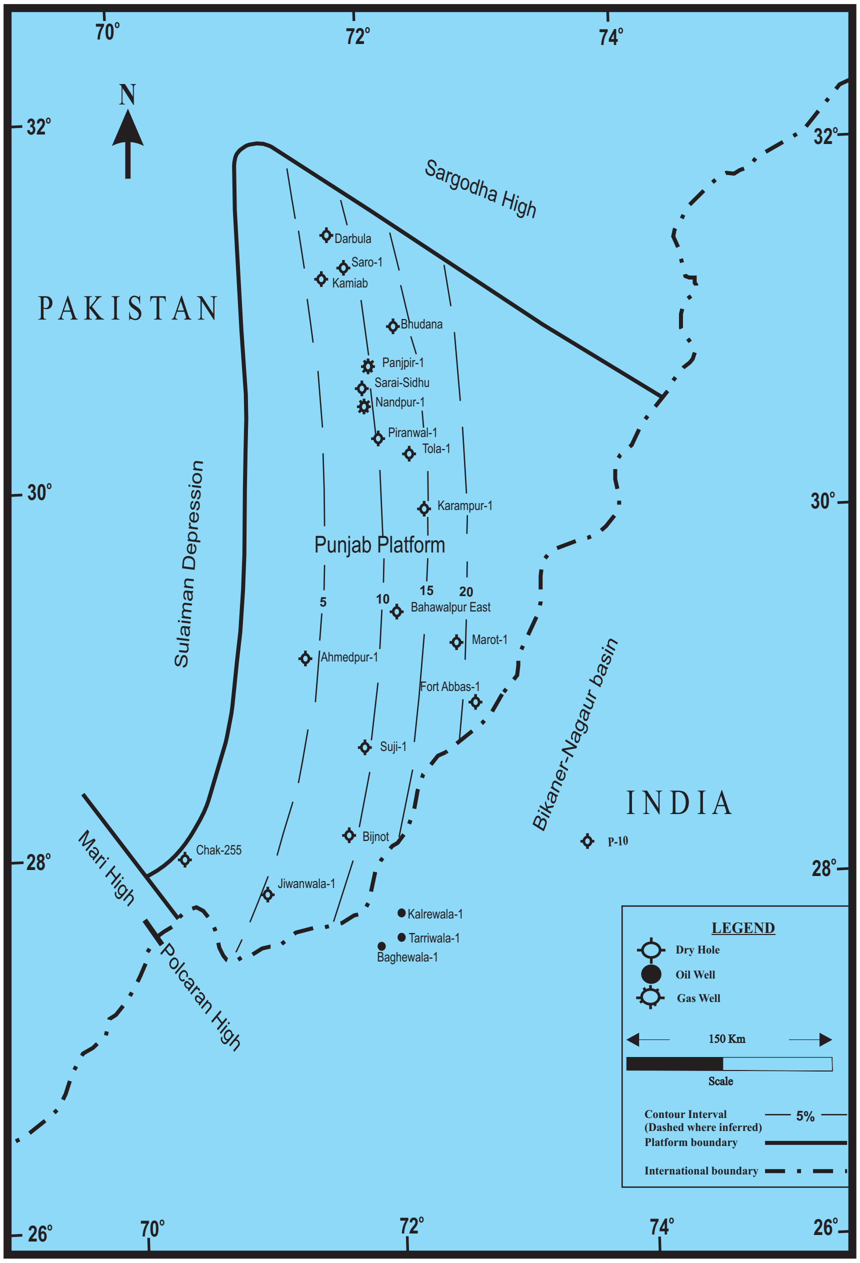


Figure 32 - Average Porosity Map of Baghanwala Formation.

PERMIAN

Warcha Formation:

The Warcha Formation has an average porosity of 25% in the sandstone intervals of Bahawalpur East well. The probable porosity trend indicates 30% porosity in the east which decreases towards west (Figure 33).

Amb Formation:

The sandstones of Amb Formation have an average porosity of 10% in Piranwal-1 well. The probable porosity trend indicates good porosity range from central part towards east (Figure 34).

JURASSIC

Datta Formation:

The sandstone of Datta Formation has an average porosity of 14% in Bahawalpur East. The porosity trend indicates a probable decrease in porosity towards west (Figure 35).

Shinwari Formation:

The formation is mostly missing in the eastern part. It has an average porosity of 25% in Ahmedpur-1 well. The speculative average porosity trend indicates an increase in porosity towards east (Figure 36).

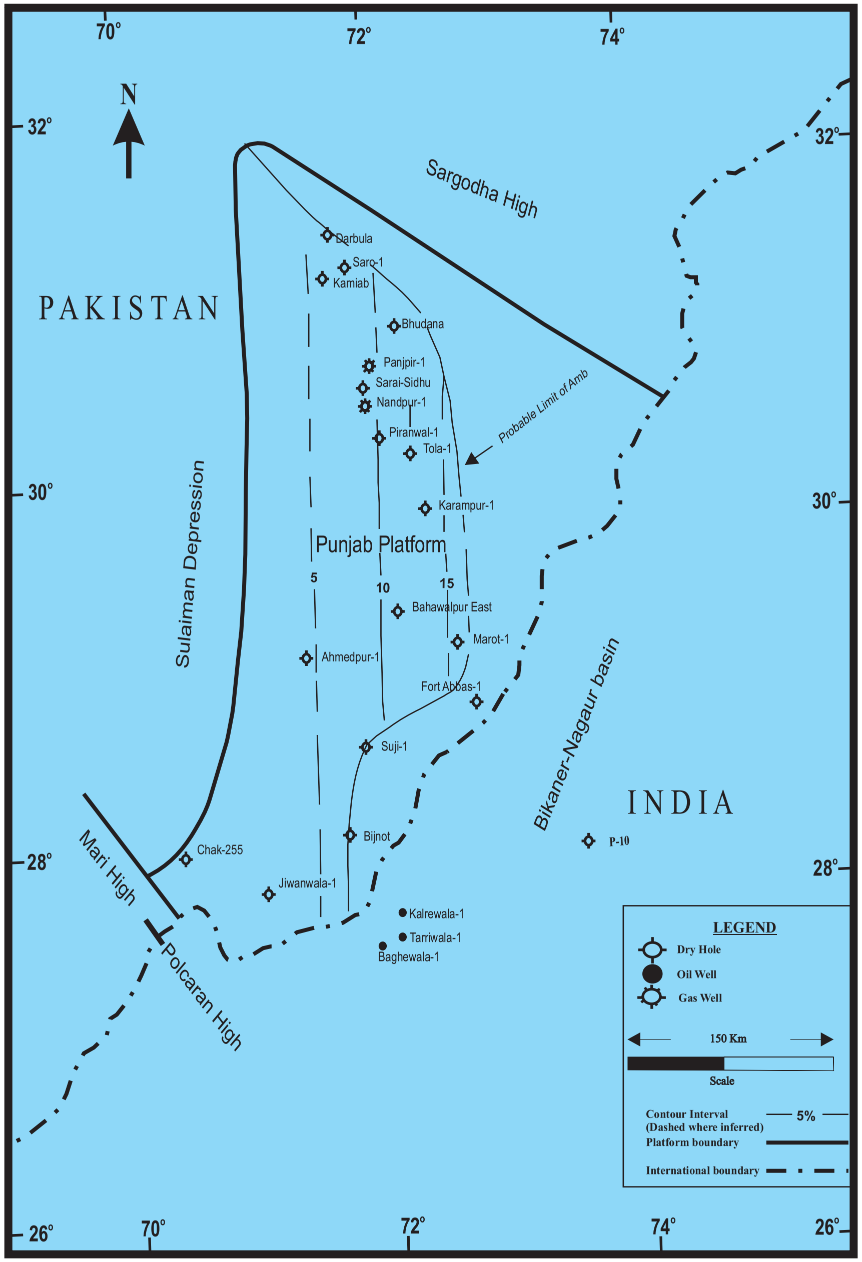


Figure 34 - Average Porosity Map of Amb Formation.

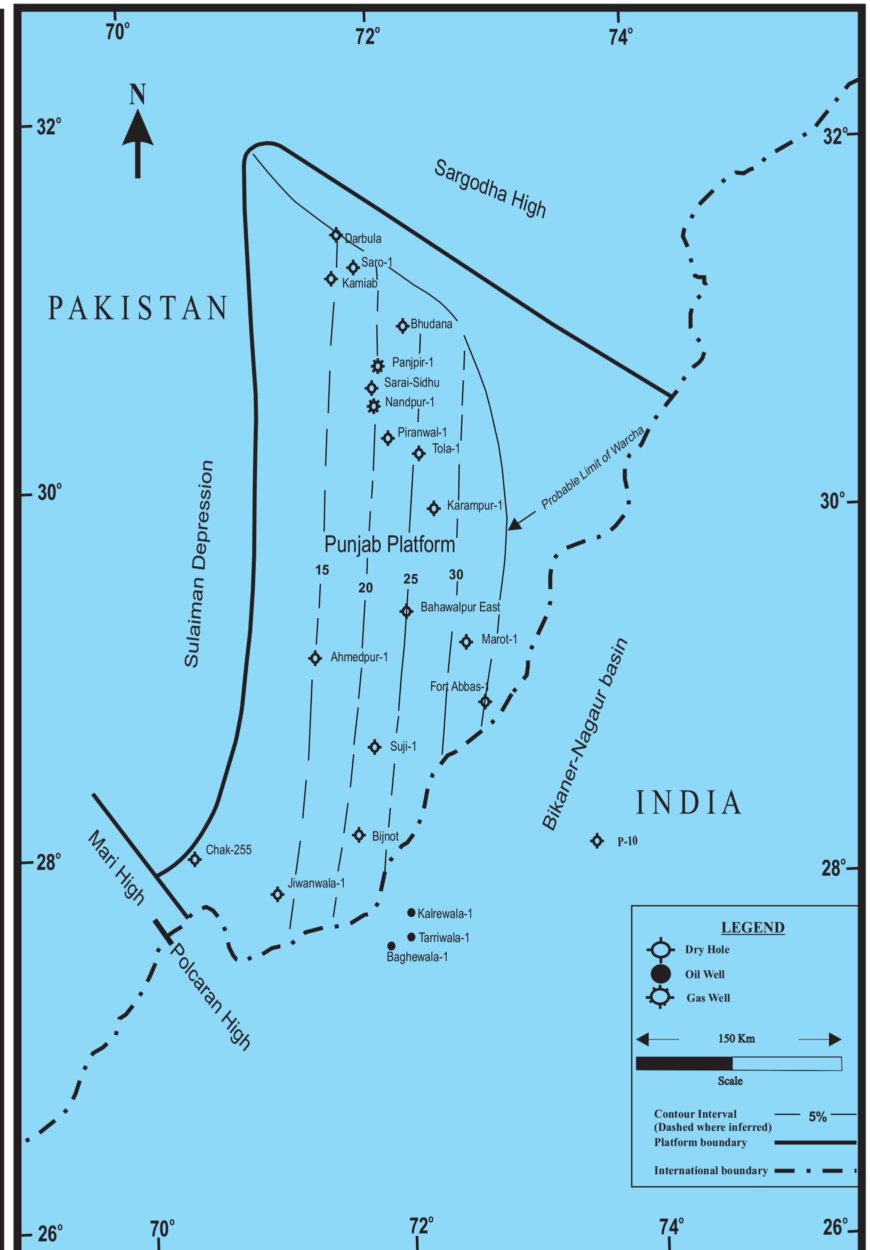


Figure 33 - Average Porosity Map of Warcha Formation.

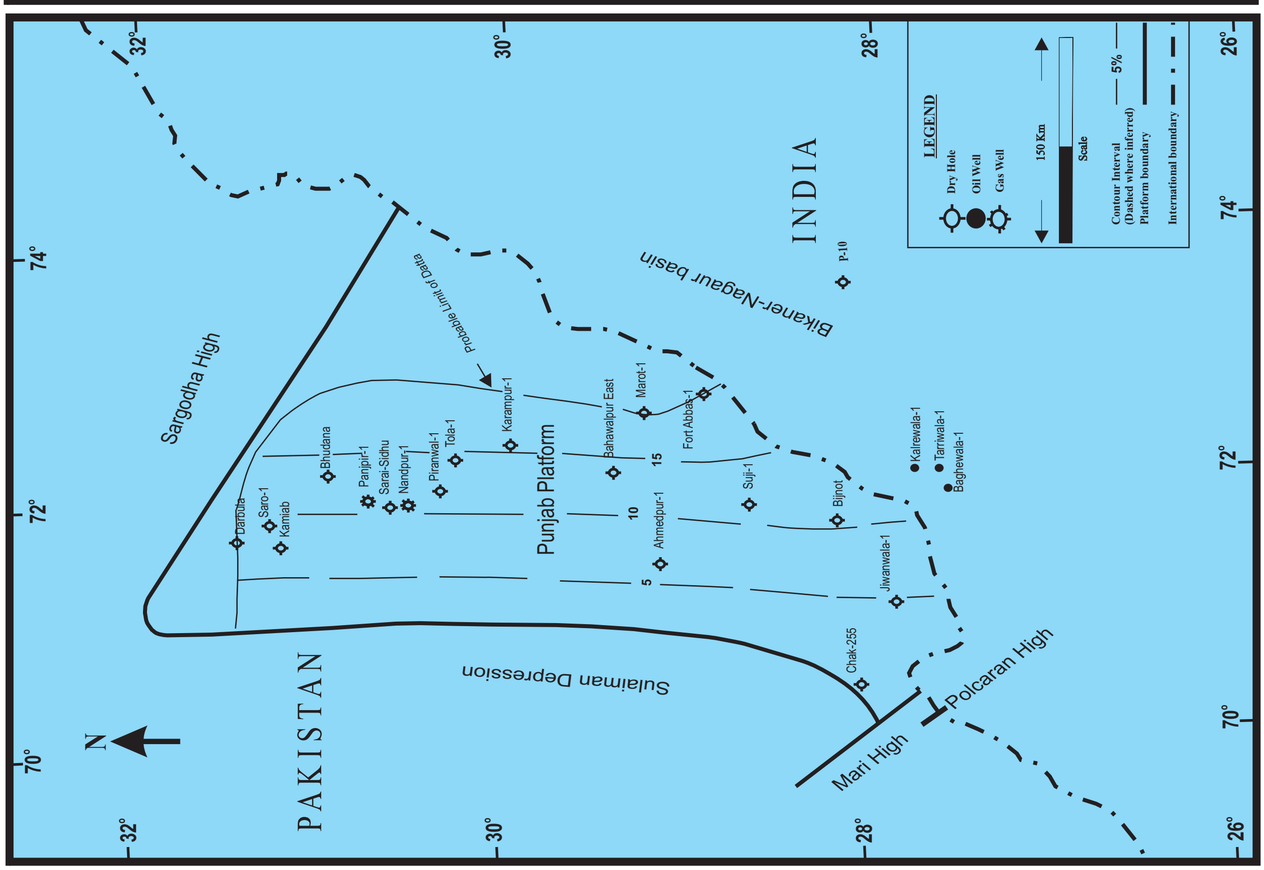


Figure 35 - Average Porosity Map of Datta Formation.

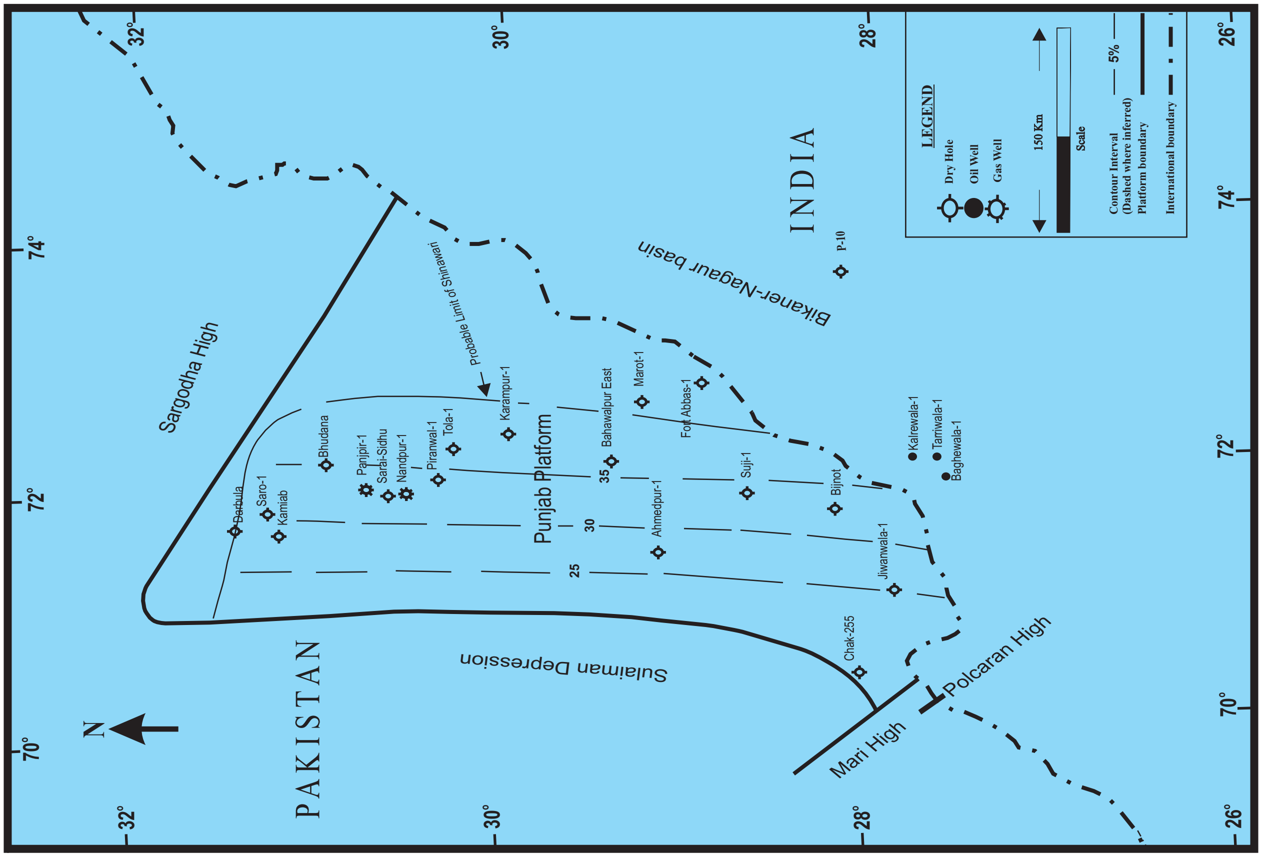


Figure 36 - Average Porosity Map of Shinawari Formation.

Samana Suk/Chiltan Formation:

The Formation is less widely distributed in Punjab Platform than the overlying Shinwari Formation. It has an average porosity of 12% in Bahawalpur East-1, 16% in Piranwal-1, 15% in Nandpur-1 and also 15% in Panjpir-1. The probable average porosity trend shows an overall decrease in porosity from east to west (Figure 37).

CRETACEOUS

Lumshiwal/Lower Goru Formation:

The Formation is missing in the eastern part. The sandstones of Lumshiwal/Lower Goru have an average porosity of 20% in Chak-225, 24% in Jiwanwala-1, 28% in Ahmedpur-1, 25% in Bhudana-1 and 23% in Kamiab-1. It has more than 25% average porosity towards east, which decreases westward (Figure 38).

PALEOCENE

Ranikot/Hangu Formation:

The Formation is distributed in the central and western part of Punjab Platform. The sandstone beds have an average porosity of 20% in Chak-225 and 35% in Kamiab-1. The expected average porosity is more than 30% toward east and 20% in the west (Figure 39).

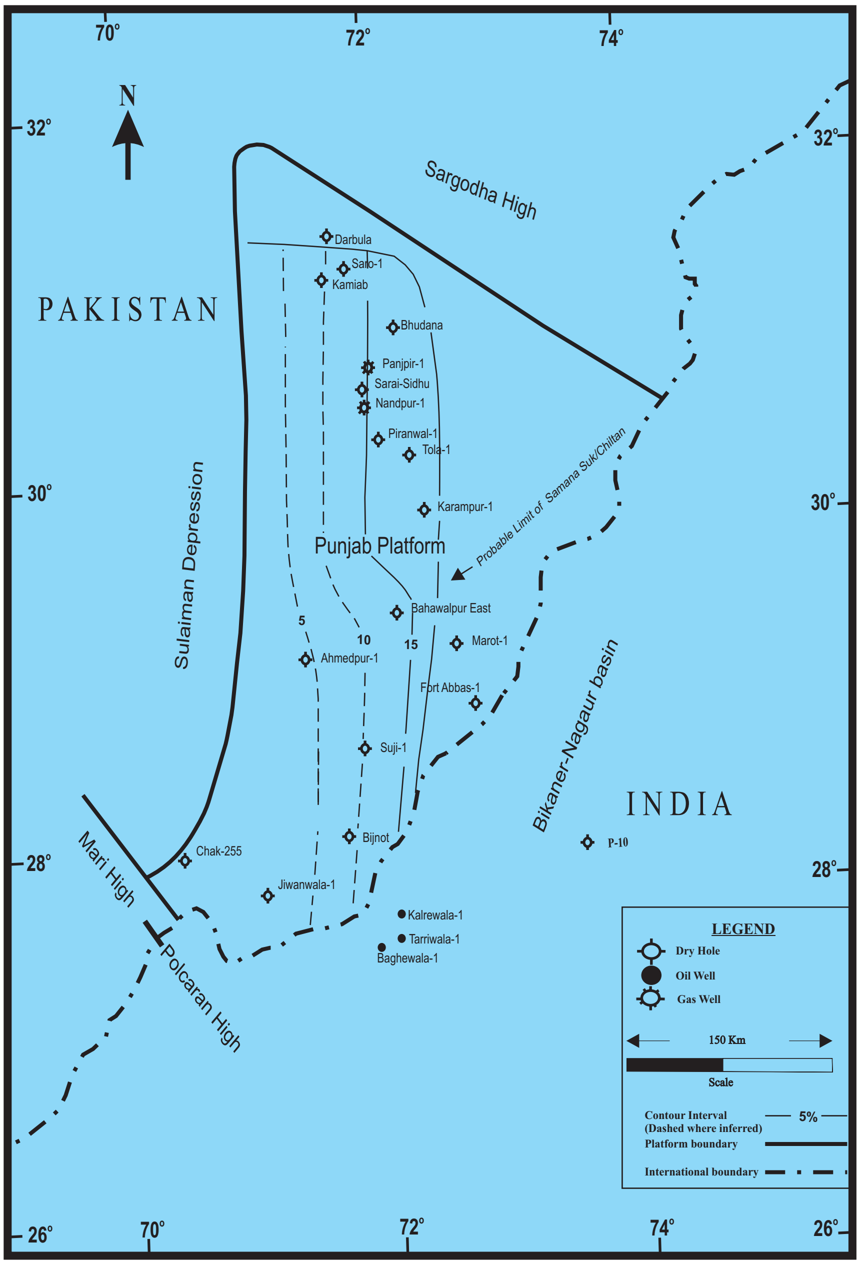


Figure 37 - Average Porosity Map of Samana Suk/ Chiltan Formation.

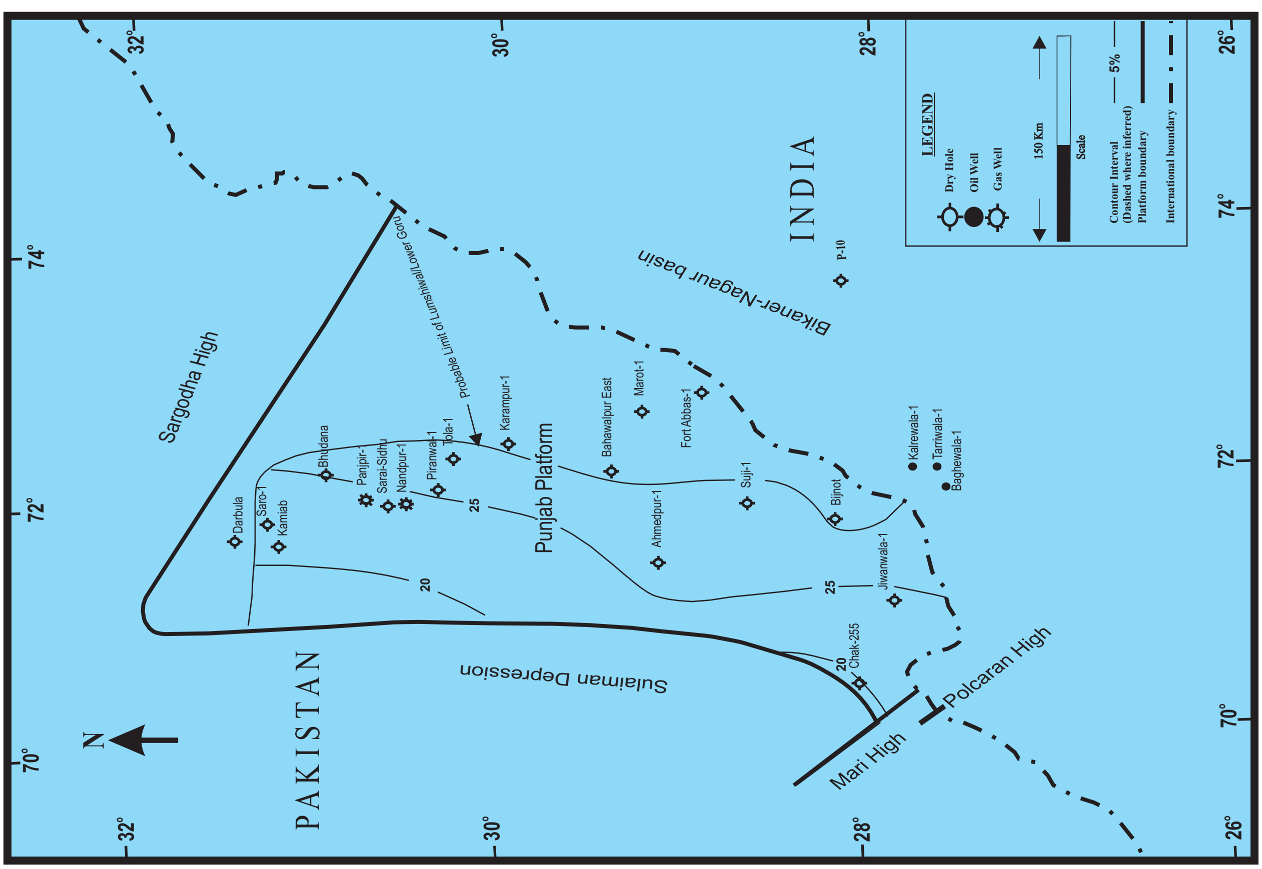


Figure 38 - Average Porosity Map of Lumshiwal/ Lower Goru Formation.

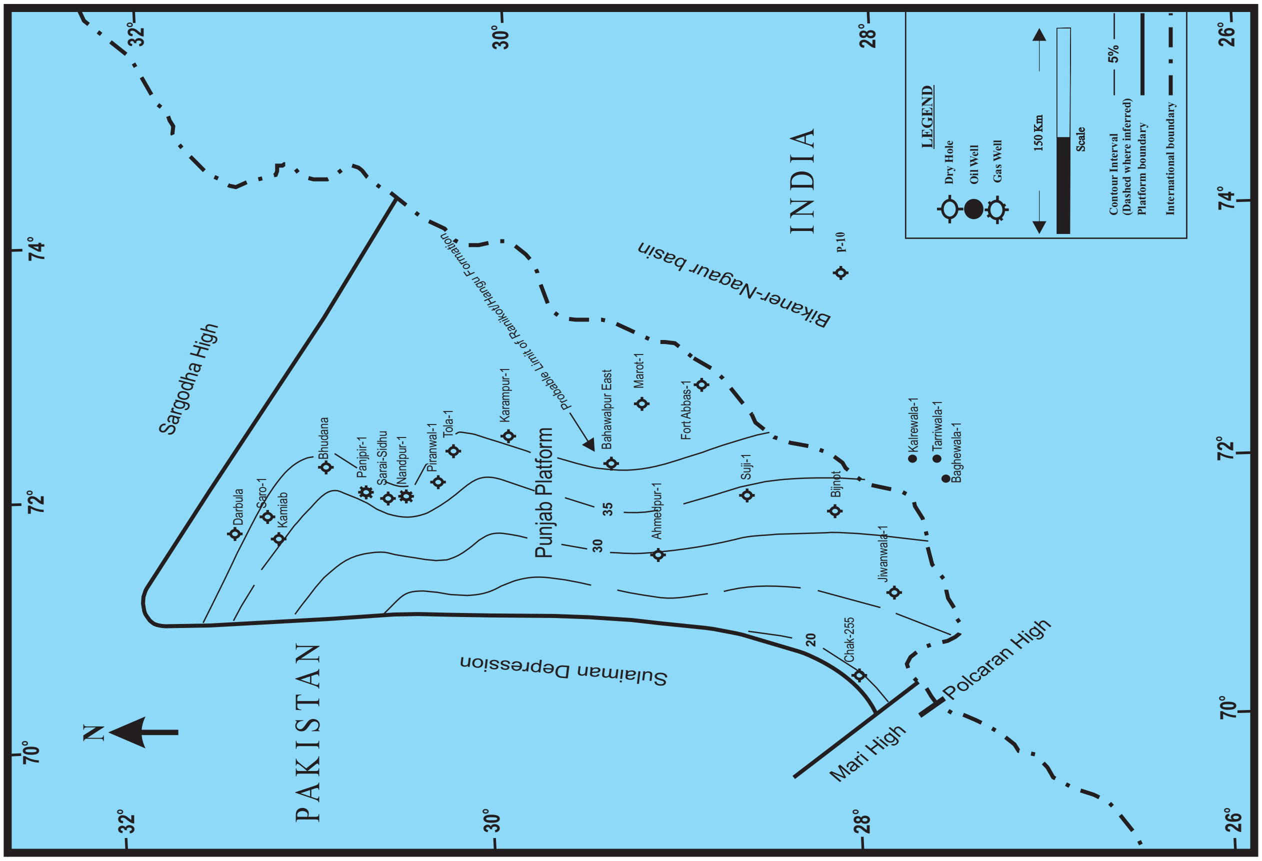


Figure 39 - Average Porosity Map of Ranikot/ Hangu Formation.

EOCENE

Laki/Sakesar/Chorgali Formation:

The formations have wider areal extent in Punjab Platform than the underlying Paleocene strata. The Sui Main Limestone member of Laki Formation has an average porosity of 20% in Chak-225. The average porosity of Sakesar Limestone is 15% in Bahawalpur-East, 12% in Kamiab, 17% in Marot, 15% in Karampur-1 and 13% in Nandpur and Panjpi-1. The overlying Chorgali Formation has an average porosity of 12% in Bhudana. The average porosity map shows overall decrease in porosity towards west (Figure 40).

PROSPECTIVE AREAS

On the basis of aforementioned study the prospective areas of Infra-Cambrian to Eocene age have been delineated on Punjab Platform (pages 28 to 31) and summarized as under:

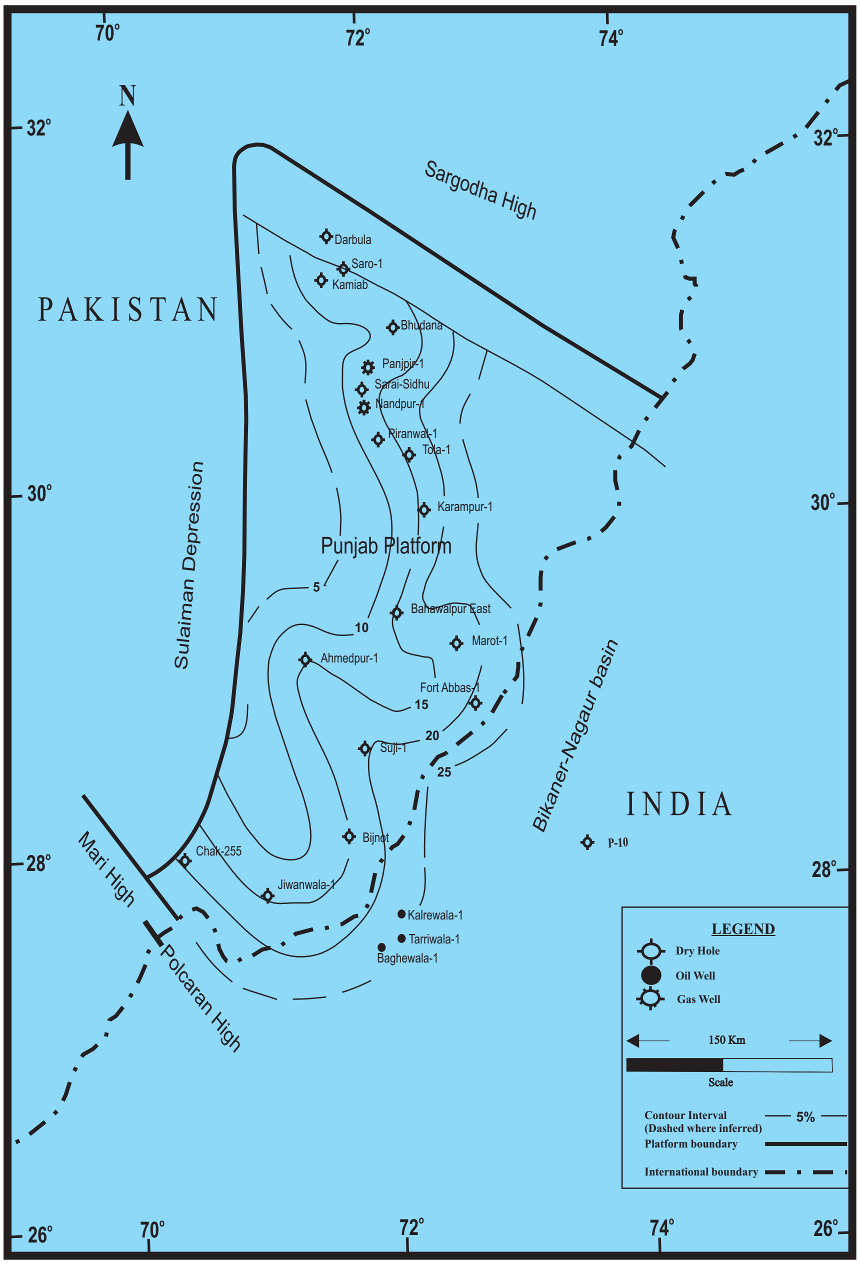


Figure 40 - Average Porosity Map of Laki/Sakesar/ Chorgali Formation.

Prospective Area of Infra-Cambrian

Reservoirs:

Bilara: Marginal to very good porosities (Avg 5% - >20%)

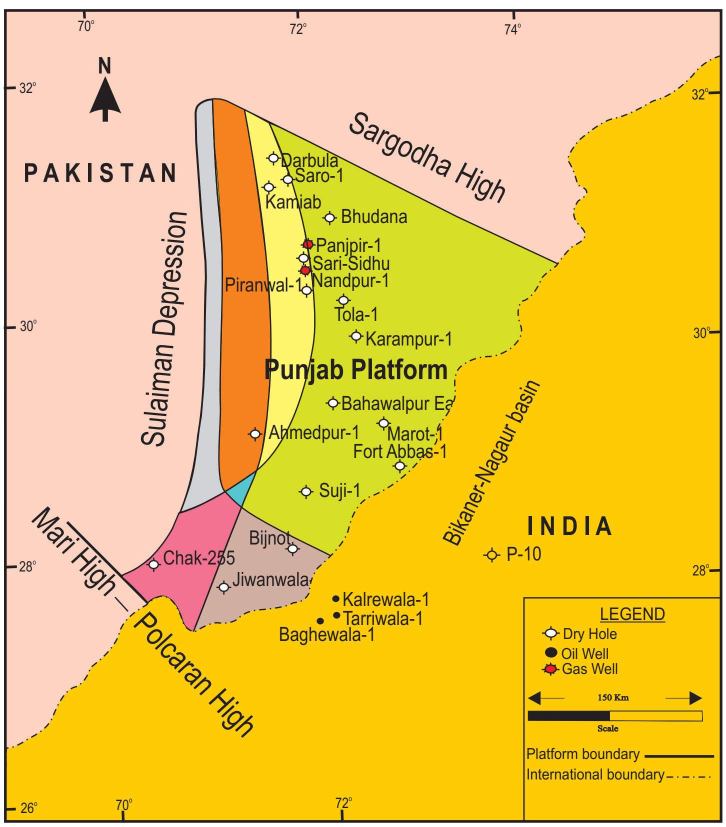
Jodhpur and Salt Range:
Jodhpur: Marginal to very good porosities (Avg 5% - >20%)
Salt Range: Marginal to good porosities (Avg 5% - >10%)

Source Rocks:

- Carbonates of Bilara (Probable source) and oil shales of Salt Range (Potential source)
- The potential source rocks drilled on structural high (horst) are marginally mature
- The source rocks may be mature in structural lows (graben areas) due to increased overburden

Hydrocarbon Traps:

- Normal fault blocks, salt pushed anticlines and onlap structural patterns



Prospective Area of Cambrian

Reservoirs:

Khewra, Kussak and Baghanwala Formations
- Marginal to very good porosities (Avg 5% - >20%)

Kussak and Baghanwala Formations
- Marginal to good porosities (Avg 5% - >10%)

Kussak Formation
- Marginal to very good porosities (Avg 5% - >10%)

Khewra Formation
- Marginal to good porosities (Avg 5% - >10%)

Khewra and Baghanwala Formations
- Marginal to good porosities (Avg 5% - >10%)

Khewra and Kussak Formations
- Marginal to good porosities (Avg 5% - >10%)

Source Rocks:

- No source potential in Cambrian strata
- The reservoirs may have been charged by the underlying Infra-Cambrian source rocks through vertical migration and fult conduits

Hydrocarbon Traps:

- Normal fault blocks and salt pushed anticlines

No potential, poor reservoirs (Avg Por: < 5%)

Prospective Area of Permian

Reservoirs:

Warcha and Amb Formations

- Marginal to very good porosities (Avg 5% - >15%)

Warcha Formation

- Marginal to very good porosities(Avg 10% - >30%)

Source Rocks:

- Shales of Amb Formation
- The reservoirs may be charged by own source rock or from deeper source of Infra-Cambrian through fault conduits

Hydrocarbon Traps:

- Normal fault blocks, salt pushed anticlines and unconformity

No potential, strata absent

Prospective Area of Jurassic

Reservoirs:

Datta, Shinawari,Samanasuk/Chiltan Formations

- Marginal to very good porosities (Avg 5% - >20%)
- Carbonates of Samanasuk are producing reservoirs in Panjpir and Nandpur gas fields

Datta and Shinawari Formation

- Marginal to very good porosities (Avg 5% - >20%)

Datta Formation

- Marginal to good porosities (Avg 5% - >10%)

Source Rocks:

- Shales of Datta and Samanasuk formations
- The reservoirs may be charged by own source rock, from deeper source of Infra-Cambrian and Permian Lying in the graben (structural lows) through fault conduits or through long distance migration from Sulaiman Depression

Hydrocarbon Traps:

- Normal fault blocks, salt pushed anticlines and unconformity

No potential for Datta and Samana Suk, poor reservoirs (Avg Por: < 5%)

No potential, strata absent

Prospective Area of Cretaceous

Reservoirs:

Lumshiwal / Lower Goru Formation

- Very good porosities (Avg. >20%)
- Lumshiwal sands are the gas producing reservoirs in Nandpur and Panjpir wells

Source Rocks:

- Shales of Chichali and carbonates of Parh and Mughalkot formations
- The reservoirs may have been charged by own source, deeper source of Infra-Cambrian and Permian lying in graben (structural lows) through fault conduits or by long distance migration from Sulaiman Depression

Hydrocarbon Traps:

- Normal fault blocks, salt pushed anticlines and unconformity

No potential, strata absent

Prospective Area of Paleocene

Reservoirs:

Sandstones of Ranikot / Hangu Formations

- Very good porosities (Avg. >20%)

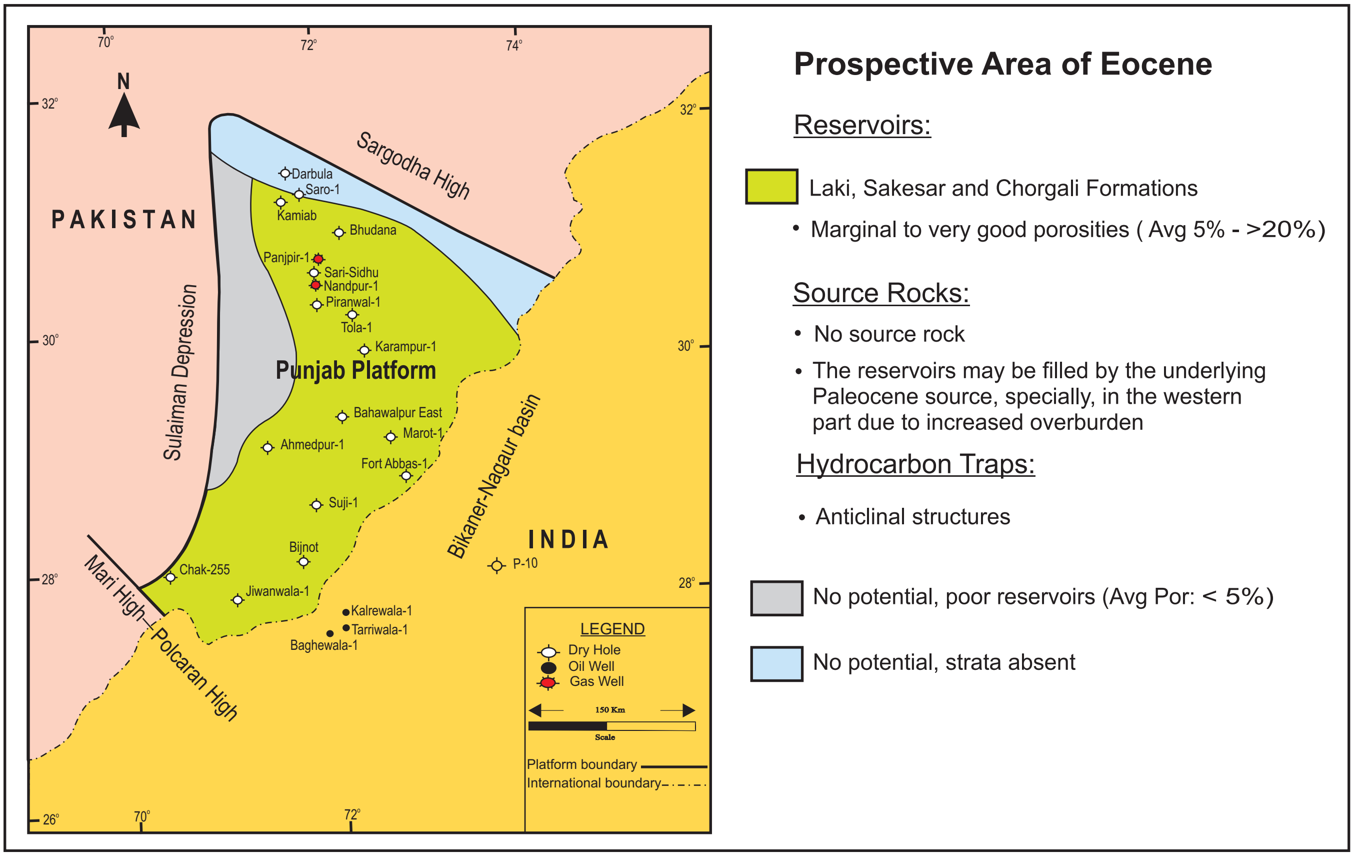
Source Rocks:

- Shales of Ranikot and Dungan Formatons
- The reservoirs may have been charged by own source rock which might be mature in the western part due to increased overburden or due to long distance migration from Sulaiman Depression

Hydrocarbon Traps:

- Anticlinal structures

No potential, strata missing



CONCLUSIONS

- The study indicates that tectonics, structural styles and stratigraphy of Bikaner-Nagaur basin of India is 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 - Mesozoic 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, onlap structure pattern and drop folds.
- Structural/Stratigraphic traps in these areas have not been explored so far.
- Source rocks in Nandpur, Panjpir area are immature, whereas the reservoir gases are mature as indicated by carbon stable isotopic values. This indicates either deep seated source rocks in structural lows or long distance migration of hydrocarbons through fault conduits.
- Only Saro-1(dry hole) was drilled by OGDCL (1992) to test a stratigraphic trap delineated through seismic survey showing truncation of Lumshiwal Formation (Cretaceous) underneath Tertiary unconformity.
- The other hydrocarbon traps identified are salt pushed anticlines, normal fault block up to Mesozoic and traps associated with Tertiary unconformity.
- Geochemical analysis of well samples indicate that shales of Salt Range, Amb, Datta, Chichali, Mughalkot, Ranikot and Carbonates of Samana Suk, Parh and Dunghan formations contain adequate organic carbon content but generally suffer from lack of maturity in the eastern part of Punjab Platform due to inadequate overburden.
- Tectonic, structural and depositional history indicate that the Infra-Cambrian to Paleocene 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.
- Dolomites of Bilara Formation are considered to be the main source of heavy oil in Bikaner-Nagaur basin, India.
- Sandstones of Jodhpur, Khewra, Kussak, Baghanwala, Warcha, Amb, Datta, Shinawari, Lumshiwal/Lower Goru, Ranikot/Hangu and carbonates of Bilara, Samana Suk/Chiltan and Laki/Sakesar/Chorgali formations show good to very good porosities in most part of Punjab Platform.
- Discovery of heavy oil in Jodhpur, Bilara, Hanseran and upper carbonate formations at Baghewala, Tarriwala, 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 and gas discovery in Lumshiwal and Samana Suk formations at Nandpur and Panjpir of Punjab Platform indicate an active petroleum system in the region.

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