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Hydrocarbon Resource Base of Pakistan

Riaz Ahmed[1]

ABSTRACT

Predictions made in the past regarding sizable oil potential of Pakistan's sedimentary basins have remained mostly unfulfilled. However, continuous addition in gas reserves upholds early estimates of its large gas potential. This paper discusses potential of individual basins, estimates their oil and gas resource and gives researched opinions on potential regional oil and gas prospects.

INTRODUCTION

Compressional geodynamics have played an important role in the evolution of sedimentary basins of Pakistan. The geology of Pakistani basins suggests that tectonic events were triggered by the intricate plate interactions in the Early Tertiary. Two major fault systems of Asia confine its large sedimentary areas measuring about 827,268 sq km onshore and offshore (Figure 1).

History of petroleum exploration in Pakistan dates back to 1866 when first oil well was drilled at Kundal, Northern Punjab by the British Government. This was world's second country where an oil well was drilled, the first country being the USA (1859). However, the first commercial oil discovery was made at Khaur, Northern Punjab in 1916 which opened up country's first major oil province, the Potwar. Discovery of good quality gas at Sui, Balochistan in 1952 was another milestone in exploration history of the country. It established a gas province in the central part of the Indus basin. The Sui field with reserves of 8.7 TCF has so far remained the main source of gas supply to country's large domestic sector. Another significant oil and gas province was added in 1981 in southern part of the Indus basin with the discovery of oil at Khaskheli, Badin (Sindh). Lately in 1997, a major gas discovery (>1 TCF) at Bhit, Kirthar Range, Sindh has established yet another gas province in the country. More recently in February 1998, a major gas discovery at Sawan has consolidated stratigraphic play of Miano and Kandanwari in the southwest of Miano field. The latest gas discovery in Zarghun South at the periphery of Sulaiman fold and thrust belt has opened up a new deeper hydrocarbon play in Indus basin. Till todate, 130 oil and gas discoveries have been made at an overall success rate of 1:3.3. Only 1020 wells including 426 exploratory wells have so far been drilled in the country. The lukewarm drilling effort (1 well in 2000 sq km) has so far resulted in discovery of 513 million barrels of oil and 31 trillion cubic feet of gas. Estimation of absolute recoverable potential based on volumetric yield method gives figures of 27 billion barrels of oil and 282 trillion cubic feet of gas (Table 1). To reach anywhere near these figures, seismic coverage and drilling density will have to be increased manifold and huge investments are to be drawn.

PETROLEUM GEOLOGY OF PAKISTANI BASINS

Indus Basin

The Indus basin belongs to the class of Extracontinental Trough Downwarp basins. It is the largest and so far only producing sedimentary basin of Pakistan (Figure 2). The basin has elongated shape and is oriented in northeast-southwest direction. Basement is exposed at two places, one in northeast (Sargodha high) and the second in southeastern corner (Nagar Parker high). It is characterized by a large easterly platform region which dips gently and monoclinally towards northwest, a ring of troughs or depressions in which platform dips and a westerly folded and thrusted, topographically uplifted region (Figure 3). The sedimentation and structuring of the basin owes itself directly to the history of events taking place on the Indian plate, i.e., its rifting, drifting, collision, underthrusting and corresponding orogeny, erosion and massive younger fluviatile deposition.

The large Indus basin got buckled and twisted under the influence of plate collision in Early Tertiary period. The India-Asia convergence events featuring promontory collision and anticlockwise rotation have been dated by Klootwijk et al. (1992) as (1) collision: Early Paleocene-Paleocene/Eocene, 65 Ma-55 Ma; (2) indentation: Eocene-Early Miocene, 55 Ma-20 Ma; and (3) rotational underthrusting and oroclinal bending: Early Miocene-Present, 20 Ma-Present. The chronology of India-Eurasia collision has been similarly taken by Gnos et al. (1997) as Early Eocene based on the timing of the accretion of the Kabul microcontinents. (Patriat and Archache, 1984) and marked reduction in Indian plate's northward motion from 20 cm/yr to 5 cm/yr (Molnar and Tapponnier, 1975). The convergence has resulted in partitioning of the basin into 3 parts, upper, middle and lower which are commonly referred to as sub-basins. Some of the basement highs present over platform area serve as dividers.

The prospectivity and the potential of the three sub-basins are discussed as under:

1 Hydrocarbon Development Institute of Pakistan, Islamabad.

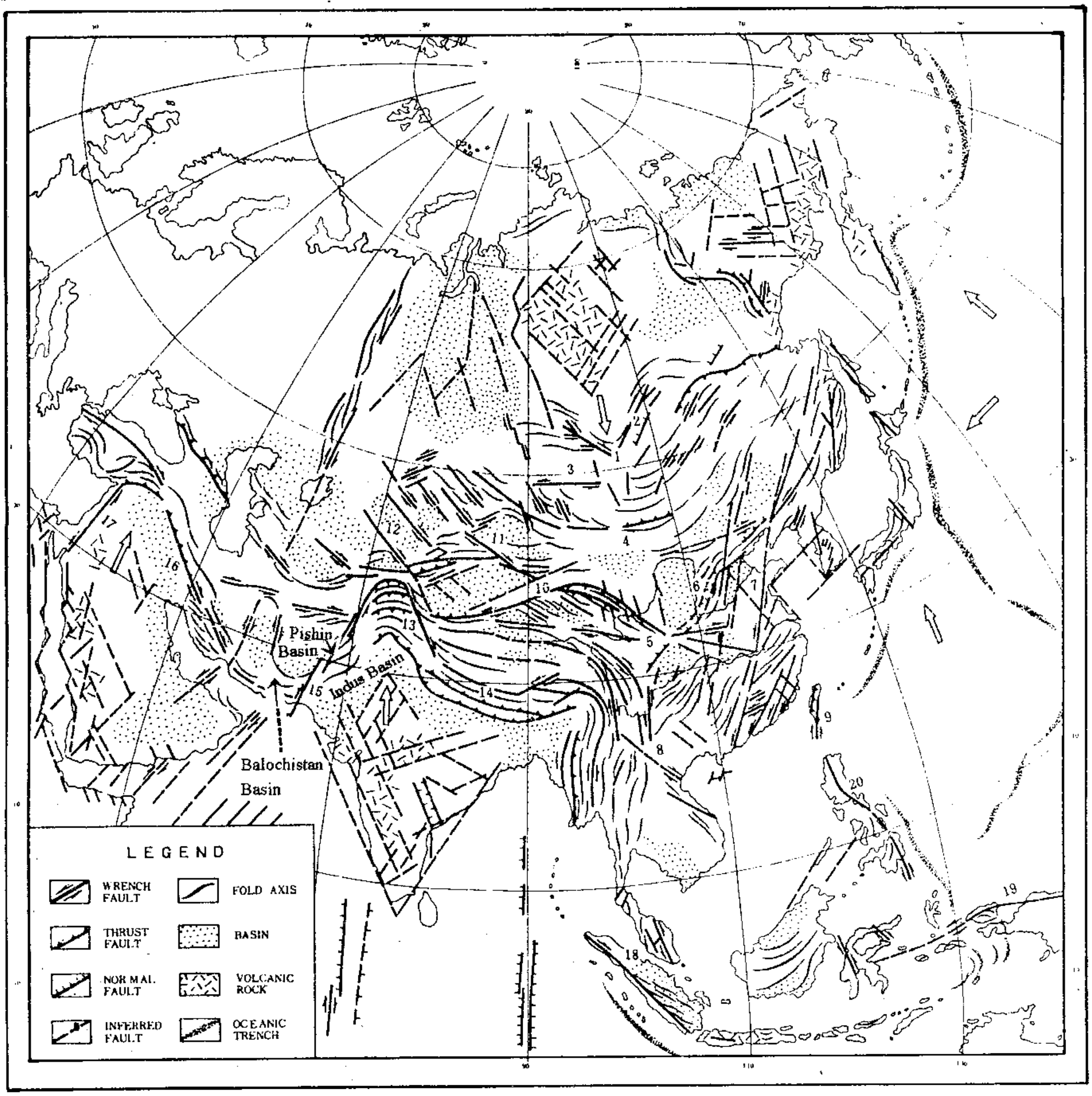

Figure 1- Principal fault systems bounding Pakistani basins (Modified after Liu Hefu, 1986).

Northern Indus Basin

Oil has been found in Paleocene-Eocene limestones, Jurassic sandstones, Permian sandstones and limestones and Cambrian sandstones (Figure 4). Paleocene Patala shales have been proven as the main source rock in the sub-basin on the basis of extensive geochemical studies carried out at Hydrocarbon Development Institute of Pakistan (HDIP) (Table 2). These organic rich shales were deposited partly in anoxic conditions prevailing during Paleocene due to buckling of the basin floor. Infra-Cambrian Salt Range Formation also contains oil shale intervals which show source rock potential. It is interesting to note that oil shales also occur in contemporaneous evaporitic sequence of Oman. The occurrence of volcanic rock "Khewrite" in the Salt Range Formation may indicate some rifting event. Inter-formational and intra-formational seals are present in the entire stratigraphic column. The Paleozoic-Tertiary dominantly marine sedimentary rocks containing all the source, reservoir and cap rocks forming

Table 1. Resource estimation of Pakistani basins (Modified after Raza and Ahmed, 1990).

NAME OF BASIN	INDUS NORTH	INDUS CENTRE	INDUS SOUTH	BALOCHISTAN	PISHIN	OFF-SHORE
Volume of sediments (cu mi)	70,000	240,000	224,000	241,000	40,000	185,000
Recovery factor (barrels per cu mi)	60,000	60,000	75,000	90,000	20,000	90,000
Ultimate recovery: (million barrel of oil or equivalent gas)	4200	14,400	15,800	21,690	800	16,650
Percentage of gas:	10	80	70	60	60	60
Oil (million barrels):	3,780	2,880	4,740	8,676	320	6,660
gas (trillion cubic feet):	7.5	69.12	64.75	78	2.88	60

Total Ultimate Recovery - Pakistan
Oil: 27 billion barrels
Gas: 282 trillion cubic feet

petroleum systems in Potwar are exposed in Salt Range along a thrust front. Thick overburden of fluviatile clastics over marine section has greatly facilitated generation of hydrocarbons. Structuring is related to compression and thrusting. The Infra-Cambrian salt forms a convenient zone of decollement. Traps have been developed due to thin-skinned tectonics which have produced faulted anticlines, pop-up and positive flower structures above infra-Cambrian salt. A subthrust play in southeastern Potwar where some closures are indicated on seismic involving repeated Paleozoic-Tertiary section along an overthrust (Hiller and Ahmad, 1989) also offers opportunities but with higher risk. Oil show encountered in the Lower sheet in OPPI's Diaal-1 which was drilled to test sub-thrust objectives could open up sub-thrust play to extensive exploration. Northern part of the sub-basin has good potential for oil, gas and condensate, provided structural complications related to steepness of folds are sorted out through advanced seismic techniques, e.g., 3-D. Gas and condensate discoveries in northwestern portion and presence of oil shows and seepages in northeastern portion of this part prompt for more active exploration.

The Kohat-Bannu area which has so far remained devoid of oil and gas discoveries is more or less similar to producing Potwar plateau in its sedimentary fill and geological setting. Development of Eocene salt has created additional salt cut small dome-like features in a narrow belt along Kohat portion where accurate delineation of sub-salt structures is critical. The target horizons in structural situations are Eocene and Paleocene limestones (Kohat, Shekhan and Lockhart) and Cretaceous and Jurassic sandstones (Lumshiwal and Datta). Structuring is prominent in Kohat portion, where as it is less conspicuous in Bannu trough portion. Thrusted and faulted anticlines with repeated sub-surface sections are developed in Kohat area where exploration needs strong seismic support to reach objective formations. Facies variation from Potwar to Kohat-Bannu area have to be understood in order to attempt further exploration in Bannu trough where purely structural traps seem rare and combination traps are possible but require a lot of pre-drilling work and modelling for prospect generation. The silver lining is the presence of extremely good quality oil shales associated with Jatta Gypsum (E. Eocene) which have tremendous potential for producing oil in Karak-Bannu basinal area (Table 2).

Central Indus Basin

The Central Indus Basin is a gas and condensate producing area. Its exploration history goes way back to 1885 when a number of shallow oil wells were drilled on an oil seeping area near Kathan in the Sulaiman foldbelt. The sub-basin contains thick sediments of Mesozoic and Cenozoic ages in its western part, while Paleozoic, Mesozoic and Cenozoic sediments in moderate thickness are present over the basement in its eastern part (Figure 3) which continues as a platform area into India where petroliferous basins are locally formed (Figure 1). The sedimentary rocks present in basins west of Aravali Range (Bikaner-Nagaur) include Infra-Cambrian, Cambrian, Permo-Carb, Jurassic and Paleocene-Eocene sequences overlain by alluvium and desert sand of Pleistocene-Recent age. Cambrian sequence contains glaciated boulder bed overlain by evaporitic assemblage similar to Salt Range Formation of Salt Range. Boulder bed equivalent of Tobra Formation of Salt Range is present in Permian sequence. Between Cretaceous and Eocene sequences lies the basalt of Deccan Trap. Heavy oil has been discovered in Lower Paleozoic sedimentary sequence within Jodhpur and Bolara Formations (Early Cambrian-Infra-Cambrian) below the salt beds and asphaltic crude oil has been found in Upper Carbonate Formation (Late Cambrian). Only the heavy oil from the Jodhpur sandstone is producible (Das Gupta and Bulgauda, 1994). A comparison of properties of this oil with the Cambrian oil from Joyamier field, Potwar, Pakistan, is given in Table 3.

The western part of the sub-basin contains source rocks of Jurassic, Early Cretaceous and Paleocene-Eocene ages

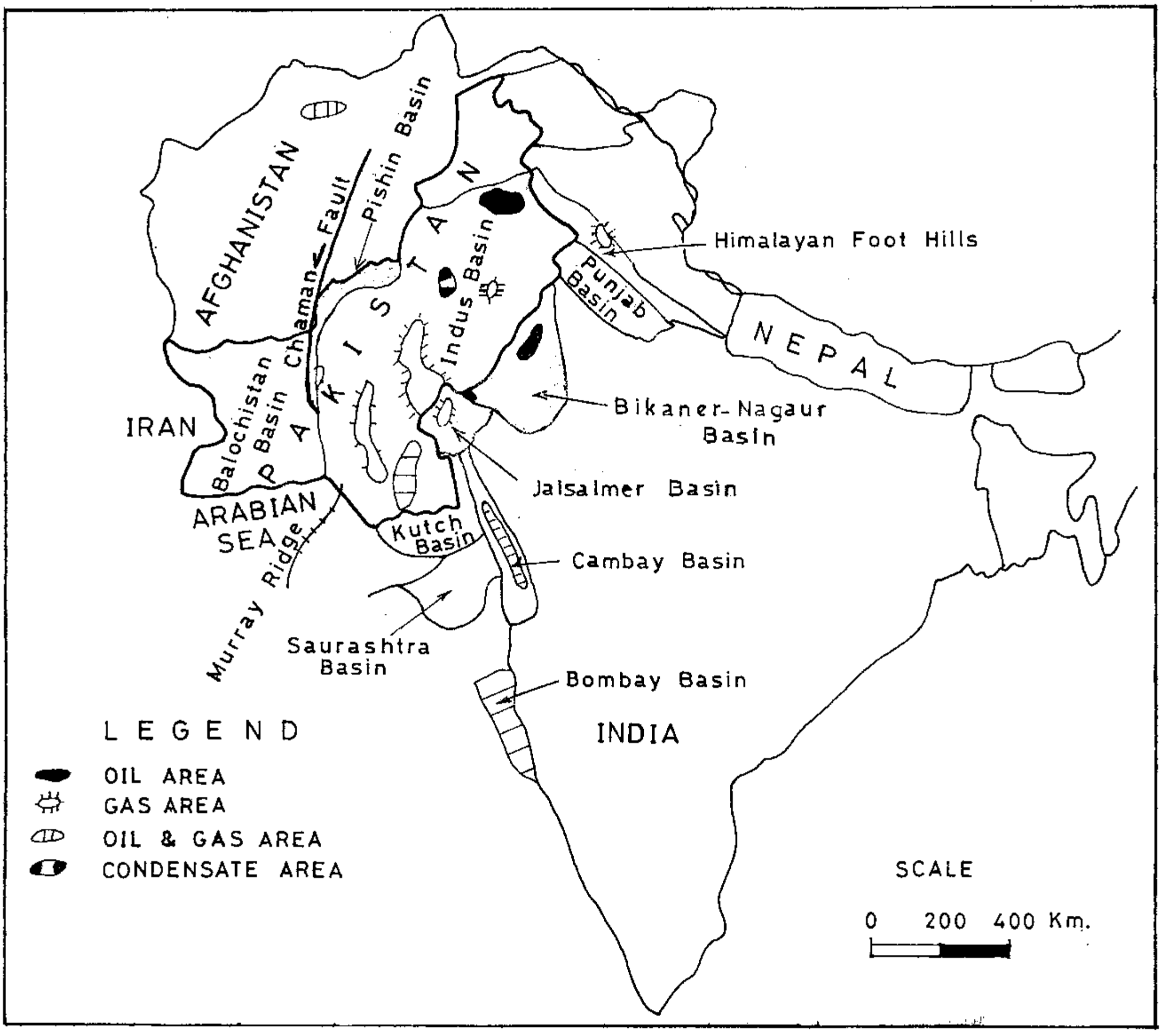

Figure 2- Oil and gas producing areas of Pakistan and adjoining areas of India.

(Table 2). The eastern part has infra-Cambrian source rocks. The configuration of the sub-basin is conducive to lateral migration from centre to east and west. The western part of the platform slab close to Sulaiman foredeep is extremely favourable for entrapment of hydrocarbons migrating east from the kitchen. There are a number of large surface anticlinal structures in the western fold and thrust belt area created as a consequence of plate collision. Cretaceous-Tertiary sequence in different thrust sheets contains exploration-worthy petroleum systems. The easterly part of the sub-basin lies away from the deformation zone and the structures there are simple, mainly associated with salt movement or paleotopography. Stratigraphic trap situations also appear on seismic data in the western part of the platform below Tertiary sequence.

Sui gas field discovered in 1952 in this sub-basin is the largest field in Pakistan. It had original recoverable reserves of 8.624 TCF, the balance recoverable reserves are now 2.428 TCF. The producing reservoir is a reefal (foraminiferal) limestone of Early Eocene age. Gas and condensate have been discovered at Dodhak and Savi Ragha mainly from Early Paleocene Lower Ranikot sands (continental facies) and Late Cretaceous Pab Sandstone (coastal facies). Gas has been found in Paleocene sands (Pirkoh field), E. Eocene reefal limestone (Loti, Zin and Uch fields), Late Cretaceous limestones (Jandran field) and Jurassic-Cretaceous sands (Nandpur and Panjpir fields). The September 1998 gas discovery in multiple reservoirs (Chiltan, Mughal Kot and Dungan) will have far-reaching effects on future exploration programmes in Indus basin where this first discovery in Chiltan is bound to generate

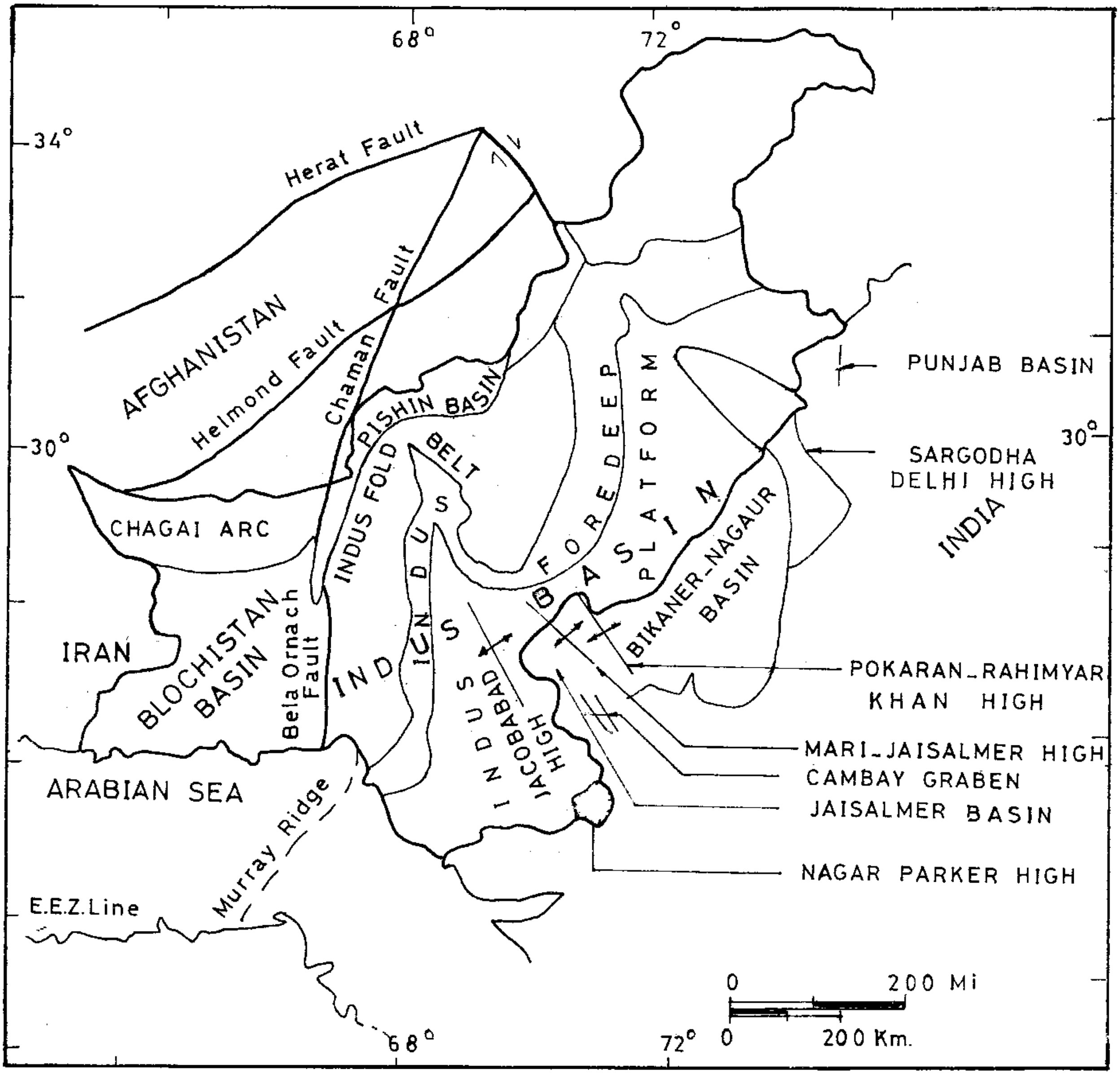

Figure 3- Tectonic elements in Pakistani basins.

new interest in this thick and extensively distributed carbonate unite.

The Sulaiman fold and thrust belt generally contains large sized structures but their potential is mainly dependent on quality and extent of the reservoir facies. Seismic coverage in this hilly part of the sub-basin is poor. Drilling cost is also higher due to terrain factor. Field life is, however long, about 20 years.

Gas quality in the sub-basin is unpredictable, as 10-15% CO_2 may appear at any site. Mix of gases from multi-sourced horizons during migration could be one of the reasons. The characteristics of low Btu gases in Jurassic-Eocene section are compared with similar gases in Jaisalmer basin, India (Table 4). A separate geochemical study is needed for prediction of gas quality in various parts of the sub-basin.

Southern Indus Basin

The Southern Indus Basin contains sedimentary rock fill upto 10,000 m thick, comprising Mesozoic and Cenozoic sections. Precambrian basement is exposed in the south-

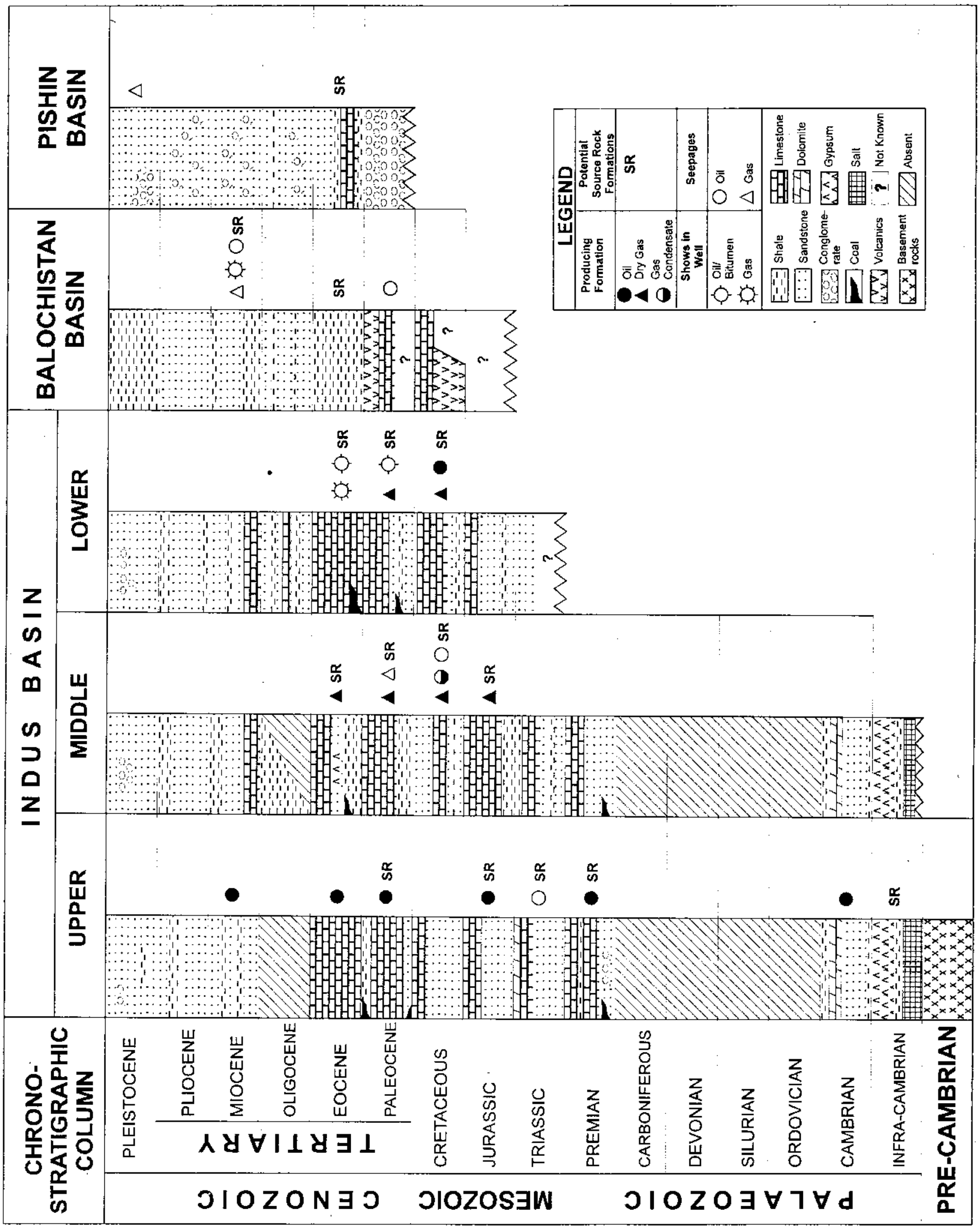

Figure 4- Generalized stratigraphy in Pakistani basins (Modified after Khan and Raza, 1986).

Table 2. Main source rocks in Pakistani basins (Source: HDIP).

INDUS BASIN			BALOCHISTAN BASIN	PISHIN BASIN
North	Centre	South		
			Talar/Hinglaj (Claystone) TOC: about 0.5% Parkini (Mudstone) TOC: <0.5-1.70 Panjgur (Shale) TOC: 0.6 - 5.62%	Murgha Faqirzai (Shale) TOC: > 0.5%
Jatta Gypsum (Oil Shale) TOC: 20% HI: 600	Kirthar (Oil Shale) TOC: 11% HI: 600	Kirthar (Oil Shale) TOC: 8% HI: 600		Nisai (Shale) TOC: > 0.5%
Patala (Shales) TOC: 1.57% HI: 268	Dunghan (Limestone) TOC: 0.7% HI: 437	Lakhra (Shale) TOC: >1% HI: >200		
Salt Range (Oil Shale)	Sembar (Shale) TOC: > 1% HI: about 200	Sembar (Shale) TOC: 3% (Badin wells)		
Upper Horizon TOC: 26% HI: 635		Anjira (Shale) TOC: 0.70% HI: 257		
Lower Horizon TOC: 4% HI: 500%				

eastern corner (Nagar Parker high), the thickness of sediments increases westward. Potential source rocks occur within Cretaceous, Paleocene and Eocene sequence (Table 1, Figure 4). Proven reservoirs in the sub-basin are sandstones of Cretaceous age and limestones of Paleocene and Eocene ages (Figure 4). A number of small oil and gas fields have been discovered in the western Sindh platform in tilted fault blocks of the Early Cretaceous sandstones (Lower Goru Formation) which are sealed by the overlying shales of Upper Goru Formation and sourced by the underlying shales of Sembar Formation. The size of pools ranges from 2-30 million barrels (oil) and 20-150 billion cubic feet (gas). The drilling depth to the target is convenient (shallow) and the terrain is flat which makes drilling cheaper and faster in this area. The western Sindh platform (oil and gas producing Badin Area) has remained the most attractive area for oil companies since early eighties. The area around giant Mari gas field (6.3 TCF) has also found attraction for oil companies because of multiple targets. In Mari gas field, 6.3 TCF reserves of low Btu gas with significant Nitrogen content were found in Habib Rahi Limestone of M. Eocene age in 1957. Recently, about 1 TCF additional gas reserves have been found in the same field in Cretaceous Lower Goru sands in faulted structures (negative flower type). Reserves of good quality gas have been found in significant quantities around this area in stratigraphic traps formed by sands of Lower Goru Formation (Miano, Kandanwari and Sawan fields). The Mari area is an extension of India's Cambay rift area. Although it is an aborted rift in Pakistan as compared to India, yet the heat flow is on the higher side (In Cambay area geothermal gradient is 6-7^{o}C/100 m and in Mari-Sui area it is 3-4^{o}C/100 m).

In Jaisalmer basin of India, which forms the eastern contiguous platform part of Indus basin, more than 6 km thick sediments of Permian to Quaternary age are present. Gas prone organic matter with occasional occurrence of oil prone organic matter is found in Goru, Pariwar (Early Cretaceous-Sembar) and Baisakhi-Bedsir (Upper Jurassic) formations (Dhannawat and Mukherjee, 1997). However, Pariwar and Barsakhi-Bedsir formations are considered as mature source rocks with fair to good generative potential. Gases discovered in Jaisalmer basin from Jurassic, Cretaceous and Tertiary reservoirs are generally lean in hydrocarbons and rich in nitrogen. Carbondioxide is also significantly present in Jurassic, Cretaceous and Tertiary reservoirs, maximum percentage of about 33% is reached in Jurassic section in Bhuana-1, southeast Jaisalmer.

UTP's Marvi well in the eastern Sindh platform being drilled to test Paleozoic and older prospects might bring interesting information having bearing on future exploration in the sub-basin.

Talbe 3. Comparison of properties between Cambrian heavy oils in Pakistan (Potwar) and India (Bikaner-Nagaur).

	Joyamir Field, Potwar, Pakistan	Well BGW-1, Bikaner-Nagaur Basin, India
API Gravity	17°	17°
Pour Point	15°C	27°C
Viscosity	2597Cst @ 37.7°C	267 CP @ 90°C 1700 CP @ 60°C 6667 CP @ 30°C
Initial Boiling Point	65°C	115°C

Talbe 4. Comparison of characteristics between low Btu gases in Pakistan (Indus) and India (Jaisalmer).

Charactesistics	Paksitan (Indus)	India (Jaisalmer)
	Eocene	
Hydrocarbons (%)	29 - 73	21 - 25
Carbondioxide (%)	8 - 46	1 - 2
Nitrogen (%)	2 - 19	73 - 78
	Cretacous - Jurassic	
Hydrocarbons (%)	39 - 60	10 - 28
Carbondioxide (%)	2 - 32	4 - 33
Nitrogen (%)	7 - 60	57 - 58

There is a revived interest in Kirthar fold belt after the discovery of more than 1 TCF gas reserves in Pab Sandstone in Bhit anticline. Pab Sandstone is developed as a thick porous sandstone unit in Kirthar Range where it is now an attractive reservoir target when buried and in trap position. A little north of this field, small Mazarani gas discovery (0.033 TCF) on Early Eocene Sui Main Limestone has remained dormant for a number of years. Oil companies are now exploring extensively in Kirthar fold belt and its attached troughs in the east. Even sub-thrust play in Mazarani area has caught the eye of exploration companies.

New and better terms and conditions offered by the Government have once again attracted oil companies to explore offshore. Presence of gas in Miocene sands in the Indus offshore is confirmed by the last round of exploration in eighties. Structuring similar to western Sindh platform i.e. fault blocks is known from previous seismic data. Delta-associated plays and Early Tertiary carbonate build-ups are also being evaluated as exploration targets in the Indus offshore.

Balochistan Basin

It is the second largest sedimentary basin of Pakistan, measuring 149,000 sq km onshore where 8 wells have so far been drilled without success. It is a Cenozoic subduction basin created as a result of subduction of an oceanic slab belonging to the Arabian Plate under a block (Afghan block) of the Eurasian Plate. Thick clastic sediments (> 10,000m) deposited over arc-trench gap form the sedimentary fill. The sedimentation commenced at around Maastrichtian/Danian time in an area south of the now dormant Chagai arc and continued further southward in time. Accretionary prism in the form of a pile of folded slices is exposed in the middle of the basin. An active trench is located offshore. A major transform fault system bounds the basin in the east.

Since no oil or gas field has so far been discovered in the basin, therefore no confirmed petroleum system is known. However, based on existing data, it is anticipated that the source rocks exist within Eocene-Miocene clastic section (Figure 3) where clays/shales in large thickness include intervals with TOC ranging on average between 0.4-0.7% (Table 2). Sandstones with high primary porosity (12-20%) ranging in age from Oligocene to Pliocene representing turbiditic to inner shelf facies could form ideal reservoirs for accumulation of hydrocarbons. There are a large number of east-west directed anticlinal folds present to contain these reservoirs in trap position. Exploring stratigraphic traps involving Parkini source and Talar accumulating sands in the northern flanks of these anticlines could be equally rewarding. Inter and intra-formational clay/shales may act as convenient cap rocks to complete any existing petroleum system in the basin. Turbiditic facies of Panjgur Formation (Miocene) may have self-contained source-reservoir-cap trilogy and form primary target for drilling.

The critical factor in the prospectively evaluation of the basin is the generation of hydrocarbons which todate have been linked to a chain of mud volcanoes with gaseous emissions located along the coastline. The phenomenon of gas hydrates have been confirmed by the recent German cruise offshore Makran (SONNE Cruise SO 122/123, Fall 1997) and there could be some gas-hydrate-cemented sediments offshore. During the second German cruise (SO 130: April/May 1998), the focus will be on the organic geochemistry of organic-rich sediments deposited in the oxygen minimum zone and gas seeps associated with submarine mud volcanoes at the foot of the accretionary prism. Unconfirmed reports of an oil seepage at Khawash, near Iranian border raise hopes of finding hydrocarbons in the basin. Kharan desert area may hold some prospects in Paleogene section. Seismic survey of the area is needed for understanding its potential.

Pishin Basin

The Pishin basin is located between the Chaman transform fault zone in the west and the Muslim Bagh-Waziristan ophiolite and melange zone in the south and east. It extends into Afghanistan where it is known as Katawaz basin. The Pishin basin is a small extracontinental median basin of Tertiary age (Ahmed, 1991) developed as a remnant of the Neo-Tethys ocean basin before the collision of the western margin of the Indian plate with the Afghan block of the Eurasian plate.

The basin, in terms of oil and gas exploration, is considered as "frontier" because it is totally unexplored. Scattered gas occurrences associated with mud volcanoes are known which have been found to be thermally mature and confirm generation of hydrocarbons in the basin. The basin fill comprises more than 8000 m of Tertiary and Quaternary, dominantly clastic sediments deposited in marine, deltaic and fluviatile environments (Figure 5). These sediments have been deformed by compressional tectonics. A large number of anticlinal folds and faults have been produced by thrusting during Plio-Pleistocene times. Geological-geochemical data indicate occurrence of mature source rocks in Early Eocene Nisai Formation (Table 2). There are a number of reservoirs that may have received hydrocarbons (Figure 5). These include limestones of Nisai Formation, sandstones of Murgha Faqirzai, Shaigalu and Multana formations. The most attractive area for future exploration in the basin appears to be the northeastern segment where large and well formed anticlines are located.

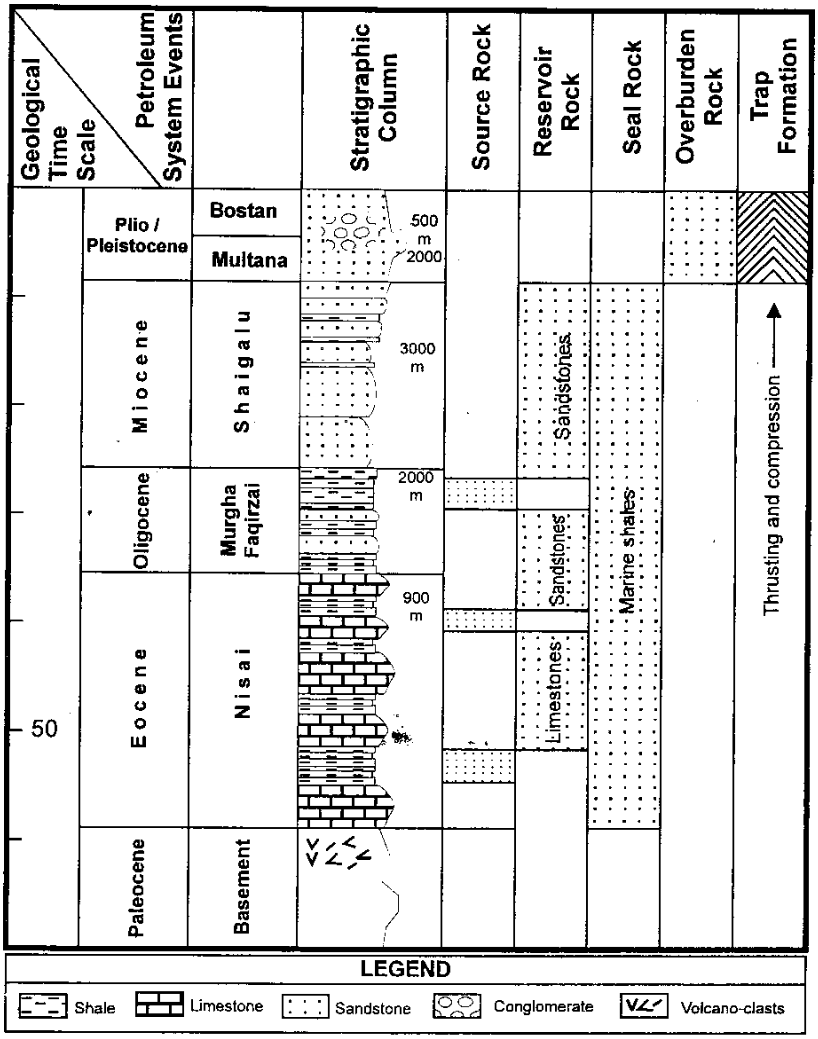

Figure 5- Anticipated petroleum system in Pishin basin.

RESOURCE ESTIMATION OF PAKISTANI BASINS

The last assessment of hydrocarbon resource of Pakistan was carried out by the Hydrocarbon Development Institute of Pakistan (HDIP) using volumetric yield method (Raza and Ahmed, 1990). It estimated an ultimate recovery of 40 billion barrels of oil and 200 trillion cubic feet of gas. These figures have been reviewed in the present study in the light of new discoveries made since 1990 (more than 60 new discoveries have been made from 1990-98). This revised estimation has given more weightage to gas in percentage of oil and gas in potential reserves on the basis of discovery trends (major new discoveries are of gas: Bhit, Sawan and Mari Deep, reserves > 1 TCF each). The recovery factor, i.e., yield per cubic mile has been derived from the analog producing basins in each category of Pakistani counterparts. The total ultimate recovery for Pakistan has now been assessed as 27 billion barrels of oil and 282 trillion cubic feet of gas (Table 1). These figures should generate enough enthusiasm in the domestic petroleum industry to accelerate petroleum exploration through indigenous efforts.

CONCLUSION

Pakistan is fortunate to have a large sedimentary area, about 827,268 sq km where oil and gas could have been generated. A resource base of 27 billion barrels of oil and 282 trillion cubic feet of gas has been estimated. However, the exploratory activities in the country have so far remained sporadic, cyclic and dependent mainly on the response of foreign oil companies. Sustained national exploration programmes can result in better success. There is a strong need for continuity in indigenous R&D efforts in order to re-establish confidence in prospectivety of Pakistani sedimentary basins which is manifested by their favourable geological characteristics as discussed in this paper.

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