PETROLEUM GEOLOGY OF OFFSHORE INDUS BASIN, PAKISTAN

BACHELORS OF SCIENCE (HONS.) IN GEOLOGY

BY

KASHIF SAEED

FACULTY OF EARTH AND ENVIRONMENTAL SCIENCES
BAHRIA UNIVERSITY, ISLAMABAD

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This project is submitted to Faculty of Earth and Environmental Sciences, Bahria University, Islamabad in a partial fulfillment of the requirement for the degree of

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Certificate

This thesis submitted by **Mr. Kashif Saeed** is accepted in the present form by Faculty of Earth & Environmental Sciences, Bahria University, Islamabad as satisfying the partial fulfillment of the requirement for the degree of **Bachelor of Sciences (Hons)** in **Geology.**

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ABSTRACT

The project involves the in-depth study of petroleum system including source, reservoir, seal/cap, maturity, trapping mechanisms, and stratigraphy of Offshore Indus Basin Pakistan. The study helps in the prediction of hydrocarbon accumulations, maturity and extent of source rocks. Offshore Indus Basin, Pakistan is under-explored sedimentary basin of Pakistan. Ten (10) exploratory wells have been drilled by the foreign oil companies but no economic discovery has been made so far, however only gas shows were observed in two wells. Cretaceous and younger stratigraphy is encountered in these exploratory wells. Sembar, Goru, Mughalkot, Pab, Khadro, Bara, Laki - Gazij, Kirthar, Nari, Gaj formations are encountered in wells explored followed by Siwalik Group. Shales, limestones, and argillaceous layers of Gaj, Nari, Laki, Ranikot, and Mughalkot formations are main petroleum source rocks where as sandstones and limestones of Gaj, Nari, Kirthar, and Ranikot formations are acting as the main reservoir rocks in the basin. The intra-formational shales and compact limestones act as seal/cap rock. Isopach maps and migration fairway models are attached for better understanding of hydrocarbon generation and migration.

CHAPTER – 1
INTRODUCTION

The Offshore Indus Basin of Pakistan is located between the coordinates 64° 25´ E to 68° 10´ E and 23° 00´ N to 25° 00´ N in the east of Murray Ridge covering an area of about 90,000 – 240,000 sq. km (Baluch and Quirk, 1998). It is a vast but under explored offshore area of Pakistan.

The geological boundaries of the Offshore Indus extend upto Dabbo-Creek Anticline in the northeast, failed Kutch Rift Basin in east, Murray Ridge in the northwest and west, and southern boundary is taken along significant lobes of delta (Figure 1).

The Indus Offshore basin has been developed as a result of sedimentary deposition associated with Himalayan uplift. The sedimentation is continuing at present as the Indus River system drains the Himalayan Mountains into Indus delta. The Indus River is about 2,900 kms long and travels about 1,200 kms in the plains after leaving the high mountains with the total drainage area of 966,000 sq. kms. Indus River has developed Indus offshore basin, which is the second largest offshore basin in the world after Bengal delta.

The offshore Indus Basin can be divided into Indus deltaic platform, the Indus Fan and the Arabian Sea abyssal plain. The Indus Fan can be divided into upper, middle, and lower fans (Coumes and Kolla, 1984) (Figure 2). The offshore Indus covers the upper fan only.

Between the Murray Ridge in the west and the coast line in the east, there is three fold division of the Indus fan:

1. The offshore deltaic area platform
2. A hinge or transition zone
3. The offshore depression

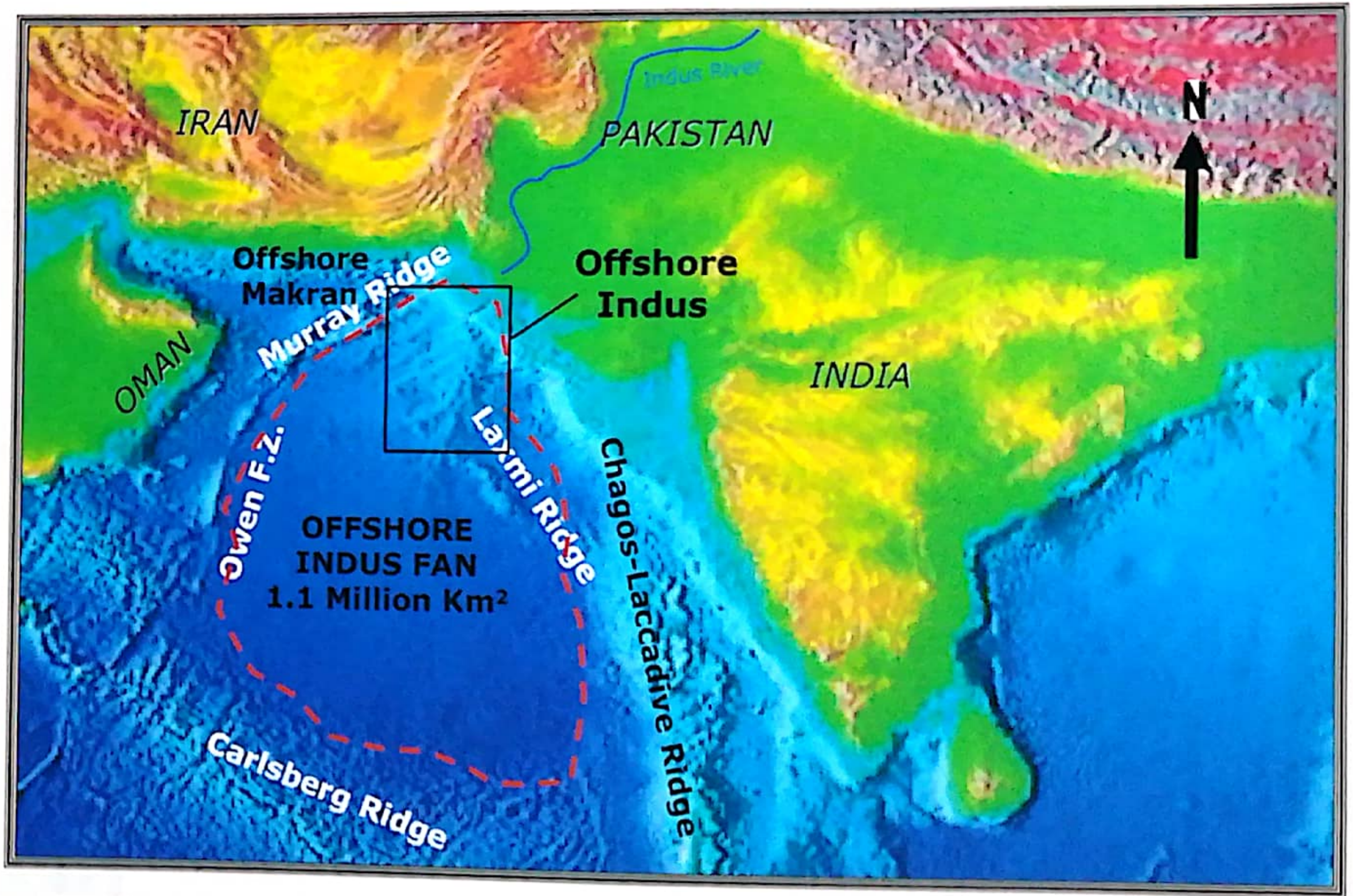


Figure 1: Location Map of Offshore Indus Basin, Pakistan. The Study area has been squared. (after Raza, 2007)

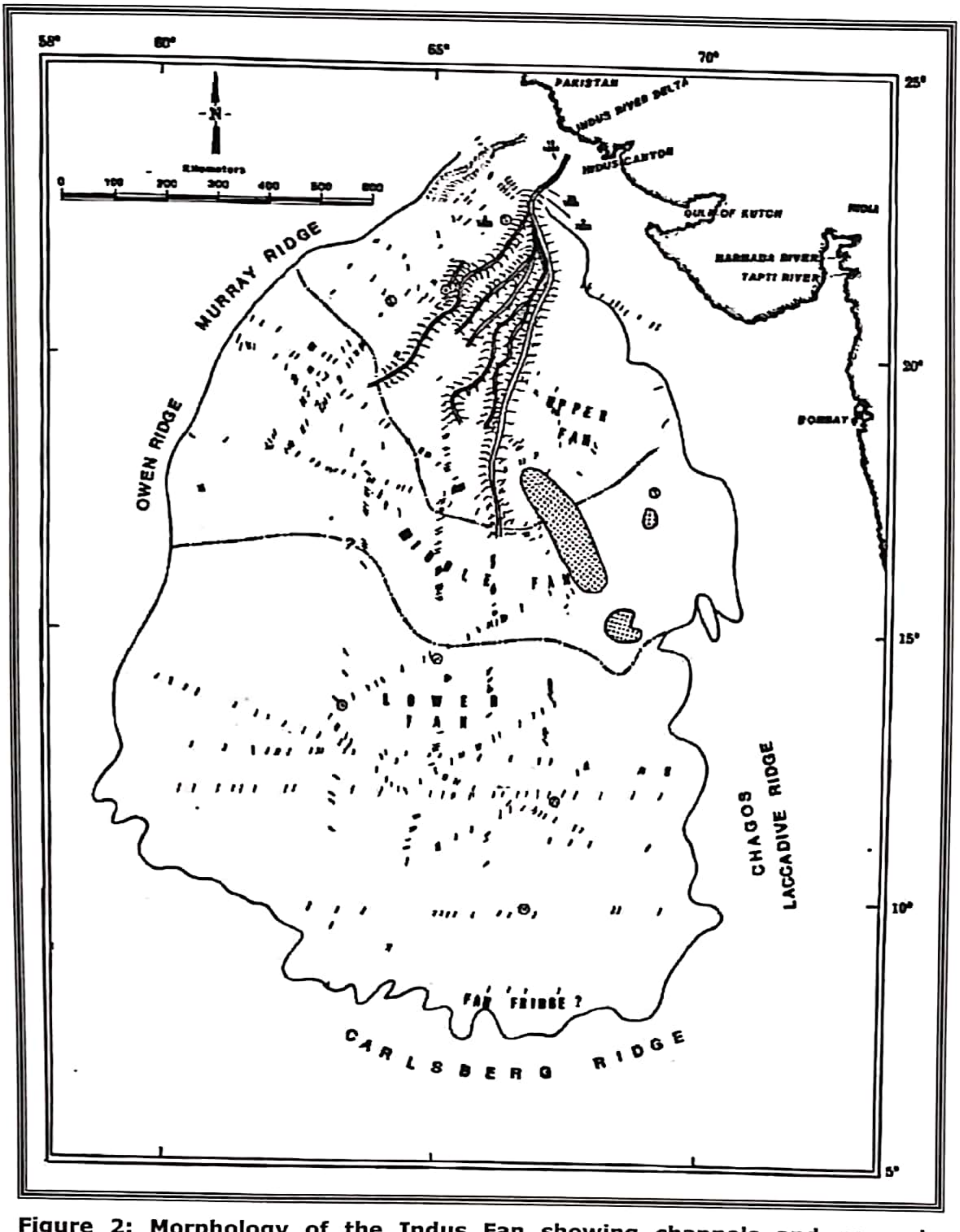


Figure 2: Morphology of the Indus Fan showing channels and general lithology in the upper, middle, and lower fan. Only pattern of channels in the upper fan corresponding to the most recent Indus Canyon is shown.
(after Coumes and Kolla, 1984)

CHAPTER – 2
TECTONIC HISTORY AND SETTINGS

2.1 Tectonic History

Passive margin thermal subsidence in the Early Jurassic resulted in the deposition of a thick succession of fine-grained clastics in western Pakistan. By the Late Jurassic, the combination of widespread passive margin conditions and tectonic quiescence resulted in the establishment of a widespread carbonate platform over most of the country.

Continued breakup of Gondwanaland during the Late Jurassic to Early Cretaceous caused gentle uplift of the interior of the Indian Plate, so that Late Jurassic carbonate platform was replaced by shallow marine to deltaic shales and sandstones.

Separation of the Indian and Madagascan plates occurred at approximately 90 Ma to 82 Ma. This breakup appeared to have resulted from a shearing movement along the Owen Fracture Zone and its northern extension, The Murray Ridge System which separates the Offshore Indus Basin from Offshore Makran Basin, Pakistan (Figure 3).

After Indian and Madagascan plates split during the Cretaceous, northwestern India passed over the reunion hotspot, resulting in the eruption of Deccan Trap (Khadro Formation) and widespread erosion over the Indian Indian Plate. Opening of the Arabian Sea occurred as the Seychelles split off the Indian plate. A regional unconformity or disconformity is developed throughout the Offshore Indus Basin at the base of the Paleocene, beneath the Khadro formation or Ranikot Group.

During the Paleocene and Eocene Tectonic instability associated with the impending approach of Eurasia resulted in frequent lateral and vertical facies changes.

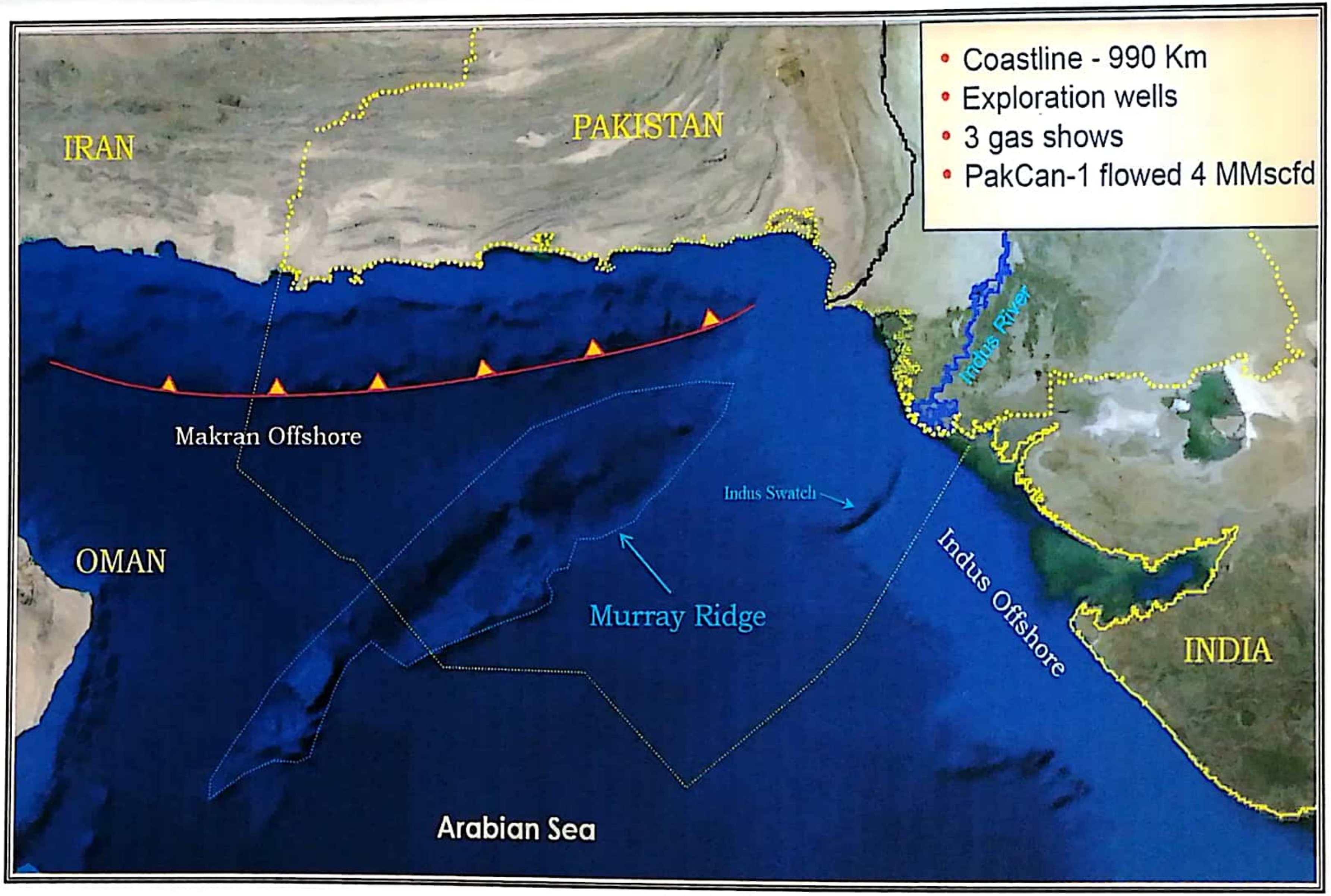


Figure 3: Tectonic elements of Offshore Indus, Pakistan. Murray Ridge is boundary between Makran Offshore and Indus Offshore. (modified after Raza, 2007).

Paleocene carbonate mounds developed in the Offshore Indus Basin. Carbonate deposition was concentrated in the platform area to the east of the hinge zone. Shales and volcanics overlie transitional to oceanic crust in the Middle and Lower Fans (Alam and Daley, 2005). The volcanics from large ridge on which isolated carbonate buildups may occur.

The Paleogene carbonates in the Offshore Indus Basin were drowned by the influx of the large volumes of clastic sediments following the Oligocene start the main phase of continental-continental collision between the Indian plate and Eurasia. The collision was probably most intense from Middle Miocene, including the uplift and tilting of turbidites east of Murray Ridge in the Middle Miocene. The upper Oligocene to Recent Indus Fan clastics were deposited as a thick succession of channel leeve systems. Leeves are particularly well developed in the upper Indus Fan. The Indian Ocean coastline gradually migrated southwards during the Oligocene, so that marine conditions in the Indus Basin were progressively replaced by continental conditions. Himalayan uplift caused deposition of widespread red bed molasse deposits in the Sulaiman and Kirthar ranges by the Middle Miocene, with marine conditions still prevailing in the southernmost part of the Indus Basin.

Closure was complete by the Late Pliocene, and continental conditions prevailed over almost all of present day onshore Pakistan. The uplift of the Himalayas has accelerated, resulting in enormous quantities of clastic material being transported out to the Indus Fan.

The major computed subsidence episodes generated for the basin using Terra Mod software include the following:

The first episode from about 60 – 55 Ma shows evidence of minor subsidence in the basin. This was a time of extension and transtension along the north-western marginal basins of Indo-Pak Craton including offshore Indus Basin of Pakistan.

The second episode is associated with the Paleocene thermal cooling event of the basin. The concave-up shapre is interpreted to represent secular cooling, often related to the thermal contraction which occurs after rifting, which suggests tectonic subsidence due to an advancing orogenic load. The effect was recorded along the slope and in the basinal area.

The third episode from 45 – 35 Ma represents slow rate of subsidence that may indicate the flexuring of this foreland basin. This indicates that the sediments load was not significant during the episode representing Eocene. A possible explanation of this is that Indo-Pak Craton was advancing northward preventing the major loading and then subsequently entered a passive margin phase, with development of carbonate during Eocene.

The fourth episode from about 35 – 25 Ma was recorded as a result of advancing load caused by the Himalayan Orogeny.

The fifth important episode between 25 – 7 Ma with the convex-up shape is representing rapid subsidence event followed by high sediment supply rate during Miocene tectonism.

The rest of events younger than Middle Miocene include the convex-up curve between 7 – 2.2 Ma representing the regional subsidence of Late Miocene-Pliocene, followed by orogenic event of the Karakoram range.

The younger curve between 2.2 – 0 Ma represents the latest Plio-Plietocene phase of tectonisms with the deformations evidenced in the siliciclastic sediments of younger strata.

2.2 Tectonic Settings

Tectonically, three plates namely, Indian, Arabian and Eurasian seem to interact directly to shape the sedimentary basins in Pakistan offshore. A fourth plate (African plate) has also contributed in the evolution of these basins in the past (Figure 4). The offshore Indus Basin represents the western part of the trailing edge of the Indian Plate.

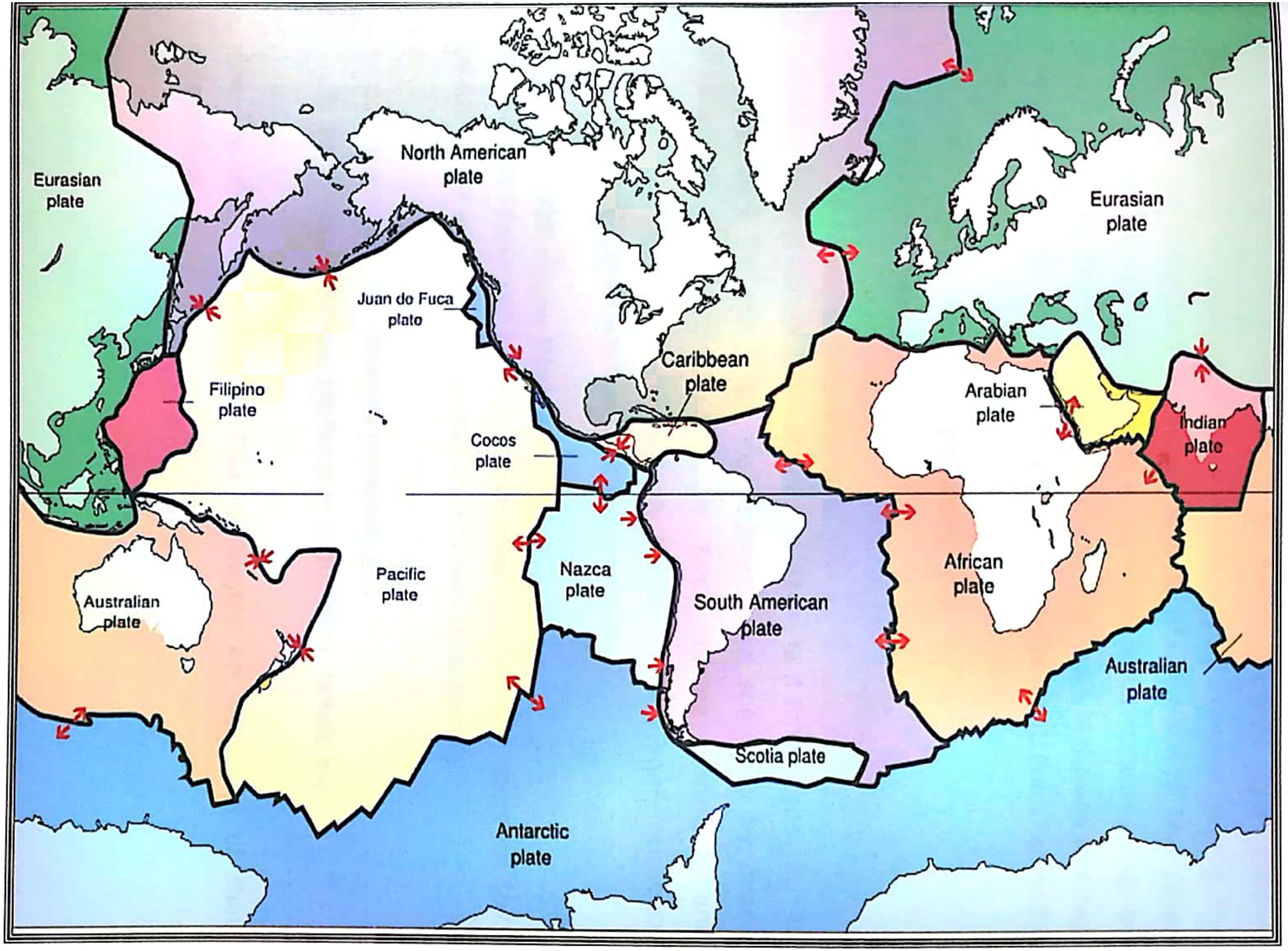


Figure 4: Regional tectonic map of the world showing major plates, Indian and surrounding plates are highlighted. (after Tarbuck and Lutgens, 1999)

The Indus offshore is considered as typical Atlantic Type passive margin which is developed as a breakup of Gondwana during the Mesozoic and is across the continental crust of extension of Thar Slope Platform and Kirthar Foredeep. It is cut in the southeastern corner by the submarine canyon of the Indus River. The basin is divided into two tectonic units with hinge zone/shelf limit as the dividing line (Figure 5). The units are:

1. Offshore Depression (in the west), and
2. Offshore Platform (in the east)

2.2.1 Offshore Depression

Offshore Depression is between Murray Ridge and hinge zone (66° to 67° E). Here the pot Oligocene sedimentation seems to be nearly continuous. It is represented by thick marine calcarious and terrigenous Miocene clastics, a fairly continuous silty-shaly sequence with lenses of sandstone and bands of limestone.

2.2.2 Offshore Platform

Offshore Platform lies between hinge zone and Pakistan shoreline (67° to 68° E). It may be further divided into two units namely:

1. Karachi Trough offshore platform, and
2. Thar Slope offshore platform or Indus river deltaic area

The boundary between the two is roughly an extension of their onshore boundary.

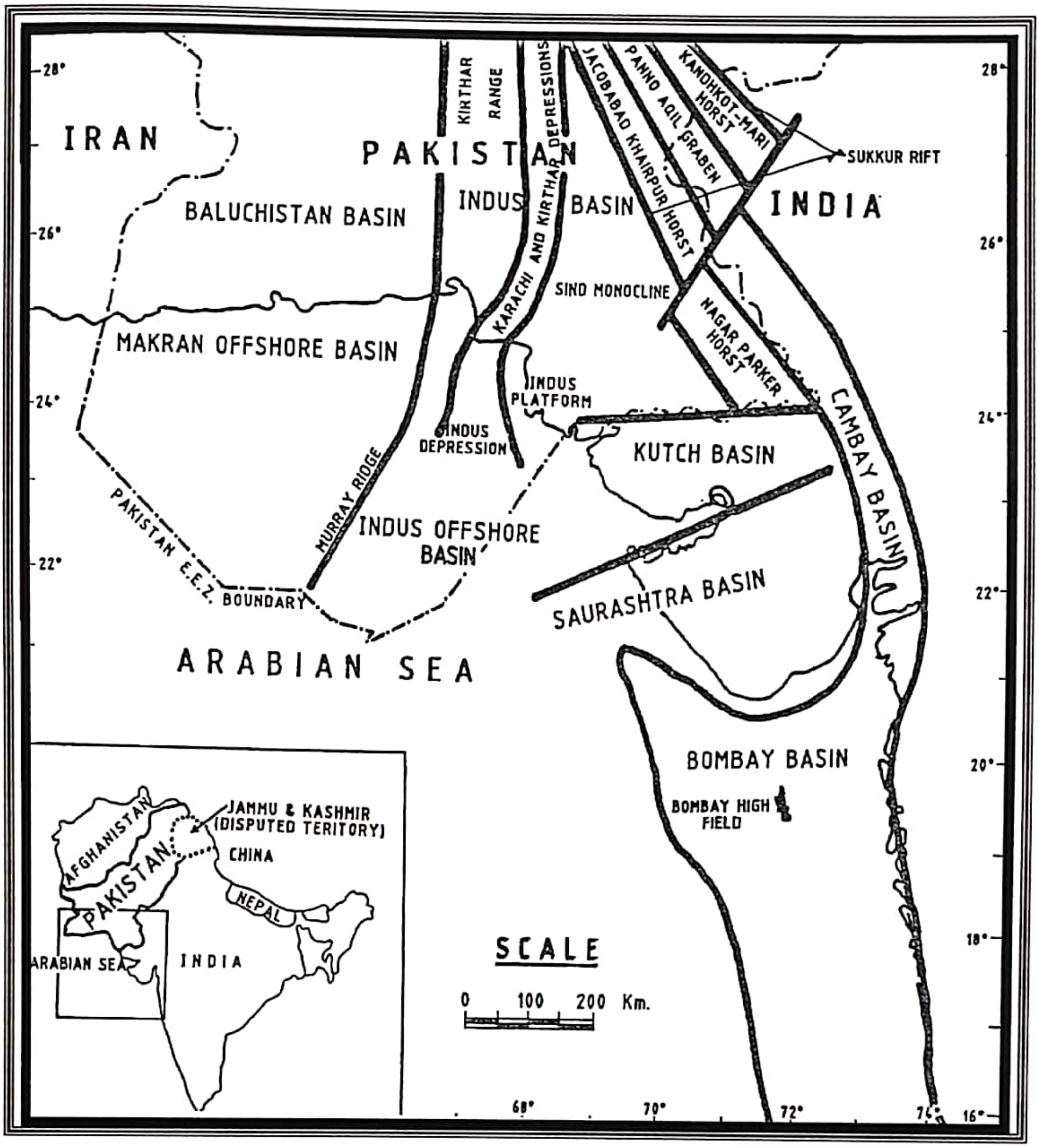


Figure 5: Tectonic map of the Offshore Indus and surrounding areas showing various tectonic elements like Indus Depression and Indus Platform. (after Raza et al, 1990)

Karachi trough is generally a rocky area and is characterized by thick post Eocene cretaceous sediments, whereas Thar Slope is mostly covered by alluvium. Post-early Cetaceous sediments are either lacking or thinning out in Thar Slope. Post Oligocene sedimentation seems to have been continuous, except for a short break during late Miocene as encountered in offshore wells. Post Oligocene strata have a maximum thickness of more then 10,660 ft (3,249 m) in Indus marine B-1. Post-early Miocene sediments are missing in Korangi Creek - 01, Patiani Creek - 01, and Dabbo Creek - 01. So the Karachi trough offshore may be divided tectonically as eastern offshore platform and western offshore depression.

Structurally the Indus offshore consists of following units:

1. A half graben, which is extension of Kutch basin.
2. A platform area which is considered as prolongation of onshore sindh monocline but it may be a part of Kutch basin due to its similarity of sedimentary rocks encountered in creek wells.
3. A deep depression which may be linked with the onshore depressions, this area is severely faulted by sinous and gravity growth faults. The south western margin of this depression is bounded by a gentle uplift running parallel to the axis of the deep. Huge diapiric features are developed in the west of the depression towards Murray ridge.
4. The fault patterns fit in the regional tectonic setting resulting from northward flight of the Indian plate. And subsequent rifting in its southeastern part.

CHAPTER – 3
EXPLORATION HISTORY

Exploratory efforts in the offshore Indus basin comprised of 34,984 km of seismic survey (Table 1) and 10 exploratory wells (Table 2), out of which three did not reach their objectives due to technical problems while other four appear to have been located on inadequate traps through gas shows were recorded in all wells (Shuaib and Shuaib, 1994). Exploration in the Indus Offshore dates back to 1961 when Sun Oil Company (USA) carried out seismic surveys and then drilled three near-shore wells, Dabbo Creek-1 (1963), Patiani Creek-1 (1964), and Korangi Creek-1 (1964). Subsequently, Wintershall (Germany) drilled three wells, Indus Marine A-1 (1972), Indus Marine B-1 (1972) and Indus Marine C-I (1975) which can be truly categorized as offshore wells. Husky (USA) also drilled one well, Karachi South A-l (1978). All these seven Offshore Indus wells, drilled till 1978, did not test movable hydrocarbons, although gas shows were reported in most wells. Some of these wells even failed to reach target objectives after having encountered high pressures. Non-commercial gas quantities flowed in OGDCL's PakCan-1 well (1986) drilled with Canadian assistance, remained the only discovery till that time. Occidental (USA), after conducting modern surveys, Ocean Energy (USA) drilled two more wells during 2000-01, which also ran dry. Seismic in their Indus Delta Exploration Licence, drilled a well Sadaf - 1 (1989); however, the well turned out to be a dry hole.

Sun Oil Company carried out single and double seismic survey of 3,816 km in 1961-62, and drilled three near shore wells, Dabbo Creek-1 (1963), Patiani Creek - 01 (1964), and Korangi Creek – 01 (1964). Wintershall A.G. conducted multiple-fold 9,400 km of seismic survey from 1969-72 and drilled three wells: Indus Marin A-1 (1972), Indus Marine B-1 (1972), and Indus Marine C-1 (1975). Shell International Petroleum carried out multi-fold seismic survey of 506 km in 1973.

Phillips Petroleum carried out a pre-license survey in deep water Indus cone area of 2,557 km in length in 1977 (Figure 6). Husky Oil digitized and reprocessed Sun Oil's data and conducted seismic survey on about 2,380 km from 1976-78, and drilled one well (Karachi South A - 01) in 1978. ELF-Acquitaine carried out multi-fold seismic survey of 3,004 km in 1977 as shown in Table 1.

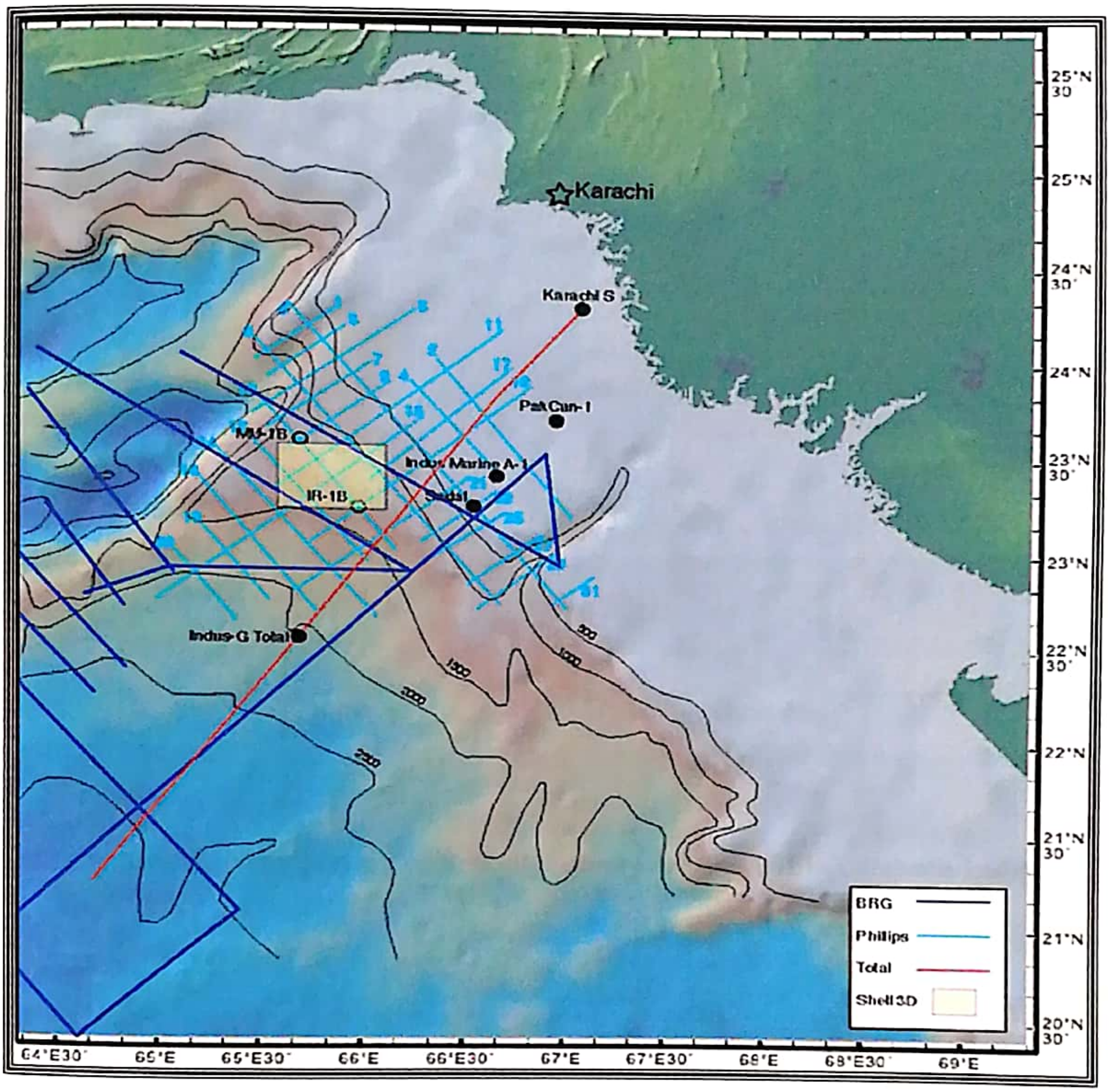


Figure 6: Orientation and pattern of Seismic Lines in Offshore Indus Basin by BRG, Phillips, Total, and Shell. (after Alam and Daley, 2005)

S. No.	Company	Folds	Year	Length (Km.)
1	Sun Oil Co.	Single and double fold only	1961-62	3,816
2	Wintershall	24 Fold	1969-72	9,400
3	Shell International	12 Fold	1973	506
4	Phillips	24 Fold	1977	2,557
5	Husky	24 Fold	1976-78	2,380
6	E.L.F.- Acquaitaine	24 – 36 Fold	1977	3,004
7	OGDC – NORAD	48 Fold	May 1982	1,150
8	OGDC – PCIAC	60 Fold	April-May-June 1986	5,732
9	Occidental	60 Fold	1988-89	5,685
10	Canterbury	24-28 Fold	1990	754
		Total		**34,984**

Table 1: Summarized history of Seismic Survey carried out in Offshore Indus Basin, Pakistan.

A total of 10 exploratory wells were drilled by the foreign oil companies in the Indus Offshore area namely Dabbo Creek - 01 (Shelf area), Korangi Creek – 01 (Shelf area), Patiani Creek – 01 (Shelf area), Indus Marine – A1 (Basin area), Indus Marine – B1 (Basin area), Indus Marine C1 (Basin area), Karachi South – A1 (Shelf area), PakCan – 01 (Basin area), and Sadaf – 01 (Basin area) as discussed in Table 2 and displayed in Figure 7. Mesozoic and Tertiary sedimentary successions have been encountered in these offshore Indus wells. All the wells were abandoned as they proved to be dry although gas shows and traces were found. However, there are prospects of oil and gas in Indus Offshore as the discovery has been made in the Bombay offshore basin (in Eocene and Miocene sandstone and Limestone) as well as the discovery of Khaskeli oil field by Union Texas, in Early Cretaceous lower Goru sandstone at the depth of about 1,040 m. This field is located 150 Km east of Karachi city in Thar slope. Reinterpretation of seismic data shows Dabbo Creek to have been drilled on the downthrown side of fault block structure, Patiani Creek to be located on the northern flank, while the seismic as well as drilling results don't justify the presence of east boundary fault providing closure for the trap tested in Karachi South A-1. All the three Indus Marine wells were stopped due to technical difficulties without reaching objective reservoirs.

The oil and gas discoveries and shows in different formations of Southern Indus Basin and Offshore extension are described in Table 3.

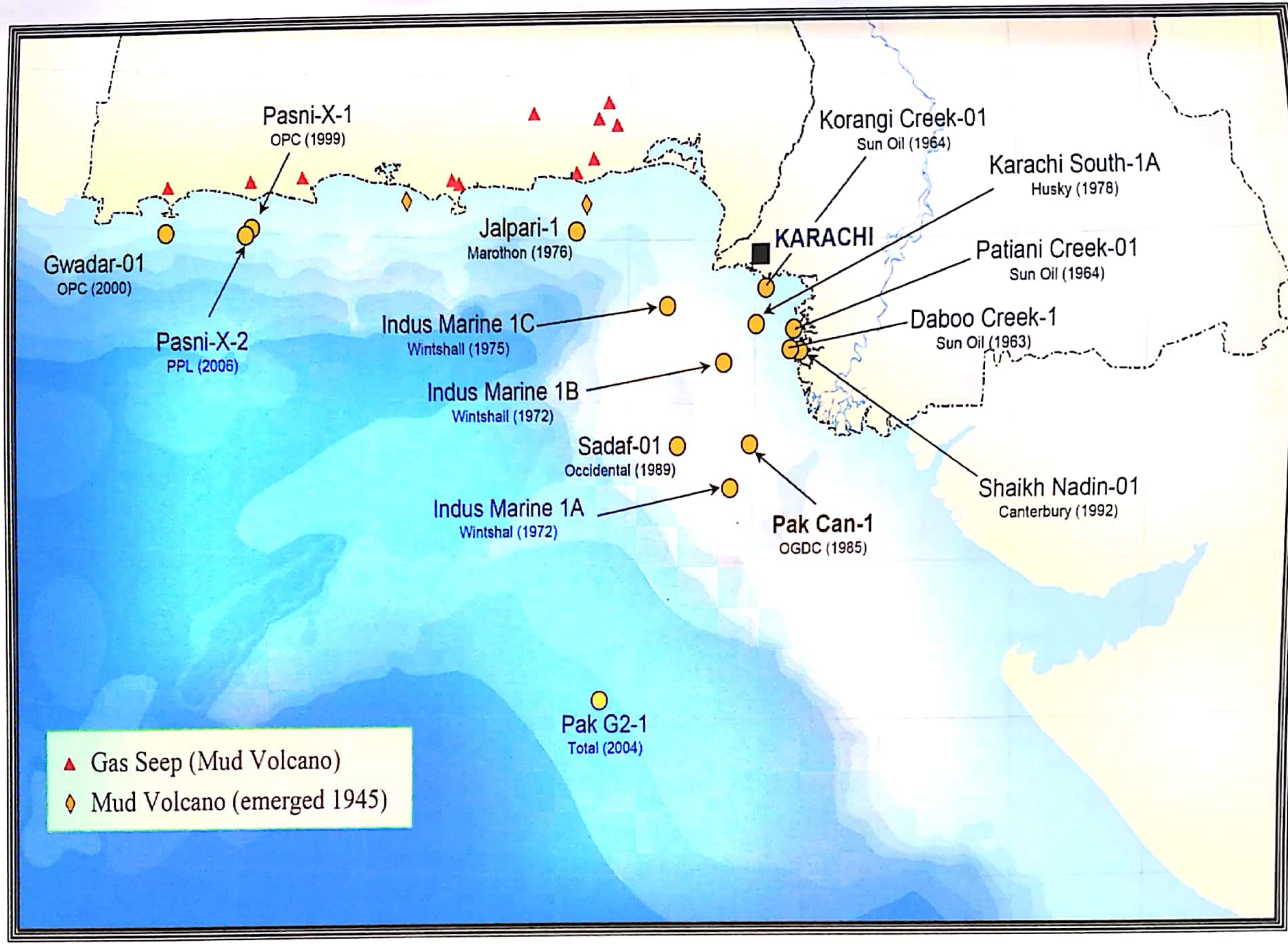


Figure 7: well Location Map of Offshore Indus Basin, Pakistan. (modified after Raza, 2007)

				Reached	In meters)	Reached	Status
Dabbo Creek – 01	Sun Oil	1963-64	24°20´02" N 67°16´42" E	Yes	4354 (-435)	E.Cretaceous / Sembar Fm.	Abandoned
Korangi Creek - 01	Sun Oil	1964-65	24°42´42" N 67°04´14" E	Yes	4140 (-4124)	U.Cretaceous / Mughalkot Fm.	Abandoned
Patiani Creek – 01	Sun Oil	1964	24°27´00" N 67°17´30" E	Yes	2659 (-2643)	U.Cretaceous / Mughalkot Fm.	Abandoned
Indus Marine – A1	Wintershall	1972	23°27´28" N 66°48´26" E	Partially	2841 (-2831)	M.Miocene / Gaj Formation	Abandoned
Indus Marine – B1	Wintershall	1972-73	24°15´03" N 66°45´20" E	Partially	3804 (-3793)	E.Miocene / Gaj Formation	Abandoned
Indus Marine C1	Wintershall	1975	24°36´01" N 66°18´24" E	No	1942 (-1932)	E.Eocene / Ghazij Fm.	Abandoned
Karachi South– A1	Husky	1978	24°29´08" N 67°00´30" E	No	3353 (-3343)	U.Cretaceous / Mughalkot Fm.	Abandoned
PakCan – 01	OGDCL	1985-86	23°44´33" N 66°57´36" E	Yes	3701 (-3684)	M.Miocene / Gaj Formation	Abandoned
Sadaf – 01	Occidental	1990	23°44´08" N 66°23´39" E	Yes	3981(-3965)	M/E.Miocene / Gaj Formation	Abandoned
G2 – 01	Total	2004	22°06´24" N 65°47´34" E	Yes	4725(-4700)	Paleogene	Abandoned

Table 2: Summary of the drilling activities in the Offshore Indus Basin Pakistan (modified after Quadri, 1984)

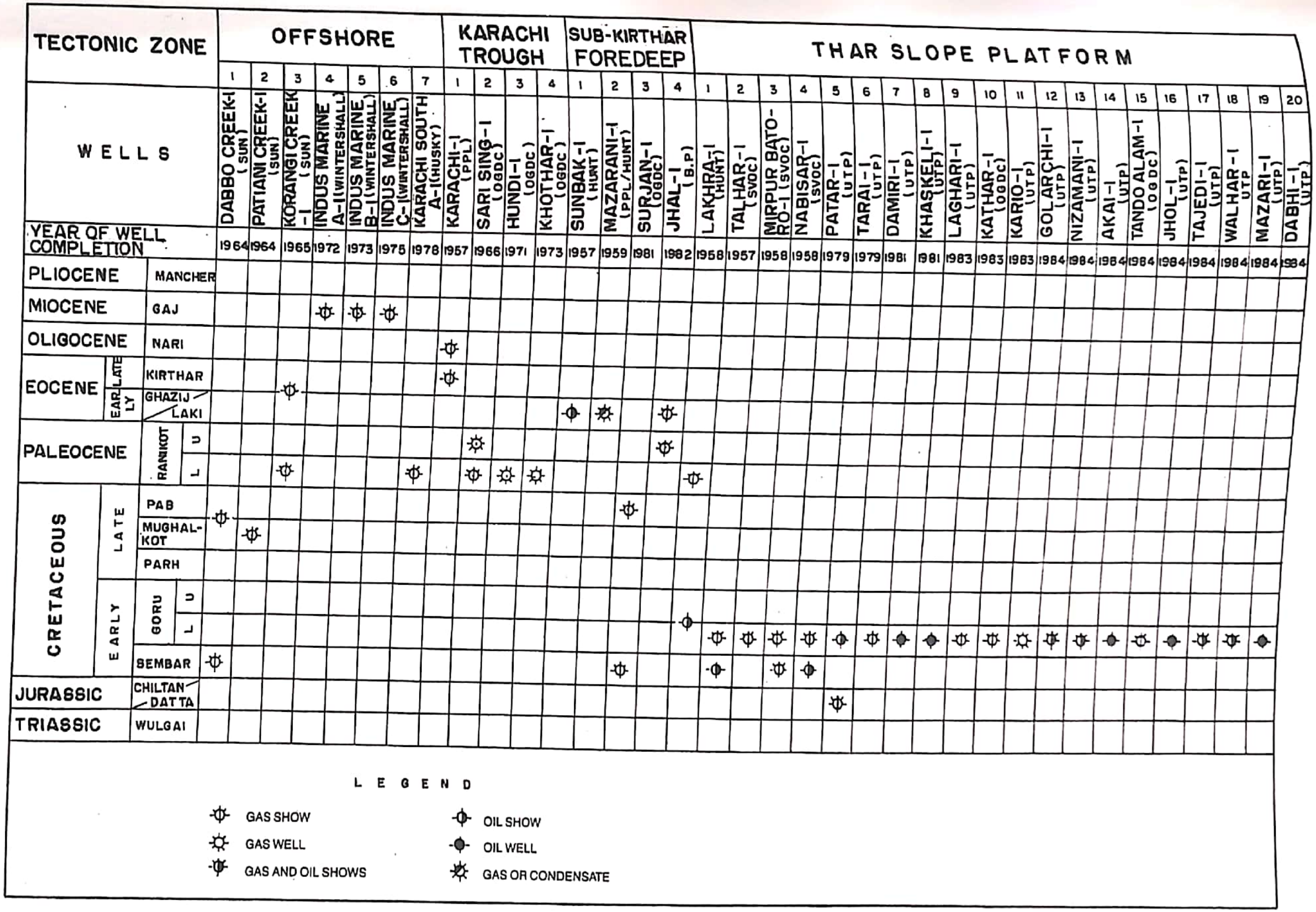


Table 3: Oil and gas discoveries and shows in the Offshore Indus Basin and surrounding areas. (after Quadri et al, 1986)

CHAPTER – 4
STRATIGRAPHY

The Offshore Indus Stratigraphy includes the Mesozoic through the Recent rocks as encountered in the offshore wells. The oldest rocks penetrated by the offshore exploratory wells are of Cretaceous age. The seismic data interpretation and analogy with the Indus Basin suggest that the older rocks are present at depth but could not be reached due to exploratory hurdles like overpressure etc. The lithostratigraphic units recognized within the Offshore Indus Basin and nearby onshore have shown that many of the formations present are displaying the extreme lateral lithological variations, both from NS as well as from EW. Mesozoic – Cenozoic sedimentary sequence presumably overlies the Pre- Cambrian crystalline basement, sedimentation commenced with the opening of the basin by first marine transgression in the Late Triassic/ Early Jurassic. The overlying Cretaceous and Cenozoic strata were deposited on a gentle slope in a generally transgressive environment with a few regressive intervals. In each sedimentary sequence, sand appears close to the craton in the east which generally thins out to the west. The Paleogene is characterized by the development of carbonate banks and reefal build-ups over the shelf area (Figure 8).

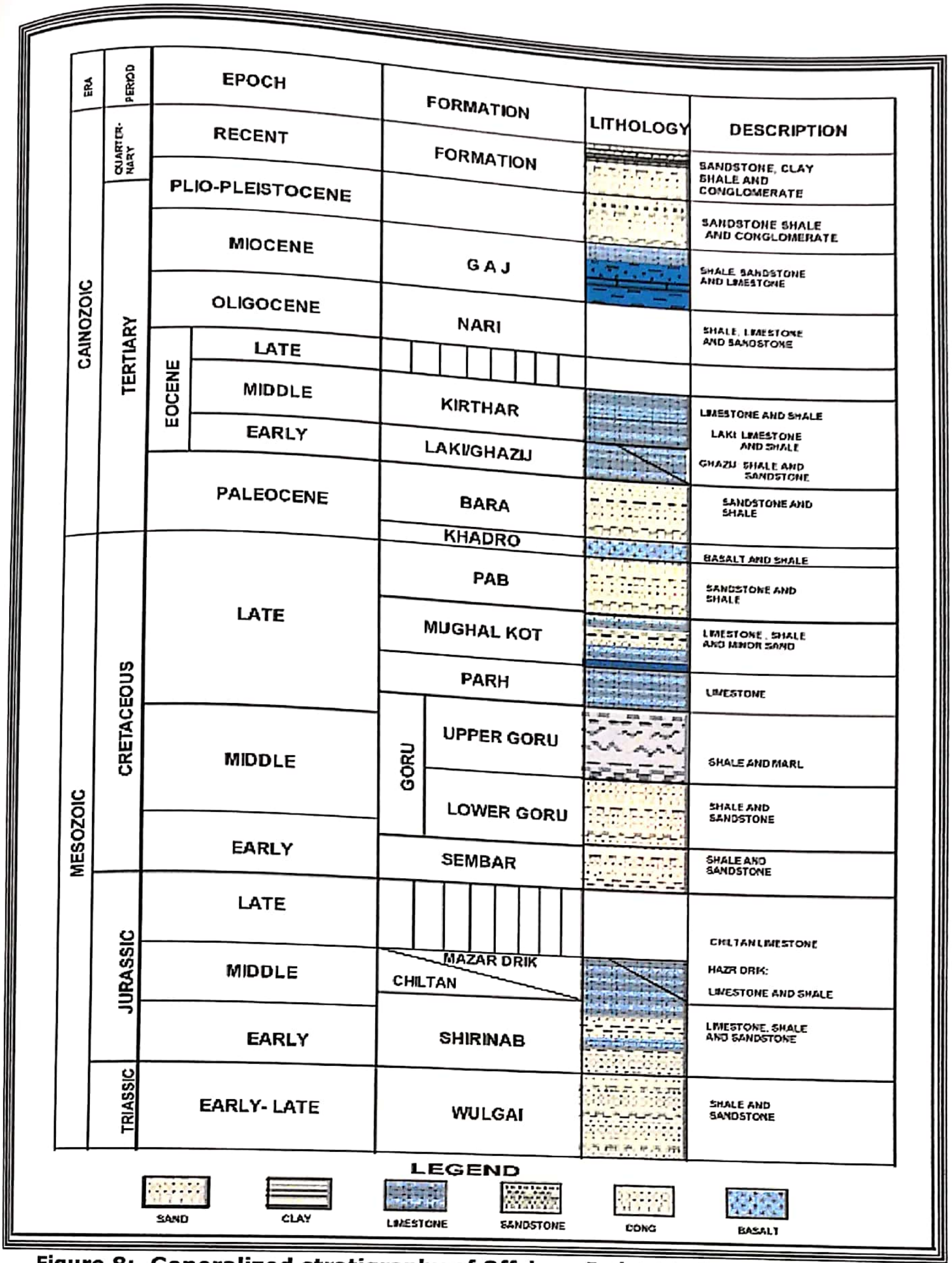


Figure 8: Generalized stratigraphy of Offshore Indus Basin, Pakistan. (after Raza et al, 1990)

The lithostratigraphy of the Offshore Indus Basin is given below in ascending stratigraphic order.

4.1 Sembar Formation

Sembar formation consists mainly of shales with subordinates sand/silt. There is an increasing trend of sand westward due to the proximity of the feeding area, which increases the possibilities of sand reservoirs development in the western area. The shales are expected as a good source rocks due to two reasons: Firstly, these are proven as potential petroleum source rock in Badin area with TOC up to 3%, and secondly, there is evidence of maturation of these shales throughout the area. No specific data is available for the thickness of the Sembar Formation within the Offshore Indus Basin but isopachs trend indicates that its thickness decreases in NE-SW direction in offshore area. There is an increasing trend of thickness southward. The sediments as encountered in Dabbo Creek - 01 at 3639 m (top of Sembar Formation) contained a thin assemblage having Albian age. This is considerably younger than the latest Sembar Formation sediments recorded in the Lower Indus Basin and is a more characteristic age of Lower Goru sediments.

4.2 Lower Goru Formation

Lower Goru sediments are most widely distributed of the Lower Cretaceous strata. The formation consists mainly of shales and sandstone. There is an increasing trend of sand content towards southeast. The shales present in western part are within the range of oil window and may act as potential petroleum source rock. The sand/shale ratio of Badin area (oil producing) seems to continue in the southeastern offshore areas which enhance the possibilities of reservoir in the areas. The evidence of the presence of Lower Goru Formation has been provided by Dabbo Creek - 01 at 752 m.

Thickness of the Lower Goru decreases from onshore to offshore in NW-SW direction. There is an increasing trend in the thickness towards northeast and southwest.

The Lower Goru Formation ranged in age from Barremian to Albian in the onshore Lower Indus Plateform Basin. In offshore, it was only penetrated by Dabbo Creek - 01, where data was not sufficient, possibaly because there was not enough sampling done. However the existing data indicated Albian age.

4.3 Upper Goru Formation

Sediments of Upper Goru Formation are also penetrated only by the Dabbo Creek – 01 offshore exploratory well. Upper Goru Formation is dominantly composed of shale or marl. Carbonates are subordinate lithologies and have a westward increasing trend in thickness. From the Badin area it can be deduced that these shales can act as seal/cap rock in the area. There is a similar trend in the thickness to that of underlying Lower Goru Formation.

The maximum thickness of 2008 m is encountered in Damiri well and it thins out in towards east and west. Only 419 m thick sediments of Upper Goru has been drilled in Offshore Platform Area and may thin towards west and south in Offshore Basin.

4.4 Parh Formation

The Parh Formation has little extent in the offshore Indus Basin. It has been encountered only in Dabbo Creek – 01 where its only 15 m thick. Parh formation is thought to be absent in most of the offshore basin, south and west of the shelf edge.

Parh Formation is exclusively represented by light grey to white, often creamy, thin to medium bedded, platy to occasionally slabby, argillaceous, fossiliferous limestone together with subordinate fossiliferous calcarious shale and marl intercalations. It is only distributed in the northwestern part of area, where it is thinly developed. Its compaction is main causative agent for proving it a failure for source or reservoir rock.

The upper contact of the Parh Formation with the overlying Mughal Kot Formation is believed to be conformable whereas the lower contact with the underlying Goru Formation is also thought to be conformable.

4.5 Mughalkot Formation

Mughal Kot Formation is well defined in the Offshore Indus Basin. Isopach trend shows that it extends roughly upto Indus Marine A – 01 in the south. The formation is has 748 m thickness in Dabbo Creek – 01 well.

Mughalkot Formation is composed dominantly of argillaceous, micritic limestone with subordinate marl, shale and some intercalations of sandstone. There is an increasing trend in shale towards northwest side. This formation is restricted to Indus Basin, the depocenter is around Karachi South – A1 and Patiani Creek wells. As we go coastward the shale content improves and formation may hold source or reservoir potential, but there is no available evidence so far to prove it. In Dabbo Creek – 01, basalts have been encountered.

The formation displays an apparently conformable contact with the overlying sediments of Pab Formation and similarly a conformable stratigraphic relationship with the underlying Parh Formation.

4.6 Pab Formation

Sediments assigned to Pab Formation are only poorly developed in the Offshore Indus Basin and may extend some distance south of Dabbo Creek – 01. Pab Formation is dominantly composed of creamy white to light grey, quartzose sandstone. There is also a shale dominant sequence in the western coastal area (Korangi Creek and Karachi wells). This formation is only present in the Indus Basin. The thickness is variable and it increases northward (Figure - 9). There are unconfirmed occurrences of source and reservoir within the formation but there is no direct evidence of occurrence of hydrocarbons up till now.

The Pab Formation displays an unconformable contact with overlying Ranikot Group. Within the Offshore Indus Basin, the lower stratigraphic relationship of the formation is seen to generally display a conformable contact with the underlying Mughal Kot Formation.

Upper Cretaceous (Maastrichtian) age was assigned to Pab Formation and represents deposition of marginal marine sandstones in shallow water (Kadri, 1995).

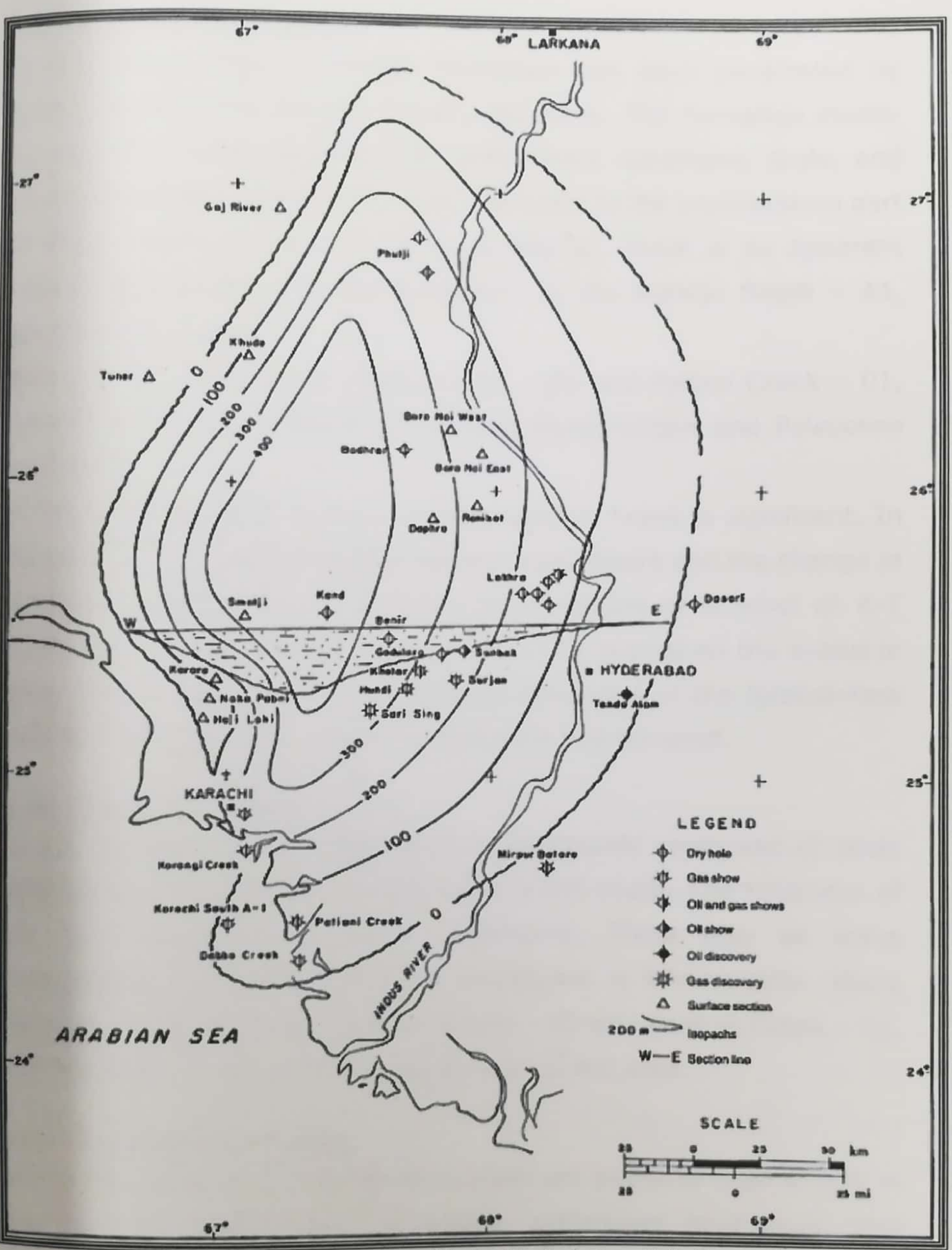


Figure 9: Isopachs and facies of Late Cretaceous Pab Formation. Contour Interval = 100 m. (modified after Quadri et al, 1986)

4.7 Khadro Formation

In the Indus Offshore, Khadro Formation has been penetrated by Dabbo, Patiani, and Korangi Creek – 01 wells. The formation mostly consists of volcanic deposits with subordinate sandstone, shale, and limestone. Khadro Formation is only restricted to the southeastern part of Indus Basin, where it is thinly developed. There is no apparent hydrocarbon potential in the formation. In the Karachi South – A1, basalts were absent.

Within Indus Offshore, in Dabbo Creek – 01 and Patiani Creek – 01, basalts of Khadro Formation separated Maastrichtian and Paleocene sediments.

In the offshore wells studied, the stratigraphic break is significant. In Karachi South – A1, the Khadro basalts were absent and the change in lithology possibly marked a break in deposition at a level of K-T boundary. Atleast, no significant gap could be proved on the available data. The change in the environmental tolerances of the foraminifera indicated that an event of some importance had occurred.

4.8 Bara Formation

In the northern part the formation is dominantly composed of shale whereas in the sandstone is dominant in the south. The thickness of the Bara Formation increases northwards. There may be some hydrocarbon potentials when we investigate it lithologically. There were some gas shows from Dabbo Creek – 01 and Korangi Creek – 01. The formation is within oil window in most of the area.

4.9 Ranikot Formation

Sediments assigned to Ranikot Formation are primarily represented in the Offshore Indus Basin as shales, calcareous mudstones, and argillaceous limestones displaying packstone texture, whilst to the north, in the Lower Indus Basin, they are found to be represented by more well developed sandstone and cleaner limestone lithologies. The unit is present throughout the majority of Offshore Indus Basin, including the Karachi Offshore Platform, although it is thought to be absent in the extreme western margin of the basin (Quadri and Quadri, 1997).

The thickness of Ranikot Formation decreases towards east on Badin area. The formation is 1329 m thick in Korangi Creek - 01, where Upper Ranikot is present.

Within the Offshore Indus Basin, the group is divided stratigraphically into upper and lower units on the basis of lithological variations. The Upper Ranikot has been encountered in only one well drilled in Karachi Offshore Platform (Korangi Creek - 01). The Lower Ranikot unit consists of sandstone interbedded with shale. Lower Ranikot sediments are sand rich and are represented in Patiani Creek – 01 well.

The upper contact of the formation with the overlying Dungan Formation, whereas the lower contact is thought to be unconformable with the underlying Pab Formation.

4.10 Laki/Ghazij Formation

Lower Eocene strata has been penetrated in the offshore platform area wells, where Laki and Ghazij Formations cannot be differentiated. They have varied lithology and correlation has been possible only on the basis of microfossil content. The formation is composed of limestone and shales with subordinate beds of marl, sandstone and some laterite. The limestones are thick to thin bedded, chalky to creamy, nodular in the lower stratigraphic levels. The shales range in colour from gray to greenish-yellow.

The thickness has an increasing trend towards the coastal region. There are good source / reservoirs potentials in the south southeastern parts, where carbonates including reefs are probably better developed. The formation is within oil window in most of the area.

The upper stratigraphic boundary of Laki/Gazhij Formation with overlying carbonate sequence of Kirthar Formation is conformable whereas an unconformable contact can sometimes be discerned with the underlying Dungan Formation.

In the Offshore Indus Basin, based upon the larger microfaunal assemblage present in the formation, Lower Eocene (Ypresian) age was assigned.

The depositional environmental of the formation is moderately shallow to deeper marine, with occasional deposition of the finer grained lithologies within deeper, off-shelf basinal paleo-environments.

4.11 Kirthar Formation

The formation is composed dominantly of limestone, dolomite, with subordinate shales and minor marls, which were intersected in Dabbo Creek – 01, Patiani Creek – 01, Karachi South – A1, and Korangi Creek - 01. The formation is relatively well constrained where well data is available, but become less developed towards the center of the basin and is found to be absent in the eastern part of the basin. It has increasing thickness trend towards north.

The limestones are light grey to creamy in colour, thick bedded to massive, and occasionally nodeular; the shales are poorly consolidated, calcarious, and range in colour from olive to orange to grey. The limestone is generally fossiliferous and contains a diverse assemblage of both macro- and microfauna. It has typical shelf carbonate deposit. The thickness of formation in Offshore Indus Basin is variable ranging from 117 m (Dabbo Creek - 01) to 335 m (Korangi Creek - 01) (Figure 10).

The upper contact of the formation is mostly unconformable with overlying Nari Formation, whereas the lower stratigraphic boundary with Laki/Ghazij Formation is conformable and transitional.

In the Offshore Indus Basin, the limestones of the Kirthar Formation have an apparently restricted to Middle Eocene age and the depositional environment is marine, primarily middle to outer shelf.

The good reservoir can be of carbonates and some gas shows were also encountered in Karachi – 01.

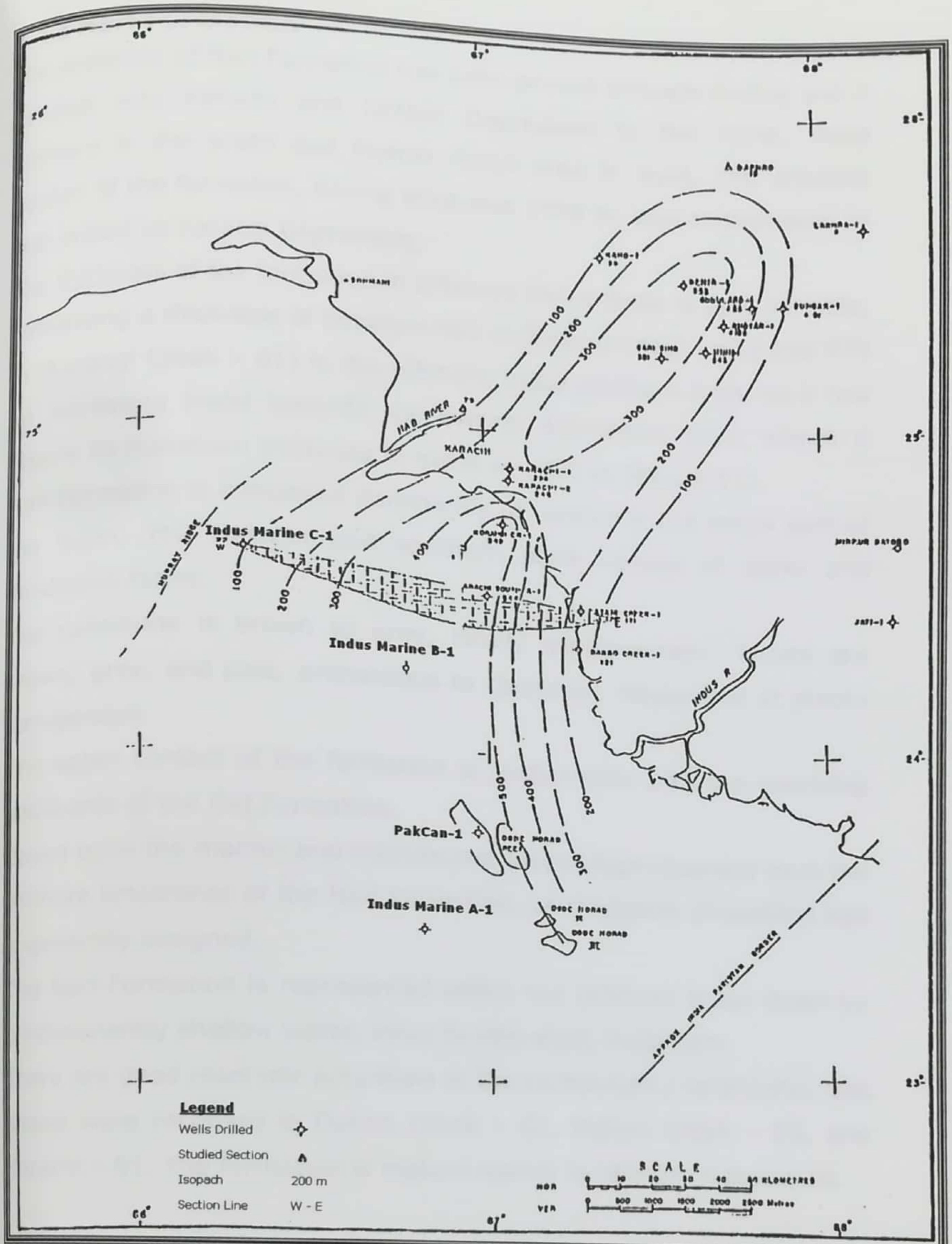


Figure 10: Isopachs and facies of Late Eocene Kirthar Formation in Offshore Indus Basin, Pakistan based on well logs and studies sections (modified after Shuaib et al, 1994)

4.12 Nari Formation

The presence of Nari Formation has been proved through drilling and it extends into Karachi and Kirthar Depression in the north, deep offshore in the south and Murray Ridge area in west. The thickest section of the formation, having thickness 1798 m, was encountered in well drilled on Karachi Depression.

The thickness of the formation in Offshore Indus Basin is very variable, possessing a thickness of between 463 m (Dabbo Creek - 01) and 970 m (Korangi Creek – 01) in the offshore Indus platform area, so it has an increasing trend towards the central depression area, where it attains its maximum thickness in exces of 1500 m (Figure 11).

Nari Formation is composed dominantly of clastics in the major part of the basin. The western and southern parts consist of shale and sandstone facies.

The sandstone is brown to grey, locally conglomeratic. Shales are brown, grey, and pale, arenaceous to calcerous, clayey and at places ferrogenous.

The upper contact of the formation is conformable with the overlying sediments of the Gaj Formation.

Based upon the macro- and microfaunal assemblage recorded from the onshore limestones of the Nari Formation, an Oligocene (Rupelian) age is generally assigned.

The Nari Formation is represented within the Offshore Indus Basin by predominantly shallow water, inner to mid-shelf, limestone.

There are good reservoir potentials in the carbonates / sandstone. Gas shows were recorded in Dabbo Creek – 01, Patiani Creek – 01, and Karachi – 01. The formation is mature mainly in offshore depression.

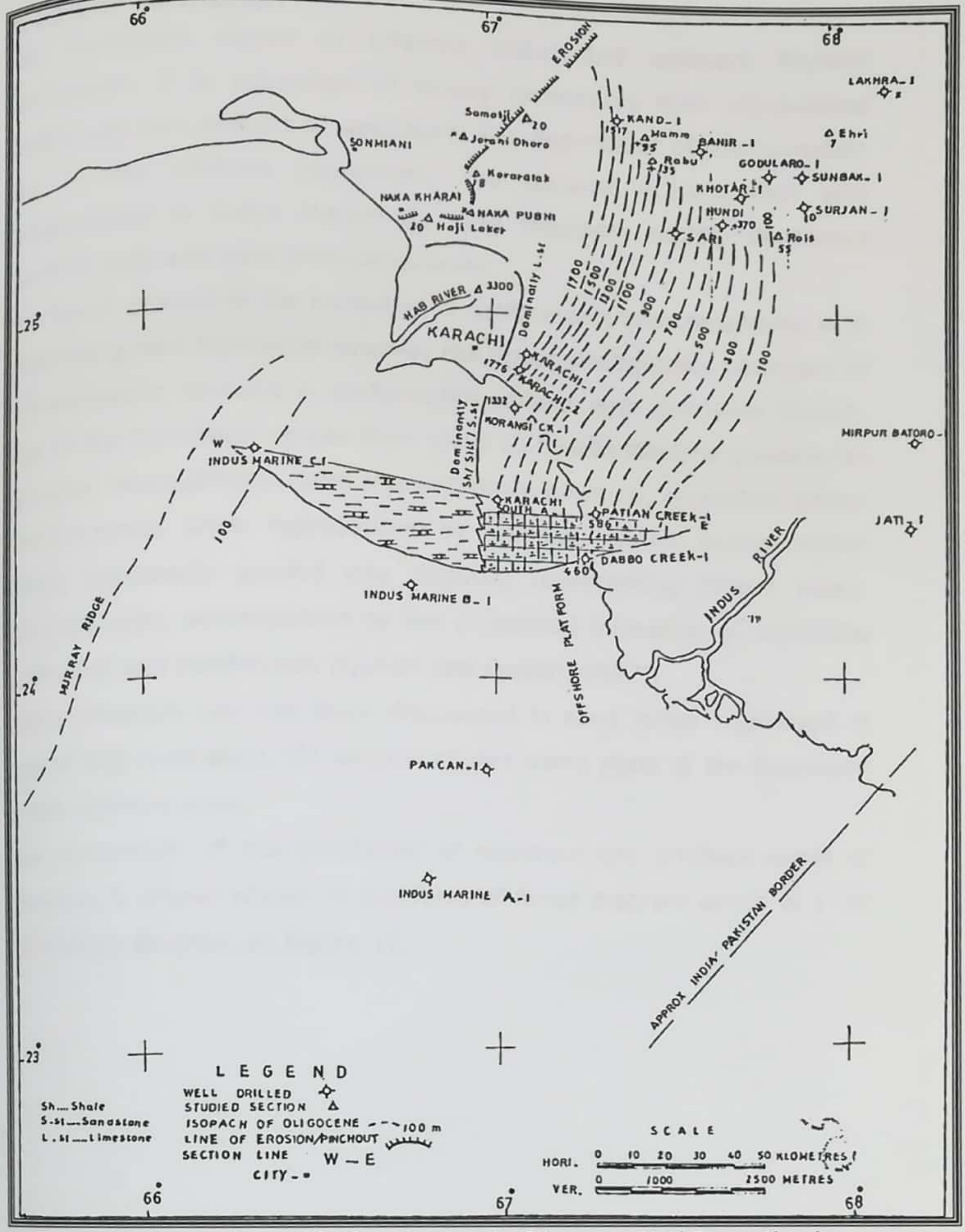


Figure 11: Isopachs and facies changes in Oligocene Nari Formation in Offshore Indus Basin and adjoining areas. (modified after Shuaib et al, 1994)

4.13 Gaj Formation

Gaj Formation occurs in offshore Indus and adjacent Karachi depression. It is composed of mainly carbonates with interbedded shales and rare amount of sandstone. The depocenter of the formation lies in the offshore depression. The thickest accumulation was encountered in Indus Marine B1. The thickness rapidly decreases towards east and west from depocenter.

The lower contact of the formation is conformable and transitional with underlying Nari Formation whereas the upper stratigraphic boundary of the formation displays a conformable contact with overlying Siwalik. Age of the formation ranges from lower to middle Miocene (Aquitanian to upper Serravallian). From Miocene times onwards, deposition paleo-environments were represented by shallow marine sedimentation which repeatedly graded into deposits representing littoral paleo-environments, accompanied by the occasional formation of supratidal dolomites and sandstones (Quadri and Quadri, 1997).

Noncommercial gas has been discovered in sand facies equivalent in age of Gaj Formation. Oil window covers some parts of the formation in the offshore area.

The correlation of the lithofacies of southern and offshore areas of Pakistan is shown shown in the form of fence diagram which is a 3D correlation diagram as Figure 12.

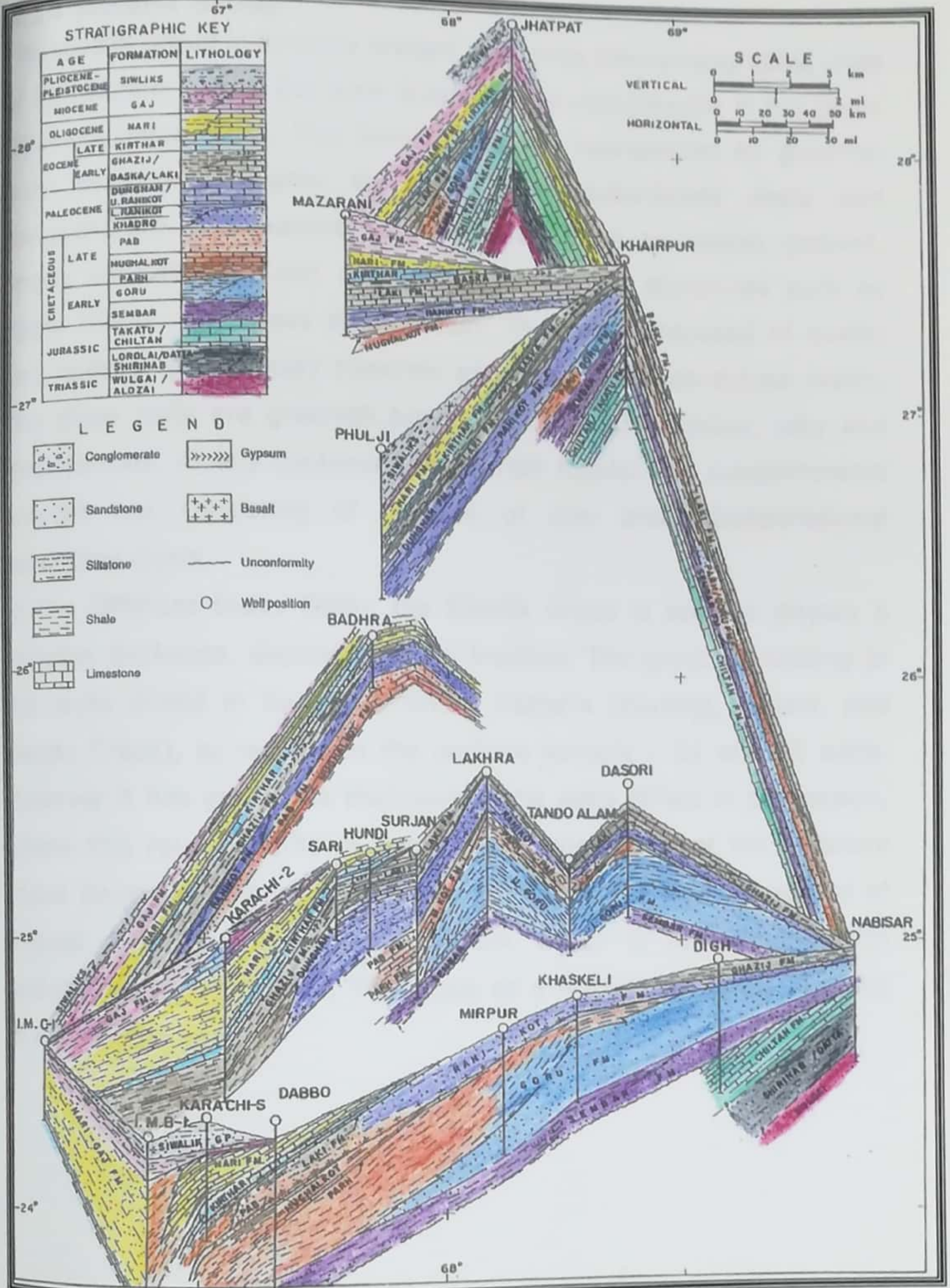


Figure 12: Fence diagram showimg 3D correlation of lithofacies and their distribution in Southern and Offshore Indus Basin, Pakistan. (after Quadri et al, 1986)

4.14 Siwalik Group

The siwalik group is formally divided into three litho-stratigraphic units of formational status, but such division is not recognizable in the Indus Offshore Indus Basin. The Siwalik Group is represented by greenish grey to brownish grey sandstone with subordinate shale and conglomerate. The sandstone is generally fine to coarse grained, poorly consolidated, and displaying sedimentary structures such as ripple marks, and cross stratification. They are composed of quartz and feldspar grains, clay minerals and intra-clastic sandstone clasts. The shale units are greenish brown to brick red in colour, silty and fossiliferrous, mostly containing vertebrate fossils. The conglomerates present are consisting of nodules of clay and intraformational sandstone clasts.

In the Offshore Indus Basin, the Siwalik Group is seen to display a variable thickness, depending upon location. The group is missing in the wells drilled in Karachi Offshore Platform (Korangi, Patiani, and Dabbo Creek), as well as in the onshore Karachi – 01 and 02 wells. However it has enormous thickness in the wells drilled in depression, where this roup is 2330 m thick. Within the center of the Offshore Indus Basin, it is thought to attain a thickness of many thousand of meters. The lower contact of Siwalik Group is conformable with underlying Gaj Formation. The group as a whole is assigned Pliocene to Pleistocene age.

CHAPTER – 5
PETROLEUM SYSTEM

Geological components and processes necessary to generate and store hydrocarbon including a mature source rock, migration pathway, reservoir rock, trap and seal. Appropriate relative timing of formation of these elements and the processes of generation, migration and accumulation are necessary for hydrocarbons to accumulate and be preserved.

5.1 Source Rock

A rock rich in organic matter which, if heated sufficiently, will generate oil and gas. Typical source rocks, usually shales or limestones, contain about 1% organic matter and at least 0.5% total organic carbon (TOC), although a rich source rock might have as much as 10% organic matter. Rocks of marine origin tend to be oil-prone, where as terrestrial source rocks tend to be gas-prone.

5.1.1 Total Organic Carbon (TOC)

TOC of a rock is a direct measure of it organic richness and is expressed as weight percent of organic carbon present in the potential source rock.

Shales containing less than 0.5% TOC and carbonates with less than 0.2% TOC are generally not considered as source rock.

Source Rock Grade	Clastics (%TOC)	Carbonates (%TOC)
Very poor	<0.5	<0.3
Poor	0.5 – 1	0.3 – 0.5
Fair	1 - 2	0.5 – 1
Good	2 – 4	1 – 2
Very Good	4 - 12	2 – 6

Table 4: Classification of source rock richness in the basis of TOC.

5.1.2 Kerogen

The naturally occurring solids, insoluble organic matter that occurs in source rocks and can yield oil upon heating. Typical organic constituents of kerogen are algae and woody plant material.

Types of Kerogen

Kerogen Type	Source	Yield Type
Type – I	Proteins, algae, bacteria, and lipids	Oil prone
Type – II	Mixed marine and terrestrial material, spores, cuticles	Waxy Oil and condensate prone
Type – III	Woody terrestrial material, land plants, cellulose	Gas prone
Type – IV (Residue)	Polycyclic aromatics, dead carbon	No Potential to produce Hydrocarbons

Table 5: Description of Kerogen types their source and yield type.

5.2 Maturity

The state of a source rock with respect to its ability to generate oil or gas. As a source rock begins to mature, it generates gas. As an oil prone source rock matures, the generation of heavy oils is succeeded by medium and light oils.

5.2.1 Diagenesis

Diagenesis is the process of converting living organic material in sediments into kerogene. It involves biological, physical and chemical alteration at temperature upto 50°C (122°F). It proceeds thermal oil and gas generation which is called catagenesis.

5.2.2 Catagenesis

Catagenesis is the process by which organic material in sedimentary rocks is thermally altered, by increasing temperature, resulting in the generation of oil and gas. Catagenesis covers the temperature range between diagenesis and metagenesis, approximating 50°C to 200°C (122°F to 392°F).

5.2.3 Metagenesis

At this stage, the oil generation has stopped and the maturation of oil generated during catagenesis stage proceeds, oil is thermally transformed and become progressively lighter. At the metagenesis stage, only methane, hydrogen sulfide and non-reactive kerogen residue remain. Metagenesis generally occurs at a temperature above 150°C and results in the complete destruction of liquid hydrocarbons, forming gas which is also generated from kerogen.

5.3 Techniques for Maturity Measurements

5.3.1 Pyrolysis

Pyrolysis is the thermo-chemical decomposition of a substance in the absence of oxygen and is useful method source rock maturity evalution.

Standard procedure for pyrolysis is known as Rock-Eval pyrolysis. About 100 mg of finely ground rock sample is placed in furnace at 250° C in an inert atmosphere and temperature is raised upto 550° C. Amount of hydrocarbon products evolved is recorded. Three peaks are typically recorded, known as S_1, S_2, and S_3. Maximum temperature at which S_2 peak is recorded is called T_{max} and is an indicator of source rock maturity.

T_{max} Values for maturity are as under:

Immature - < 435° C

Oil window – 435° C to 450° C

Start of Gas Window - > 450° C

5.3.2 Vitrinite Reflectance

Vitrinite is a type of woody kerogen. Its reflectance changes predictably and constantly upon heating. Vitrinite particles are studied under the microscope and their reflectance is measured. The measurements are given in the units of reflectance, R_o, with the values ranging from 0.2% R_o to 3% R_o.

Typical values for vitrinite reflectance for source rock maturity are:

Immature - <0.5% R_o

Oil Window – 0.5 – 1.25% R_o

Gas Window – 1.25 – 2.5% R_o

5.4 Source rocks of Indus Offshore Basin

The presence of gas shows in most of the wells and testing of non-commercial gas (from offshore standard) from one well proves the occurrence of source rocks and its maturity is subject to sufficient overburden and suitable geothermal gradient.

The conventional source rock of Badin area, Sembar Shales, is present in the Offshore Indus and has been encountered in one of the Creek wells. The shales do not show any significant organic matter in this well; however source richness is expected to improve westwards in the Depression and Platform areas and are expected to be within oil window.

In the offshore, oil shows in a nearby Indian well, oil fields on the south, and source rock evaluation of already drilled offshore exploratory wells provide evidence of liquid and gaseous hydrocarbon generation.

Source rock data for the Offshore Indus Basin is limited and originated from wells, concentrated within the Miocene section. The source rock potential is discussed below on stratigraphic basis.

5.4.1 Plio-Pleistocene Source Rocks

Source rock data for Plio-Pleistocene is limited to Indus Marine A-1. TOC values falls between 0.04 and 1.74%. Pyrolysate yield (Py) is from less than 1 kg Py/t rock to 2.84 kg Py/t rock.

5.4.2 Miocene Source Rocks

Very thick Miocene sediments are present in the Offshore Depression where the targets are Miocene reservoirs. The TOC values in Miocene sediments, generally falling between 0.04% and 3.34% and Pyrolysate yields of less than 1 kg Py/t rock. On the base of available data, Miocene sediments have little significant hydrocarbon generating potential. These rocks are mostly lean with TOC improving towards west; however this organic matter is land derived and accounts for poor source for gas.

5.4.3 Oligocene Source rocks

Varied lithology of Oligocene age has been penetrated in many of the offshore wells but unfortunately no source rock data is available. As in deep offshore, Nari formation of Oligocene age is mixture of sandstone and shale. Source potential for Oligocene sediments can't be totally ruled out. Thin silt beds of Nari Formation having very good potential for gas generation in the coastal areas.

5.4.4 Eocene Source Rock

Eocene sediments have been penetrated in wells Karachi South A-1 and Indus Marine C-1 for which source rock data is available. TOC content is less than 0.5% and Pyrolysate yields reach only 0.1 kg Py/t rock.

5.4.5 Paleocene Source Rocks

Available source rock data for Paleocene sediments is limited to Karachi South A-1 well. TOC values are fair to good with values ranging from 0.5% to 2%. Available data suggest that fair to good oil-prone source rocks may be common in the Ranikot Formation. Ranikot Formation consists of about 2-3 meters of net interval of coal in near-shore wells. In these wells the TOC ranges from 3 – 8 %.

5.4.6 Cretaceous Source Rocks

Very little source rock data for the Cretaceous interval available. TOC data ranges from 1 % to 1.32 % for Pab and Mughal Kot formations. Available data suggest that fair to good oil potential is present in both the Pab and Mughal Kat Formation.

Age	Formation	Depositional Environment	Rock Type
Miocene	Gaj Formation	Basin	Shale
Oligocene	Nari Formation	Outer shelf and slope	Packstone
Eocene	Laki Formation	Basin	Shale
Paleocene	Korara Ranikot	Basin Outer shelf	Shale Packstone
Cretaceous	Mughalkot	Basin	Argillaceous micstine

Table 6: Source rocks of Offshore Indus Basin, Pakistan. (after Quadri et al, 1986)

5.5 Oil & Gas Windows

Source rock analysis from the Karachi South A – 01 well has estimated an oil window from 1,981 to 3,505 m, covering the section from the Oligocene Nari Formation to the Upper Cretaceous Mughalkot Formation (Robertson Research, 1978). In Indus Marine B – 01 well, hydrocarbon maturation occurred between 2,438 and 3,810 m in the lower Miocene Gaj Formation. In Indus Marine C -01 well, sediments from 1,005 to 1,493 m contain dominantly oil-prone matter (oil window) in the lower to middle Miocene Gaj Formation, whereas those from 1,493 to 1,926 m are mainly gas-prone matter (gas window) covering the section from the lower Eocene Laki Formation to the lower Miocene Gaj Formation (Shuaib, 1982).

Hydroarbon generation from the kerogen is controlled by geothermal gradient, burial depth, and duration of source rock burial (Tissot and Welte, 1978). Both paleogeothermal gradients and present geothermal gradients are important for assessing the hydrocarbon potential of the basin. Because the data on paleogradients are not adequate in the Offshore Indus Basin, the present gradient has been mapped and displayed as Figure 13.

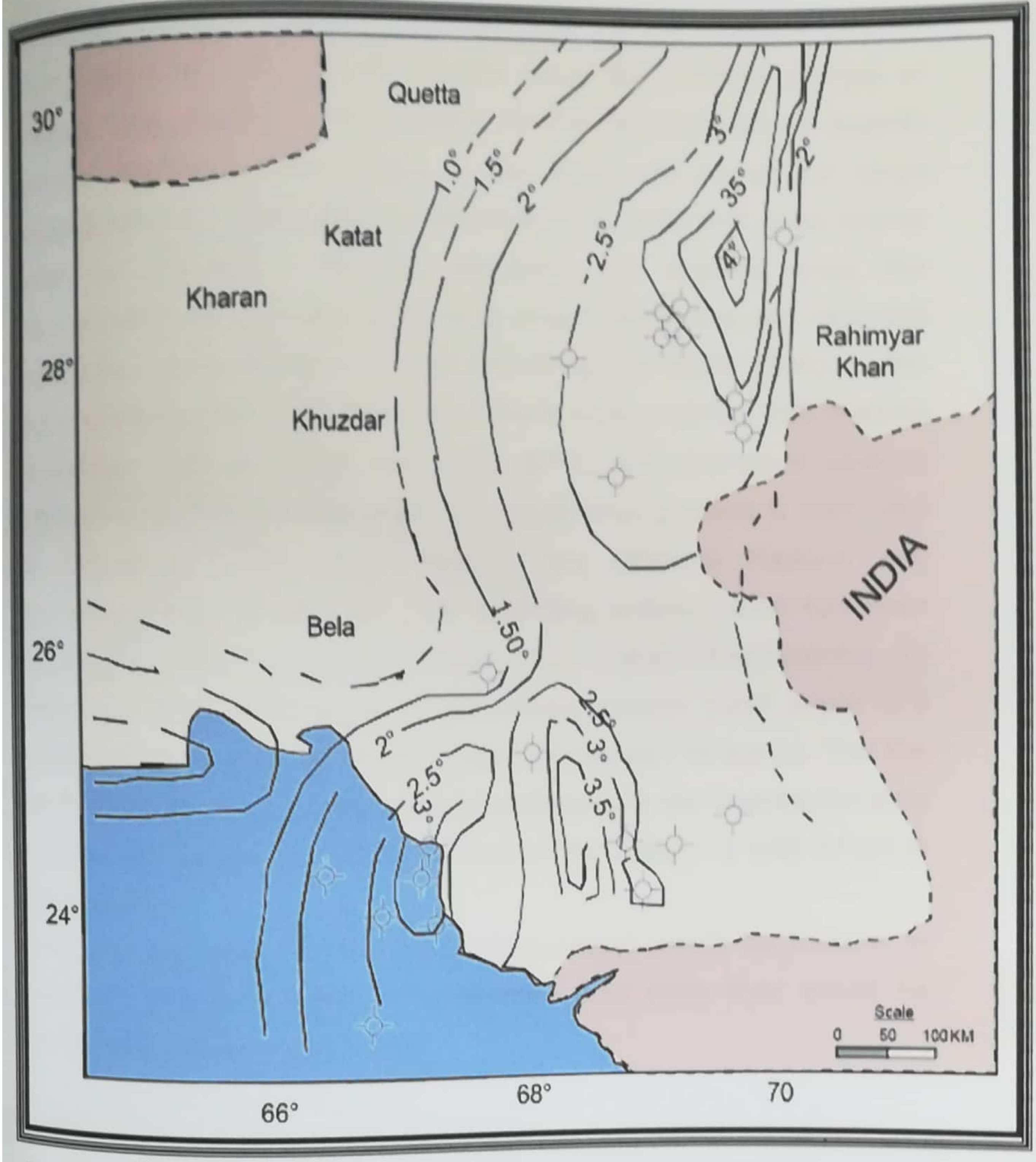


Figure 13: Geothermal gradient map of Offshore Indus Basin, Pakistan and surrounding area. (modified after Quadri et al, 1986)

At present, a thick oxygen minimum zone (< 0.5 ml/liter) extends from depths of 100 – 1,500 meters along the northern margin of Arabian Sea, which is very prolific for the preservation of organic matter. Analogs of this basin in the world are known for large accumulation of hydrocarbons. Therefore, it is likely that good source rocks in Miocene / Pliocene sequence are present since the environment for the deposition and preservation has not changed drastically during Miocene / Pliocene (McHargue & Webb, 1986). In the Indus Offshore, the geothermal gradient is highest (3°C / 100 meters) nearshore close to hinge line (Long 67°E) and decreases towards Offshore Depression in the west. The geothermal gradient is controlled by Paleoslope rather than deep in the Offshore Platform and Depression area as the post Late Oligocene sedimentation has been very rapid (Indus fan contains about 7,000 meters of sediments). To attain the maturity level fro oil generation, greater burial depth is a crucial factor for younger source rocks (Oligocene / Miocene). The low geothermal gradient in the younger sediments in the Depression area may be the reason for lack of success of the Sadaf – 1 well drilled in this region.

However, the older source rocks (Cretaceous) would be mature in relatively shallower nearshore (platform) area while they would be overlooked in Depression areas.

5.6 Reservoir Rock

A subsurface body of rock having sufficient porosity and permeability to store and transmit fluids. Sedimentary rocks especially sandstones and limestones (having secondary porosity) are the most common reservoir rocks.

5.6.1 Porosity

The percentage of pore volumes or void space, or that volume within a rock which can contain fluids. the porosity of a porous medium (such as rock or sediment) describes how densely the material is packed. It is the proportion of the non-solid volume to the total volume of material, and is defined by the ratio:

$$n = \frac{V_v}{V} \times 100$$

where

n = Porosity in percentage

V_v = Vloume of void spaces in a unit volume of earth material

V = Unit volume of earth material, including both voids and solids

Both φ and *n* are used to denote porosity.

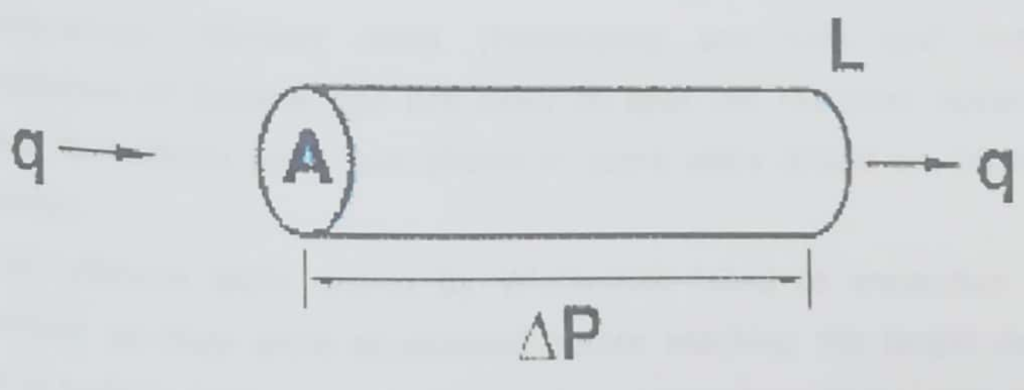
Types of Porosity

- Primary porosity is the main or original porosity system in a rock or unconfined alluvial deposit.
- Secondary porosity is a subsequent or separate porosity system in a rock, often enhancing overall porosity of a rock. This can be a result of chemical leeching of minerals or the generation of a fracture system. This can replace the primary porosity or coexist with it.

5.6.2 Permeability

The ability, or measure of rock's ability to transmit fluids, typically measured in darcies or millidarcies. Formations that transmit fluids readily, such as sandstones, are described as permeable and tend to have many large, well-connected pores.

Permeability is the proportionality "constant" between the fluid flow rate and an applied pressure or potential gradient.



According to Darcy, for a single incompressible fluid, permeability is given as:

$$K = \frac{Q\mu L}{A\Delta P}$$

Where

K = Permeability

Q = Rate of flow

μ = Fluid dynamic viscosity

L = Length of flow path

A = Cross-sectional area

ΔP = Hydraulic Gradient

5.7 Reservoir Rocks of Offshore Indus Basin

Cretaceous and Paleocene reservoirs would be quite deep in the offshore depression areas and the objectives would, therefore, be restricted to Miocene / Pliocene sand – silt sequence. In the Platform areas the potential reservoirs are compatible with their counterparts in Karachi Trough and Thar Slope onshore. Sembar and Goru Sands (Cretaceous), Ranikot Sand (Paleocene) and Laki and Kirthar Limestones of Eocene age are likely to bear the reservoir potential. These formations have gas shows in some wells drilled on Offshore Platform.

Three offshore wells drilled by Wintershall failed to encounter any reservoir as they were abandoned before reaching the target depth due to technical reasons after encountering high formation pressures.

OGDCL's well PakCan – 1 encountered certain Miocene reservoir intervals which were tested for 2 – 3 MMcfd of gas. Although Oxy's well Sadaf – 1 failed to prove the presence of any hydrocarbons, it encountered some sand intervals with very good porosity.

Cretaceous and Paleocene sandstones are proved oil and gas bearing zones in the onshore Thar slope and Karachi trough, respectively (Shuaib, 1982). The Khaskli well, situated about 150 km east of Karachi city on the Thar slope, was drilled in May 1980 and encountered oil bearing Early Cretaceous lower Goru sandstone at the depth of about 1,040 m. The Sari and Hundi wells situated about 70 km and 80 km, respectively, northeast of Karachi city in the Karachi trough are producing gas from Paleocene sandstone and limestone at the depth of about 1,250 m. Oil and gas deposits were discovered in Bombay offshore basin of India in its southeast direction in Eocene and Miocene sandstone and limestone (biomicrite). Therefore, Cretaceous and Paleocene sandstone or limestone in the offshore depression may be primary objectives for hydrocarbon reservoirs.

5.7.1 Miocene – Oligocene Reservoirs

The Oilgocene Nari Formation and Miocene Gaj Formation may be potential reservoirs. Gas shows were encountered in Miocene sediments in Indus Marine A – 01, B – 01, and C – 01 offshore wells.

Superimposed or parallel with Upper Paleocene – Lower Eocene reefs, along the base of the Tertiary hinge zone in the Offshore Indus, possible Oligocene and Miocene undaform banks, as well as clastic wedges of cyclic deltaic sequences are observed in seismic sections. The high amplitude reflections seem to represent coarse channel sediments

5.7.2 Eocene Reservoirs

The Kirthar Formation of Eocene age consist of limestones with shale intercalations and bands of sandstones in place. It has produced gentle flow of gas in Karachi – 01 and 02 wells. In the Korangi Creek – 01 well, a sandy zone in Kirthar produced a good blow and gas - cut mud on a drill stem test. To date, it is not oil or gas productive in the Southern Indus Basin.

5.7.3 Paleocene Reservoirs

The Lower Ranikot sandy unit is comparatively widespread and consists mainly of quartz arenite type sandstone intercalated with arenaceous shale, layers of basalt, and in places carbonaceous limestone with leaf imprints and lignitic residue. Coal seams of varying thicknesses are being mined in several places from this unit in Karachi Trough. The lower sandy unit seems to have been deposited in a low energy marginal marine environment. It is mainly of igneous provenance and is a more important reservoir than the upper carbonate unit. Porosity is 11 – 15 % in the Sari gas field in Southern Indus Basin.

The upper Ranikot carbonate unit is composed primarily of fossiliferrous limestone, interbedded with dolomatic shale, calcareous sandstone, and abundant bituminous material. This unit seems to have been deposited in a restricted marine platform. It is mainly confined to an area along the Patiani Creek – 01 well of the central part of Karachi Trough.

Age	Formation	Potential Reservoir Porosity	Rock Type
Middle – Early Miocene	Gaj	Vadose and Fracture Intergranular	Boundstone Sandstone
Oligocene	Nari	Fracture Intergranular	Packstone (Granular Limestone) Sandstone
Eocene	Kirthar	Fracture	Limestone (Biomicrite)
Paleocene	Ranikot	Fratcure Intergranular	Limestone (Biomicrite) Sandstone

Table 7: Reservoir rocks with age and potential reservoir porosity. (after Quadri et al, 1986)

Since the Stratigraphy of the Miocene / Pliocene sequence of the Depresseion is not very clear, it is believed that the reservoir characteristics are to be picked by seismic stratigraphy and their extent mapped for prospect evaluation.

5.8 Seismic Characteristics

Since the lithology and the source / reservoir characteristics of different rock units in the subsurface is not known, the only tool to decipher the lithological, reservoir, and sedimentological patterns is 'seismic stratigraphy'.

On the basis of seismic stratigraphy, Indus Fan is characterized by four facies based on their amplitude, continuity, and geometry (McHargue & Webb, 1986). The facies are:

1. Low amplitude, continuous (L - C)
2. High amplitude, continuous (H - C)
3. Low amplitude, discontinuous (L - D)
4. High amplitude, discontinuous (H - D)

In this context, high amplitude, discontinuous (H - D) facies is considered to have the best economic value. This represents mixed coarse and fine clastics, including reservoir quality sand. The other facies are interpreted to represent fine clastics of reservoir quality.

Figure 14 shows typical representative seismic section of Offshore Indus Basin with seismic facies distribution.

Possible reefal complexes have been observed on seismic sections of good quality data collected in the Offshore Indus. All direct criteria including boundary outline with onlap of overlying reflections and seismic facies changes as well as indirect criteria of drape, velocity anomalies, spurious events, and basin architecture indicate reefal prospects of Late Cretaceous to Miocene ages along trends at the edges of Cretaceous, Paleocene, and Oligocene carbonate platforms.

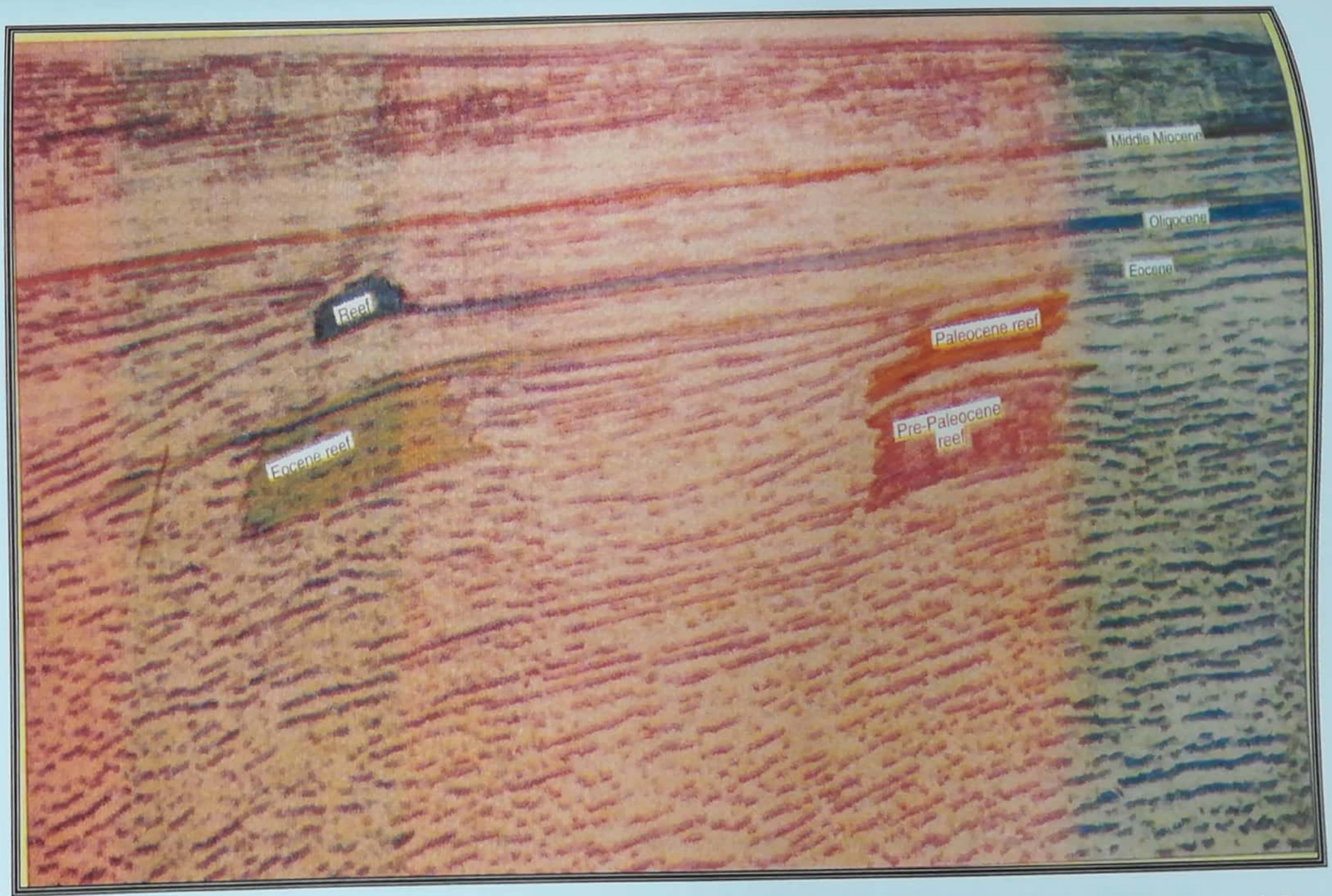


Figure 14: Offshore Indus representive seismic section showing various seismic parameters. (after Quadri and Quadri, 1996)

The typical figure of source, reservoir, cap / seal rocks and playfairway and traps is as under:

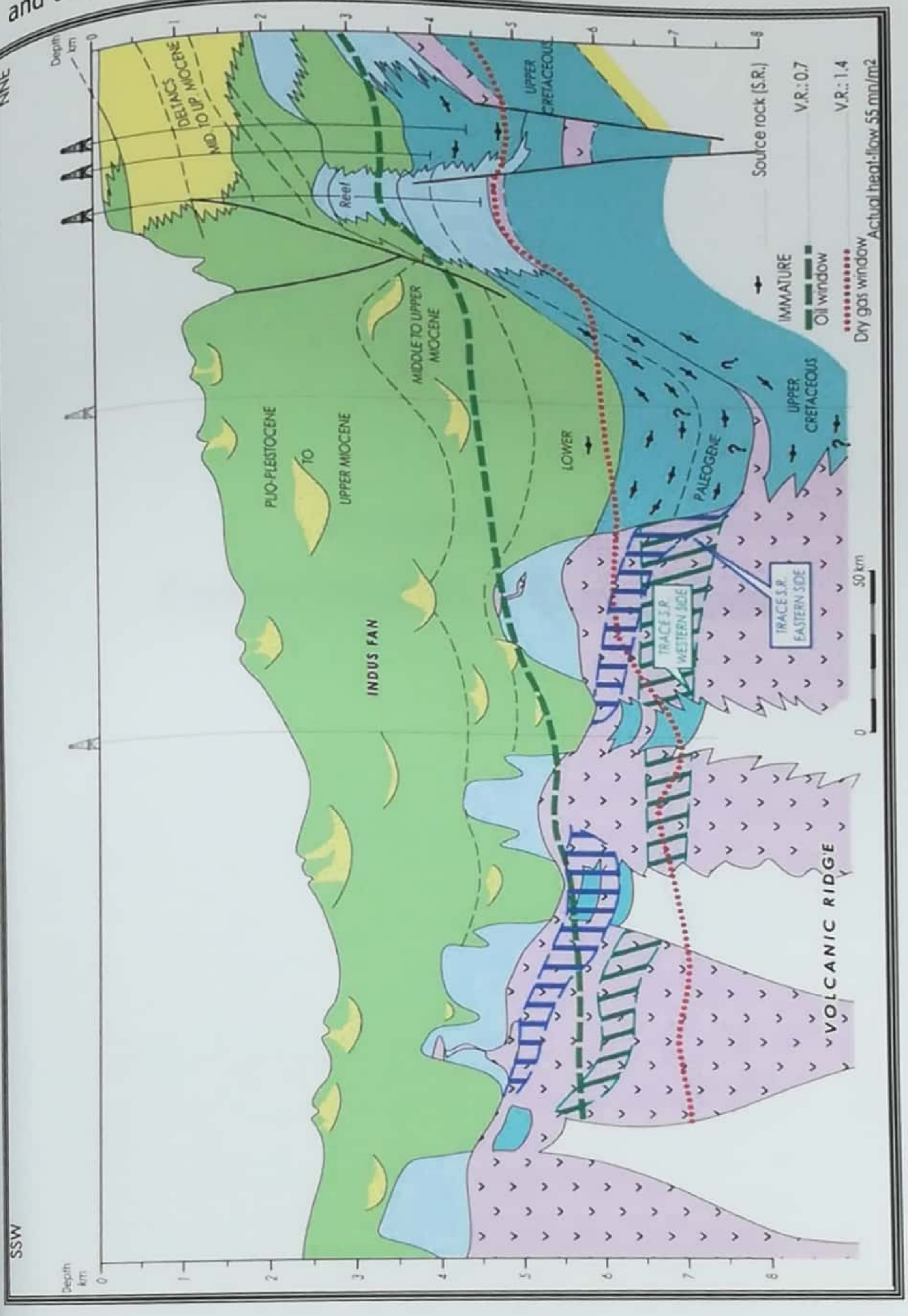


Figure 15: Typical representation of petroleum system including source, reservoirs, seals, traps, and play fairway of Offshore Indus Basin, Pakistan. (modified after Raza, 2007)

CHAPTER – 6
CONCLUSIONS & DISCUSSION

6.1 Conclusions

1. The Offshore Indus Basin, Pakistan is relatively under-explored basin of Pakistan due to many technical and drilling difficulties. The tectonics, stratigraphy, and hydrocarbon generation in the offshore has been studied and it has been revealed that the basin has got tremendous hydrocarbon potential. Source, reservoir, and seal/cap rocks are being examined by the oil sector with a thoroughly professional and intellectual aim of targeting hydrocarbons.

2. The computed interpretation reveals generation of hydrocarbon through kerogen type – II both the shelf and basin areas. The shelf area represents generation of hydrocarbons through type – II kerogen in Cretaceous and Early Paleogene carbonate and siliciclastics. The basin area has also indicated generation of hydrocarbons through type – II kerogen in Early Miocene (Aquitanian) to Middle Miocene (Burdigalian).

3. The source rock contains vitrinite in Cretaceous Sembar Formation, Lower Goru Formation, and Eocene Laki – Gazij Formation in the shelf area.

4. Vitrinite containing source rocks in the basin area in the Neogene Formations exist within intra-formational shales of Early – Middle Miocene.

5. The late Cretaceous and Eocene shales which are which are important source rocks in the shelf area may also provide hydrocarbon migration through high angle normal faults in the proximal basin area. However, in the distal basin area, where the younger sediments are very thick, the source potential of Late Cretaceous may get over-mature or even over-cooked due to the overlying sediment load and high temperature conditions.

6. Good quality reservoir rocks are present within formations of Cretaceous, Paleocene, and Eocene age. In the shelf area of the Offshore Indus Basin, hydrocarbon generation took place in the Cretaceous Mughalkot Formation and Paleocene Ranikot Formation.

7. Indus Marine B – 01 and PakCan – 01 wells contain high quality data. Indus Marine B – 01 well is the deepest well which penetrated the Aquitanian (Early Miocene) whereas PakCan – 01 though not drilled as deep as Indus Marine B – 01, but it produced hydrocarbon on DST, due to its position on the pro-gradational sediments of Early – Middle Miocene in the slope area. The well Indus Marine B – 01 well data not only found in calibration of rigorous tectonic events of Miocene and younger strata but also reveals high water depth, heat flow, matrix porosity and liquid and gaseous hydrocarbon generation in the basin area. Indus Marine A – 01 and Indus Marine C – 01 wells, due to their position in the basin, though reveals representative tectonic curves for Miocene and younger events, but does not indicate significant hydrocarbon generation.

6.2 Discussion

Offshore Indus Basin, Pakistan is filled with thick marine sedimentary rocks of varying lithologies, which commonly forms source, reservoir, seal trilogies. Basins similar to Offshore Indus are mostly producing hydrocarbons throughout the world. Although, still there is not a single discovery in this region, yet existence of thick sediments, oil and gas seeps / shows in and around the region, and suitable geothermal gradients furnish positive evidence of occurrence of hydrocarbons. Surveys have also identified potential traps, both structural and stratigraphic. It is therefore, imperative that the search for undiscovered hydrocarbons be accelerated by intensifying geological and geophysical investigations, including reprocessing of existing seismic and well log data using latest techniques and conducting more multi-fold seismic surveys.

In the offshore extension of Sothern Indus Basin, geochemical studies indicated that oil-prone Paleogene and Lower Miocene source rocks are present. Main hydrocarbon play fairways are large compressional anticlines, drape anticlines, reefal undaform banks, rollover anticlines against growth faults, and submarine canyon fan system.

Traps associated with lineaments, Upper Paleocene to Lower Eocene reefal banks, and drape anticlines and traps associated with distribution and continuity of sanstone reservoirs are expected hydrocarbon play fairways. Sembar Shales may be gas prone but the shales of Lower Goru are capable of generating light oil or condensates.

Petroleum Zones G_1 (Indus Platform) and G_2 (Indus Depression) have been identified in the Offshore Indus Basin. G_1 is prolongation of onshore sindh monocline and is cut in the south-eastern corner by canyon of the Indus River. Cretaceous, Eocene and Oligo – Miocene objective plays are in this zone. G_2 represents deep depression which appears to be a direct prolongation of the onshore Karachi Depression. The area is severely faulted by sinuous and gravity growth faults. Eocene and Oilgo – Miocene plays are objectives of investigation.

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